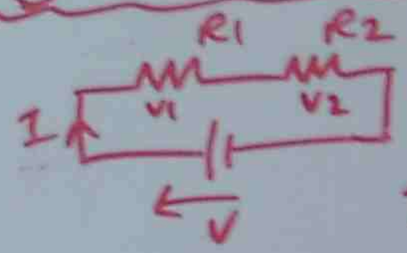
① DC SERIES CIRCUITS

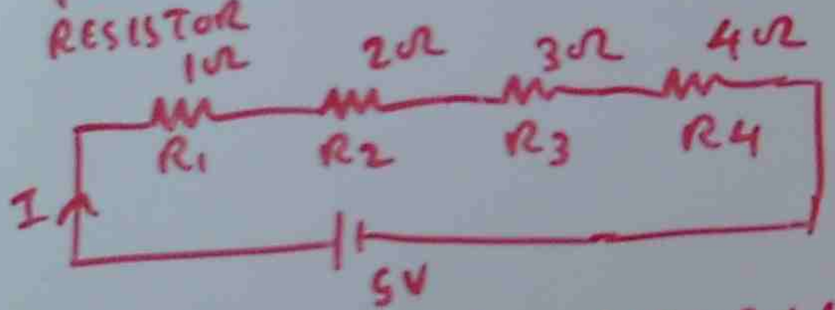


$R_T = R_1 + R_2$

$V = V_1 + V_2$

$I = \frac{V}{R_T} = \frac{V}{R_1 + R_2}$

pb FOUR RESISTORS 1Ω, 2Ω, 3Ω & 4Ω ARE CONNECTED IN SERIES TO 5V SUPPLY. CALCULATE THE CIRCUIT CURRENT AND POTENTIAL DIFFERENCE ACROSS EACH RESISTOR



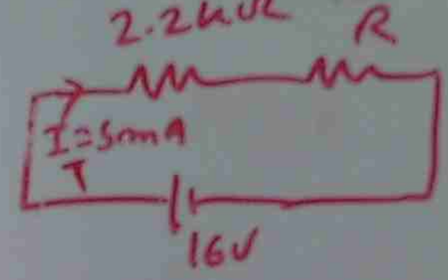
$R_T = R_1 + R_2 + R_3 + R_4 = 1 + 2 + 3 + 4 = 10\Omega$

$I_T = \frac{V}{R_T} = \frac{5}{10} = 0.5A$

$V_1 = I_T R_1 = 0.5 \times 1 = 0.5V$, $V_2 = I_T R_2 = 0.5 \times 2 = 1V$

$V_3 = I_T R_3 = 0.5 \times 3 = 1.5V$, $V_4 = I_T R_4 = 0.5 \times 4 = 2V$

b A 2.2 KΩ RESISTOR IS CONNECTED IN SERIES WITH A RESISTOR OF UNKNOWN VALUE ACROSS A 16V SUPPLY. IF THE CIRCUIT CURRENT IS 5mA, CALCULATE THE VALUE OF UNKNOWN RESISTOR

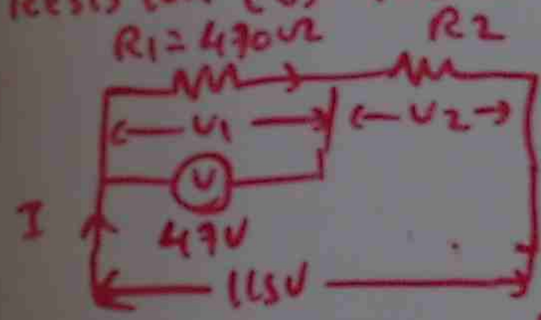


$R_T = 2.2K + R$

$R_T = \frac{V}{I_T} = \frac{16}{5 \times 10^{-3}} = 3.2k\Omega$

$3.2 = 2.2 + R \rightarrow R = 3.2 - 2.2 = 1k\Omega$

pb TWO RESISTORS ARE CONNECTED IN SERIES TO A 115V SUPPLY. ONE IS KNOWN TO HAVE A RESISTANCE OF 47Ω AND A VOLTMETER CONNECTED ACROSS IT SHOWS A READING OF 47V. CALCULATE (a) THE VALUE OF SECOND RESISTOR (b) THE CIRCUIT CURRENT.



$I = \frac{V_1}{R_1} = \frac{47}{47} = 0.1A$

$V_1 + V_2 = V$

$47 + V_2 = 115 \rightarrow V_2 = 115 - 47 = 68V$

$R_2 = \frac{V_2}{I} = \frac{68}{0.1} = 680\Omega$

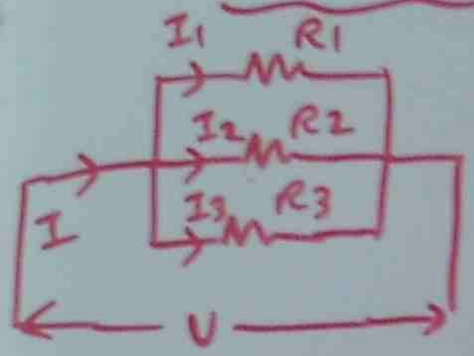
ELECTRICAL WORKSHOP

E003 - (8) DC CIRCUIT

SLIDE 1 ⟶ 9

@ 67 ⟶ @ 72

THE DC PARALLEL CIRCUITS

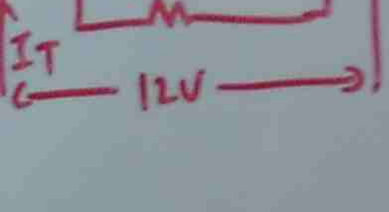


$I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$, $I_3 = \frac{V}{R_3}$

$I_T = I_1 + I_2 + I_3$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

pb RESISTORS OF 5Ω, 10Ω AND 30Ω ARE CONNECTED IN PARALLEL TO A 12V SUPPLY CALCULATE SUPPLY CURRENT.



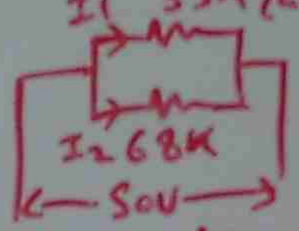
$I_1 = \frac{V}{R_1} = \frac{12}{5} = 2.4\,A$

$I_2 = \frac{V}{R_2} = \frac{12}{10} = 1.2\,A$

$I_3 = \frac{V}{R_3} = \frac{12}{30} = 0.4\,A$

$I_T = I_1 + I_2 + I_3 = 2.4 + 1.2 + 0.4 = 4\,A$

pb RESISTORS OF 33kΩ AND 68kΩ ARE CONNECTED IN PARALLEL TO A 50V SUPPLY CALCULATE (a) TOTAL CIRCUIT RESISTANCE (b) TOTAL CIRCUIT CURRENT AND (c) THE INDIVIDUAL BRANCH CURRENTS.



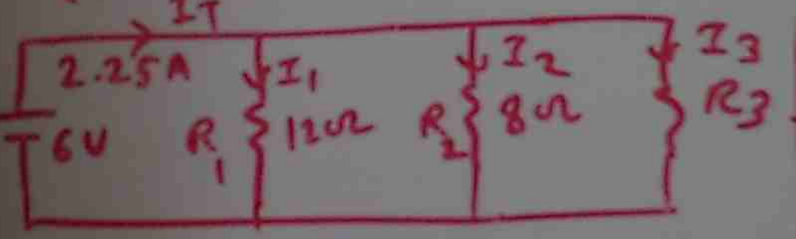
(a) $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{33} + \frac{1}{68} = \frac{68+33}{33\times 68}$

$R_T = \frac{33\times 68}{68+33} = \frac{2244}{101} = 22.2\,k\Omega$

(b) $I_T = \frac{V}{R_T} = \frac{50}{22.2} = 2.25\,mA$

(c) $I_1 = \frac{V}{R_1} = \frac{50}{33k} = 1.5\,mA$, $I_2 = \frac{V}{R_2} = \frac{50}{68k} = 0.74\,mA$

pb RESISTORS OF VALUES 12Ω AND 8Ω ARE CONNECTED IN PARALLEL WITH A RESISTOR R_3 OF UNKNOWN VALUE ACROSS 6V SUPPLY, WHEN THE CURRENT FROM THE SUPPLY IS FOUND TO BE 2.25A, CALCULATE (a) THE VALUE OF R_3 (b) THE CURRENT FLOWING IN TO R_3



$I_1 = \frac{V}{R_1} = \frac{6}{12} = 0.5A$

$I_2 = \frac{V}{R_2} = \frac{6}{8} = 0.75A$

$I_1 + I_2 + I_3 = I_T$

$0.5 + 0.75 + I_3 = 2.25$

$I_3 = 2.25 - (0.5 + 0.75)$

$= 1A$

$R_3 = \frac{V}{I_3} = \frac{6}{1} = 6\,\Omega$

ELECTRICAL WORKSHOP

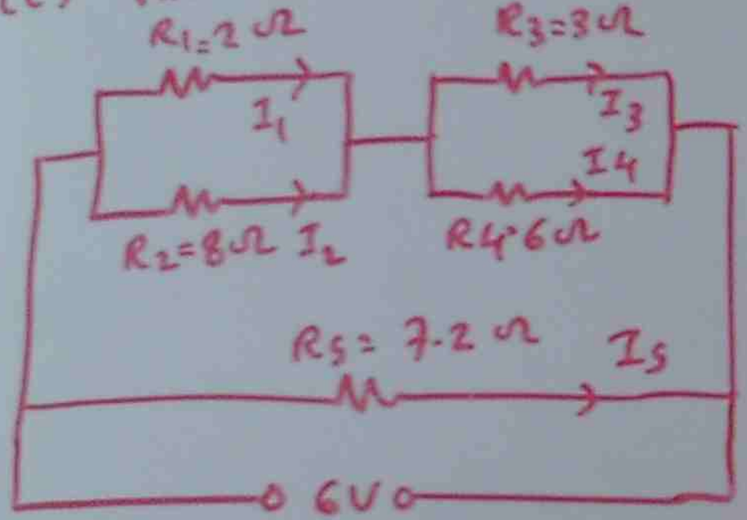
E003

SLIDE (10) → (17)

Q73 → Q77

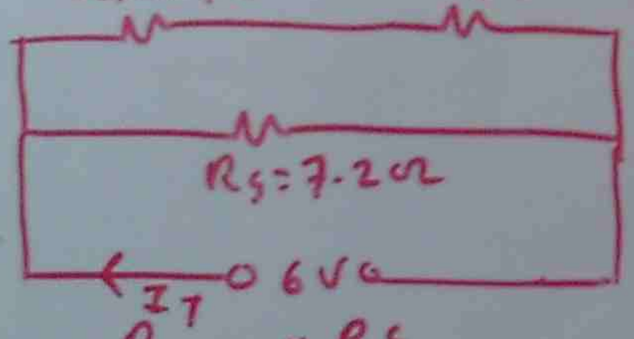
Pb FIVE RESISTORS ARE CONNECTED IN A SERIES PARALLEL GROUPING TO A 6V SUPPLY AS SHOWN IN FIGURE. CALCULATE

(a) THE TOTAL RESISTANCE OF THE CIRCUIT
(b) THE CURRENT PROVIDED BY THE SUPPLY
(c) THE CURRENT FLOWING IN 2Ω RESISTOR

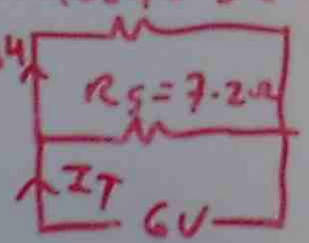


$R_{12} = \frac{R_1 R_2}{R_1 + R_2} = \frac{2 \times 8}{2+8} = 1.6\,\Omega$

$R_{34} = \frac{R_3 R_4}{R_3 + R_4} = \frac{3 \times 6}{3+6} = 2\,\Omega$



$I_{1234} \equiv$



$R_T = \frac{R_{1234} \times R_5}{R_{1234} + R_5} = \frac{3.6 \times 7.2}{3.6+7.2} = 2.4\,\Omega$

$I_T = \frac{V}{R_T} = \frac{6}{2.4} = 2.5A$

ELECTRICAL WORKSHOP
(9) DC SERIES PARALLEL CIRCUITS
SLIDE (1) → 9
@ 78 → @ 84

EOD 3

$I_{1234} = \frac{V}{R_{1234}} = \frac{6}{3.6} = 1.67A$

$V_{12} = I_{1234} \times R_{12} = 1.67 \times 1.6 = 2.67V$

$I_{R_1} = I_{2\Omega} = \frac{V_{12}}{R_1} = \frac{2.67}{2} = 1.33A$

POWER

POWER = VOLTAGE × CURRENT = $V \times I$

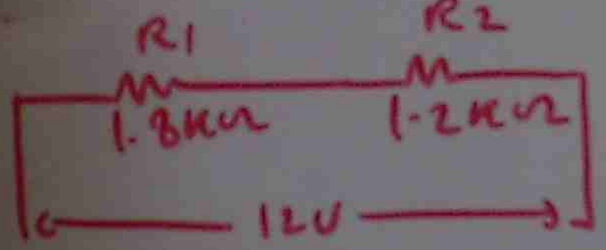
POWER = $\frac{(\text{VOLTAGE})^2}{\text{RESISTANCE}} = \frac{V^2}{R}$

POWER = $(\text{CURRENT})^2 \times \text{RESISTANCE} = I^2 R$

$P_T = P_1 + P_2$



Pb A CIRCUIT HAS RESISTORS OF 1.8kΩ AND 1.2kΩ IN SERIES TO A 12V SUPPLY CALCULATE THE POWER DISSIPATED IN EACH RESISTOR AND TOTAL CIRCUIT POWER



$R_T = R_1 + R_2 = 1.8 + 1.2 = 3\,k\Omega$

$I_T = \frac{V}{R_T} = \frac{12}{3k\Omega} = 4mA$

$P_T = V \times I_T = 12 \times 4 \times 10^{-3} = 0.048W$

$P_1 = I_T^2 R_1 = (4 \times 10^{-3})^2 \times 1.8 \times 10^{3} = 0.0288W$

$P_2 = I_T^2 R_2 = (4 \times 10^{-3})^2 \times 1.2 \times 10^{3} = 0.0192W$

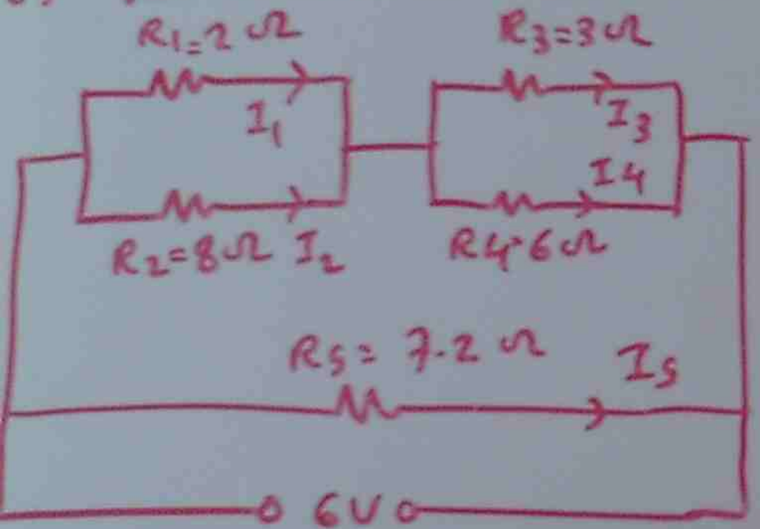
$P_T = P_1 + P_2 = 0.0288 + 0.0192 = 0.048W$

Pb FIVE RESISTORS ARE CONNECTED IN A SERIES PARALLEL GROUPING TO A 6V SUPPLY AS SHOWN IN FIGURE. CALCULATE

(a) THE TOTAL RESISTANCE OF THE CIRCUIT

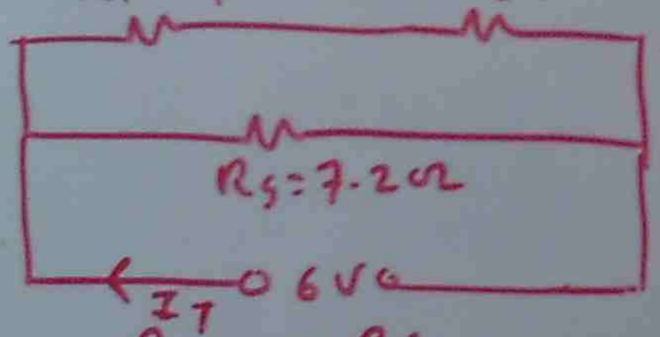
(b) THE CURRENT PROVIDED BY THE SUPPLY

(c) THE CURRENT FLOWING IN 2Ω RESISTOR

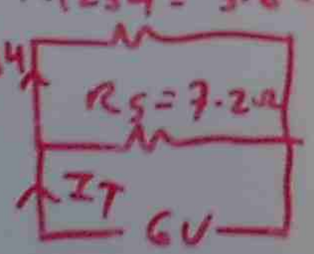


$$R_{12} = \frac{R_1 R_2}{R_1 + R_2} = \frac{2 \times 8}{2+8} = 1.6\,\Omega$$

$$R_{34} = \frac{R_3 R_4}{R_3 + R_4} = \frac{3 \times 6}{3+6} = 2\,\Omega$$



I_{1234} ≡



$$R_T = \frac{R_{1234} \times R_5}{R_{1234} + R_5} = \frac{3.6 \times 7.2}{3.6+7.2} = 2.4\,\Omega$$

$$I_T = \frac{V}{R_T} = \frac{6}{2.4} = 2.5A$$

ELECTRICAL WORKSHOP
(9) DC SERIES PARALLEL CIRCUITS
SLIDE (1) → 9
2.72 → 2.84

$$I_{1234} = \frac{V}{R_{1234}} = \frac{6}{3.6} = 1.67A$$

$$V_{12} = I_{1234} \times R_{12} = 1.67 \times 1.6 = 2.67V$$

$$I_{R_1} = I_{2\Omega} = \frac{V_{12}}{R_1} = \frac{2.67}{2} = 1.33A$$

POWER

POWER = VOLTAGE × CURRENT = V × I

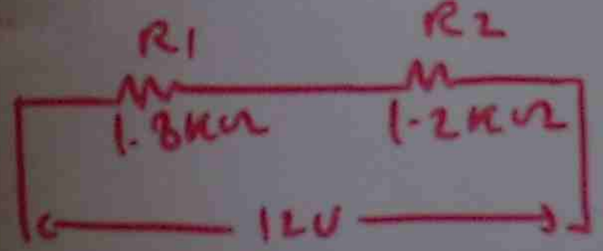
$$\text{POWER} = \frac{(\text{VOLTAGE})^2}{\text{RESISTANCE}} = \frac{V^2}{R}$$

POWER = (CURRENT)^2 × RESISTANCE = I^2R

$P_T = P_1 + P_2$



Pb A CIRCUIT HAS RESISTORS OF 1.8kΩ AND 1.2kΩ IN SERIES TO A 12V SUPPLY CALCULATE THE POWER DISSIPATED IN EACH RESISTOR AND TOTAL CIRCUIT POWER



$$R_T = R_1 + R_2 = 1.8 + 1.2 = 3\,k\Omega$$

$$I_T = \frac{V}{R_T} = \frac{12}{3k\Omega} = 4mA$$

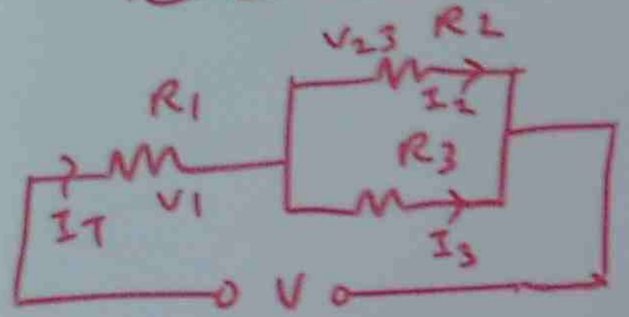
$$P_T = V \times I_T = 12 \times 4 \times 10^{-3} = 0.048W$$

$$P_1 = I_T^2 R_1 = (4 \times 10^{-3})^2 \times 1.8 \times 10^3 = 0.0288W$$

$$P_2 = I_T^2 R_2 = (4 \times 10^{-3})^2 \times 1.2 \times 10^3 = 0.0192W$$

$$P_T = P_1 + P_2 = 0.0288 + 0.0192 = 0.048W$$

DC SERIES & PARALLEL CIRCUITS



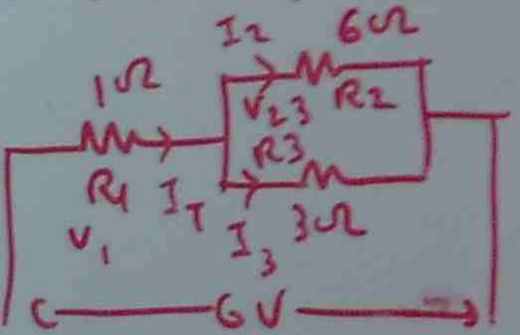
$$R_T = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

$$I_T = \frac{V}{R_T}$$

$V_1 = I_T R_1$, $V_1 + V_{23} = V \rightarrow V_{23} = V - V_1$

$$I_2 = \frac{V_{23}}{R_2}, \quad I_3 = \frac{V_{23}}{R_3}$$

(a) 1Ω RESISTOR IS CONNECTED IN SERIES WITH THE PARALLEL COMBINATION OF A 6Ω AND A 3Ω RESISTOR TO A 6 V SUPPLY. CALCULATE (a) THE EFFECTIVE OVERALL RESISTANCE OF THE CIRCUIT (b) THE CURRENT IN EACH OF THREE RESISTORS.



$$R_T = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

$$= 1 + \frac{6 \times 3}{6+3} = 3\Omega$$

$$I_T = \frac{V}{R_T} = \frac{6}{3} = 2A$$

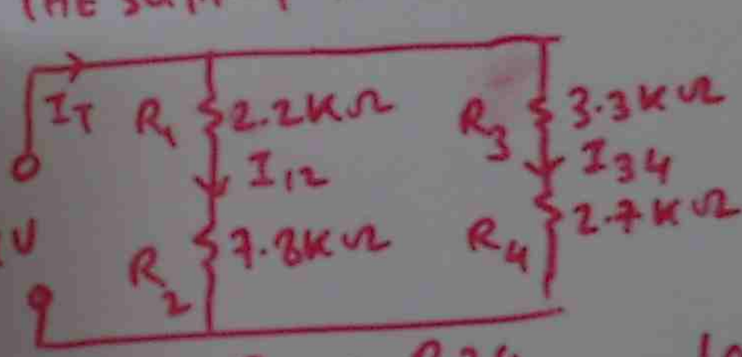
$V_1 = I_T \times R_1 = 2 \times 1 = 2V$

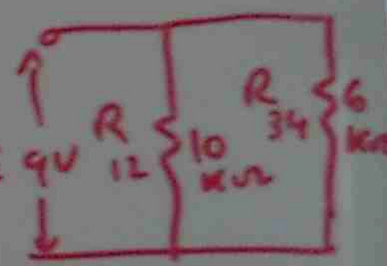
$V_{23} = V - V_1 = 6 - 2 = 4V$

$$I_2 = \frac{V_{23}}{R_2} = \frac{4}{6} = 0.66A$$

$$I_3 = \frac{V_{23}}{R_3} = \frac{4}{3} = 1.33A$$

(b) RESISTORS of 2·2kΩ AND 7·8kΩ ARE CONNECTED IN SERIES AND IN PARALLEL ACROSS THEM IS A SECOND SERIES GROUP OF 3·3kΩ AND 2·7kΩ RESISTORS. THE COMPLETE CIRCUIT IS CONNECTED TO A 9 V SUPPLY. CALCULATE (a) TOTAL RESISTANCE OF THE CIRCUIT AND (b) THE CURRENT FROM THE SUPPLY AND IN EACH RESISTOR.





$$R_T = \frac{R_{12} \times R_{34}}{R_{12} + R_{34}} = \frac{10 \times 6}{10+6} = 3.75k\Omega$$

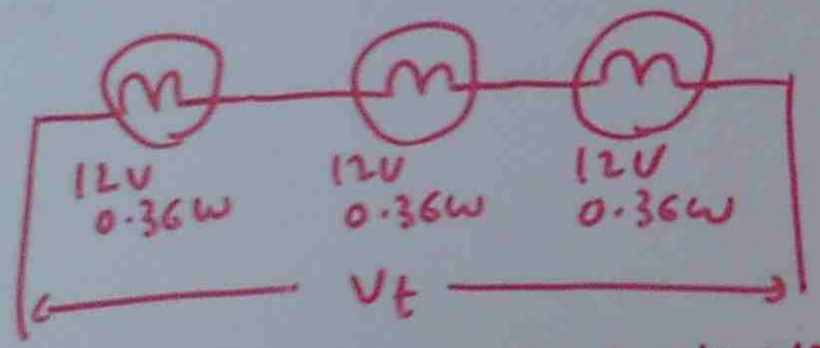
$$I_T = \frac{V}{R_T} = \frac{9\,V}{3.75k\Omega} = 2.4mA$$

$$I_{12} = \frac{V}{R_{12}} = \frac{9\,V}{10k\Omega} = 0.9mA$$

$$I_{34} = \frac{V}{R_{34}} = \frac{9\,V}{6k\Omega} = 1.5mA$$

LAMPS AND RESISTOR CIRCUITS

Pb THREE FILAMENT LAMP INDICATORS ARE EACH RATED AT 12V, 0·36W, IF THEY ARE CONNECTED IN SERIES, WHAT SUPPLY VOLTAGE SHOULD BE USED. WHAT CIRCUIT CURRENT WILL FLOW AND WHAT POWER WILL THE CIRCUIT DISSIPATE?



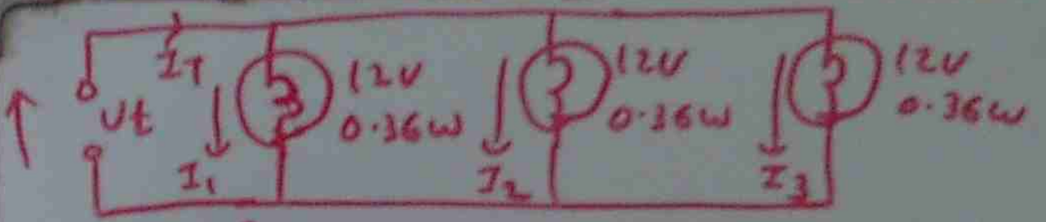
TOTAL SUPPLY VOLTAGE = 12+12+12 = 36 V

EACH LAMP CURRENT (I) = $\frac{P}{V} = \frac{0·36}{12} = 0·03$ A

$P_T = V_t \times I_t = 36 \times 0·03 = 1·08$ W

(OR) $P_T = P_1 + P_2 + P_3 = 0·36 + 0·36 + 0·36 = 1·08$ W

Pb THE SAME THREE 12V, 0·36W LAMPS ARE CONNECTED IN PARALLEL, FIND THE SUPPLY VOLTAGE, CIRCUIT CURRENT AND TOTAL POWER DISSIPATED.



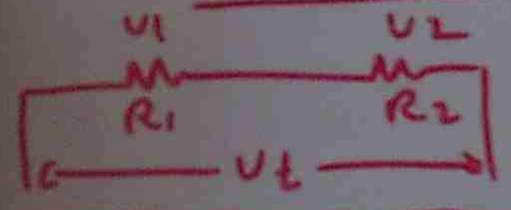
$I_1 = \frac{P}{V} = \frac{0·36}{12} = 0·03$ A, $I_2 = \frac{0·36}{12} = 0·03$ A

$I_3 = \frac{0·36}{12} = 0·03$ A

$I_T = I_1 + I_2 + I_3 = 0·03 + 0·03 + 0·03 = 0·09$ A

$P_t = V_t \times I_T = 12 \times 0·09 = 1·08$ W

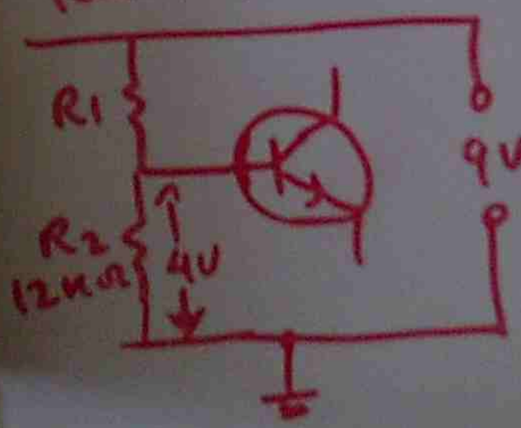
POTENTIAL DIVIDER



$V_1 = V_t \times \frac{R1}{R_1+R_2}$

$V_2 = V_t \times \frac{R_2}{R_1+R_2}$

Pb A CIRCUIT IS FED WITH A 9V SUPP BUT A 4V POTENTIAL TO GROUND IS REQUI AT THE BASE OF PARTICULAR TRANSISTO CALCULATE THE VALUE OF THE SECOND RESI FORMING THE NECESSARY POTENTIAL DIVI



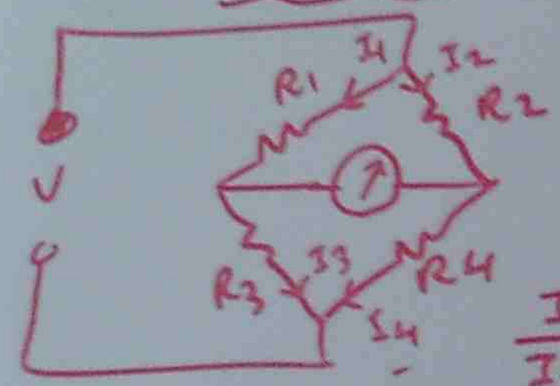
$V_{R2} = V_T \times \frac{R_2}{R_1+R_2}$

$4 = 9 \times \frac{12}{R_1+12}$

$R_1 + 12 = \frac{9 \times 12}{4} = 27$ kΩ

$R_1 = 27 - 12 = 15$ kΩ

WHEATSTONE BRIDGE



BRIDGE BALANCE

$I_1R_1 = I_2R_2$ — ①

$I_3R_3 = I_4R_4$ — ②

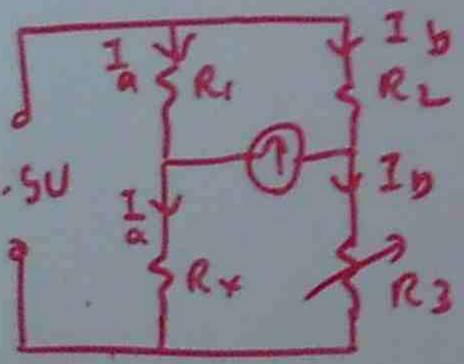
$\frac{I_1R_1}{I_3R_3} = \frac{I_2R_2}{I_4R_4}$

But $I_1 = I_3$, $I_2 = I_4$ $\therefore \frac{R1}{R3} = \frac{R2}{R4}$

PD THE BRIDGE CIRCUIT IN FIGURE HAS THE FOLLOWING VALUES AT BALANCE

$R_1 = 1000\Omega$, $R_2 = 1000\Omega$, $R_3 = 2715\Omega$

CALCULATE THE VALUE OF UNKNOWN RESISTOR (R_X).



$I_aR_1 = I_bR_2$ — ①

$I_aR_X = I_bR_3$ — ②

$\frac{I_aR_1}{I_aR_X} = \frac{I_bR_2}{I_bR_3}$

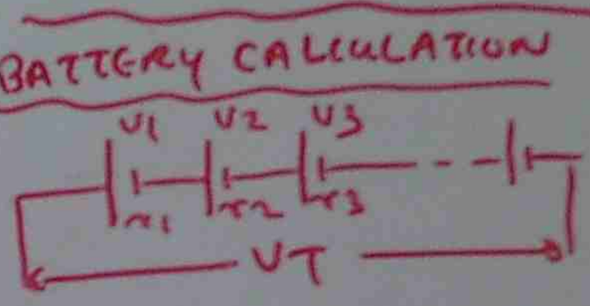
$\frac{R_1}{R_X} = \frac{R_2}{R_3}$

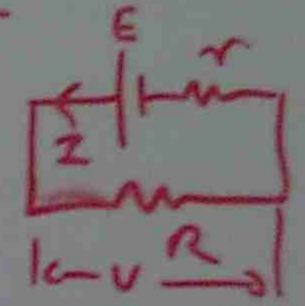
$\frac{1000}{R_X} = \frac{1000}{2715} \rightarrow R_X = \frac{1000 \times 2715}{1000} = 2715\Omega$

ELECTRO CHEMISTRY

$I = \frac{E}{R+r}$

BATTERY CALCULATION





$V = E + Ir$

Pb A CELL HAS AN E.M.F OF 1.5V AND AN INTERNAL RESISTANCE OF 0.5Ω.

CALCULATE IT'S TERMINAL VOLTAGE (a) ON NO LOAD

(b) WHEN PROVIDING A CURRENT of 200mA

(c) WHEN CONNECTED TO A LOAD of RESISTANCE 8Ω

(a) $E = V + Ir \Rightarrow 1.5 = V + (0) \times 0.5 \rightarrow V = 1.5$

(b) $E = V + Ir \Rightarrow 1.5 = V + 200 \times 10^{-3} \times 0.5$

$1.5 = V + 0.1 \longrightarrow V = 1.5 - 0.1 = 1.4V$

(c) $I = \frac{E}{R+r} = \frac{1.5}{8+0.5} = \frac{1.5}{8.5} = 0.176A$

$E = V + Ir \rightarrow 1.5 = V + 0.176 \times 0.5$

$V = 1.5 - 0.176 \times 0.5 = 1.41V$

PD A BATTERY IS MADE BY CONNECTING 8 CELLS IN SERIES, EACH CELL HAS EMF 1.5V, INTERNAL RESISTANCE 0.35Ω. CALCULATE (a) E_T & r_t (b) TERMINAL VOLTAGE AT 300mA

$E_T = 1.5 \times 8 = 12V$

$r_t = 0.35 \times 8 = 2.8\Omega$

$E_t = V_t + I(r_t)$

$12 = V_t + 300 \times 10^{-3} \times 2.8$

$V_t = 10.11V$

ELECTRICAL WORKSHOP

E003 + (E004)

(10) LAMP AND RESISTOR CIRCUITS

SLIDE (1) ⟶ (9)

Q85 ⟶ Q91

(11) WHEAT STONE BRIDGE

SLIDE (1) ⟶ (14)

Q92 ⟶ Q100

EOH + EOH RISK ANALYSIS
+ OHS

(1) HAZARDS OF ELECTRICITY

- HAZARDS OF ARC / FLASH EFFECT
  BURNS, HEARING DAMAGE, LOSS OF EYE SIGHT, LUNG COLLASPE, MEMORY LOSS, INJURIES FROM FLYING SHRAPNEL, INJURIES FROM FALL

PREVENTION

- ELIMINATION / SUBSTITUTION
- ENGINEERING CONTROL
- ADMINISTRATIVE CONTROL
- WORK PRACTICE CONTROL
- PERSONAL PROTECTIVE EQUIPMENT

INITIAL RESPONSE TO ELECTRICAL INJURY

SHUT OFF POWER, NOT TO MOVE THE PERSON
CHECK FOR RESPIRATION & PULSE
RUN COOL WATER OVER THE BURN, SEE DOCTOR

(1) HAZARDS OF ELECTRICITY & RISK ASSESSMENT
SLIDE (1) → (7) | Q1 → Q7

ELECTRICAL MAINTENANCE / SAFETY

- RELOCATE FUEL DEPOT FROM ELECTRICAL POWER SYSTEM
- COVER THE PROTECTIVE EQUIPMENT WITH PROPER INSULATION.
- REPLACE THE DEFECTIVE PARTS
- PERIODIC MAINTENANCE

PLAN, INSPECT, CLEAN, TIGHTEN, LUBRICATE TEST, RECORD, EVALUATE (TO REDUCE THE RISK, PERFORM PERIODIC INSPECTION)

RISK ANALYSIS	RISK LEVEL
- ELIMINATE THE RISK	SEVERE
- REPLACE THE RISK	HIGH
- CONTROL THE RISK	MEDIUM
- REDUCE THE RISK	LOW
	NO RISK

FOLLOW RISK REDUCTION PROCEDURES IN ELECTRICAL MAINTENANCE WORK

- FOLLOW SAFETY INSTRUCTION / PROCEDURE
- FOLLOW STANDARD WORK MANUALS
- FOLLOW APPROPRIATE RISK CONTROL PROCEDURES

(2) RISK ANALYSIS
SLIDE (1) → (3) { Q8 → Q12

LOW VOLTAGE SAFETY

LOW VOLTAGE - HIGHER THAN 50V (AC)
120 V dc . LOWER THAN
HIGH VOLTAGE

VOLTAGE HAZARDS CAN BE REDUCED BY PROPER SYSTEM GROUNDING

STEP VOLTAGE, TOUCH VOLTAGE, MESH VOLTAGE, TRANSFERRED VOLTAGE.

THE NATURE OF HAZARDS

THE RELATION SHIP OF FREQUENCY TO ELECTRICAL HAZARD - UP TO 100 Hz → SIMILAR EFFECT of AC & DC CURRENT

ABOVE 100Hz → 10 → 100mA THRESHOLD

CAPACITIVE DISCHARGE-

1μF, 10KV → VENTRICULAR FIBRILLATION

SPECIFIC HAZARDS of ELECTRONIC EQUIPMENT

ELECTRIC SHOCK FROM 120 → 240, 480V POWER SUPPLY, RADIO FREQUENCY, INDUCED VOLTAGE, NON IONIZING RF RADIATION HAZARDS

- ELECTRICAL HAZARD, CHEMICAL HAZARD EXPLOSION HAZARD

(3) LOW VOLTAGE SAFETY

SLIDE (1) → (6), @13 → @16

MEDIUM & HIGH VOLTAGE SAFETY

- OPEN CIRCUIT OF THE SECONDARY OF C.T CAUSES HIGH VOLTAGE
- SYSTEM GROUND → THE CONNECTION OF ONE OF THE CONDUCTORS TO EARTH.

REDUCE THE RISK TO ELECTROCUTION

PROTECTIVE EQUIPMENTS MUST BE USED
- HARD HAT, EYE PROTECTION, ARC PROTECTION RUBBER INSULATION EQUIPMENTS, VOLTAGE TESTING DEVICES

SAFETY PROCEDURES

- APPROACH DISTANCE MUST BE REGARDED
- QUALIFIED PERSON TO PERFORM THE TASK
- COMPLETE RISK ANALYSIS
- REVIEW & APPROVE THE PLAN & RISK ANALYSIS
- DOCUMENTATION / APPROVAL PROCEDURE
- WORKING BY MINIMIZING THE RISK
- P.P.E MUST BE USED

(4) SAFETY IN SUBSTATION

SLIDE (2) → (5) @17 → @18

SAFETY PROCEDURES & METHODS

- THINK BE AWARE
- UNDERSTAND YOUR PROCEDURE
- FOLLOW YOUR PROCEDURE
- USE APPROPRIATE SAFETY EQUIPMENTS
- ASK IF YOU ARE UNSURE. DO NOT ASSUME
- DO NOT ANSWER IF YOU DO NOT KNOW.

THE STEPS REQUIRED BEFOR DE-ENERGIZATION

- ALL ENERGY CONTROL DEVICES FEEDING THE AREA MUST BE OPENED
- LOCKS & TAGS PLACED ON ENERGY CONTROL DEVICES
- VOLTAGE MEASUREMENT
- SAFETY GROUNDING
- QUALIFIED INSPECTOR INSPECTS THE WORK AREA

- TEST THE INSTRUMENT
- MEASURE THE EQPT BEING VERIFIED
- RETEST THE INSTRUMENT

ONE MINUTE SAFETY AUDIT

1. NOTIFY THE RESPONSIBLE PERSONNEL OF YOUR PRESENCE IN AREA
2. LISTEN TO ANY ABNORMAL SOUND SNIFF FOR UNUSUAL ODORS.
3. LOCATE ALL FIRE EMERGENCY EXITS.
4. LOCATE ALL FIRE ALARMS AND TELEPHONES
5. INSPECT ALL TRANSFORMER LIQUID LEVEL, TEMPERATURE, PRESSURE
6. LOCATE STATION ONE LINE DIAGRAM
7. MAKE CERTAIN ROOM IS NEAT & TIDY
8. BE CERTAIN THAT ALL REQUIRED EQUIPMENT IS READILY AVAILABLE & EASILY REACHED
9. CHECK TO SEE THAT ALL PROTECTIVE RELAY AND OTHER OPERATIONAL FLAGS ARE PROPERLY RESET.

ELECTRICAL INSTALLATION SAFETY

- PROPER DESIGN
- SELECTION
- INSTALLATION
- CALIBRATION

ENGINEERING

PROPERTY TESTING & PHYSICAL SETTING OF DEVICE SHOULD BE CARRIED OUT TO ENSURE THAT THE EQUIPMENT IS CAPABLE OF PERFORMING WHEN CALLED UPON.

HUMAN FACTORS IN ELECTRICAL SAFETY

- SENSE PHYSICAL STIMULI
- PERCEIVE AND PROCESS INFORMATION
- ACT

SLOW REACTION

- SLEEP DEPRIVATION
- FATIGUE
- TIME OF DELAY
- ENVIRONMENTAL EXTREME

- ALCOHOL
- DRUG USE
- MEDICAL PROBLEM
- NUTRITION

(5) INSTALLATION SAFETY

SLIDE 3 → 5

@19 → @20

(6) WORKING NEAR EXPOSED MAIN

SLIDE 1 → 3

@21 → @22

PERFORM THE ASSIGNMENT EXERCISE OUTLINED IN STUDY GUIDE

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E011 + E017

PART(1) + PART(2)

www.esipowersystem.zoomshare.com

- STUDY PACKAGE(1) SAFETY & INSTALLATION PROCEDURE
- STUDY PACKAGE(2) PLANNING

- REGULATORY REQUIREMENTS

PART(3) - RISK MANAGEMENT STRATEGIES

PART(4) EVALUATE RISK MANAGEMENT STRATEGIES

E017

PART(1)

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STUDY PACKAGE(1) SAFETY & INSTALLATION PROCEDURE

ESI SAFETY PART 1 → 5

DO EXERCISES

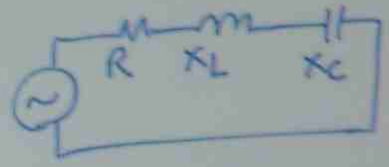
PART(2)

PERFORM EXERCISE(2)

PART(3)

PERFORM EXERCISE(3)

(1) SERIES RESONANT CIRCUIT



$$Z = R + jX_L - jX_C$$

$$X_L = 2\pi fL$$

$$X_C = \frac{1}{2\pi fC}$$

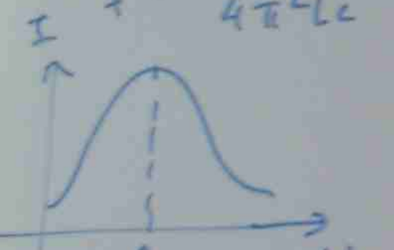
AT RESONANCE, $X_L = X_C \longrightarrow Z = R$

$$I = \frac{E}{Z} = \frac{E}{R} \quad \text{(MAXIMUM CURRENT)}$$

$$2\pi fL = \frac{1}{2\pi fC}$$

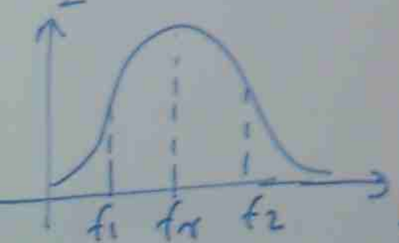
$$f^2 = \frac{1}{4\pi^2 LC} \longrightarrow f_r = \frac{1}{2\pi\sqrt{LC}}$$

f_r RESONANT FREQUENCY



QUALITY FACTOR

$$Q = \frac{\text{REACTIVE POWER}}{\text{AVERAGE POWER}} = \frac{X_L}{R}$$

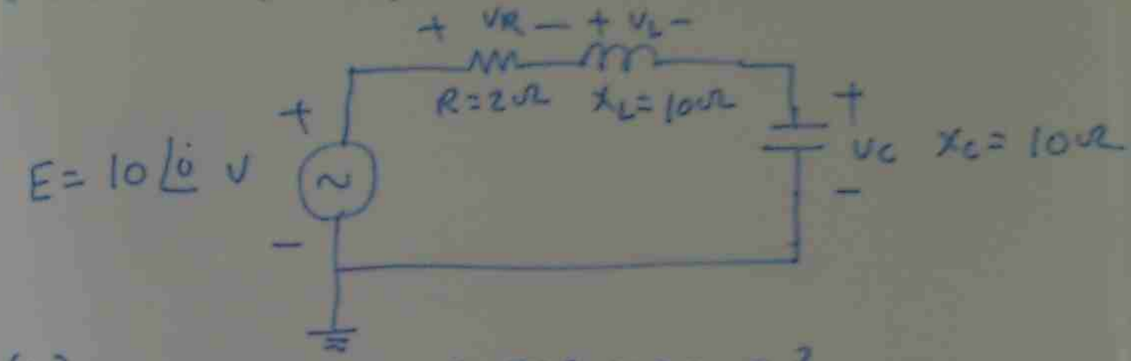


$$BW = f_2 - f_1 = \frac{f_r}{Q}$$

P_{HPF} (HALF POWER FREQUENCY) $= \frac{1}{2} P_{MAX}$

Pb. FOR THE GIVEN SERIES RESONANT CIRCUIT,

(a) FIND I, V_R, V_L AND V_C AT RESONANCE.



(b) WHAT IS Q OF THE CIRCUIT?

(c) IF RESONANT FREQUENCY IS 5000 HZ, FIND BANDWIDTH

(d) WHAT IS POWER DISSIPATED IN CIRCUIT AT HALF POWER FREQUENCY?

(a) $Z = R + jX_L - jX_C = 2 + j10 - j10 = 2\Omega$

$$I = \frac{E}{Z} = \frac{10\angle 0}{2\angle 0} = 5\angle 0 \text{ Amp}, \quad V_R = 5 \times 2 = 10 \text{ V}$$

$$V_L = I X_L = 5\angle 0 \times 10\angle 90 = 50\angle 90 \text{ V}$$

$$V_C = I X_C = 5\angle 0 \times 10\angle -90 = 50\angle -90 \text{ V}$$

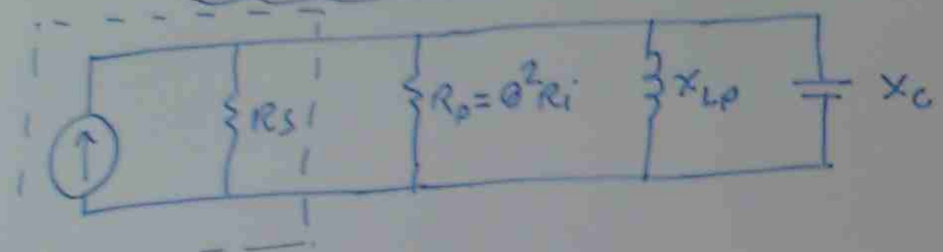
(b) $Q = \frac{X_L}{R} = \frac{10}{2} = 5$

(c) $BW = f_2 - f_1 = \frac{f_r}{Q} = \frac{5000}{5} = 1000 \text{ Hz}$

(d) $P_{HPF} = \frac{1}{2} P_{MAX} = \frac{1}{2} I_{MAX}^2 R$

$= \frac{1}{2} \times 5^2 \times 2 = 25 \text{ W}$

PARALLEL RESONANT CIRCUIT

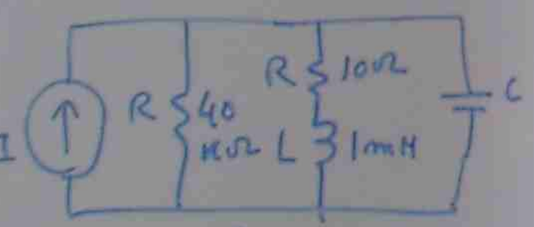


$$R_p = \frac{L}{R_L C}, \quad Z_{TP} = R_s // R_p = R_s // Q_L^2 R_L$$

$$f_p = f_s \sqrt{1 - \frac{1}{Q_L^2}}, \quad BW = \frac{R_L}{2\pi f L}$$

Pb/ FOR THE GIVEN NETWORK WITH f_p PROVIDED,

(a) DETERMINE Q_L
(b) DETERMINE R_P
(c) CALCULATE Z_{TP}
(d) FIND "C" AT RESONANCE
(e) FIND Q_P
(f) CALCULATE BW



$f_p = 0.04\,MHz$

(a) $Q_L = \frac{X_L}{R_L} = \frac{2\pi f_p L}{R_L} = \frac{2 \times 3.14 \times 0.04 \times 10^6 \times 1 \times 10^{-3}}{10}$

$= 25.12$

(b) $R_p = Q_L^2 R_L = (25.12)^2 \times 10 = 6.31\ K\Omega$

(c) $Z_{TP} = R_s // R_p = \frac{R_s R_p}{R_s + R_p} = \frac{40 \times 6.31}{40 + 6.31}$

$= 5.45\ K\Omega$

(d) $C = \frac{1}{4\pi^2 f^2 L} = \frac{1}{4 \times 3.14^2 \times (0.04 \times 10^6)^2 \times 1 \times 10^{-3}}$

$= 15.9 \times 10^{-9}\ F$

$= 15.9\ nF$

(e) $Q_p = \frac{Z_{TP}}{X_L} = \frac{5.45 \times 10^3}{2\pi f_p L} = \frac{5.45 \times 10^3}{2 \times 3.14 \times 0.04 \times 10^6 \times 1 \times 10^{-3}}$

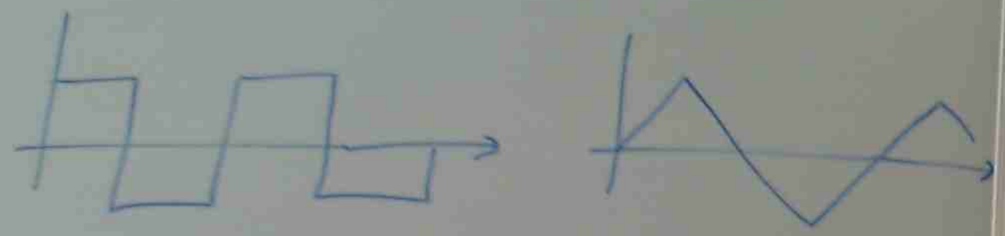
$= 21.68$

(f) $BW = \frac{f_p}{Q_p} = \frac{0.04 \times 10^6}{21.68} = 1.85\ KHz$

STUDY EQ2S [2] SLIDE 2. → 4

DO EXERCISES

(2) NON SINUSOIDAL CIRCUITS

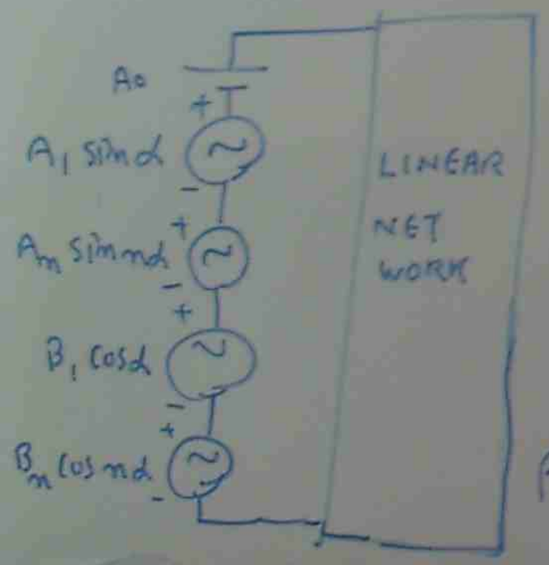


FOURIER SERIES

$$f(t) = \underbrace{A_0}_{\text{DC (OR) AVERAGE VALUE}} + A_1 \sin\omega t + A_2 \sin 2\omega t + \cdots + B_1 \cos\omega t + B_2 \cos 2\omega t + \cdots$$

$$A_0 = \frac{1}{T}\int_0^T f(t)\,dt, \quad A_m = \frac{2}{T}\int_0^T f(t)\sin m\omega t\,dt$$

$$B_m = \frac{2}{T}\int_0^T f(t)\cos m\omega t\,dt$$



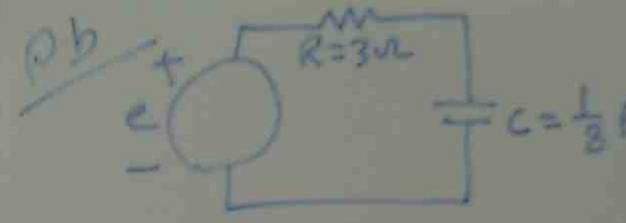
$$V_{eff} = \sqrt{V_0^2 + \frac{V_{m_1}^2 + V_{m_2}^2 + \cdots}{2}}$$

$$V_{eff} = \sqrt{V_0^2 + V_{1\,eff}^2 + V_{2\,eff}^2 + \cdots}$$

SIMILAR FOR I_{eff}

$$P_T = V_0 I_0 + V_1 I_1 \cos\theta_1 + \cdots + V_m I_m \cos\theta_m$$

Pb



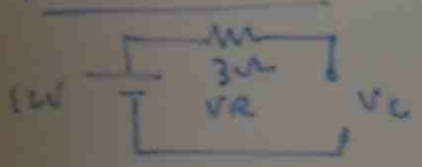
THE INPUT TO THE CIRCUIT IS $e = 12 + 10\sin 2t$

(a) FIND THE CURRENT i AND VOLTAGE V_R & V_C

(b) THE EFFECTIVE VALUE OF i, V_R, V_C

(c) FIND THE POWER DELIVERED TO THE CIRCUIT

FOR DC SUPPLY

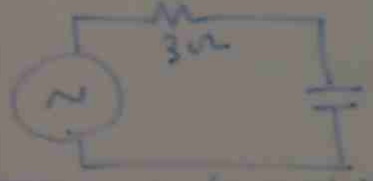


$V_R = 0$, $I = 0$, $V_C = 12V$

FOR $10\sin 2t$ SUPPLY

$\sin 2t$

$\omega = 2$



$$X_C = \frac{1}{\omega C} = \frac{1}{2 \times 1/8} = 4\,\Omega$$

$$Z = \sqrt{R^2 + X_C^2}\,\angle -\tan^{-1}\frac{X_C}{R} = \sqrt{3^2+4^2}\,\angle -\tan^{-1}\frac{4}{3}$$

$$I = \frac{E}{Z} = \frac{10/\sqrt{2}\,\angle 0}{5\,\angle -53.2} = 1.4142\,\angle 53.2 \text{ A}$$

$$V_R = I \times R = 1.4142\,\angle 53.2 \times 3\,\angle 0 = 4.24\,\angle 53.2 \text{ V}$$

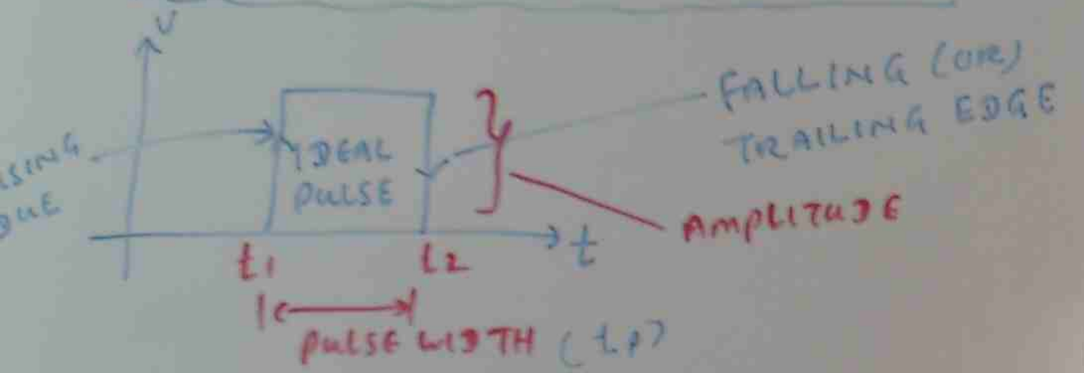
$$V_{C\,eff} = I X_C = 1.4142\,\angle 53.2 \times 4\,\angle -90 = 5.64\,\angle -36.8$$

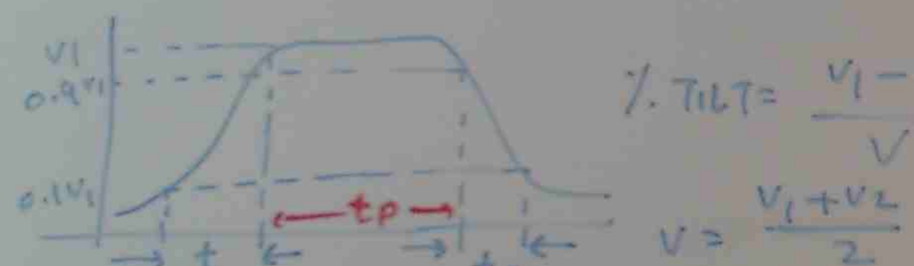
$I_{eff} = \sqrt{0^2 + 1.414^2} = 1.414$ Amp

$P_{eff} = I_{eff}^2 R = 1.414^2 \times 3 = 6$ W

$V_{C\,eff} = \sqrt{12^2 + 5.64^2} = 13.67$ V ✓

(3) PULSE WAVE FORMS AND RC RESPONSE





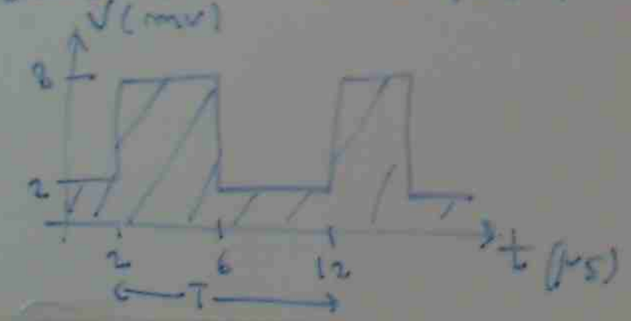
$\%\ TILT = \frac{V_1 - V_2}{V}$

$V = \frac{V_1 + V_2}{2}$

DUTY CYCLE = $\frac{\text{PULSE WIDTH}}{\text{PERIOD}} = \frac{t_p}{T}$

FREQUENCY = $\frac{1}{\text{PERIOD}}$, $f = \frac{1}{T}$

DETERMINE THE AVERAGE VALUE FOR PERIODIC PULSE WAVE FORM



AVERAGE VALUE (G) = $\frac{\text{AREA UNDER CURVE}}{T}$

$G = \frac{8(6-2) + 2(12-6)}{12-2} = \frac{8\times4 + 2\times6}{10}$

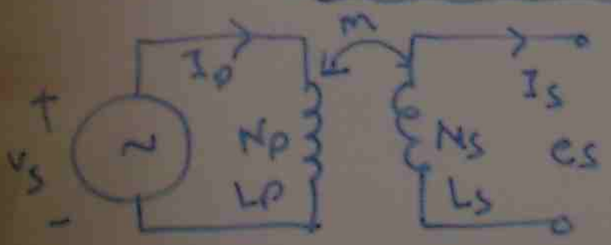
$= \frac{44}{10} = 4.4\,mV$

DUTY CYCLE = $\frac{t_p}{T} = \frac{6-2}{12-2} = \frac{4}{10} = 0.4$

STUDY E025/4 | SLIDE 1 ⟶ 6

DO THE EXERCISES

(4) TRANSFORMER

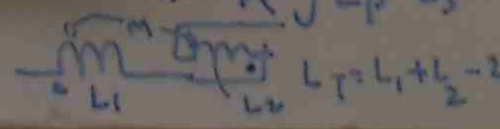


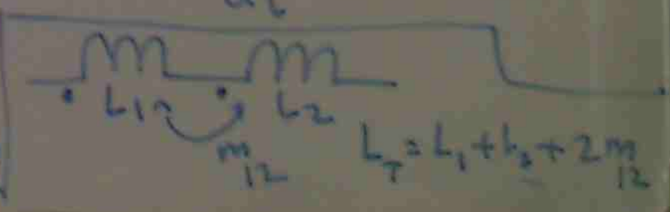
$e_p = L_p \frac{di_p}{dt}$

$e_p = N_p \frac{d\phi_p}{dt}$

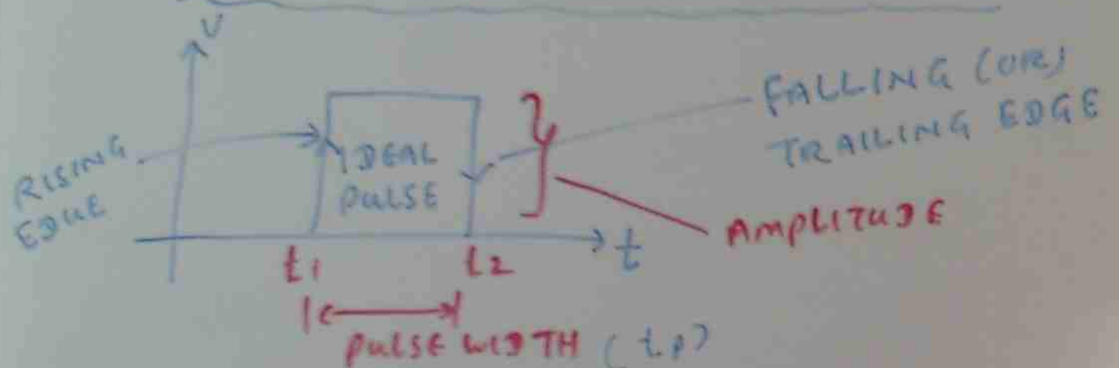
$e_s = L_s \frac{dI_s}{dt}$, $e_s = N_s \frac{d\phi_s}{dt}$

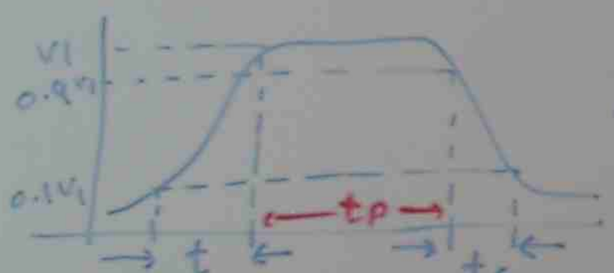
$m = k\sqrt{L_p L_s}$





③ PULSE WAVE FORMS AND RC RESPONSE





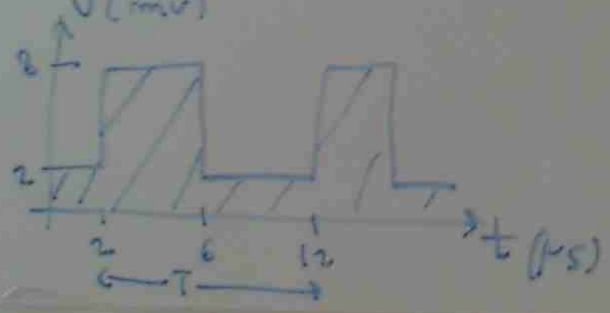
$\%\ TILT = \frac{V_1 - V_2}{V}$

$V = \frac{V_1 + V_2}{2}$

$DUTY\ CYCLE = \frac{PULSE\ WIDTH}{PERIOD} = \frac{t_p}{T}$

$FREQUENCY = \frac{1}{PERIOD}, \quad f = \frac{1}{T}$

Pb/ DETERMINE THE AVERAGE VALUE FOR PERIODIC PULSE WAVE FORM



$AVERAGE\ VALUE\ (G) = \frac{AREA\ UNDER\ CURVE}{T}$

$G = \frac{8(6-2) + 2(12-6)}{12-2} = \frac{8\times4 + 2\times6}{10}$

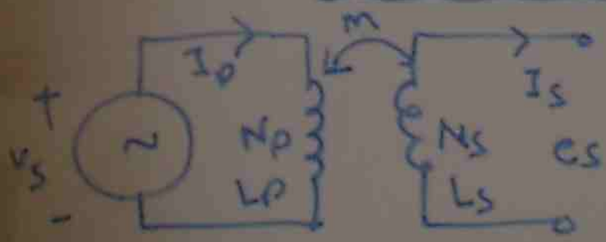
$= \frac{44}{10} = 4.4\ mV$

$DUTY\ CYCLE = \frac{t_p}{T} = \frac{6-2}{12-2} = \frac{4}{10} = 0.4$

STUDY E025/4 | SLIDE 1 ⟶ 6

DO THE EXERCISES

④ TRANSFORMER

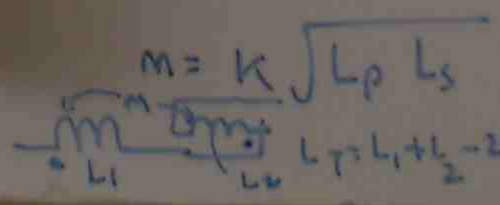


$e_p = L_p \frac{di_p}{dt}$

$e_p = N_p \frac{d\phi_p}{dt}$

$e_s = L_s \frac{dI_s}{dt}, \quad e_s = N_s \frac{d\phi_s}{dt}$

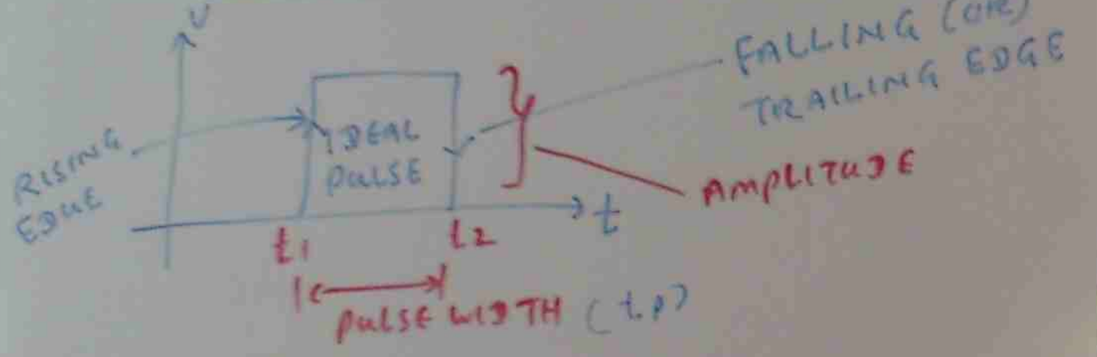
$M = K\sqrt{L_p L_s}$

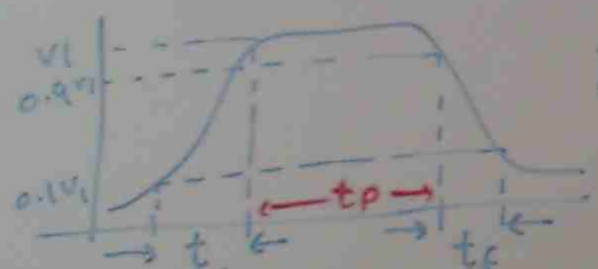


$L_T = L_1 + L_2 - 2M$

$L_T = L_1 + L_2 + 2M_{12}$

③ PULSE WAVE FORMS AND RC RESPONSE





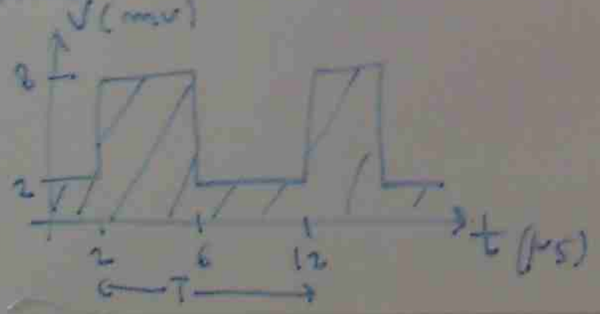
$\%\ TILT = \frac{V_1 - V_2}{V}$

$V = \frac{V_1 + V_2}{2}$

DUTY CYCLE = $\frac{\text{PULSE WIDTH}}{\text{PERIOD}} = \frac{t_p}{T}$

FREQUENCY = $\frac{1}{\text{PERIOD}}$, $f = \frac{1}{T}$

Pb/ DETERMINE THE AVERAGE VALUE FOR PERIODIC PULSE WAVE FORM



AVERAGE VALUE = $\frac{\text{AREA UNDER CURVE}}{T}$

(a)

$G_1 = \frac{8(6-2) + 2(12-6)}{12-2} = \frac{8\times4 + 2\times6}{10}$

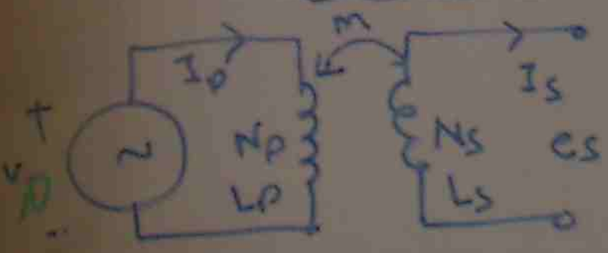
$= \frac{44}{10} = 4.4\,mV$

DUTY CYCLE = $\frac{t_p}{T} = \frac{6-2}{12-2} = \frac{4}{10} = 0.4$

STUDY EO25/4 | SLIDE 1 ⟶ 6

DO THE EXERCISES

④ TRANSFORMER

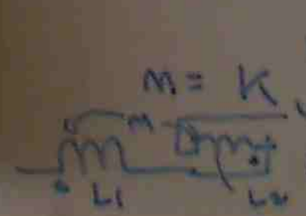


$e_p = L_p \frac{di_p}{dt}$

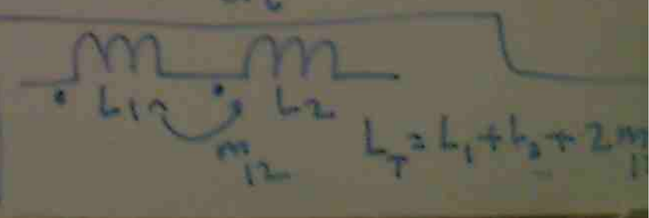
$e_p = N_p \frac{d\phi_p}{dt}$

$e_s = L_s \frac{dI_s}{dt}$, $e_s = N_s \frac{d\phi_s}{dt}$

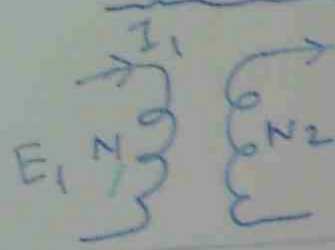
$M = K\sqrt{L_p L_s}$



$L_T = L_1 + L_2 - 2M_{12}$



TRANSFORMER



$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

$$E_1 = 4.44 f N_1 \phi_m$$

ϕ_m = flux
f = FREQUENCY
E_1 = PRIMARY VOLTAGE
E_2 = SECONDARY VOLTAGE
N_1 = PRIMARY TURN
N_2 = SECONDARY TURN
I_1 = PRIMARY CURRENT
I_2 = SECONDARY CURRENT

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a$$

a = TURN RATIO

Pb.

$E_p = 200V$, $N_p = 50$, $E_s = 2400V$, $N_s = ?$, $f = 60Hz$

CALCULATE
(a) MAXIMUM FLUX ϕ_m
(b) SECONDARY TURN N_s

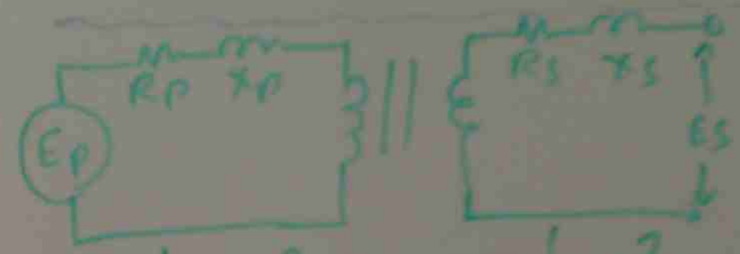
$$E_p = 4.44 N_p f \phi_m$$

$$\phi_m = \frac{E_p}{4.44 \times N_p \times f} = \frac{200}{4.44 \times 50 \times 60} = 15.02 \times 10^{-3} wb$$

15.02 m wb

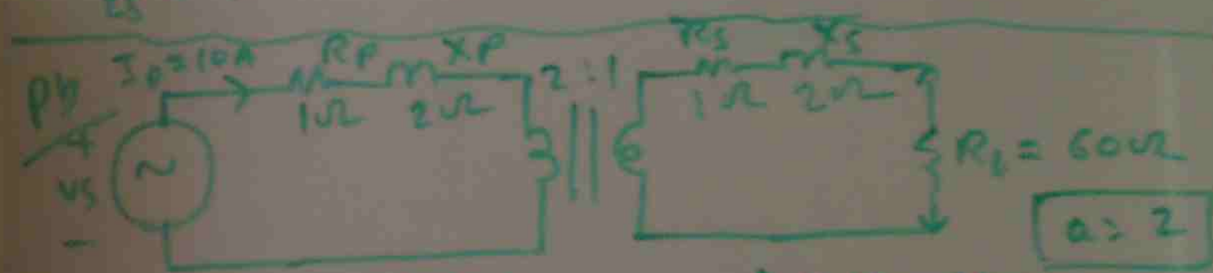
$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \rightarrow N_s = \frac{E_s N_p}{E_p} = \frac{2400 \times 50}{200} = 600 \text{ TURNS}$$

REFLECTED IMPEDANCE & POWER



$$R_s' = a^2 R_s, \quad X_s' = a^2 X_s, \quad Z_s' = a^2 Z_s$$

R_s' = SECONDARY RESISTANCE REFER TO PRIMARY
X_s' = SECONDARY REACTANCE REFER TO PRIMARY
Z_s' = SECONDARY IMPEDANCE REFER TO PRIMARY



DETERMINE (a) R_e, X_e, (b) V_L, V_S

(a) $R_e = R_p + a^2 R_s = 1 + 2^2 \times 1 = 5\Omega$

$X_e = X_p + a^2 X_s = 2 + 2^2 \times 2 = 10\Omega$

(b) $a V_L = I_p \times a^2 R_L = 10 \times 2^2 \times 60 = 2400V$

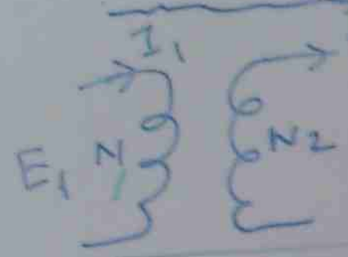
$$V_L = \frac{2400}{a} = \frac{2400}{2} = 1200V$$

$$V_S = I_p (R_e + a^2 R_L + j X_e)$$

$$= 10(5 + 2^2 \times 60 + j10)$$

$$= 10(245 + j10) = 10 \times \sqrt{245^2 + 10^2} = 2452.04V$$

TRANSFORMER



$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

$$E_1 = 4.44 f N_1 \phi_m$$

ϕ_m = flux

f = FREQUENCY

E_1 = PRIMARY VOLTAGE
E_2 = SECONDARY VOLTAGE
N_1 = PRIMARY TURN
N_2 = SECONDARY TURN
I_1 = PRIMARY CURRENT
I_2 = SECONDARY CURRENT

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a$$

a = TURN RATIO

Pb.

$E_p = 200V$
$N_p = 50$
$E_s = 2400V$
$N_s = ?$
$f = 60Hz$

CALCULATE
(a) MAXIMUM FLUX ϕ_m
(b) SECONDARY TURN N_1

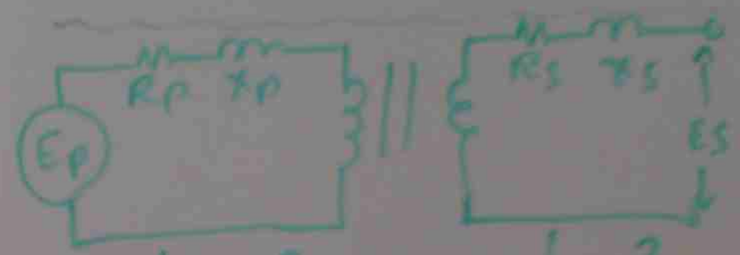
$$E_p = 4.44 N_p f \phi_m$$

$$\phi_m = \frac{E_p}{4.44 \times N_p \times f} = \frac{200}{4.44 \times 50 \times 60} = 15.02 \times 10^{-3} wb$$

15.02 m wb

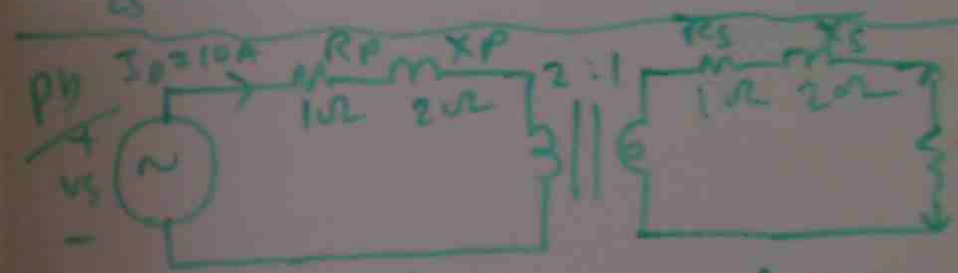
$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \rightarrow N_s = \frac{E_s N_p}{E_p} = \frac{2400 \times 50}{200} = 600 \text{ TURNS}$$

REFLECTED IMPEDANCE & POWER



$$R_s' = a^2 R_s, \quad X_s' = a^2 X_s, \quad Z_s' = a^2 Z_s$$

R_s' = SECONDARY RESISTANCE REFER TO PRIMARY
X_s' = SECONDARY REACTANCE REFER TO PRIMARY
Z_s' = SECONDARY IMPEDANCE REFER TO PRIMARY



DETERMINE (a) R_e, X_e, (b) V_L, V_S

(a) $R_e = R_p + a^2 R_s = 1 + 2^2 \times 1 = 5\Omega$

$X_e = X_p + a^2 X_s = 2 + 2^2 \times 2 = 10\Omega$

(b) $a V_L = I_p \times a^2 R_L = 10 \times 2^2 \times 60 = 2400V$

$$V_L = \frac{2400}{a} = \frac{2400}{2} = 1200V$$

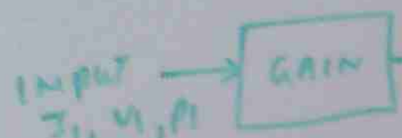
$$V_S = I_p (R_e + a^2 R_L + j X_e)$$
$$= 10 (5 + 2^2 \times 60 + j10)$$
$$= 10 (245 + j10) \quad 10 \times \sqrt{245^2 + 10^2} = 2452.04V$$

V

TRANSFORMER EXERCISE

E025/7/SLIDE 1 → 6

(6) DECIBEL, FILTERS, BODE PLOTS



VOLTAGE GAIN $= \frac{V_2}{V_1}$, POWER GAIN $= \frac{P_2}{P_1}$

CURRENT GAIN $= \frac{I_2}{I_1}$

DECIBEL

$dB_{\text{POWER GAIN}} = 10 \log_{10} \frac{P_2}{P_1}$

$dB_{\text{VOLTAGE GAIN}} = 20 \log_{10} \frac{V_2}{V_1}$

$dB_{\text{CURRENT GAIN}} = 20 \log_{10} \frac{I_2}{I_1}$

Pb IF A SYSTEM HAS A VOLTAGE GAIN of 36 dB, FIND THE APPLIED VOLTAGE IF OUTPUT VOLTAGE IS 6.8V

$dB_{\text{VOLTAGE}} = 20 \log \frac{V_0}{V_i}$

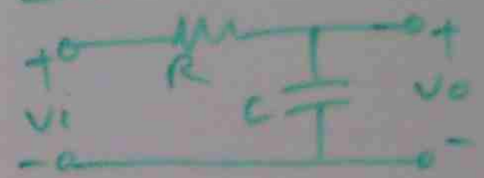
$36 = 20 \log \frac{6.8}{V_i}$

$\frac{36}{20} = \log_{10} \frac{6.8}{V_i}$ → $1.8 = \log_{10} \frac{6.8}{V_i}$ → $\frac{6.8}{V_i} = 10^{1.8}$

$V_i = \frac{6.8}{10^{1.8}} = 0.109V$

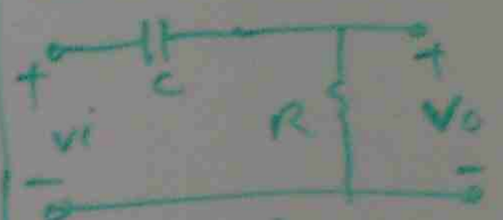
FILTERS

RC LOW PASS FILTER



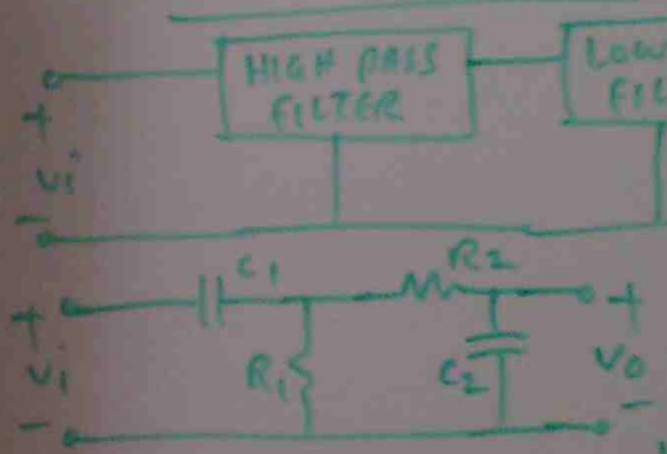
$V_0 = \frac{V_i}{\sqrt{(\frac{R}{X_C})^2 + 1}}$

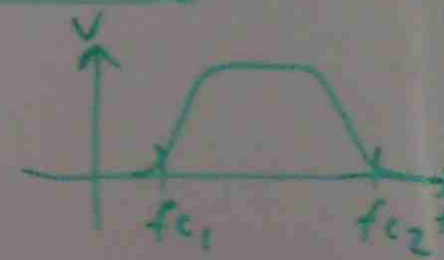
RC HIGH PASS FILTER



$V_0 = \frac{V_i}{\sqrt{(\frac{X_C}{R})^2 + 1}}$

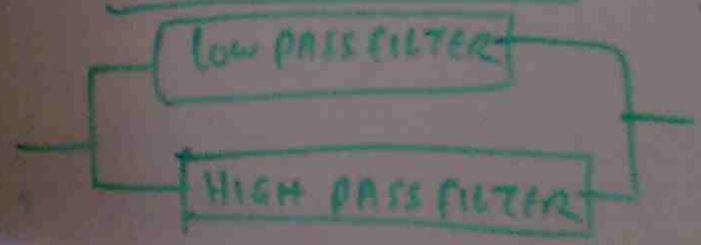
BAND PASS FILTER

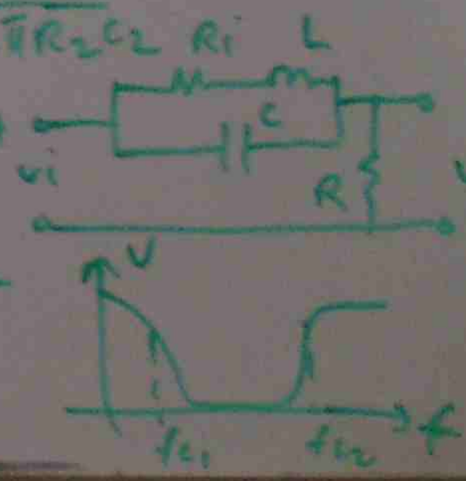




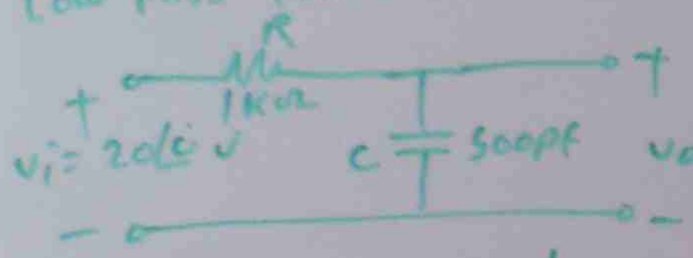
$f_{c_1} = \frac{1}{2\pi R_1 C_1}$, $f_{c_2} = \frac{1}{2\pi R_2 C_2}$

BAND STOP FILTER





Pb SKETCH THE OUTPUT VOLTAGE V_O VERSUS FREQUENCY FOR GIVEN LOW PASS FILTER



$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\times 3.1416\times 1\times10^{3}\times 500\times10^{-12}}$$
$$= 318.31\ KHz$$

$$V_O = \frac{V_i}{\sqrt{\left(\frac{R}{X_c}\right)^2+1}} \quad \frac{V_i}{\sqrt{(2\pi f_c R)^2+1}}$$

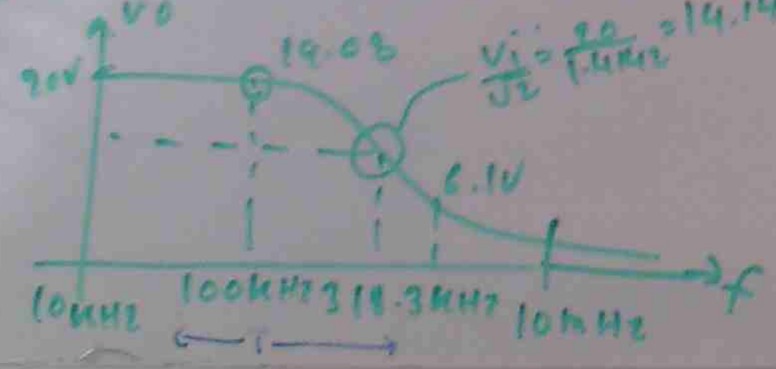
$f = 10KHz \rightarrow 100KHz \rightarrow 1mHz \rightarrow 10mHz$

$f = 10KHz (V_O) = \frac{20}{\sqrt{(2\times3.14\times10\times10^{3}\times500\times10^{-12}\times1\times10^{3})^2+1}}$

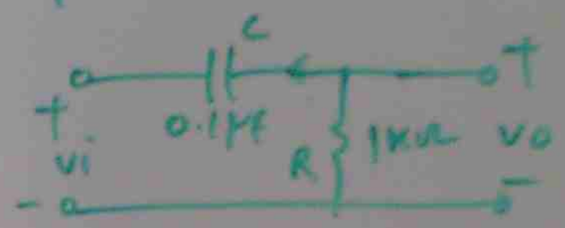
$\simeq 20V$

$f = 100KHz \rightarrow V_O = 19.08V$ $\quad f = 10mHz$

$f = 1mHz \rightarrow V_O = 6.1V$ $\quad \hookrightarrow V_O \simeq 0$



Pb SKETCH $A_{V\,dB}$ FOR GIVEN HIGH PASS FILTER CIRCUIT

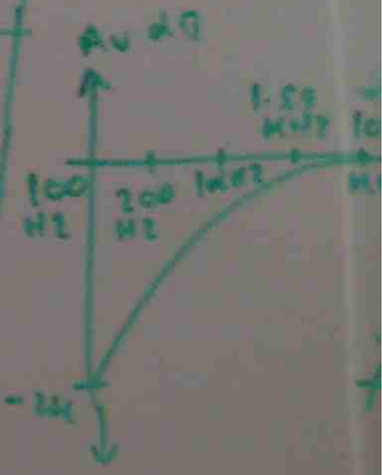


$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\times3.14\times1\times10^{3}\times0.1\times10^{-6}}$$
$$= 1592.36\ Hz$$

$$|A_{V\,dB}| = 20\log_{10}\frac{1}{\sqrt{1+\left(\frac{f_c}{f}\right)^2}}$$

f 100Hz → 200Hz → 1KHz → 1.59 KHz → 10 KHz

f	$A_{V\,dB}$	dB
100Hz	$20\log_{10}\frac{1}{\sqrt{1+\left(\frac{1592}{100}\right)^2}}$	−24
200	$20\log_{10}\frac{1}{\sqrt{1+\left(\frac{1592}{200}\right)^2}}$	−20
1KHz=1000	$20\log_{10}\frac{1}{\sqrt{1+\left(\frac{1592}{1000}\right)^2}}$	−6
1.59KHz	$20\log_{10}\frac{1}{\sqrt{1+\left(\frac{1592}{1592}\right)^2}}$	−3
10KHz	$20\log_{10}\frac{1}{\sqrt{1+\left(\frac{10000}{1592}\right)^2}}$	0



BODE PLOT + FILTER EXERCISES

STUDY

- E025/11/SLIDE 1 → 2

  Q 48 → 57

  DO THE EXERCISES

E025/5/SLIDE 1 → 5

Q 21 → 29

E025/6/SLIDE 1/2:

Q 30 → 32

80 sin ωt

$X_L = 2\pi fL$
$= 250 \times 0.2 = 50\Omega$



$\omega = 250$ rad/sec

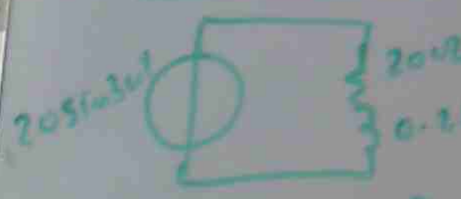
$Z = \sqrt{R^2 + X_L^2}$
$= \sqrt{20^2 + 50^2}$
$= 53.85\ \Omega$

$\theta = \tan^{-1}\frac{50}{20} = 68.2^\circ$

$I = \frac{E}{Z} = \frac{80}{53.85} = 1.49$, $I = \frac{1.49}{\sqrt{2}} \sin(250t - 68.2)$
$= 1.05 \sin(250t - 68.2)$

20 sin 3ωt

$X_L = 3\omega L = 3 \times 250 \times 0.2$
$= 150\Omega$



$Z = \sqrt{20^2 + 150^2} = 151.3\Omega$

$\theta = \tan^{-1}\frac{150}{20} = 82.4^\circ$

$I = \frac{E}{Z} = \frac{20}{151.3} = 0.132$, $I = \frac{0.132}{\sqrt{2}} \sin(750t - 82.4)$

$I = 0.093 \sin(750t - 82.4)$

$E_{rms} = \sqrt{25^2 + \left(\frac{80}{\sqrt{2}}\right)^2 + \left(\frac{20}{\sqrt{2}}\right)^2} = 63.5\ V$

$I_{rms} = \sqrt{1.25^2 + \left(\frac{1.49}{\sqrt{2}}\right)^2 + \left(\frac{0.132}{\sqrt{2}}\right)^2} = 1.64\ A$

TOTAL POWER $= 1.25^2 \times 20 + 1.05^2 \times 20 + 0.093^2 \times 20$
$= 53.5$ WATT

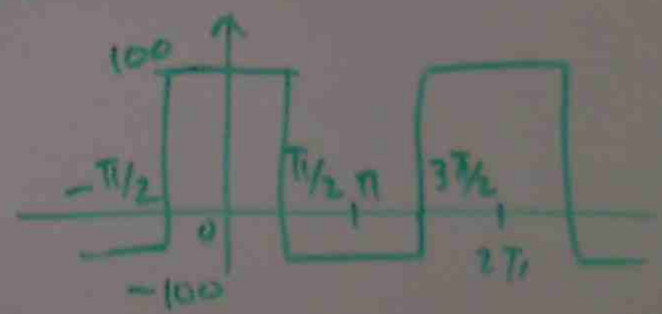
TRIGONOMETRIC FOURIER SERIES

$f(t) = A_0 + \sum (A_n \cos n\omega t + B_n \sin n\omega t)$

$A_n = \frac{1}{\pi} \int_0^{2\pi} f(t) \cos(n\theta)\, d\theta$

$B_n = \frac{1}{\pi} \int_0^{2\pi} f(t) \sin(n\theta)\, d\theta$

Pb FIND THE FIRST FOUR TERMS IN THE TRIGONOMETRIC FOURIER SERIES FOR GIVEN SQUARE



① HARMONICS & FOURIER ANALYSIS


PURE SINE WAVE


SQUARE WAVE


DISTORTED SINE WAVE


DISTORTED SQUARE WAVE

DISTORTED WAVE = FUNDAMENTAL + HIGHER FREQUENCY WAVES

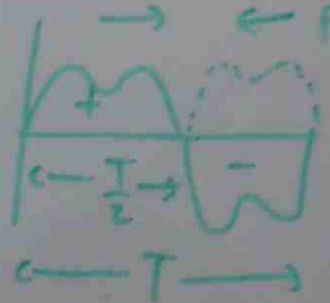
FUNDAMENTAL = BASE FREQUENCY ($\sin \omega t$)

2nd HARMONIC = 2× BASE FREQUENCY ($\sin 2\omega t$)

3rd HARMONIC = 3× BASE FREQUENCY ($\sin 3\omega t$)

$$f(t) = \frac{1}{2}a_0 + a_1 \cos\omega t + a_2 \cos 2\omega t + \cdots + b_1 \sin\omega t + b_2 \sin 2\omega t + \cdots$$

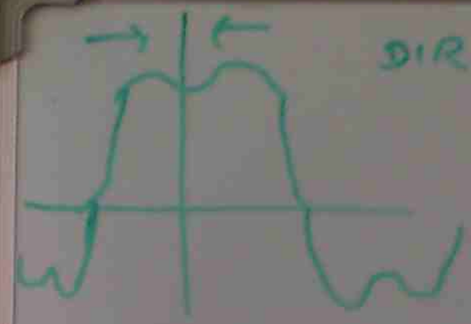
HALF WAVE SYMMETRY



$$f(t) = -f\left(t + \frac{T}{2}\right)$$

ODD HARMONIC

$f(t) = b_1 \sin\omega t + b_2 \sin 2\omega t + \cdots$

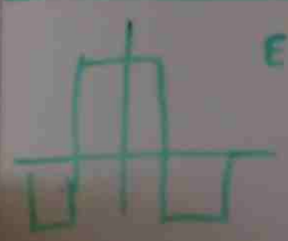


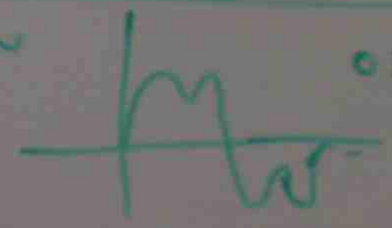
DIRECT FOLD – EVEN HARMONIC

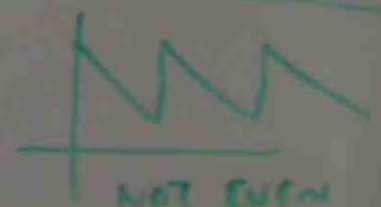
$f(t) = f(-t)$

$f(t) = a_0 + a_1 \cos\omega t + a_2 \cos 2\omega t + \cdots$ (+ − −)

DC


EVEN

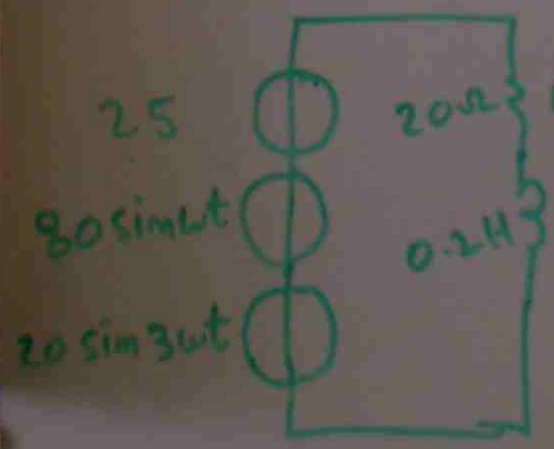

ODD

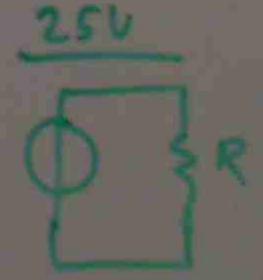

NOT EVEN
NOT ODD

NOT EVEN
NOT ODD → $f(t) = \frac{1}{2}a_0 + a_1 \cos\omega t + a_2 \cos 2\omega t + \cdots + b_1 \sin\omega t + b_2 \sin 2\omega t + \cdots$

$f(t) = \frac{2}{\pi}\sin\omega t + \frac{2}{3\pi}\sin 3\omega t + \cdots$ ODD

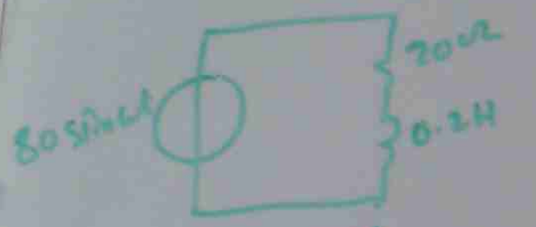
$f(t) = 70 \sin\omega t + 20 \sin 2\omega t + 10 \sin 3\omega t + 40 \cos\omega t + 10 \cos 2\omega t - \cdots$ NOT EVEN NOT ODD





$I = \frac{E}{R} = \frac{25}{20} = 1.25\,A$

80 sin ωt



$\omega = 250$ rad/sec

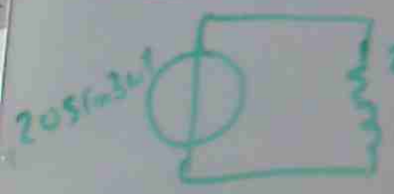
$X_L = 2\pi fL$
$= 250 \times 0.2 = 50\Omega$

$Z = \sqrt{R^2 + X_L^2}$
$= \sqrt{20^2 + 50^2}$
$= 53.85\Omega$

$\theta = \tan^{-1}\frac{50}{20} = 68.2^\circ$

$I = \frac{E}{Z} = \frac{80}{53.85} = 1.49$, $I = \frac{1.49}{\sqrt{2}} \sin(250t - 68.2)$
$= 1.05 \sin(250t - 68.2)$

20 sin 3ωt



$X_L = 3\omega L = 3 \times 250 \times 0.2$
$= 150\Omega$

$Z = \sqrt{20^2 + 150^2} = 151.3\Omega$

$\theta = \tan^{-1}\frac{150}{20} = 82.4^\circ$

$I = \frac{E}{Z} = \frac{20}{151.3} = 0.132$, $I = \frac{0.132}{\sqrt{2}} \sin(750t - 82.4)$

$I = 0.093 \sin(750t - 82.4)$

$E_{rms} = \sqrt{25^2 + \left(\frac{80}{\sqrt{2}}\right)^2 + \left(\frac{20}{\sqrt{2}}\right)^2} = 63.5V$

$I_{rms} = \sqrt{1.25^2 + \left(\frac{1.49}{\sqrt{2}}\right)^2 + \left(\frac{0.132}{\sqrt{2}}\right)^2} = 1.64A$

TOTAL POWER $= 1.25^2 \times 20 + 1.05^2 \times 20 + 0.093^2 \times 20$
$= 53.5$ WATT

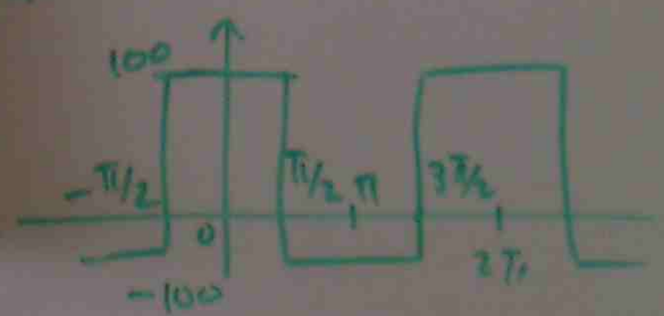
TRIGONOMETRIC FOURIER SERIES

$f(t) = A_0 + \sum (A_n \cos n\omega t + B_n \sin n\omega t)$

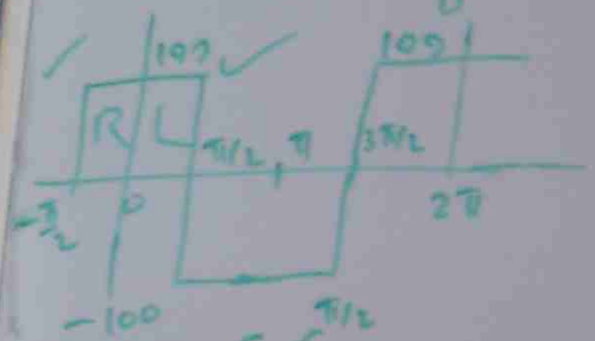
$A_n = \frac{1}{\pi} \int_0^{2\pi} f(t) \cos(n\theta)\, d\theta$

$B_n = \frac{1}{\pi} \int_0^{2\pi} f(t) \sin(n\theta)\, d\theta$

Ph FIND THE FIRST FOUR TERMS IN THE TRIGONOMETRIC FOURIER SERIES FOR GIVEN SQUARE



$$A_n = \frac{1}{\pi}\int_0^{2\pi} V(t)\cos n\theta\, d\theta$$



EVEN symmetry

$B_n = 0$

$A_n = \checkmark$

$$A_n = \frac{1}{\pi}\left[\int_0^{\pi/2} 100\cos n\theta\, d\theta + \int_{\pi/2}^{3\pi/2}(-100)\cos n\theta\, d\theta + \int_{3\pi/2}^{2\pi} 100\cos n\theta\, d\theta\right]$$

$$= \frac{1}{\pi}\left[100\int_0^{\pi/2}\frac{\cos n\theta\, dn\theta}{n} - 100\int_{\pi/2}^{3\pi/2}\frac{\cos n\theta\, dn\theta}{n} + 100\int_{3\pi/2}^{2\pi}\frac{\cos n\theta\, dn\theta}{n}\right]$$

$$\frac{100}{\pi n}\left[\int_0^{\pi/2}\cos n\theta\, dn\theta - \int_{\pi/2}^{3\pi/2}\cos n\theta\, dn\theta + \int_{3\pi/2}^{2\pi}\cos n\theta\, dn\theta\right]$$

$$\frac{100}{\pi n}\left[(\sin n\theta)_0^{\pi/2} - (\sin n\theta)_{\pi/2}^{3\pi/2} + (\sin n\theta)_{3\pi/2}^{2\pi}\right]$$

$$\frac{100}{\pi n}\left[\sin n\frac{\pi}{2} - \left(\sin\frac{3\pi n}{2} - \sin\frac{n\pi}{2}\right) + \sin 2\pi n - \sin\frac{3\pi n}{2}\right)$$

$$\frac{200}{\pi n}\left[\sin\frac{n\pi}{2} - \sin\frac{3\pi n}{2}\right]$$

$n = 1 \longrightarrow A_1 = \frac{200}{\pi\times 1}\left(\sin\frac{\pi}{2} - \sin\frac{3\pi}{2}\right) =$

$= \frac{200}{\pi\times 1}(\sin 90 - \sin 270) = \frac{400}{\pi}$

$n = 2 \longrightarrow A_2 = 0$, $n = 3 \rightarrow A_3 = \frac{-400}{3\pi}$

$f(t) = a_0 + a_1\cos\theta + a_2\cos 2\theta + \cdots = \frac{400}{\pi}\cos\theta - \frac{400}{3\pi}\cos 3\theta + \cdots$

HARMONICS &
FOURIER ANALYSIS

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EO 26

(1) HARMONIC & FOURIER
ANALYSIS

SLIDE (1) → (15)

(2) CALCULATION OF
HARMONIC

SLIDE 1 → 20

(3) ORDINARY DIFFERENTIAL EQUATIONS

Pb① FIND A GENERAL SOLUTION FOR THE DIFFERENTIAL EQUATION.

$\frac{dy}{dx} = 3x^2$

$dy = 3x^2 dx$

$\int dy = \int 3x^2 dx + C$

$= 3\frac{x}{2+1} + C$

$y = \frac{3x^3}{3} + C = x^3 + C$

Pb② Solve $y'' = 3x - 2$

$y(0) = 2 \quad y'(1) = -3$

$y'' = 3x - 2$

$\int y'' dy = \int (3x - 2) dx$

$y'(x) = \int 3x^{1} dx - \int 2dx + C_1$

$= 3\frac{x}{1+1} - 2x + C_1$

$y'(x) = 3\frac{x^2}{2} - 2x + C_1$

$y'(1) = -3$

$y'(1) = 3\frac{1^2}{2} - 2(1) + C_1 = -3$

$C_1 = -5/2$

$y'(x) = 3\frac{x^2}{2} - 2x - \frac{5}{2}$

$\int y'(x) dx = \int 3\frac{x^2}{2} dx - \int 2x dx - \int \frac{5}{2} dx + C_2$

$y(x) = 3\frac{x}{2+1} - 2\frac{x}{1+1} - \frac{5}{2}x + C_2$

$y(x) = 3\frac{x^3}{3} - 2\frac{x^2}{2} - \frac{5}{2}x + C_2$

$y(x) = x^3 - x^2 - \frac{5}{2}x + C_2$

$y(0) = 0^3 - 0^2 - \frac{5}{2}(0) + C_2$

$2 = C_2$

$\therefore y(x) = x^3 - x^2 - \frac{5}{2}x + 2$

Pb③ Solve $(4x + x y^2)dx + (y + x^2 y)dy = 0$

$x(4 + y^2)dx + y(1 + x^2)dy = 0$

DIVIDE BY $(1 + x^2)(4 + y^2)$

$\frac{x(4 + y^2)}{(1 + x^2)(4 + y^2)} dx + \frac{y(1 + x^2)dy}{(4 + y^2)(1 + x^2)} = 0$

$\frac{x\,dx}{1 + x^2} + \frac{y\,dy}{4 + y^2} \rightarrow \int \frac{x\,dx}{1 + x^2} + \int \frac{y\,dy}{4 + y^2} = 0$

Pb (3)

$d(1+x^2) = d1 + dx^2$

$= 0 + 2x\,dx$

$d(1+x^2) = 2x\,dx$

$x\,dx = \frac{1}{2} d(1+x^2)$

$d(4+y^2) = dy + dy^2$

$= 0 + 2y\,dy$

$d(4+y^2) = 2y\,dy$

$2y\,dy = d(4+y^2)$

$y\,dy = \frac{d(4+y^2)}{2}$

$\int \frac{1}{u} du = \ln u$

$\therefore \int \frac{x\,dx}{1+x^2} + \int \frac{y\,dy}{4+y^2} = 0$

$\int \frac{\frac{1}{2} d(1+x^2)}{1+x^2} + \int \frac{\frac{1}{2} d(4+y^2)}{4+y^2} = 0$

$\frac{1}{2} \ln(1+x^2) + \frac{1}{2} \ln(4+y^2) = 0$

EXERCISES

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E026

(3) ORDINARY DIFFERENTIAL EQUATION

SLIDE (1) ⟶ (8)

EXERCISE (16) ⟶ (22)

GAMMA, BETA AND OTHER SPECIAL FUNCTIONS

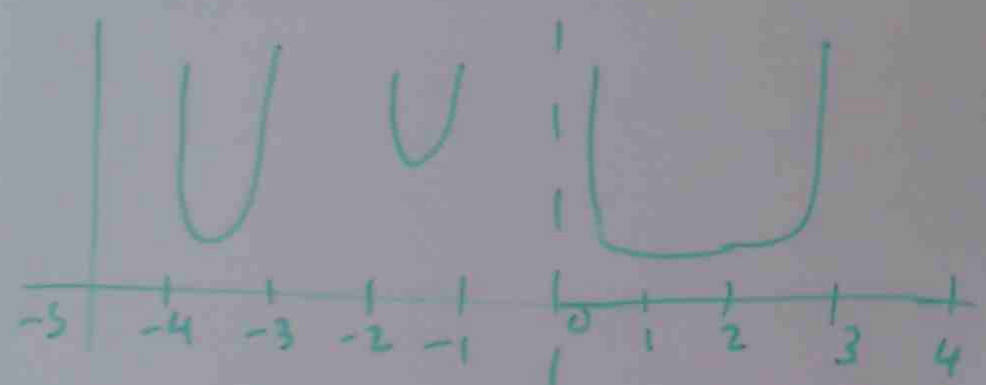


TABLE OF GAMMA FUNCTIONS

n	$\Gamma(n)$
1.00	1.00
1.10	0.9514
⋮	
1.60	0.8435
1.90	0.9618
2.00	1.00

$$\Gamma(n) = \int_0^\infty x^{n-1} e^{-x}\, dx$$

$$\Gamma(n+1) = n\,\Gamma(n)$$

$$\Gamma\left(\tfrac{1}{2}\right) = \sqrt{\pi} \qquad \Gamma(n+1) = n!$$

$4! = 4\times3\times2\times1$

$3! = 3\times2\times1$

$2! = 2\times1$

$1! = 1$

p.b

$$\frac{\Gamma(6)}{2\Gamma(3)} = \frac{\Gamma(5+1)}{2\,\Gamma(2+1)} = \frac{5!}{2\times 2!}$$

$$= \frac{5\times4\times3\times\cancel{2}\times1}{2\times\cancel{2}\times1} = 30$$

p.b

$$\frac{\Gamma\left(\frac{5}{2}\right)}{\Gamma\left(\frac{1}{2}\right)} = \frac{\Gamma(1+3/2)}{\sqrt{\pi}} = \frac{\frac{3}{2}\Gamma(3/2)}{\sqrt{\pi}}$$

$$= \frac{\frac{3}{2}\times\Gamma\left(1+\frac{1}{2}\right)}{\sqrt{\pi}} = \frac{\frac{3}{2}\times\frac{1}{2}\Gamma\left(\frac{1}{2}\right)}{\sqrt{\pi}}$$

$$= \frac{\frac{3}{4}\times\sqrt{\pi}}{\sqrt{\pi}} = \frac{3}{4}$$

BETA FUNCTIONS

$$B(m,n) = \int_0^1 x^{m-1}(1-x)^{n-1}\, dx$$

$$B(m,n) = \frac{\Gamma(m)\,\Gamma(n)}{\Gamma(m+n)}$$

Pb $\int_0^1 x^4 (1-x)^3 dx = ?$

COMPARE WITH $\int_0^1 x^{m-1} (1-x)^{n-1} dx$

$\therefore m-1 = 4 \longrightarrow m = 1+4 = 5$

$n-1 = 3 \longrightarrow n = 1+3 = 4$

$\int_0^1 x^{m-1} (1-x)^{n-1} dx = \frac{\Gamma(m)\,\Gamma(n)}{\Gamma(m+n)}$

$\frac{\Gamma 5\ \Gamma 4}{\Gamma(5+4)} = \frac{\Gamma(4+1)\ \Gamma(3+1)}{\Gamma 9} = \frac{4!\ 3!}{\Gamma(8+1)}$

$\frac{4!\ 3!}{8!} = \frac{4\times3\times2\times1 \times 3\times2\times1}{8\times7\times6\times5\times4\times3\times2\times1}$

$= \frac{1}{256}$

$\int_0^{\pi/2} \sin^{2m-1}\theta \cos^{2m-1}\theta\, d\theta = \frac{1}{2} B(m,n)$

$= \frac{1}{2} \frac{\Gamma(m)\,\Gamma(n)}{\Gamma(m+n)}$

Pb $\int_0^{\pi/2} \sin^6\theta\, d\theta = ?$

COMPARE WITH $\int_0^{\pi/2} \sin^{2m-1}\theta \cos^{2n-1}\theta\, d\theta$

$\therefore 2m-1 = 6 \longrightarrow m = 7/2$

$2n-1 = 0 \longrightarrow n = 1/2$

$\therefore B(7/2, 1/2) = \frac{1}{2} \frac{\Gamma(7/2)\,\Gamma(1/2)}{\Gamma(7/2+1/2)}$

$= \frac{1}{2} \frac{\Gamma(1+5/2) \times \sqrt{\pi}}{\Gamma 4}$

$= \frac{1}{2} \times \frac{5/2\,\Gamma 5/2 \times \sqrt{\pi}}{\Gamma(3+1)}$

$\frac{5}{4} \times \frac{\Gamma(1+3/2)\,\sqrt{\pi}}{3!}$

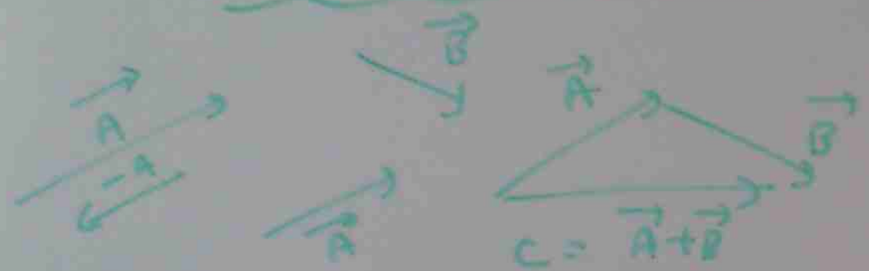
$\frac{5}{4} \times \frac{3/2\,\Gamma 3/2 \times \sqrt{\pi}}{3!}$

$\frac{5}{4} \times \frac{3/2 \times 1/2\,\Gamma 1/2 \times \sqrt{\pi}}{3!}$

$\frac{5}{4\times3\times2\times1} \times \frac{3}{4} \times \frac{1}{2} \times \sqrt{\pi} \times \sqrt{\pi}$

$\frac{5\pi}{32}$

VECTOR ANALYSIS



LAW OF VECTOR ALGEBRA

$A + B = B + A$

$A + (B + C) = (A + B) + C$

$(m + n)A = mA + nA$

$A_T = A_1 i + A_2 j + A_3 k$

$= |A| = \sqrt{A_1^2 + A_2^2 + A_3^2}$

DOT PRODUCT $A = A_1 i + A_2 j + A_3 k$

$B = B_1 i + B_2 j + B_3 k$

$A \cdot B = A_1 B_1 + A_2 B_2 + A_3 B_3$

CROSS PRODUCT

$$A \times B = \begin{vmatrix} i & j & k \\ A_1 & A_2 & A_3 \\ B_1 & B_2 & B_3 \end{vmatrix}$$

$$i \begin{vmatrix} A_2 & A_3 \\ B_2 & B_3 \end{vmatrix} - j \begin{vmatrix} A_1 & A_3 \\ B_1 & B_3 \end{vmatrix} + k \begin{vmatrix} A_1 & A_2 \\ B_1 & B_2 \end{vmatrix}$$

$$i \left[A_2 B_3 - B_2 A_3\right] - j \left[A_1 B_3 - B_1 A_3\right]$$

$$+ k \left[A_1 B_2 - B_1 A_2\right]$$

(Q) $A = i + j$, $B = 2i - 3j + k$

$C = 4j - 3k$

find (a) $(A \times B) \times C$

$$A \times B = \begin{vmatrix} i & j & k \\ 1 & 1 & 0 \\ 2 & -3 & 1 \end{vmatrix}$$

$$i\begin{vmatrix} 1 & 0 \\ -3 & 1 \end{vmatrix} - j\begin{vmatrix} 1 & 0 \\ 2 & 1 \end{vmatrix} + k\begin{vmatrix} 1 & 1 \\ 2 & -3 \end{vmatrix}$$

$$i\left[1\times 1 - (-3)0\right] - j\left[1\times 1 - 2\times 0\right] + k\left[1\times(-3) - 2\times 1\right]$$

$$A \times B = i - j - 5k$$

$$(A \times B) \times C = (i - j - 5k)\ (4j - 3k)$$

$$\begin{vmatrix} i & j & k \\ 1 & -1 & -5 \\ 0 & 4 & -3 \end{vmatrix}$$

$$i\begin{vmatrix} -1 & -5 \\ 4 & -3 \end{vmatrix} - j\begin{vmatrix} 1 & -5 \\ 0 & -3 \end{vmatrix} + k\begin{vmatrix} 1 & -1 \\ 0 & 4 \end{vmatrix}$$

$$i\left[(-1)(-3) - 4(-5)\right] - j\left[1(-3) - 0(-5)\right] + k\left[1\times 4 - 0(-1)\right]$$

$$23i + 3j + 4k$$

(1) VECTOR ANALYSIS

SLIDE 1 -> 1C

(2) 29

MULTIPLE INTEGRATION

Pb. FIND THE VOLUME of THE REGION "R" BOUNDED BY THE PARABOLIC CYLINDER $z = 4 - x^2$ AND THE PLANES $x=0$, $y=0$, $y=6$ $z=0$

WHEN $z=0 \longrightarrow$ $z = 4 - x^2$

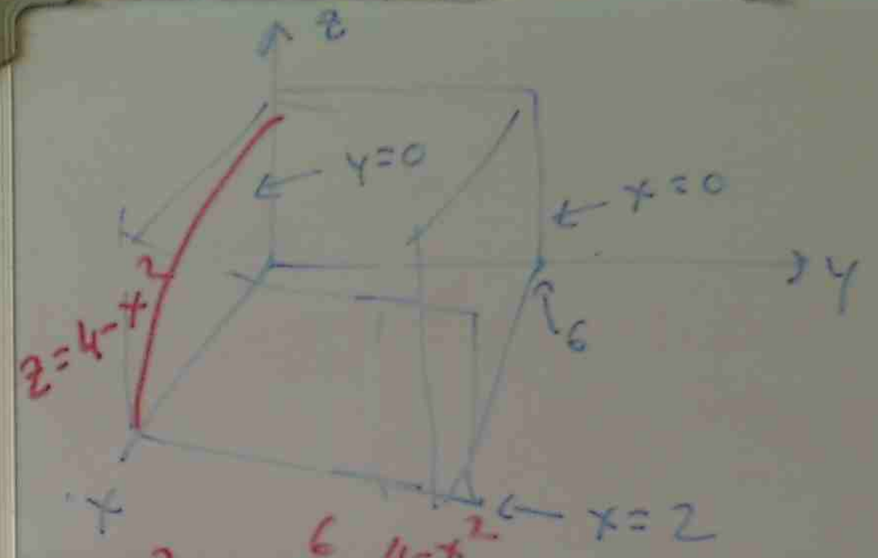
$0 = 4 - x^2$

$x^2 = 4 \longrightarrow x = \pm 2$.

$\therefore$ LIMIT $x = -2 \longrightarrow 2$

$y = 0 \longrightarrow 6$

$z = 0 \longrightarrow 4 - x^2$



$$\int_{x=0}^{2}\int_{y=0}^{6}\int_{z=0}^{4-x^2} f(z)\,dz\,dy\,dx$$

$$\int_{x=0}^{2}\int_{y=0}^{6}(4-x^2)\,dy\,dx$$

$$\int_{x=0}^{2}\Big[(4-x^2)y\Big]_0^6\,dx$$

$$\int_{x=0}^{2}6(4-x^2)\,dx$$

$$\int_0^2 24\,dx - \int_0^2 6x^2\,dx$$

$$24\Big[x\Big]_0^2 - 6\Big[\frac{x^3}{3}\Big]_0^2$$

$$24(2-0) - 6\Big(\frac{2^3-0}{3}\Big)$$

$$= 32$$

LAPLACE TRANSFORM

NUMERICAL OPERATION	LOGARITHMIC OPERATION
MULTIPLY	ADDITION
DIVIDE	SUBSTRACTION

CALCULUS	LAPLACE TRANSFORM
INTEGRATION	MULTIPLICATION
DIFFERENTIATION	DIVISION

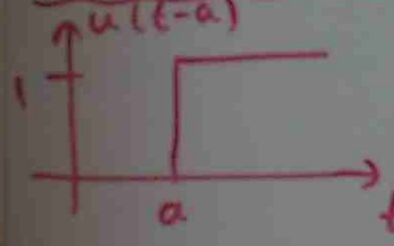
$$\mathcal{L}\{f(t)\} = F(s) = \int_0^\infty e^{-st} f(t)\,dt$$

↑ TIME DOMAIN ↑ FREQUENCY DOMAIN

$f(t)$	$\mathcal{L}f(t) = F(s)$	$\mathcal{L}^{-1}F(s)$	$f(t)$
1	$\frac{1}{s}$, $s>0$	$\mathcal{L}^{-1}\frac{1}{s}$	1
t^m $m=1,2,3,4$	$\frac{m!}{s^{m+1}}$ $s>0$	$\mathcal{L}^{-1}\frac{m!}{s^{m+1}}$	t^m
t^p $p>-1$	$\frac{p(p+1)}{s^{p+1}}$	$\mathcal{L}^{-1}\frac{p}{s^{p+1}}$	t^p

$f(t)$	$\mathcal{L}f(t) = F(s)$	$\mathcal{L}^{-1}F(s)$	$f(t)$
e^{at}	$\frac{1}{s-a}$ $s>a$	$\mathcal{L}^{-1}\frac{1}{s-a}$	e^{at}
e^{-at}	$\frac{1}{s+a}$	$\mathcal{L}^{-1}\frac{1}{s+a}$	e^{-at}
$\cos\omega t$	$\frac{s}{s^2+\omega^2}$	$\mathcal{L}^{-1}\frac{s}{s^2+\omega^2}$	$\cos\omega t$
$\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$	$\mathcal{L}^{-1}\frac{\omega}{s^2+\omega^2}$	$\sin\omega t$

THE UNIT STEP FUNCTION



$$\mathcal{L}\{u(t-a)\} = \frac{e^{-as}}{s}$$

Pb FIND LAPLACE TRANSFORM OF $5\sin 2t - 3\cos 2t$

$$\mathcal{L}\sin 2t = \frac{2}{s^2+2^2} = \frac{2}{s^2+4}$$

$$\mathcal{L}\cos 2t = \frac{s}{s^2+2^2} = \frac{s}{s^2+4}$$

$$LT \rightarrow \frac{5\times 2}{s^2+4} - \frac{3s}{s^2+4} = \frac{10-3s}{s^2+4}$$

Ph FIND $\mathcal{L}^{-1}\dfrac{4(s)-3}{(s)^2+4}$

$\dfrac{4(s)-3}{(s)^2+4} = \dfrac{4(s)}{(s)^2+4} - \dfrac{3}{(s)^2+4}$

$\mathcal{L}^{-1}\dfrac{(s)}{(s)^2+\omega^2} = \cos\omega t \rightarrow \mathcal{L}^{-1}\dfrac{4(s)}{(s)^2+4} = 4\mathcal{L}^{-1}\dfrac{(s)}{(s)^2+2^2} = 4\cos 2t$

$\mathcal{L}^{-1}\dfrac{\omega}{(s)^2+\omega^2} = \sin\omega t \rightarrow \mathcal{L}^{-1}\dfrac{3}{(s)^2+4} = 3\mathcal{L}^{-1}\dfrac{1}{(s)^2+2^2}$

$= \dfrac{3}{2}\mathcal{L}^{-1}\dfrac{2}{(s)^2+2^2} = \dfrac{3}{2}\sin 2t$

$\therefore \mathcal{L}^{-1}\dfrac{4(s)-3}{(s)^2+4} = 4\cos 2t - \dfrac{3}{2}\sin 2t$

$\mathcal{L}^{-1}\dfrac{1}{(s)^p} = \dfrac{t^{p-1}}{\Gamma(p)}$ $\quad \Gamma(\tfrac{1}{2}) = \sqrt{\pi}$ $\quad \Gamma(n+1) = n\,\Gamma(n)$

$\Gamma 3/2 = \Gamma(1+1/2) = \frac{1}{2}\Gamma\frac{1}{2}$

$= \frac{1}{2}\sqrt{\pi}$

Ph FIND $\mathcal{L}^{-1}\dfrac{4-5(s)}{(s)^{3/2}}$

$\mathcal{L}^{-1}\dfrac{4}{(s)^{3/2}} - \dfrac{5(s)}{(s)^{3/2}}$

$4\,\mathcal{L}^{-1}\dfrac{1}{(s)^{3/2}} - 5\,\mathcal{L}^{-1}\dfrac{1}{(s)^{1/2}}$

$4\,\dfrac{t^{3/2-1}}{\Gamma 3/2} - 5\,\dfrac{t^{1/2-1}}{\Gamma\frac{1}{2}}$

$4\,\dfrac{t^{1/2}}{\Gamma(1+\frac{1}{2})} - 5\,\dfrac{t^{-1/2}}{\sqrt{\pi}}$

$4\,\dfrac{t^{1/2}}{\frac{1}{2}\Gamma\frac{1}{2}} - 5\,\dfrac{t^{-\frac{1}{2}}}{\sqrt{\pi}}$

$8\,\dfrac{t^{\frac{1}{2}}}{\sqrt{\pi}} - \dfrac{5t^{-\frac{1}{2}}}{\sqrt{\pi}} = \dfrac{8t^{\frac{1}{2}} - 5t^{-\frac{1}{2}}}{\sqrt{\pi}}$

Pb FIND $\mathcal{L}^{-1}\dfrac{1}{s^2+2s}$

$$\mathcal{L}^{-1}\frac{1}{s^2+2s} = \mathcal{L}^{-1}\frac{1}{s(s+2)}$$

$$\frac{1}{s(s+2)} = \frac{A}{s} + \frac{B}{s+2}$$

$$\frac{1}{s(s+2)} = \frac{A(s+2)+Bs}{s(s+2)}$$

$$A(s+2)+Bs = 1$$

IF $s=0 \rightarrow A(0+2)+B\times 0 = 1$

$$2A = 1 \longrightarrow A = \frac{1}{2}$$

IF $s=-2 \rightarrow A[-2+2)+B(-2) = 1$

$$A\times 0 - 2B = 1$$

$$0 - 2B = 1 \longrightarrow B = -\frac{1}{2}$$

$$\frac{1}{s(s+2)} = \frac{\frac{1}{2}}{s} + \frac{-\frac{1}{2}}{s+2}$$

$$= \frac{\frac{1}{2}}{s} - \frac{\frac{1}{2}}{s+2}$$

$$\mathcal{L}^{-1}\frac{1}{s(s+2)} = \mathcal{L}^{-1}\frac{\frac{1}{2}}{s} - \mathcal{L}^{-1}\frac{\frac{1}{2}}{s+2}$$

$$= \frac{1}{2}\mathcal{L}^{-1}\frac{1}{s} - \frac{1}{2}\mathcal{L}^{-1}\frac{1}{s+2}$$

$$= \frac{1}{2}t - \frac{1}{2}e^{-2t}$$

SOLUTION TO DIFFERENTIAL EQUATION

$$\mathcal{L}\,y'' = s^2Y - sy(0) - y'(0)$$

$$\mathcal{L}\,y' = sY - y(0)$$

$$\mathcal{L}\,y = Y$$

Pb SOLVE $y'' - 3y' + 2y = 2e^{-t}$

WHERE $y(0)=2$, $y'(0)=-1$

$$\mathcal{L}\,y'' = s^2Y - sy(0) - y'(0)$$

$$= s^2Y - s\times 2 - (-1)$$

$$= s^2Y - 2s + 1$$

$$\mathcal{L}\,y' = sY - y(0) = sY - 2$$

$$\therefore s^2Y - 2s + 1 - 3[sY - 2] + 2Y$$

$\mathcal{L}\,2e^{-t}$
$2\mathcal{L}\,e^{-t}$
$\dfrac{2}{s+1}$

$$= \frac{2}{s+1}$$

$$(s)^2 Y - 2(s) + 1 - 3(s)Y + 6 + 2Y = \frac{2}{(s)+1}$$

$$(s)^2 Y - 2(s) - 3(s)Y + 2Y + 7 = \frac{2}{(s)+1}$$

$$(s)^2 Y - 3(s)Y + 2Y = \frac{2}{(s)+1} + 2(s) - 7$$

$$Y((s)^2 - 3(s) + 2) = \frac{2 + ((s)+1)(2(s)-7)}{(s)+1}$$

$$Y = \frac{2 + 2(s)^2 + 2(s) - 7(s) - 7}{((s)^2 - 3(s) + 2)((s)+1)}$$

$$Y = \frac{2(s)^2 - 5(s) - 5}{((s)-2)((s)-1)((s)+1)}$$

$(s)^2 - 3(s) + 2 = (s) - 2 \times (s) - 1$

$$\frac{2(s)^2 - 5(s) - 5}{((s)-2)((s)-1)((s)+1)} = \frac{A}{(s)-2} + \frac{B}{(s)-1} + \frac{C}{(s)+1}$$

$$\therefore A((s)-1)((s)+1) + B((s)-2)((s)+1) + C((s)-2)((s)-1) = 2(s)^2 - 5(s) - 5$$

$(s) = 1$

$A(1-1)(1+1) + B(1-2)(1+1) + C(1-2)(1-1) = 2(1)^2 - 5(1) - 5$

$-2B = -8 \longrightarrow B = 4$

$(s) = -1$

$A(-1-1)(-1+1) + B(-1-2)(-1+1) + C(-1-2)(-1-1) = 2(-1)^2 - 5(-1) - 5$

$C(-3)(-2) = 2$

$6C = 2 \longrightarrow C = \frac{2}{6} = \frac{1}{3}$

$(s) = 2$

$A(2-1)(2+1) + B(2-2)(2+1) + C(2-2)(2-1) = 2 \times 2^2 - 5 \times 2 - 5$

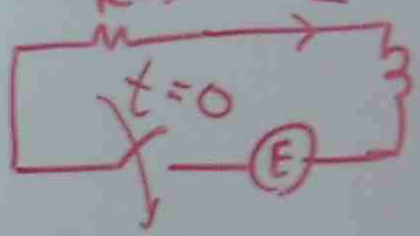
$3A = -7 \longrightarrow A = -7/3$

$$\frac{-7/3}{(s)-2} + \frac{4}{(s)-1} + \frac{1/3}{(s)+1} \xrightarrow{\mathcal{L}^{-1}} -\frac{7}{3}e^{2t} + 4e^{t} + \frac{1}{3}e^{-t}$$

SOLVING ELECTRICAL PROBLEMS

pb A RESISTOR OF $R = 10\Omega$, AN INDUCTOR OF $L = 2H$ AND A BATTERY OF E VOLT ARE CONNECTED IN SERIES WITH A SWITCH "S". AT $t=0$ THE SWITCH IS CLOSED AND THE CURRENT $I=0$. FIND I FOR $t>0$

IF $E = 40V$



$$L\frac{dI}{dt} + IR = E$$

$$2\frac{dI}{dt} + I\times 10 = 40$$

$$\frac{dI}{dt} + 5I = 20$$

$$I' + 5I = 20$$

$$\mathcal{L}\{I' + 5I\} = \mathcal{L}\{20\}$$

$$\textcircled{s}\,I(s) - I(0) + 5\,I(s) = \frac{20}{\textcircled{s}}$$

$I(0) = 0$ WHEN THE SWITCH IS OFF

$$\textcircled{s}\,I(s) - 0 + 5\,I(s) = \frac{20}{\textcircled{s}}$$

$$I(s)\,(\textcircled{s} + 5) = \frac{20}{\textcircled{s}}$$

$$I(s) = \frac{20}{\textcircled{s}\,(\textcircled{s}+5)}$$

$$\frac{20}{\textcircled{s}\,(\textcircled{s}+5)} = \frac{A}{\textcircled{s}} + \frac{B}{\textcircled{s}+5}$$

$$= \frac{A\,(\textcircled{s}+5) + B\,\textcircled{s}}{\textcircled{s}\,(\textcircled{s}+5)}$$

$$A\,(\textcircled{s}+5) + B\,\textcircled{s} = 20$$

$\textcircled{s} = -5 \rightarrow A(-5+5) + B(-5) = 20$ (the A term $\rightarrow 0$)

$$B = -4$$

$\textcircled{s} = 0 \rightarrow A(0+5) = 20 \rightarrow A = 4$

$$\mathcal{L}^{-1}\left(\frac{4}{\textcircled{s}} + \frac{-4}{\textcircled{s}+5}\right) = 4t - 4e^{-5t}$$

(8) LAPLACE TRANSFORM

SLIDE 1 → 13

Pb 32 → 35

(9) INVERSE LAPLACE

SLIDE 1 → 6

Pb 31

(11) GAMMA FUNCTION IN LAPLACE TRANSFORM

Pb 32 → 35 | SLIDE 1+2

(12) LAPLACE TRANSFORM IN DIFFERENTIAL EQUATIONS

SLIDE 1 → 14

Pb 36 + 37

MATRICES

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \leftarrow \text{ROW}$$

↑ COLUMN

ADD / SUBSTRACT

$$A = \begin{bmatrix} 2 & 1 & 4 \\ -3 & 0 & 2 \end{bmatrix} \quad B = \begin{bmatrix} 3 & -5 & 1 \\ 2 & 1 & 3 \end{bmatrix}$$

$$A+B = \begin{bmatrix} 2+3 & 1+(-5) & 4+1 \\ -3+2 & 0+1 & 2+3 \end{bmatrix} = \begin{bmatrix} 5 & -4 & 5 \\ -1 & 1 & 5 \end{bmatrix}$$

$$A-B = \begin{bmatrix} 2-3 & 1-(-5) & 4-1 \\ -3-2 & 0-1 & 2-3 \end{bmatrix} = \begin{bmatrix} -1 & 6 & 3 \\ -5 & -1 & -1 \end{bmatrix}$$

A^T = CHANGE ROW TO COLUMN $= \begin{bmatrix} 2 & -3 \\ 1 & 0 \\ 4 & 2 \end{bmatrix}$

$$a_{11}x_1 + a_{12}x_2 + \cdots a_{1n}x_n = r_1$$
$$a_{21}x_1 + a_{22}x_2 + \cdots a_{2n}x_n = r_2$$
$$\vdots$$
$$a_{m1}x_1 + a_{m2}x_2 + \cdots a_{mn}x_n = r_n$$

$$\begin{bmatrix} a_{11} & a_{12} \cdots a_{1n} \\ a_{21} & a_{22} \cdots a_{2n} \\ \vdots \\ a_{m1} & a_{m2} \cdots a_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{bmatrix}$$

MULTIPLICATION

$$A = \begin{bmatrix} 2 & 1 & 4 \\ -3 & 0 & 2 \end{bmatrix} \quad B = \begin{bmatrix} 3 & 5 \\ 2 & -1 \\ 4 & 2 \end{bmatrix}$$

$$A \times B = \begin{bmatrix} \text{1st MATRIX ROW 1} \times \text{2nd MATRIX COLUMN 1} & \text{1st MATRIX ROW 1} \times \text{2nd MATRIX COLUMN 2} \\ \text{1st MATRIX ROW 2} \times \text{2nd MATRIX COLUMN 1} & \text{1st MATRIX ROW 2} \times \text{2nd MATRIX COLUMN 2} \end{bmatrix}$$

$$= \begin{bmatrix} 2\times3+1\times2+4\times4 & 2\times5+1\times(-1)+4\times2 \\ -3\times3+0\times2+2\times4 & -3\times5+0\times-1+2\times2 \end{bmatrix}$$

$$= \begin{bmatrix} 24 & 17 \\ -1 & -11 \end{bmatrix}$$

DETERMINANT

$$\begin{vmatrix} 3 & -2 & -2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = 3\begin{vmatrix} 2 & -3 \\ 1 & 2 \end{vmatrix} - (-2)\begin{vmatrix} 1 & -3 \\ 4 & 2 \end{vmatrix} + 2\begin{vmatrix} 1 & 2 \\ 4 & 1 \end{vmatrix}$$

$$= 3[2\times 2 - 1(-3)] + 2[1\times 2 - 4(-3)] + 2[1\times 1 - 4\times 2] = 35$$

TRACE of MATRIX

$$\begin{bmatrix} 5 & 2 & 0 \\ 3 & 1 & -2 \\ -1 & 4 & 2 \end{bmatrix}$$

= TRACE OF MATRIX = $5+1+2 = 8$

CO FACTOR

$$\begin{bmatrix} 2 & -1 & 1 & 3 \\ -3 & 2 & 5 & 0 \\ 1 & 0 & -2 & 2 \\ 4 & -2 & 3 & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} 2 & -1 & 3 \\ 1 & 0 & 2 \\ 4 & -2 & 1 \end{bmatrix}$$

SOLVE THE FOLLOWING EQUATION

$$3x_1 - 2x_2 + 2x_3 = 10$$
$$x_1 + 2x_2 - 2x_3 = -1$$
$$4x_1 + x_2 + 2x_3 = 3$$

$$\begin{bmatrix} 3 & -2 & 2 \\ 1 & 2 & -2 \\ 4 & 1 & 2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 10 \\ -1 \\ 3 \end{bmatrix}$$

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 10 \\ -1 \\ 3 \end{bmatrix} \begin{bmatrix} 3 & -2 & 2 \\ 1 & 2 & -2 \\ 4 & 1 & 2 \end{bmatrix}^{-1}$$

$$A = \begin{bmatrix} 3 & -2 & 2 \\ 1 & 2 & -2 \\ 4 & 1 & 2 \end{bmatrix}$$

$$A^{-1} = \frac{(A\,jk)^T}{\det A}$$

$$\det A = \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -2 \\ 4 & 1 & 2 \end{vmatrix} = 3\begin{vmatrix} 2 & -2 \\ 1 & 2 \end{vmatrix} - (-2)\begin{vmatrix} 1 & -2 \\ 4 & 2 \end{vmatrix} + 2\begin{vmatrix} 1 & 2 \\ 4 & 1 \end{vmatrix}$$

$$= 3[2\times 2 - (1)(-2)] + 2[1\times 2 - 4(-2)] + 2[1\times 1 - 4\times 2]$$

$$= 35$$

$(A_{JK})^T$ = TRANSPOSE MATRIX OF COFACTOR MATRIX A

(A_{JK})

$$A_{JK} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

$$A_{11} = (-1)^{1+1} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = (-1)^2 \begin{vmatrix} 2 & -3 \\ 1 & 2 \end{vmatrix}$$

$$= 1\,[2\times 2 - 1(-3)] = 7$$

$$A_{12} = (-1)^{1+2} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = (-1)^3 \begin{vmatrix} -2 & 2 \\ 1 & 2 \end{vmatrix}$$

$$= -1\,[-2\times 2 - 1\times 2]$$

$$= -14$$

$$A_{13} = (-1)^{1+3} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = (-1)^4 \begin{vmatrix} 1 & 2 \\ 4 & 1 \end{vmatrix}$$

$$= 1\,(1\times 1 - 4\times 2)$$

$$= -7$$

$$A_{21} = (-1)^{2+1} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = (-1)^3 \begin{vmatrix} 1 & -3 \\ 4 & 2 \end{vmatrix}$$

$$= -1\,[1\times 2 - 4(-3)]$$

$$= 6$$

$$A_{22} = (-1)^{2+2} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = (-1)^4 \begin{vmatrix} 3 & 2 \\ 4 & 2 \end{vmatrix}$$

$$= 1\,(3\times 2 - 4\times 2) = -2$$

$$A_{23} = (-1)^{2+3} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = (-1)^5 \begin{vmatrix} 3 & -2 \\ 4 & 1 \end{vmatrix}$$

$$= -1\,[3\times 1 - 4(-2)]$$

$$= -11$$

$$A_{31} = (-1)^{3+1} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = (-1)^5 \begin{vmatrix} -2 & 2 \\ 2 & -3 \end{vmatrix}$$

$$= -1\,[(-2)(-3) - 2\times 2] = 2$$

$$A_{32} = (-1)^{3+2} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = -1 \begin{vmatrix} 3 & 2 \\ 1 & -3 \end{vmatrix} = -1\,[3(-3) - 1\times$$

$$= 11$$

$$A_{33} = (-1)^{3+3} \begin{vmatrix} 3 & -2 & 2 \\ 1 & 2 & -3 \\ 4 & 1 & 2 \end{vmatrix} = -1 \begin{vmatrix} 3 & -2 \\ 1 & 2 \end{vmatrix} = -1\,[3\times 2 - 1($$

$$= 8$$

$$A_{JK} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

$$= \begin{bmatrix} 7 & -14 & -7 \\ 6 & -2 & -11 \\ 2 & 11 & 8 \end{bmatrix} \begin{matrix} \leftarrow \text{Row 1} \\ \leftarrow \text{Row 2} \\ \leftarrow \text{Row 3} \end{matrix}$$

Row 1 $\longrightarrow$ col 1
Row 2 $\longrightarrow$ col 2
Row 3 $\longrightarrow$ col 3

$$(A_{JK})^T = \begin{bmatrix} 7 & 6 & 2 \\ -14 & -2 & 11 \\ -7 & -11 & 8 \end{bmatrix}$$

$$A^{-1} = \frac{(A_{JK})^T}{\det A}$$

$$= \frac{\begin{bmatrix} 7 & 6 & 2 \\ -14 & -2 & 11 \\ -7 & -11 & 8 \end{bmatrix}}{35} = \begin{bmatrix} \frac{7}{35} & \frac{6}{35} & \frac{2}{35} \\ \frac{-14}{35} & \frac{-2}{35} & \frac{11}{35} \\ \frac{-7}{35} & \frac{-11}{35} & \frac{8}{35} \end{bmatrix}$$

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} \frac{7}{35} & \frac{6}{35} & \frac{2}{35} \\ \frac{-14}{35} & \frac{-2}{35} & \frac{11}{35} \\ \frac{-7}{35} & \frac{-11}{35} & \frac{8}{35} \end{bmatrix} \begin{bmatrix} 10 \\ -1 \\ 3 \end{bmatrix}$$

$$= \begin{bmatrix} \frac{7}{35} \times 10 + \frac{6}{35}(-1) + \frac{2}{35} \times 3 \\ \frac{-14}{35} \times (-1) + (\frac{-2}{35})(-1) + \frac{11}{35} \times 3 \\ \frac{-7}{35} \times 10 + \frac{-11}{35} \times (-1) + \frac{8}{35} \times 3 \end{bmatrix}$$

$$= \begin{bmatrix} 2 \\ 3 \\ 1 \end{bmatrix}$$

$\therefore x_1 = 2$
$x_2 = 3$
$x_3 = 1$

$$A_{JK} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

$$= \begin{bmatrix} 7 & -14 & -7 \\ 6 & -2 & -11 \\ 2 & 11 & 8 \end{bmatrix} \begin{matrix} \leftarrow \text{ROW 1} \\ \leftarrow \text{ROW 2} \\ \leftarrow \text{ROW 3} \end{matrix}$$

ROW 1 $\longrightarrow$ COL 1
ROW 2 $\longrightarrow$ COL 2
ROW 3 $\longrightarrow$ COL 3

$$(A_{JK})^T = \begin{bmatrix} 7 & 6 & 2 \\ -14 & -2 & 11 \\ -7 & -11 & 8 \end{bmatrix}$$

$$A^{-1} = \frac{(A_{JK})^T}{\det A}$$

$$= \frac{\begin{bmatrix} 7 & 6 & 2 \\ -14 & -2 & 11 \\ -7 & -11 & 8 \end{bmatrix}}{35} = \begin{bmatrix} \frac{7}{35} & \frac{6}{35} & \frac{2}{35} \\ \frac{-14}{35} & \frac{-2}{35} & \frac{11}{35} \\ \frac{-7}{35} & \frac{-11}{35} & \frac{8}{36} \end{bmatrix}$$

$$\begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} = \begin{bmatrix} \frac{7}{35} & \frac{6}{35} & \frac{2}{35} \\ \frac{-14}{35} & \frac{-2}{35} & \frac{11}{35} \\ \frac{-7}{35} & \frac{-11}{35} & \frac{8}{35} \end{bmatrix} \begin{bmatrix} 10 \\ -1 \\ 3 \end{bmatrix}$$

$$= \begin{bmatrix} \frac{7}{35} \times 10 + \frac{6}{35}(-1) + \frac{2}{35} \times 3 \\ \frac{-14}{35} \times (-1) + (\frac{-2}{35})(-1) + \frac{11}{35} \times 3 \\ \frac{-7}{35} \times 10 + \frac{-11}{35} \times (-1) + \frac{8}{35} \times 3 \end{bmatrix}$$

$$= \begin{bmatrix} 2 \\ 3 \\ 1 \end{bmatrix}$$

$\therefore X_1 = 2$
$X_2 = 3$
$X_3 = 1$

LEGENDRE FUNCTIONS

$$(1-x^2)y'' - 2xy' + n(n+1)y = 0$$

GENERAL SOLUTION

$$y = C_1 P_n(x) + C_2 Q_n(x)$$

$$y = C_0\left[1 - \frac{n(n+1)}{2!}x^2 + \frac{n(n-2)(n+1)(n+3)}{4!}x^4 + - - \right] + C_1\left[x - \frac{(n-1)(n+2)}{3!}x^3 + \frac{(n-1)(n-3)(n+2)(n+4)}{5!}x^5\right]$$

RECURRANCE FORMULA

$$P_{n+1}(x) = \frac{2n+1}{n+1} x P_n(x) - \frac{n}{n+1} P_{n-1}(x)$$

$$P'_{(n+1)}(x) - P'_{n-1}(x) = (2n+1) P_n(x)$$

Ex

$$P_{n+1}(x) = \frac{2n+1}{n+1} x P_n(x) - \frac{n}{n+1} P_{n-1}(x)$$

If $P_0(x) = 1$, $P_1(x) = x$

FIND (a) $P_2(x)$ (b) $P_3(x)$

$$P_2(x) = P_{1+1}(x) = \frac{2\times1+1}{1+1} x P_1(x) - \frac{1}{1+1} P_{1-1}(x)$$

($1+1 \rightarrow 2$, $n=1$)

$$= \frac{3}{2} x \cdot P_1(x) - \frac{1}{2} P_0(x)$$

$$= \frac{3}{2} x \cdot x - \frac{1}{2} \times 1$$

$$= \frac{3}{2}x^2 - \frac{1}{2}$$

$$P_3(x) = \frac{2\times2+1}{2+1} x P_2(x) - \frac{2}{2+1} P_{2-1}(x)$$

($1+2 \rightarrow 3$, $n=2$)

$$= \frac{5}{3} x \left[\frac{3}{2}x^2 - \frac{1}{2}\right] - \frac{2}{3} \times P_1(x)$$

$$= \frac{5}{3} x \left[\frac{3x^2-1}{2}\right] - \frac{2}{3} \times x$$

$$= \frac{2x}{3}\left[\frac{15x^2-5-2}{2}\right]$$

$$= \frac{2x}{3}\left[\frac{15x^2-7}{2}\right]$$

BINOMIAL THEOREM

$$(p+v)^n = 1 + pv + \frac{p(p-1)}{2!}v^2 + \frac{p(p-1)(p-2)}{3!}v^3$$

(14) LEGENDRE FUNCTION

SLIDE 1 → 9, Pb 41 + 42

PARTIAL DIFFERENTIAL EQUATION

Pb IF $u = F(y-3x)$

PROVE $\frac{\partial v}{\partial x} + 3\frac{\partial v}{\partial y} = 0$

$$\frac{\partial v}{\partial x} = \frac{\partial}{\partial x} F(y-3x)$$

$$= f'(y-3x)\frac{\partial}{\partial x}[y-3x]$$

$$= f'(y-3x)\left[\frac{\partial y}{\partial x} - \frac{\partial 3x}{\partial x}\right]$$

$$= f'(y-3x)[0-3] = -3f'(y-3x)$$

$$3\frac{\partial v}{\partial y} = 3\left[\frac{\partial}{\partial y} f(y-3x)\right]$$

$$= 3f'(y-3x)\left[\frac{\partial y}{\partial y} + \frac{\partial}{\partial y}(-3x)\right]$$

$$= 3f'(y-3x)(1+0)$$

$$= 3f'(y-3x)$$

$$\frac{\partial v}{\partial x} + 3\frac{\partial v}{\partial y} = -3f'(y-3x) + 3f'(y-3x)$$

$$= 0$$

E029
G012
G006

(1) + (2) ELECTRIC MOTOR DRIVE (1)

EFFECT – CURRENTS AT NORMAL OPERATION VOLTAGE ARE GREATLY IMBALANCED
- REDUCED FULL LOAD SPEED
- NOISE, VIBRATION

$$\%\ \text{VOLTAGE IMBALANCE} = \frac{\text{MAXIMUM DEVIATION FROM AVERAGE VOLTAGE}}{\text{AVERAGE VOLTAGE}} \times 100$$

pb 3 VOLTAGES, PHASE TO NEUTRAL ARE MEASURED TO BE 220, 215 AND 210V, ON NOMINAL 415V, 50 HZ. DETERMINE % VOLTAGE IMBALANCE

$$\text{AVERAGE VOLTAGE} = \frac{220+215+210}{3} = 215\text{V}$$

$$\text{MAXIMUM DEVIATION FROM AVERAGE VALUE} = 220-215 = 5\text{V}$$

$$\%\ \text{VOLTAGE IMBALANCE} = \frac{5}{215} \times 100 = 2.32$$

$$\text{SYNCHRONOUS SPEED } (N_S) = \frac{120f}{P}, \quad f = \text{FREQUENCY}, \quad P = \text{NO. OF POLE}$$

TORQUE → STARTING TORQUE
→ LOCKED ROTOR, BREAK AWAY TORQUE
→ PULL OUT (MAXIMUM) TORQUE

CURRENT $\propto$ VOLTAGE

TORQUE $\propto$ (VOLTAGE)^2

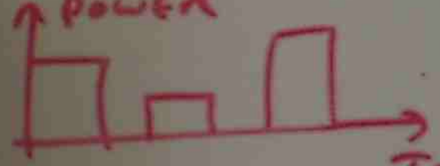
STARTING CURRENT → 450% → 600%

REDUCED VOLTAGE STARTING REQUIRED

DRIVING TORQUE

THE DRIVING TORQUE MUST BE CAPABLE OF SUPPLYING THE MAXIMUM TORQUE LIKELY TO BE ENCOUNTERED AT ANY TIME DURING

DUTY CYCLE



DUTY CYCLE

DUTY TYPES

$S_1 \rightarrow S_8$ (CONTINUOUS ETC)

CLASSES

N, NR, NS, NY, H, HR, HS
HY (HIGH TORQUE ETC)

AS1359.20, AS1359.21, AS1359.22

CLASSIFICATION 1 → 6

TYPE OF ENCLOSURE → (OPEN / SPLASH PROOF IPX, IP22, IP11, IP24, IP35, IP22 ETC)
IP43, IP44, FLAME PROOF AS 2480

$$\text{EQUIVALENT MOMENT OF INERTIA} = \text{LOAD MOMENT OF INERTIA} \left[\frac{\text{LOAD SPEED}}{\text{MOTOR SPEED}}\right]^2$$

$$\Delta t = \frac{J_T}{9.55} \times \frac{\Delta N}{T_{AV}}, \quad T = \frac{P \times 60}{2\pi N}$$

ELECTRIC MOTOR DRIVE PART(1)

(1) ELECTRIC MOTOR SELECTION & APPLICATION

SLIDE (1) ⟶ (9)

Q.1 ⟶ Q9

(2) DUTY TYPE OF MOTOR

SLIDE (1) ⟶ (11)

Q 9 ⟶ 17

ELECTRIC MOTOR DRIVE PART(2)

TYPICAL MOTOR STARTING CURRENT LIMITATION

- $I_{st} = 53 + 3.3\,K$ AMPERE
  K - KW OUTPUT
- MOTOR RATED MORE THAN 6 HP
  $I_{st} = HP \times 2.5 + 33$ A

Pb DETERMINE THE PERMISSIBLE STARTING CURRENT. MOTOR (1) 15 KW, 3φ, 415V
MOTOR (2) 15 KW,

MOTOR (1)

$I_{st} = 53 + 3.3\,K = 53 + 3.3 \times 15 = 102.5$ A

MOTOR (2)

$I_{st} = HP \times 2.5 + 33 = \frac{15000}{746}(HP) \times 2.5 + 33$

$= 20.11 \times 2.5 + 33 = 83.2$ A

MOTOR STARTERS

AUTOMATIC (SEQUENCE CONTROL)
NON AUTOMATIC (HAND OPERATION)

METHOD OF OPERATION

MANUAL, ELECTRO MAGNETIC, PNUEMATIC

INTERRUPTION

AIR BREAK, OIL IMMERSED, VACCUM BREAK

$I_{\lambda/\Delta} = \frac{I_{DOL}}{3}$, $T_{\lambda/\Delta} = \frac{T_{DOL}}{3}$ (λ/Δ)

$I_{AUTO} = \frac{\%E}{100} \times I_{DOL}$, $T_{AUTO} = \left(\frac{\%E}{100}\right)^2 T_{DOL}$

(AUTO TRANSFORMER)

SYNCHRONOUS MOTOR

DC FIELD EXCITATION, 3φ SUPPLY
(CYLINDERICAL / SALIENT POLE)

PROTECTIVE DEVICE

CURRENT SENSING
TEMPERATURE SENSING

MAGNETIC
BIMETALLIC

THE LAW of MACHINE

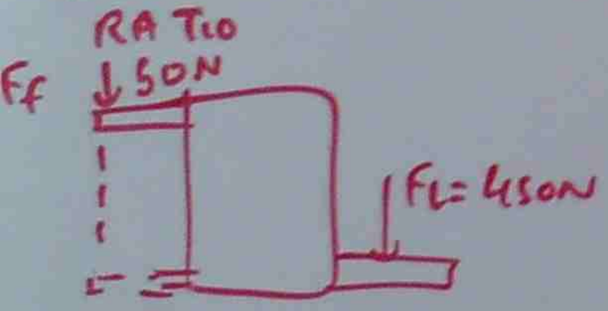
$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}}$$

$$MA = \frac{F_L}{F_f}$$

$$\text{VELOCITY RATIO} = \frac{\text{DISTANCE MOVED BY EFFORT}}{\text{DISTANCE MOVED BY LOAD}}$$

$$VR = \frac{S_f}{S_L}$$

Ex A SIMPLE MACHINE IN FIGURE, THE LOAD IS 450 N, EFFORT IS 50N. THE LOAD AND EFFORT MOVEMENT IS 100mm AND 1200m RESPECTIVELY. CALCULATE MECHANICAL ADVANTAGE AND VELOCITY RATIO



$$MA = \frac{F_L}{F_f} = \frac{450}{50} = 9$$

$$VR = \frac{S_f}{S_L} = \frac{1200}{100} = 12$$

WORK & EFFICIENCY $\eta = \frac{MA}{VR}$

THE LAW of MACHINE

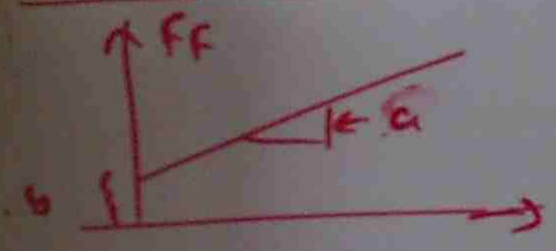
$$F_E = a F_L + b$$

F_E = EFFORT, F_L = LOAD

a = SLOPE of GRAPH

b = VERTICAL CUTTING POINT

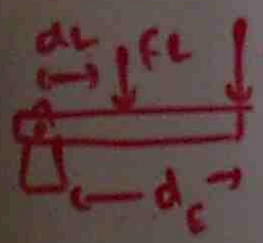
LOAD F_L (N)	0	200	400	600	800	1000
EFFORT F_F (N)	5	25	45	65	85	105



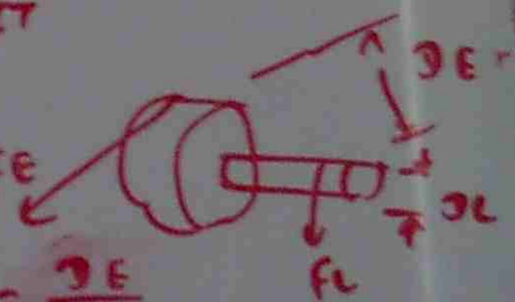
(9) THE LAW of MACHINE
SLIDE 1 → 8
Q61 → Q63

MECHANICAL DRIVE SYSTEM

$$P = \omega T = \frac{2\pi N T}{60} \text{ WATT}$$



$$VR = \frac{d_E}{d_L}$$



$$VR = \frac{D_E}{D_L}$$

(10) MECHANICAL DRIVE SYSTEM
SLIDE 1+2, Q64

STRENGTH OF MATERIALS

P7 DETERMINE THE WEIGHT OF A TUBULAR STEEL COLUMN 120mm OUT SIDE DIAMETER 100 mm INSIDE DIAMETER & 3m HIGH

$CSA = \frac{\pi}{4}\left[\left(\frac{120}{100}\right)^2 - \left(\frac{100}{100}\right)^2\right] = 3.45\times10^{-3}\ m^2$

$VOL = CSA \times l = 3.45\times10^{-3} \times 3 = 0.0104\ m^3$

WEIGHT = DENSITY x VOL x g

$= 80.86 \times 0.0104 \times 9.81$

$= 793.3\ N$

ULTIMATE STRENGTH = $\frac{\text{MAXIMUM TENSILE FORCE}}{\text{C.S.A}}$

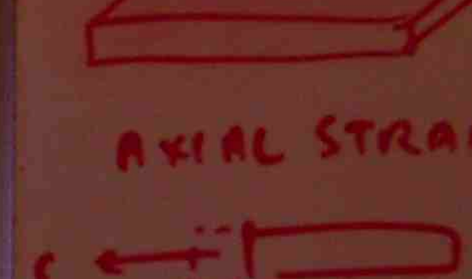
P7 A STEEL SPECIMEN 10mm DIAMETER RUPTURED UNDER 37 kN FIND ULTIMATE STRENGTH

$UTS = \frac{F}{A} = \frac{37\times10^3}{\frac{\pi}{4}(10)^2} = 471\ N/mm^2$



SHEAR STRESS = $\frac{\text{FORCE}}{\text{AREA}}$

AXIAL STRAIN = $\frac{\Delta l}{l}$





$= \frac{x}{l}$

SHEAR MODULUS = $\frac{\text{STRESS}}{\text{STRAIN}} = \frac{F}{A} \div \frac{\Delta l}{l}$

P8



F = 11.3 kN

FIND SHEAR STRESS

$A = 2\ \frac{\pi \times 10^2}{4} = 157\ mm^2$

$f = \frac{F}{A} = \frac{11.3\times10^3}{157} = 72\times10^6\ N/m^2$

FACTOR OF SAFETY = $\frac{\text{ULTIMATE STRESS}}{\text{WORKING STRESS}}$

(12) STRESS & STRAIN

SLIDE 1 → 7 0.69 → 0.72

ELECTRIC MOTOR DRIVE PART(1)

(1) ELECTRIC MOTOR SELECTION & APPLICATION

SLIDE (1) ⟶ (9)

Q.1 ⟶ Q9

(2) DUTY TYPE OF MOTOR

SLIDE (1) ⟶ (11)

Q 9 ⟶ 17

ELECTRIC MOTOR DRIVE PART(2)

TYPICAL MOTOR STARTING CURRENT LIMITATION

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  K - KW OUTPUT
- MOTOR RATED MORE THAN 6 HP
  $I_{st} = HP \times 2.5 + 33$ A

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$I_{st} = HP \times 2.5 + 33 = \frac{15000}{746}(HP) \times 2.5 + 33$

$= 20.11 \times 2.5 + 33 = 83.2$ A

MOTOR STARTERS

AUTOMATIC (SEQUENCE CONTROL)
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AIR BREAK, OIL IMMERSED, VACCUM BREAK

$I_{\lambda/\Delta} = \frac{I_{DOL}}{3}$, $T_{\lambda/\Delta} = \frac{T_{DOL}}{3}$ (λ/Δ)

$I_{AUTO} = \frac{\%E}{100} \times I_{DOL}$, $T_{AUTO} = \left(\frac{\%E}{100}\right)^2 T_{DOL}$

(AUTO TRANSFORMER)

SYNCHRONOUS MOTOR

DC FIELD EXCITATION, 3φ SUPPLY
(CYLINDERICAL / SALIENT POLE)

PROTECTIVE DEVICE

CURRENT SENSING
TEMPERATURE SENSING

MAGNETIC
BIMETALLIC

Pb 22 KW, 4 POLE, 415V, FULL LOAD CURRENT 38A, 3ϕ INDUCTION MOTOR.

LOCKED ROTOR CURRENT = 600% I_{FL}

LOCKED ROTOR TORQUE = 155% T_{FL}

DETERMINE I_{st} & T_{st} FOR (a) λ/Δ.

(b) PRIMARY RESISTANCE STARTING

(c) AUTO TRANSFORMER STARTING 55% TAP

(a) λ/Δ $\quad I_{st} = \frac{600}{3} = 200\%\ I_{FL}$

$T_{st} = \frac{155}{3} = 51.7\%\ T_{FL}$

(b) PRIMARY RESISTANCE

$I_{st} = 330\%\ I_{FL}$, $T_{st} = 600\%\ T_{FL}$

(c) AUTO TRANSFORMER

$T_{st} = \left(\frac{55}{100}\right)^2 \times 155\ T_{FL} = 46.9\%\ T_{FL}$

(3) INDUCTION MOTOR STARTING

SLIDE (1) → (10)

Q.18 → Q.24

(4) INDUCTION + SYNCHRONOUS MOTOR

SLIDE (1) → (9)

Q.25 → Q.29

MATERIALS SCIENCE (E029 + G012 + E047)

DENSITY, FRICTION, LINEAR MOTION

$$\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}} \quad \left(\frac{kg}{m^3}\right)$$

$$\text{RELATIVE DENSITY} = \frac{\text{DENSITY OF MATERIAL}}{\text{DENSITY OF WATER}}$$

$$\text{SPECIFIC VOLUME} = \frac{\text{VOLUME}}{\text{MASS}}$$

pb 600mL OF SULPHURIC ACID HAS A MASS OF 1.11kg. WHAT IS DENSITY & RELATIVE DENSITY.

$$\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}} = \frac{1.11\ kg}{0.6\ L} = 1.85\ kg/L$$
$$= 1850\ kg/m^3$$

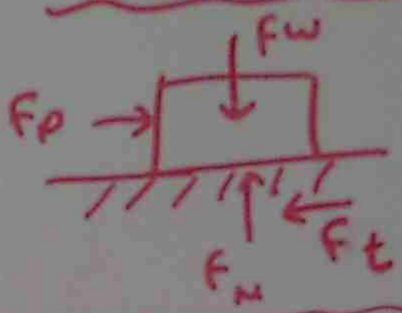
$$\text{RELATIVE DENSITY} = \frac{1850}{1000} = 1.85$$

(5) DENSITY, FRICTION, LINEAR MOTION

SLIDE (1) ⟶ (3)

Q 30 → Q 32

FRICTION

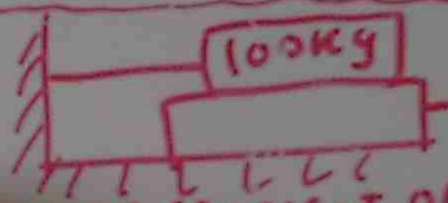


$$\mu = \frac{F_t}{F_M}$$

↑ COEFFICIENT OF STATIC FRICTION

$$F_p = F_t = \mu F_m$$

pb



A 100kg BLOCK RESTS ON A PLATE. THE COEFFICIENT OF FRICTION BETWEEN ALL SURFACES IS 0.2. DETERMINE THE FORCE REQUIRED TO PULL THE PLATE

$F_m = f_w = mg = 100 \times 9.81 = 981\ N$

$F_t = \mu f_m = 0.2 \times 981 = 196.2\ N$

$F_p = 2 F_t = 2 \times 196.2 = 392.4\ N$

(5) DENSITY, FRICTION, LINEAR MOTION

SLIDE (4) → (9)

Q 33 ⟶ Q 35

LINEAR MOTION

EQUATION OF LINEAR MOTION

$$S = t \times V_{av} = t\left(\frac{V_0 + V}{2}\right)$$

$$V = V_0 + at$$

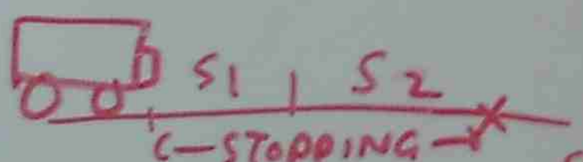
$$S = V_0 t + \frac{1}{2} a t^2$$

$$V^2 = V_0^2 + 2as$$

V_0: INITIAL VELOCITY (m/s)
t: TIME (s)
V: FINAL VELOCITY (m/s)
a: ACCELERATION (m/s^2)
S: DISPLACEMENT (m)

Pb FIND THE TOTAL EMERGENCY STOPPING DISTANCE OF A CAR AND THE TOTAL TIME TAKEN FROM THE POINT WHERE THE DRIVER SIGHT DANGER IF THE DRIVER'S REACTION TIME BEFORE APPLYING THE BRAKE IS 0.9 S AND INITIAL VELOCITY 60Km/h AND RETARDATION DUE TO BRAKE IS $7.5\ m/s^2$

$$V = 60\ Km/hr = \frac{60 \times 10^3}{3600} = 16.67\ m/s$$



FOR 0.9 Sec

$$S_1 = V \times t = 16.67 \times 0.9 = 15m$$

$$V_0^2 = V^2 + 2as$$

$$0 = (16.67)^2 + 2(-7.5) \times S_2$$

$$S_2 = \frac{(16.67)^2}{2 \times 7.5} = 18.5m$$

$$S = S_1 + S_2 = 15 + 18.5 = 33.5m$$

Pb A CAR STARTS FROM THE REST AT THE RATE of $1.2\ m/s^2$ FOR 15 SECOND. DETERMINE THE VELOCITY REACHED AFTER 15 SECOND

$$V = V_0 + at = 0 + 1.2 \times 15 = 18\ m/s$$

(5) DENSITY, FRICTION, LINEAR MOTION
SLIDE (10) → (12) @36

WORK & POWER

MECHANICAL WORK = FORCE x DISTANCE

$$W = F \times S$$

$$W = T \times \theta$$ { T: TORQUE, θ: ANGULAR DISPLACEMENT

$$POWER = \frac{WORK}{TIME}$$

Pb A FLYWHEEL MAKES 200 REVOLUTIONS, TORQUE IS 35 N-m. FIND WORK

$$W = T \times \theta = 35 \times 200 \times 2\pi = 44000J$$

Pb FORCE = 50N, DISTANCE = 3 m. FIND WORK

$$W = F \times S = 50 \times 3 = 150\ J$$

FORCE, MASS, ACCELERATION

VERTICAL MOTION

$v = v_0 + gt \quad g = 9.81$ | $v^2 = v_0^2 + 2gh$, $s = v_0 t + \frac{1}{2} g t^2$

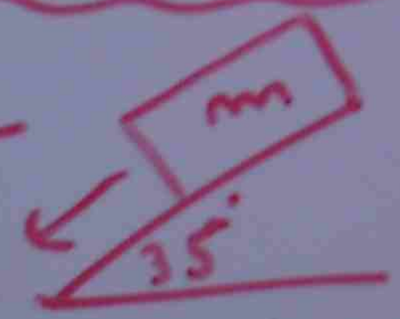
$F = m \times a$ F = FORCE (N), m = MASS (kg), a = ACCELERATION (m/s^2)

Pb DETERMINE THE ACCELERATION OF A BODY of 25 kg MASS DUE ENTIRELY TO IT'S OWN WEIGHT.

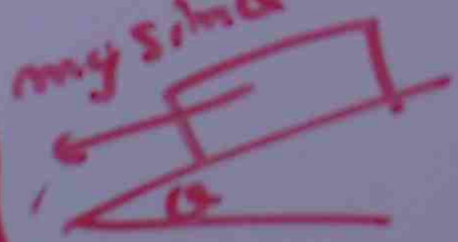
$F = m \cdot g = 25 \times 9.81 = 245.3\ N$

$a = \frac{F}{m} = \frac{245.3}{25} = 9.81\ m/s^2$

Pb



DETERMINE ACCELERATION



$F = mg \sin\alpha$

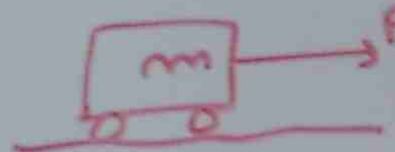
$F = ma$

$mg \sin\alpha = ma$

$a = g \sin\alpha = 9.81 \sin 35$

$= 5.63\ m/s^2$

ACCELERATION AGAINST RESISTANCE



$$a = \frac{F}{m} = \frac{F_p - F_t}{m}$$

Pb A TRAIN OF TOTAL MASS 120 TON IS TRAVELLING AT 60 Km/hr ON LEVEL TRACK. THE TRACTIVE RESISTANCE IS 80 N/TON. CALCULATE THE TRACTIVE EFFORT REQUIRED TO ACCELERATE THE TRAIN TO 100 Km/hr IN 30 Seconds.

$v_0 = 60\ Km/hr = \frac{60 \times 10^3}{3600} = 16.67\ m/s$

$v = 100\ Km/hr = \frac{100 \times 10^3}{3600} = 27.78\ m/s$

$v = v_0 + at \rightarrow 27.78 = 16.67 + a \times 30$

$a = \frac{27.78 - 16.67}{30} = 0.37\ m/s^2$

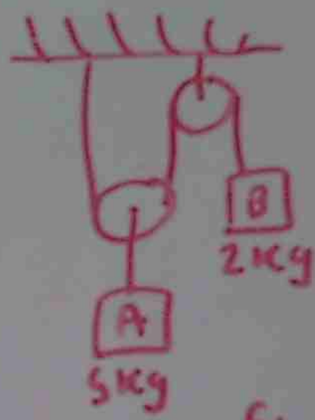
$F = F_p - F_t \rightarrow ma = F_p - f_t$

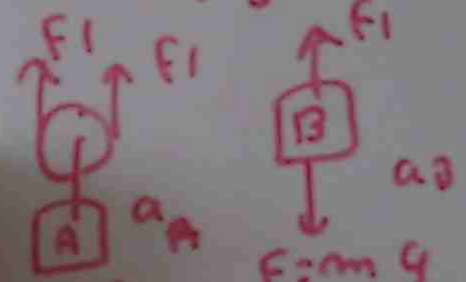
$120 \times 10^3 \times 0.37 = F_p - 80 \times 120$

$F_p = 120{,}000 \times 0.37 + 9600 = 54000\ N$

$= 54\ KN$

Pb DETERMINE THE ACCELERATION of BODIES A & B AND THE FORCE TENSION IN THE CORD





$a_A = \frac{1}{2} a_B$

FOR BODY (B)

$F = m \times a_B$

$F_1 - F_B = m \times a_B$

$F_1 - 19.62 = 2 \times a_B$ — (1)

$F_A - 2F_1 = m_A \times a_A$

$49.05 - 2F_1 = 5 \times a_A$ $\quad a_A = \frac{a_B}{2}$

$49.05 - 2F_1 = 5 \times \frac{a_B}{2}$

$49.05 - 2F_1 = 2.5\, a_B$ — (2)

(1) × 2 ⇒ $2F_1 - 39.24 = 4a_B$

$49.05 - 2F_1 = 2.5 a_B$

$49.05 - 39.24 = 6.5 a_B \rightarrow a_B = 1.51$

$a_A = \frac{1}{2} a_B = \frac{1}{2} \times 1.51 = 0.755\ m/s^2$

$F_1 = 2a_B + 19.62 = 2 \times 1.51 + 19.62 = 22.6$

(6) FORCE, MASS, ACCELERATION

SLIDE (1) ⟶ SLIDE (8)

Q37 ⟶ Q40

TORQUE, WORK, POWER, ENERGY

$T = I \times \alpha$

T = TORQUE (N-m)
I = MOMENT OF INERTIA ($kg-m^2$)
α = ANGULAR ACCELERATION (RAD/s^2)

Pa DETERMINE THE NET TORQUE REQUIRED TO GIVE A FLYWHEEL WITH MOMENT OF INERTIA 0.75 $kg-m^2$ & ANGULAR ACCELERATION 16 rad/s^2

$T = I \times \alpha = 0.75 \times 16 = 12$ N-m

Pb DETERMINE THE TORQUE REQUIRED TO ACCELERATE A TURBINE ROTOR UNDERGOING A DYNAMIC BALANCING TEST FROM REST TO 15000 RPM SPEED IN 80 SECOND IF MASS MOMENT OF INERTIA IS 11.5 $kg-m^2$

$\omega = \frac{2\pi\ RPM}{60} = \frac{2 \times 3.1416 \times 15000}{60} = 1571$

$\omega = \omega_0 + \alpha t$

$1571 = 0 + \alpha \times 80$

$\alpha = 19.63\ RAD/s^2$

$T = I\alpha = 11.5 \times 19.63 = 225.8$ N-m

CENTRIFUGAL FORCE

$F_C = \frac{mV^2}{r} = m r \omega^2$

Pa DETERMINE THE CENTRIFUGAL FORCE ACTING ON A PASSENGER OF MASS 75 kg IN A CAR TRAVELLING AT 90 km/hr AROUND A CURVE OF 100 m RADIUS

$F_C = \frac{mV^2}{r} = \frac{75 \times \left(\frac{90 \times 10^3}{3600}\right)^2}{100} = 468.75\ N$

$P = T \times \omega$, $P = F \times V$

Pb A TRAIN MOVING AT 63 km/hr REQUIRES 40 kN of TRACTIVE EFFORT DETERMINE THE DRIVING POWER

$v = 63\ km/hr = \frac{63 \times 10^3}{3600} = 17.5\ m/s$

$P = F v = 40\ kN \times 17.5\ m/s = 700\ kW$

$PE = mgh$, $KE = \frac{1}{2}mV^2$, $KE = \frac{I\omega^2}{2}$

Pa CALCULATE THE KINETIC ENERGY OF FLYWHEEL AT INERTIA 61 $kg-m^2$, ROTATING AT 250 RPM.

$KE = \frac{I\omega^2}{2} = \frac{61(2\pi\ 250/60)^2}{2} = 20904\ J$

(7) TORQUE, WORK, POWER, ENERGY

SLIDE 1 ⟶ 13, Q42 ⟶ Q55

(6) FORCE, MASS, ACCELERATION

SLIDE (1) ⟶ SLIDE (8)

Q37 ⟶ Q40

TORQUE, WORK, POWER, ENERGY

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T = TORQUE (N-m)
I = MOMENT OF INERTIA ($kg-m^2$)
α = ANGULAR ACCELERATION (RAD/s^2)

Pa DETERMINE THE NET TORQUE REQUIRED TO GIVE A FLYWHEEL WITH MOMENT OF INERTIA 0.75 $kg-m^2$ & ANGULAR ACCELERATION 16 rad/s^2

$T = I \times \alpha = 0.75 \times 16 = 12$ N-m

Pb DETERMINE THE TORQUE REQUIRED TO ACCELERATE A TURBINE ROTOR UNDERGOING A DYNAMIC BALANCING TEST FROM REST TO 15000 RPM SPEED IN 80 SECOND IF MASS MOMENT OF INERTIA IS 11.5 $kg-m^2$

$\omega = \frac{2\pi\ RPM}{60} = \frac{2 \times 3.1416 \times 15000}{60} = 1571$

$\omega = \omega_0 + \alpha t$

$1571 = 0 + \alpha \times 80$

$\alpha = 19.63\ RAD/s^2$

$T = I\alpha = 11.5 \times 19.63 = 225.8$ N-m

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$F_C = \frac{mV^2}{r} = m r \omega^2$

Pa DETERMINE THE CENTRIFUGAL FORCE ACTING ON A PASSENGER OF MASS 75 kg IN A CAR TRAVELLING AT 90 km/hr AROUND A CURVE OF 100 m RADIUS

$F_C = \frac{mV^2}{r} = \frac{75 \times \left(\frac{90 \times 10^3}{3600}\right)^2}{100} = 468.75\ N$

$P = T \times \omega$, $P = F \times V$

Pb A TRAIN MOVING AT 63 km/hr REQUIRES 40 kN of TRACTIVE EFFORT DETERMINE THE DRIVING POWER

$v = 63\ km/hr = \frac{63 \times 10^3}{3600} = 17.5\ m/s$

$P = F v = 40\ kN \times 17.5\ m/s = 700\ kW$

$PE = mgh$, $KE = \frac{1}{2}mV^2$, $KE = \frac{I\omega^2}{2}$

Pa CALCULATE THE KINETIC ENERGY OF FLYWHEEL AT INERTIA 61 $kg-m^2$, ROTATING AT 250 RPM.

$KE = \frac{I\omega^2}{2} = \frac{61(2\pi\ 250/60)^2}{2} = 20904\ J$

(7) TORQUE, WORK, POWER, ENERGY

SLIDE 1 ⟶ 13, Q42 ⟶ Q55

momentum + impulse

momentum = mv

impulse $Ft = mv - mv_0$

(2) impulse

SLIDE (1) → (3)

@ 56 → @ 57

Pb/ A BLOCK OF WOOD OF MASS 2kg IS FREELY SUSPENDED ON A STRING. A BULLET OF MASS 75g IS FIRED HORIZONTALLY INTO THE BLOCK. IF THE VELOCITY BEFORE IS 415 m/s, CALCULATE THE VELOCITY OF BLOCK.

$m_1 v_1 + m_2 v_2 = (m_1 + m_2) V$

$75 \times 10^{-3} \times 415 + 2 \times 0 = (75 \times 10^{-3} + 2) V$

$V = 15$ m/s

Pb/ WHEN A BALL 50g IS STRUCK BY CLUB THEY ARE IN CONTACT FOR 0.001 SEC. AFTER THE IMPACT, TRAVELS AT 45 m/s. FIND FORCE.

$Ft = mv - mv_0 \Rightarrow F \times 0.001 = \frac{50}{1000} \times 45 - 0$ { $F = 6000$ N

momentum + impulse

momentum = mv

impulse $Ft = mv - mv_0$

(8) impulse

SLIDE (1) → (3)

Q56 → Q57

Ph/ A BLOCK OF WOOD OF MASS 2kg IS FREELY SUSPENDED ON A STRING. A BULLET OF MASS 75g IS FIRED HORIZONTALLY INTO THE BLOCK. IF THE VELOCITY BEFORE IS 415 m/s, CALCULATE THE VELOCITY OF BLOCK.

$m_1 v_1 + m_2 v_2 = (m_1 + m_2) V$

$75 \times 10^{-3} \times 415 + 2 \times 0 = (75 \times 10^{-3} + 2) V$

$V = 15$ m/s

Ph/ WHEN A BALL 50g IS STRUCK BY CLUB THEY ARE IN CONTACT FOR 0.001 SEC. AFTER THE IMPACT, TRAVELS AT 45 m/s. FIND FORCE.

$Ft = mv - mv_0 \Rightarrow F \times 0.001 = \frac{50}{1000} \times 45 - 0$ { $F = 6000$ N

MOTION ALONG STRAIGHT LINE

DISPLACEMENT

SPEED = $\frac{\text{TOTAL DISTANCE TRAVELLED}}{\text{TIME}}$

VELOCITY = $\frac{\text{DISPLACEMENT}}{\text{TIME}}$

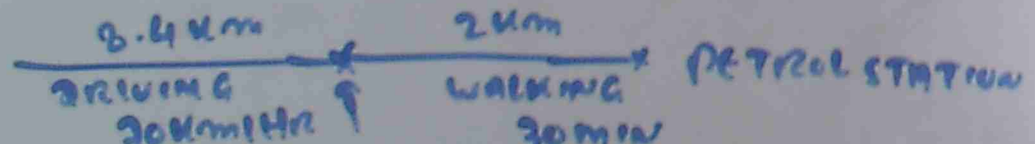
ACCELERATION = $\frac{\text{VELOCITY}}{\text{TIME}}$

Q. A CAR IS DRIVEN ALONG A STRAIGHT ROAD FOR 8.4KM AT 30 KM/HR. AT WHICH POINT, THE GASOLINE WILL RUN OUT AND STOP OVER NEXT 30 MINUTES. THEN THE DRIVER WALKS AN ANOTHER 2KM TO PETROL STATION

(a) WHAT IS OVER ALL DISPLACEMENT?

(b) WHAT IS TIME INTERVAL FROM THE BEGINNING OF THE DRIVE TO FINAL DESTINATION?

(c) WHAT IS AVERAGE VELOCITY ?



(a) OVERALL DISPLACEMENT = DRIVING DISTANCE + WALKING DISTANCE

= 8.4KM + 2KM = 10.4 KM

(b) TOTAL TIME = TIME FOR DRIVING + TIME FOR WALKING

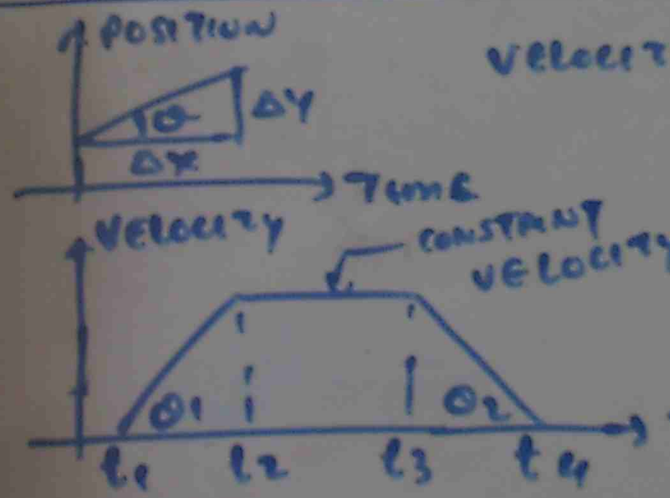
= $\frac{\text{DISTANCE}}{\text{VELOCITY}}$ + 0.5 HR

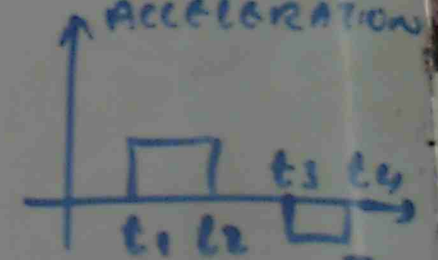
= $\frac{8.4\text{KM}}{30\text{KM/HR}}$ + 0.5 HR = 0.62 HR

AVERAGE VELOCITY = $\frac{\text{OVER ALL DISPLACEMENT}}{\text{OVER ALL TIME}}$

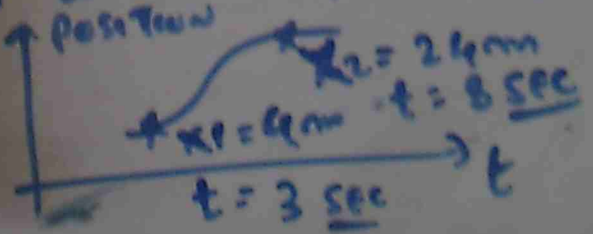
= $\frac{10.4\text{KM}}{0.62\text{HR}}$ = 16.8 KM/HR

VELOCITY = $\frac{\Delta Y}{\Delta X}$





Q. THE FOLLOWING FIGURE REPRESENTS THE PLOT FOR AN ELEVATOR CAR THAT IS INITIALLY STATIONARY. THEN MOVES UP & STOP. PLOT V(t)

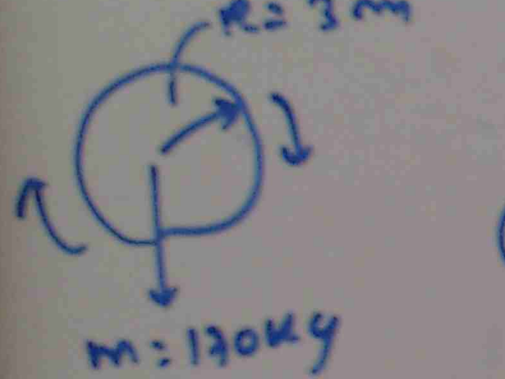


$V_{AVG} = \frac{x_2 - x_1}{t_2 - t_1}$

$= \frac{24 - 4}{8 - 3} = 4$



Pb A ROLLING OBJECT HAS LINEAR VELOCITY 342.5 m/s RADIUS 3m MASS 170kg. CALCULATE KINETIC ENERGY.



$K = \frac{1}{2} I\omega^2 + \frac{1}{2} mv^2$

$\omega = \frac{v}{R}$

$I = \frac{1}{2} mR^2$

$K = \frac{1}{2}\left(\frac{1}{2} mR^2\right)\left(\frac{v}{R}\right)^2 + \frac{1}{2} mv^2$

$= \frac{1}{4} mR^2 \times \frac{v^2}{R^2} + \frac{1}{2} mv^2$

$= \frac{1}{4} mv^2 + \frac{1}{2} mv^2$

$K = \frac{3}{4} mv^2 = \frac{3}{4} \times 170 (342.5)^2$

$= 1.5 \times 10^7 J$

EQUILIBRIUM

THE LINEAR MOMENTUM $\vec{P}$ = CONSTANT

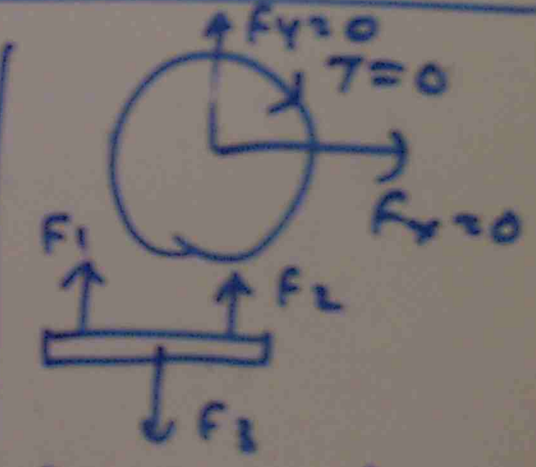
ANGULAR MOMENTUM $\vec{L}$ = CONSTANT

RATE OF CHANGE OF $P = 0 \rightarrow$ EQUILIBRIUM

$\frac{dP}{dt} = 0 \qquad F_{NET} = \frac{dP}{dt} = 0$

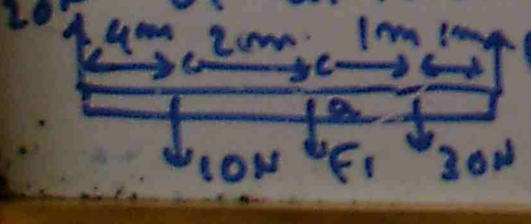
FORCE

$F_{NET} = 0 \rightarrow \Sigma F_x = 0, \Sigma F_y = 0, \tau_{NET} = 0$



$\uparrow F_1 + F_2 = \downarrow F_3$

Pb THE FIGURE GIVES AN OVERVIEW OF A UNIFORM ROD IN STATIC EQUILIBRIUM (a) FIND MAGNITUDE OF UNIFORM FORCE F_1 & F_2



(a ↑ = ↓)

$F_1(1+1) + 10 \times 2 = 30 \times 1 + 20(4+2)$

$F_1 = 45N$

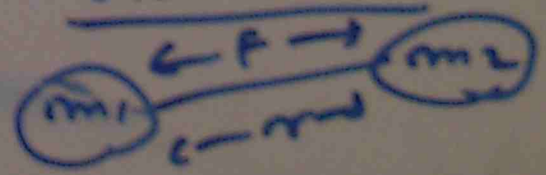
$F_2 = 65N$

$\Sigma F_y = 0 \quad \uparrow F = \downarrow F$

$20 + F_2 = 10 + F_1 + 30$

$20 + 65 = 40 + F_1$

GRAVITATION



$F_{12} = G \frac{m_1 m_2}{r^2}$

$G = 6.67 \times 10^{-11} m^3/kg \cdot s^2$

FLUID

FLUID IS A SUBSTANCE THAT CAN FLOW.

$$\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}}$$

DENSITY

AIR = 1.21 kg/m³, WATER = 1×10^3, IRON = 7.9×10^3 (20°C, 50 Atm)

PRESSURE



$$\text{PRESSURE (Pa)} = \frac{\text{FORCE}}{\text{AREA}} = \frac{F(N)}{A(m^2)}$$

$F = mg$, $P = \frac{mg}{A}$ FOR 1 UNIT AREA ⇒ A = 1, UNIT PRESSURE = mg

MASS = DENSITY × VOLUME

$m = \rho \times V$, UNIT PRESSURE = $\rho V \times g$

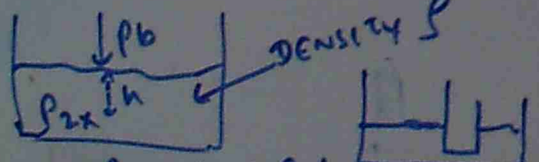
Ex A LIVING ROOM HAS THE FLOOR DIMENSION 3.5m × 4.2m AND A HEIGHT OF 2.4m (a) WHAT DOES THE AIR IN THE ROOM WEIGH WHEN AIR PRESSURE IS 1 Atm? (b) WHAT IS THE MAGNITUDE OF THE ATMOSPHERE'S DOWNWARD FORCE ON THE TOP OF YOUR HEAD WHICH WE TAKE TO HAVE OF 0.04 m²?

(a) $F_{AIR} = \rho V g = 1.21\ kg/m^3 \times (3.5\times4.2\times2.4) \times 9.8 = 420\ N$

(b) $F = P \times A \rightarrow (1\,ATm) \times \left\{\frac{1.01\times10^3\ N/m^2}{1\,ATm}\right\} \times 0.04\ m^2$

$1\,ATm \rightarrow 1.05\times10^5\ N/m^2 = 4\times10^3\ N$

FLUID PRESSURE AT DEPTH "h"



$P_2 = P_0 + \rho g h$

Ex THE U TUBE IN THE FIGURE IN STATIC EQUILIBRIUM DENSITY OF WATER $\rho_w = 998\ kg/m^3$

$l = 135\ mm$, $d = 12.3\ mm$

WHAT IS THE DENSITY OF OIL?



AT THE INTERFACE

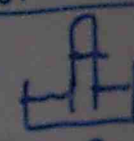
↓ OIL PRESSURE = ↑ WATER + AIR PRESSURE

$P_{INT} = P_w + P_o$

$P_{INT} = \rho_x\, g(l+d) + P_a$

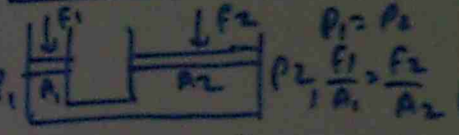
OIL DENSITY $\rho_x = \rho_w \times \frac{l}{l+d} \rightarrow \rho_x = 1 \times \frac{135}{135+12.3} = 915\ kg/m^3$

BAROMETER



$P = \rho g h$

PASCAL'S PRINCIPLE



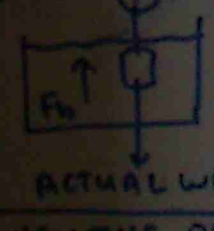
$P_1 = P_2$, $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

MASS REMOVED THE EQUAL AMOUNT OF FLUID



ARCHIMEDES' PRINCIPLE

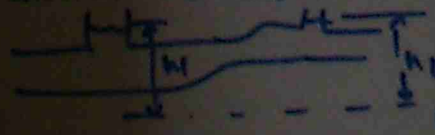
WHEN A BODY IS FULLY (OR) PARTIALLY SUBMERGED IN A FLUID, A BUOYANT FORCE $\vec{F_2}$ FROM THE SURROUNDING FLUIDS ACTS ON THE BODY. THE FORCE IS DIRECTED UPWARD AND HAS A MAGNITUDE EQUAL TO THE WEIGHT $m_f g$ OF THE FLUID THAT HAS BEEN DISPLACED BY THE BODY.



APPARENT WEIGHT = ACTUAL FORCE − MAGNITUDE OF BUYONT FORCE

BERNOULLI'S EQUATION

WHEN THE FLUID IS FLOWING, TOTAL FORCE (PRESSURE + GRAVITY (HEIGHT) + VELOCITY) IS THE SAME.



$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$

PRESSURE ↑ VELOCITY ↑ GRAVITY HEIGHT

Ex THE DIAGRAM SHOWS THE STREAM OF WATER EMERGING FROM A FAUCET NECK. $A_0 = 1.2\ cm^2$. $A = 0.35\ cm^2$. $h = 45\ mm$ FIND THE VOLUME.



$R_U = A_0 v_0$

$v^2 = v_0^2 + 2gh$

$v_0 = \sqrt{\frac{2gh\,A^2}{A_0^2 - A^2}} = \sqrt{\frac{2\times9.81\times(0.35)^2}{1.2^2 - 0.35^2}} = 0.48$

THERMAL EXPANSION

LINEAR EXPANSION

$\Delta L = L \alpha \Delta t$

VOLUME EXPANSION

$\Delta V = V \beta \Delta t$

AREA EXPANSION

$\Delta A = A \gamma \Delta t$ $\quad \gamma = 2\alpha$

L = ORIGINAL LENGTH
ΔL = LINEAR EXPANSION
α = COEFFICIENT OF LINEAR EXPANSION
Δt = CHANGE OF TEMPERATURE
V = ORIGINAL VOLUME
β = COEFFICIENT OF VOLUMETRIC EXPANSION
$\beta = 3\alpha$

Pb ON A HOT DAY OF LASVEGAS, AN OIL TANKER LOADED 37000 L OF DIESEL FUEL. IT ENCOUNTERS COLD WEATHER IN UTAH WHERE TEMPERATURE WAS 23°K LOWER THAN LAS VEGAS. HOW MANY LITERS DID IT DELIVER? VOLUMETRIC EXPANSION FOR DIESEL FUEL IS 9.5×10^{-4}/°C. COEFFICIENT OF LINEAR EXPANSION 11×10^{-6}/°C

(V) (ΔV)

$\Delta V = V \beta \Delta T = (37000) \times (4.5 \times 10^{-4}) \times (-23)$
$= -808\ L$

$V_{del} = V + \Delta V = 37000 + (-808) = 36190\ L$

TEMPERATURE AND HEAT

HEAT IS THE ENERGY TRANSFERRED BETWEEN A SYSTEM AND IT'S ENVIRONMENT. BECAUSE OF A TEMPERATURE DIFFERENCE THAT EXISTS BETWEEN THEM.

$1\ cal = 3.968 \times 10^{-3}\ BTU = 4.186\ J$

HEAT ABSORPTION / HEAT CAPACITY

$Q = C \Delta T = C (T_f - T_i)$, $C = mc$

c = SPECIFIC HEAT CAPACITY = 4190 J/kg°K, m = MASS(Kg)

$Q = mc \Delta t = mc (T_f - T_i)$

MOLAR SPECIFIC HEAT

$1\ mol = 6.02 \times 10^{23}$ ELEMENTARY UNITS

HEAT OF TRANSFORMATION

SOLID (0°C) ⟶ LIQUID (0°C)
LIQUID (100°C) ⟶ VAPOUR (100°C)

AMOUNT OF HEAT REQUIRED FOR CHANGING THE STATE = LATENT HEAT

Pb HOW MUCH HEAT MUST BE ABSORBED BY ICE OF MASS = 720 g AT −10°C TO TAKE THE LIQUID STATE AT 15°C ?

(I) **ICE** −10°C ICE ⟶ 0°C ICE
CHANGE OF TEMPERATURE → HEAT ABSORBED = $m_{ICE}\, c_{ICE}\, \Delta t$

(II) **ICE → WATER** CHANGE OF STATE 0°C (ICE) → 0°C (WATER)
$Q_2 = m_{ICE}\, L$

(III) **CHANGE OF TEMPERATURE**
$Q_3 = m_{WATER} \times c_{WATER} \times \Delta T$

$Q_t = Q_1 + Q_2 + Q_3 = m_{ICE}\, c_{ICE}\, \Delta t + m_{ICE}\, L + m_{WATER}\, c_{WATER}\, \Delta t$
$= \frac{720}{1000}\ kg \times 1110\ J/kg°K\ (0-(-10)) + \frac{720}{1000}\ (333\ J/kg \times) + \frac{720}{1000} \times 4190\ J/kg°K\ (15-0) = 300\ kJ$

Pb A COPPER SLUG WHOSE MASS m_c IS 95 g IS HEATED IN A LABORATORY OVEN TO A TEMPERATURE T OF 312°C. THE SLUG IS THEN DROPPED INTO A GLASS BEAKER CONTAINING $m_w = 220$ g OF WATER. THE HEAT CAPACITY OF BEAKER IS 45 cal/°K. INITIAL TEMPERATURE T_i OF WATER AND BEAKER IS 12°C. FIND FINAL TEMPERATURE. ASSUME WATER DOES NOT VAPORIZE.

SLUG (COPPER) ⟶ BEAKER ⟶ GLASS (Q_b) + WATER (Q_w)

Q_c = ?

$Q_w + Q_b + Q_c = 0$
$Q_w = c_w m_w (T_f - T_i)$
$Q_b = c_b (T_f - T_i)$

$Q_c = c_c m_c (T_f - T_i)$

$T_f = \frac{c_c m_c T + c_b T_i + c_w m_w T_i}{c_c m_c + c_b + c_w m_w}$

$\frac{0.092 \times 75 \times 312 + 45 \times 12}{41 \times 220 + 45}$

$\frac{0.092 \times 312 + 45}{1 \times 220} = 26°C$

GASES $PV = nRT$

P = PRESSURE, V = VOLUME, R = GAS CONSTANT

T = TEMPERATURE

K = BOLTZMANN CONSTANT $= \frac{R}{N} = \frac{8.31\ J/mol\ K}{6.02\times10^{23}\ mol^{-1}} = 1.38\times10^{-23}\ J/K$

$nR = Nk \rightarrow PV = NkT$

WORK DONE BY THE GAS AT CONSTANT TEMPERATURE

$V_1 \xrightarrow{W} V_2$

V_1 = INITIAL VOLUME, V_2 = FINAL VOLUME

$W_{(J)} = nRT \ln\frac{V_f}{V_i}$

Pa A CYLINDER CONTAINS 12L OF OXYGEN AT 20°C AND 15ATm. THE TEMPERATURE IS RAISED TO 35°C AND THE VOLUME IS REDUCED TO 8.5L. WHAT IS FINAL PRESSURE OF THE GAS IN ATMOSPHERE

$PV = nRT \rightarrow \frac{PV}{T} = nR$ (CONSTANT)

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \rightarrow \frac{15\times12}{(20+273)} = \frac{P_2\times8.5}{(35+273)}$

$P_2 = 22\ atm$

Pb ONE MOLE OF OXYGEN EXPANDS AT CONSTANT TEMP T OF 310K FROM INITIAL VOLUME V_i OF 12L TO FINAL VOLUME 19L. FIND WORK DONE

$W = nRT \ln\frac{V_f}{V_i}$:

$W = 1mol\times8.31\times310\ln\frac{19}{12}$

$= 1180J$

Pb THE MOLAR MASS 'M' OF OXYGEN IS 0.0320 Kg/mol

(a) WHAT IS AVG: SPEED AT 300°K?

(b) ROOT MEAN SQ: SPEED AT 300°K

(c) PROBABLE SPEED VP AT ? 300°K?

(a) $V_{avg} = \sqrt{\frac{8RT}{\pi m}} = \sqrt{\frac{8\times8.31\times300}{3.1416\times0.032}} \approx 445\ m/s$

(b) $V_{RMS} = \sqrt{\frac{3RT}{m}} = \sqrt{\frac{3\times8.31\times300}{0.032}} = 483\ m/s$

(c) $V_p = \sqrt{\frac{2RT}{m}} = \frac{\sqrt{2\times8.31\times300}}{\sqrt{0.032}} = 395\ m/s$

(10) HEAT, HEAT TRANSFER & WAVE

SLIDE 1 → 6, & 29 → 31

MOLAR SPECIFIC HEAT AT CONSTANT VOLUME

THE INITIAL STATE OF GAS IS HEATED TO FINAL STATE HEAT = Q , $Q = m C_V \Delta t$

CHANGE IN INTERNAL ENERGY

$\Delta E_{int} = m C_V \Delta t - W$ W - WORK DONE

IF $W = 0 \rightarrow \Delta E_{int} = m C_V \Delta t$

$C_V = \frac{\Delta E_{int}}{m \Delta t}$

CHANGE IN ENTROPY

$\Delta S = S_f - S_i = \int_i^f \frac{dQ}{T}$

FORCE DUE TO ENTROPY

$dE = dQ - dW$

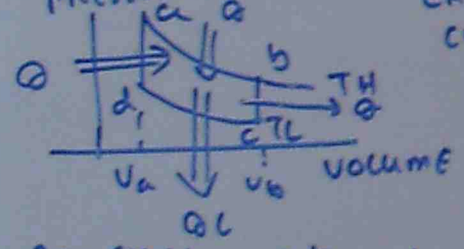
HEAT LOSS

$\Delta S_{gas} = -\frac{|Q|}{T}$

HEAT GAIN

$\Delta S_{gas} = +\frac{|Q|}{T}$

STIRLING ENGINE



CARNOT CYCLE

EXPANSION $a \rightarrow b$

VOLUME $V_a \rightarrow V_b$

COMPRESS THE GAS $c \rightarrow d$

VOLUME $\rightarrow V_b \rightarrow V_a$

HEAT Q_L DISSIPATES

COOLING $b \rightarrow c$

HEAT DISSIPATES. TEMPERATURE DECREASES FROM T_H TO T_L

HEAT THE GAS AT $d \rightarrow a$

TEMPERATURE RISES FROM T_L TO T_H, PRESSURE INCREASES

HEAT ABSORBED.

Pb THREE CARNOT ENGINES OPERATE BETWEEN RESERVOIR TEMPERATURES OF (a) 400°K & 500°K (b) 600°K AND 800°K (c) 400°K AND 600°K. RANK THE ENGINES ACCORDING TO THEIR THERMAL EFFICIENCIES.

EFFICIENCY $= 1 - \frac{T_L}{T_H}$

(a) $1 - \frac{400}{500} = 0.2 = 20\%$

(b) $1 - \frac{600}{800} = 0.25 \rightarrow 25\%$.

(c) $1 - \frac{400}{600} = 0.34 \rightarrow 34\%$

c b a

Pb IMAGINE A CARNOT ENGINE THAT OPERATES BETWEEN THE TEMPERATURES $T_H = 850°K$ AND $T_L = 300°K$. THE ENGINE PERFORMS 1200J OF WORK EACH CYCLE WHICH TAKES 0.25 sec.

(a) WHAT IS THE EFFICIENCY OF THE ENGINE?

(b) WHAT IS THE AVERAGE POWER 'P' OF THE ENGINE?

(c) HOW MUCH ENERGY $|Q_H|$ IS EXTRACTED AS HEAT FROM THE HIGH TEMPERATURE RESERVOIR EVERY CYCLE?

(d) HOW MUCH ENERGY $|Q_L|$ IS DELIVERED AS HEAT TO THE LOW TEMPERATURE RESERVOIR EVERY CYCLE?

(e) BY HOW MUCH DOES THE ENTROPY OF WORKING SUBSTANCE CHANGE AS A RESULT OF THE ENERGY TRANSFERRED TO IT FROM THE HIGH TEMPERATURE RESERVOIR? FROM IT TO LOW PRESSURE RESERVOIR?

(a) $e = 1 - \frac{T_L}{T_H} = 1 - \frac{300K}{850K} = 0.65 \rightarrow 65\%$

(b) $P = \frac{W}{t} = \frac{1200}{0.25} = 4800\,W = 4.8\,kW$

(c) $|Q_H| = \frac{W}{e} = \frac{1200J}{0.65} = 1855J$

(d) $|Q_L| = |Q_H| - W = 1855 - 1200 = 655J$

(e) $\Delta S_H = \frac{Q_H}{T_H} = \frac{1855}{850} = 2.18\,J/°K$

$\Delta S_L = \frac{Q_L}{T_L} = \frac{-655}{300} = -2.18\,J/°K$

NEGATIVE TRANSFER $\Delta S = \Delta S_H + \Delta S_L = 2.18 + (-2.18) = 0$

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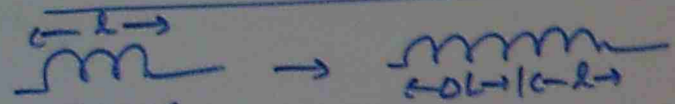
(10) HEAT, HEAT TRANSFER, WAVE

SLIDE (1) $\rightarrow$ (6) Q 29 $\rightarrow$ 31

HARMONIC MOTION AND WAVE



K = SPRING CONSTANT
m = MASS

ANGULAR VELOCITY $\omega = \sqrt{\frac{K}{m}}$

FREQUENCY $f = \frac{\omega}{2\pi}$, PERIOD $(T) = \frac{1}{f}$

Pb THE BLOCK WHOSE MASS "m" IS 680 g IS FASTENED TO A SPRING WHOSE SPRING CONSTANT IT IS 65 N/m. THE BLOCK IS PULLED A DISTANCE $x = 11$ cm FROM IT'S EQUILIBRIUM POSITION AT $x=0$ ON A FRICTIONLESS SURFACE AND RELEASED FROM REST AT $t=0$

(a) WHAT ARE ANGULAR FREQUENCY, THE FREQUENCY AND THE PERIOD OF RESULTING MOTION?

(b) WHAT IS THE AMPLITUDE OF OSCILLATION?

(c) WHAT IS THE MAXIMUM SPEED V_m OF THE OSCILLATING BLOCK AND WHERE IS THE BLOCK WHEN IT HAS THIS PERIOD?

(d) WHAT IS THE MAGNITUDE OF ACCELERATION?

(e) WHAT IS THE PHASE CONSTANT ϕ FOR THE MOTION

(f) WHAT IS THE DISPLACEMENT FUNCTION?

(a) $\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{65}{0.68}} = 9.78$ RAD/s

$f = \frac{\omega}{2\pi} = \frac{9.76}{2\times 3.1416} = 1.6$ Hz, $T = \frac{1}{f} = \frac{1}{1.6} = 0.64$ sec $= 640$ ms

(b) $x_m = 11$ cm

(c) $V_m = \omega x_m = 9.78 \times \frac{11}{100} = 1.1$ m/s

(d) $a_m = \omega^2 x_m = (9.78)^2 \times \frac{11}{100} = 11$ m/s^2

(e) At $t=0 \rightarrow x = x_m$

$\cos\phi = \frac{x}{x_m} = 1 \rightarrow \phi = 0$

(f) $x(t) = x_m \cos(\omega t + \phi)$

$x(t) = 0.11 \cos(9.78t + \phi$

$x(t) = 0.11 \cos 9.78t$

Pb At $t=0$, THE DISPLACEMENT $x(0)$ OF THE BLOCK IS -8.5 cm. THE BLOCK VELOCITY $v(0)$ IS -0.92 m/s AND IT'S ACCELERATION $a(0)$ IS 47 m/s^2

(a) WHAT IS THE ANGULAR VELOCITY OF THE SYSTEM?

(b) WHAT ARE THE PHASE CONSTANT ϕ AND AMPLITUDE x_m?

(a) $x_0 = x_m \cos\phi$ — (1), $v_0 = -\omega x_m \sin\phi$ — (2)

$a(0) = -\omega^2 x_m \cos\phi$ — (3)

$\frac{(1)}{(3)} \Rightarrow \frac{x(0)}{a(0)} = \frac{x_m \cos\phi}{-\omega^2 x_m \cos\phi} \Rightarrow \frac{x(0)}{a(0)} = -\frac{1}{\omega^2}$

$\therefore \omega^2 = -\frac{a(0)}{x(0)} \rightarrow \omega = \sqrt{-\frac{a(0)}{x(0)}} = \sqrt{-\frac{47}{(-8.5)}} = 23.5$ rad/s

$\frac{(2)}{(1)} \Rightarrow \frac{v(0)}{x(0)} = -\frac{\omega x_m \sin\phi}{x_m \cos\phi} = -\omega \tan\phi$

$\tan\phi = -\frac{v(0)}{\omega x(0)} = \frac{-(-0.92)}{23.5(-8.5)} = -0.401$

$\phi = \tan^{-1}(-0.401) = -25^\circ$ (or) 155°

$x_m = \frac{x(0)}{\cos\phi} \rightarrow \phi = -25 \rightarrow x_m = \frac{-0.085}{\cos(-25)} = -0.094$ m

$\phi = 155 \rightarrow x_m = \frac{0.085}{\cos 155} = 0.094$ m $= 9.4$ cm

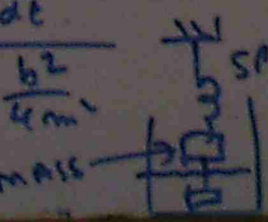
ENERGY IN SIMPLE HARMONIC MOTION

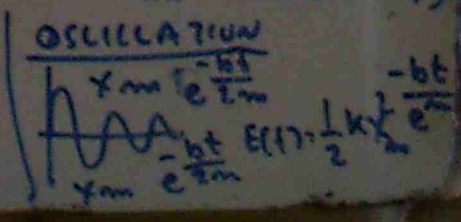
$U(t) = \frac{1}{2} K x^2 = \frac{1}{2} K x_m^2 \cos^2(\omega t + \phi)$

DAMPED SIMPLE HARMONIC MOTION

$m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + Kx = 0 \rightarrow x(t) = x_m e^{-\frac{bt}{2m}} \cos(\omega' t + \phi)$

$\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$





MAXIMUM SPEED V_m OF THE BLOCK AND WHERE IS THE BLOCK

$\phi = \tan^{-1}(-0.401) = -25$ (OR) 155

PD FOR THE DAMPED OSCILLATOR, $m = 260g$, $k = 89 N/m$, $b = 70 g/s$ (a) WHAT IS THE PERIOD OF THE MOTION?

(b) HOW LONG DOES IT TAKE FOR THE AMPLITUDE OF THE DAMPED OSCILLATIONS TO DROP THE HALF OF IT'S INITIAL VALUE?

(c) HOW LONG DOES IT TAKE FOR THE MECHANICAL ENERGY TO DROP TO ONE HALF IT'S INITIAL VALUE?

(a) $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{0.25}{89}} = 0.34$ sec

(b) $x(t) = x_m e^{-\frac{bt}{2m}}$

$\frac{1}{2}x_m = x_m e^{-\frac{bt}{2m}}$

$0.5 = e^{-\frac{bt}{2m}}$

$-\frac{bt}{2m} = \ln 0.5$

$t = -\frac{2m \ln 0.5}{b}$

$= \frac{-2 \times 0.25 \ln 0.5}{0.070}$

$t = 5$ sec

(c) $= \frac{1}{2} k x_m^2 e^{-\frac{bt}{m}}$

$= \frac{1}{2}\left(\frac{1}{2} k x_m^2\right)$

$e^{-\frac{bt}{m}} = 0.5$

$-\frac{bt}{m} = \ln 0.5$

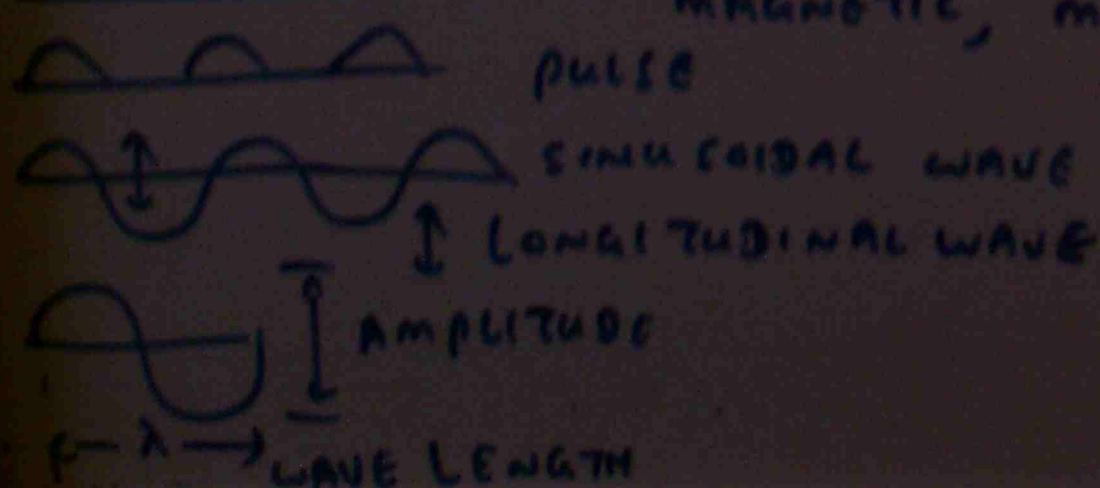
$t = -\frac{\ln 0.5 \times m}{b}$

$= \frac{-\ln 0.5 \times 0.25}{0.070}$

$= 2.5$ sec

TYPES OF WAVES

MECHANICAL, ELECTRO MAGNETIC, MATTER WAVE



k = ANGULAR WAVE NUMBER $\frac{2\pi}{\lambda}$

ANGULAR FREQ $\omega = \frac{2\pi}{T}$

$f = \frac{1}{T} = \frac{\omega}{2\pi}$, $V = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f$

THE SPEED OF TRANSVERSE WAVE

$kx = \omega t = \text{CONSTANT}$

$v = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f$

v → LINEAR VELOCITY

Pb A WAVE TRAVELLING ALONG A STRING IS DESCRIBED BY

$y(x,t) = 0.00327 \sin(72.1x - 2.72t)$

(a) WHAT IS THE AMPLITUDE OF THIS WAVE?

(b) WHAT ARE THE WAVE LENGTH, PERIOD AND FREQUENCY OF THIS WAVE?

(c) WHAT IS THE VELOCITY OF THIS WAVE?

(d) WHAT IS THE DISPLACEMENT y AT $x = 22.5$ cm, AND $t = 18.9$ SEC?

(a) $x_m = 0.00327$ m → 3.27 mm (×1000)

(b) $y(x,t) = 0.00327 \sin(72.1x - 2.72t)$

$y(x,t) \quad y_m \sin(kx - \omega t)$

$k = 72.1$ RAD/m, $\omega = 2.72$ RAD/S

$\lambda = \frac{2\pi}{k} = \frac{2 \times 3.1416}{72.1} = 0.0871$ m → 8.71 mm (×1000)

$T = \frac{2\pi}{\omega} = \frac{2 \times 3.1416}{2.72} = 2.31$ SEC

$f = \frac{1}{T} = \frac{1}{2.31} = 0.433$ Hz

(c) $V = \frac{\omega}{k} = \frac{2.72 \text{ RAD/S}}{72.1 \text{ RAD/m}} = 0.0377$ m/s

(10) HEAT, HEAT TRANSFER & WAVE

HARMONIC MOTION & WAVES

SLIDE (7) → (12)

Q 32 → 35

Ph THE FOLLOWING EQUATIONS GIVE THE POSITION $x(t)$ OF A PARTICLE IN FOUR SITUATIONS. x IN METER, t IN SECOND. $t>0$ (a) $x = 3t-2$ (b) $x = -4t^2-2$ (c) $x = \frac{1}{t^2}$ (d) $x = -2$

IN WHAT SITUATION IS THE VELOCITY v OF PARTICLE CONSTANT (b) IN WHICH IS v IN NEGATIVE DIRECTION?

(a) $x = 3t-2 \rightarrow v = \frac{dx}{dt} = \frac{d}{dt}(3t-2) = 3$ m/s

(b) $x = -4t^2-2 \rightarrow v = \frac{dx}{dt} = \frac{d}{dt}(-4t^2-2) = -8t$

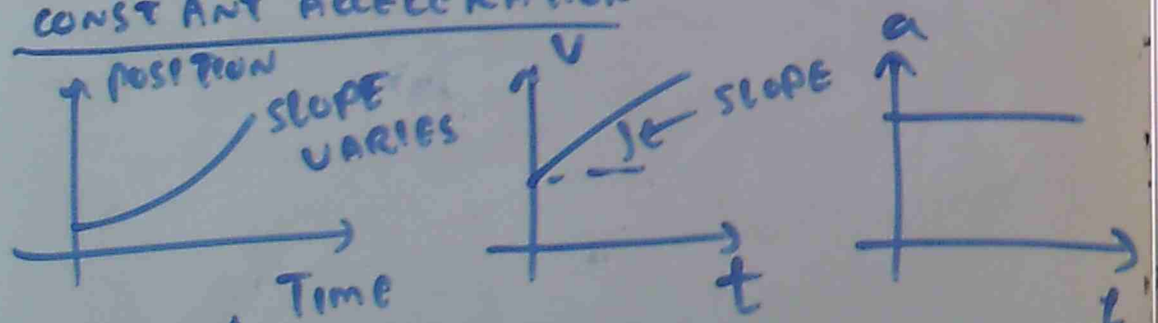
(c) $x = \frac{2}{t^2} = 2t^{-2}$

$\frac{dx}{dt} = 2\frac{d}{dt}t^{-2} = 2(-2)t^{-2-1} = -4t^{-3}$

(d) $x = -2 \rightarrow \frac{dx}{dt} = \frac{d}{dt}(-2) = 0$

(a) CONSTANT VELOCITY, (b) & (c) NEGATIVE

CONSTANT ACCELERATION



$v = v_0 + at$

$\Delta x = v_0 t + \frac{1}{2}at^2$, $v^2 = v_0^2 + 2a\Delta s$

Ph THE FOLLOWING EQUATIONS GIVE THE POSITION $x(t)$ OF THE PARTICLE IN FOUR SITUATIONS

(a) $x = 3t-4$ (b) $x = -5t^3+4t^2+6$

(c) $x = \frac{2}{t^2} - \frac{4}{t}$ (d) $x = 5t^2-3$

TO WHICH OF THESE SITUATIONS, DO THE CONSTANT ACCELERATION FORMULAE APPLY?

(a) $x = 3t-4 \rightarrow \frac{dx}{dt} = \frac{d}{dt}(3t-4) = 3$

$\frac{d^2x}{dt^2} = \frac{d}{dt}3 = 0$ (NOT APPLY)

(b) $x = -5t^3+4t^2+6$

$\frac{dx}{dt} = \frac{d}{dt}(-5t^3+4t^2+6) = -15t^2+8t$

$\frac{d^2x}{dt^2} = \frac{d}{dt}(-15t^2+8t) = -30t+8$ (NOT APPLY)

(c) $x = 2t^{-2}-4t^{-1}$

$\frac{dx}{dt} = -4t^{-3}+4t^{-2}$, $\frac{d^2x}{dt^2} = 12t^{-4}-8t^{-3}$ NOT APPLY

(d) $x = 5t^2-3$

$\frac{dx}{dt} = 10t$, $\frac{d^2x}{dt^2} = 10$ = CONSTANT (APPLY)

Ph A PITCHER TOSSES A BASE BALL UP ALONG Y AXIS WITH INITIAL VELOCITY 12 m/s

(a) HOW LONG DOES THE BALL TAKE TO REACH IT'S MAXIMUM HEIGHT?

(b) WHAT IS THE MAXIMUM HEIGHT ABOVE IT'S RELEASE POINT?

(c) HOW LONG DOES THE BALL TAKE TO REACH A POINT 5 m ABOVE IT'S RELEASE POINT?

y=0

(a) $u_0 = 12$ m/s
$v = 0$ MAX:
$a = -9.8$ m/s²

$v = u_0 + at$

$0 = 12 + (-9.8)t$

$t = \frac{-12}{-9.8} = 1.2$ sec

(b) $v^2 = u_0^2 + 2as$

$0^2 = 12^2 + 2(-9.8)h$

$h = \frac{12^2}{2 \times 9.8} = 7.3$ m

(c) $s = ut + \frac{1}{2}at^2$

$5 = 12t + \frac{1}{2}(-9.8)t^2$

$4.9t^2 - 12t + 5 = 0$

$Ax^2 + Bx + c = 0$

$x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$

$t = \frac{-(-12) \pm \sqrt{(-12)^2 - 4 \times 4.9 \times 5}}{1.2 \times 4.9}$

t = 0.53 cons
0.19 sec

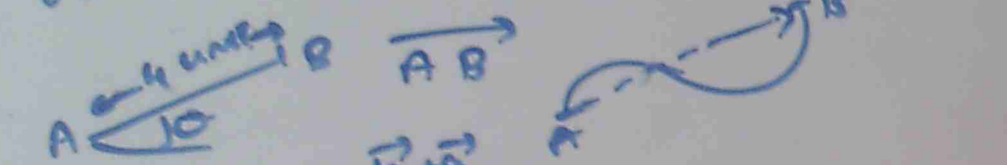
(1) MOTION ALONG STRAIGHT LINE

SLIDE (1) → (13)

Q 1 → Q5

VECTORS

VECTOR HAS MAGNITUDE AND DIRECTION

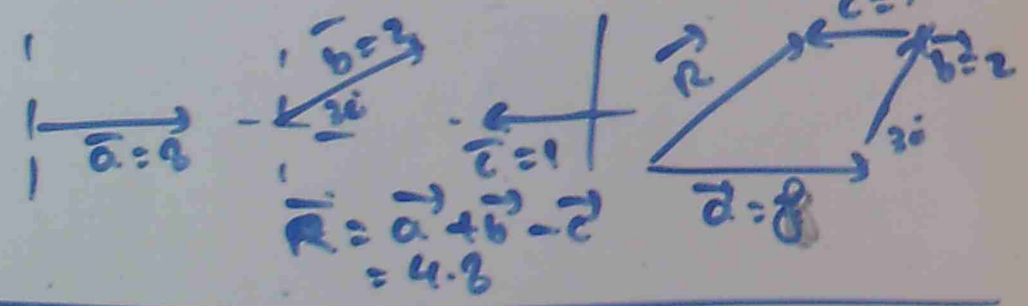


$\overrightarrow{AB}$

$\vec{a}+\vec{b}=\vec{b}+\vec{a}$

$\vec{a}+(-\vec{a})=0$

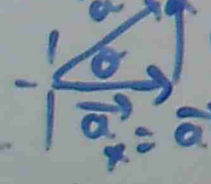
Pb THE MAGNITUDE OF $\vec{a}$ IS 8 Km DUE EAST. $\vec{b}$, 2 Km, 30° NORTH OF EAST. $\vec{c}$ = 1 Km DUE WEST. WHAT IS THE GREATEST DISTANCE AT THE END OF THIRD DISPLACEMENT?



$\vec{R}=\vec{a}+\vec{b}-\vec{c}$

$=4.8$

COMPONENTS OF VECTOR



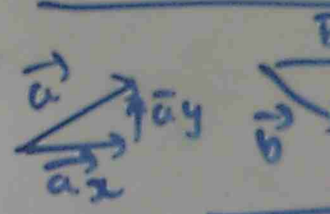
$\vec{a}_y=\vec{a}\sin\theta$

$\vec{a}_x=\vec{a}\cos\theta$

$\tan\theta=\dfrac{|\vec{a}_y|}{|\vec{a}_x|}$

$\theta=\tan^{-1}\dfrac{|\vec{a}_y|}{|\vec{a}_x|}$

ADDING VECTOR COMPONENTS



$R_x=\vec{a}_x+\vec{b}_x+\vec{c}_x$

$R_y=\vec{a}_y+\vec{b}_y+\vec{c}_y$

$R=\sqrt{(R_x)^2+(R_y)^2}\ \angle \tan^{-1}\dfrac{R_y}{R_x}$

Pb

$\vec{a}=4.2i-1.5j$

$\vec{b}=-1.8i+2.4j$

$\vec{c}=-3.9j$

FIND RESULTANT VECTOR

$\vec{a}+\vec{b}+\vec{c}=4.2i-1.5j+(-1.8i)+2.4j+(-3.9j)$

$=2.5i-2.3j$

$R=\sqrt{2.5^2+2.3^2}\ \angle -\tan^{-1}\dfrac{2.3}{2.5}$

$=3.5\ \angle -44^\circ$

SCALAR PRODUCT

$\vec{a}=a_1i+a_2j+a_3k$, $\vec{b}=b_1i+b_2j+b_3k$

$\vec{a}\cdot\vec{b}=a_1b_1+a_2b_2+a_3b_3$

Pb $\vec{a}=3i+4j+5k$, $\vec{b}=2i+1j+3k$

$\vec{a}\cdot\vec{b}=3.2+4.1+5.3=25$

VECTOR PRODUCT

$\vec{a}=a_1i+a_2j+a_3k$

$\vec{b}=b_1i+b_2j+b_3k$

$\vec{a}\times\vec{b}=\begin{vmatrix} i & j & k \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$

$i\begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix}-j\begin{vmatrix} a_1 & a_3 \\ b_1 & b_3 \end{vmatrix}+k\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}=i(a_2b_3-b_2a_3)+j(-b_1a_3+a_1b_3)+k(a_1b_2-b_1a_2)$

pb $\vec{a} = 2i + 3j + 4k$

$\vec{b} = 3i + 2j + 2k$

FIND $\vec{a} \times \vec{b}$ AND $\vec{b} \times \vec{a}$

$$\vec{a} \times \vec{b} = \begin{vmatrix} i & j & k \\ 2 & 3 & 4 \\ 3 & 2 & 2 \end{vmatrix}$$

$$= i\begin{vmatrix} 3 & 4 \\ 2 & 2 \end{vmatrix} - j\begin{vmatrix} 2 & 4 \\ 3 & 2 \end{vmatrix} + k\begin{vmatrix} 2 & 3 \\ 3 & 2 \end{vmatrix}$$

$$= i(3\times2 - 2\times4) - j(2\times2 - 3\times4) + k(2\times2 - 3\times3)$$

$$= -2i - j(-8) + k(4-9)$$

$$= -2i + 8j - 5k$$

$$\vec{b} \times \vec{a} = \begin{vmatrix} i & j & k \\ 3 & 2 & 2 \\ 2 & 3 & 4 \end{vmatrix}$$

$$= i\begin{vmatrix} 2 & 2 \\ 3 & 4 \end{vmatrix} - j\begin{vmatrix} 3 & 2 \\ 2 & 4 \end{vmatrix} + k\begin{vmatrix} 3 & 2 \\ 2 & 3 \end{vmatrix}$$

$$= i(2\times4 - 3\times2) - j(3\times4 - 2\times2) + k(3\times3 - 2\times2)$$

$$= 2i - 8j + 5k$$

$$\therefore \vec{a} \times \vec{b} = -[\vec{b} \times \vec{a}]$$

(2) VECTOR

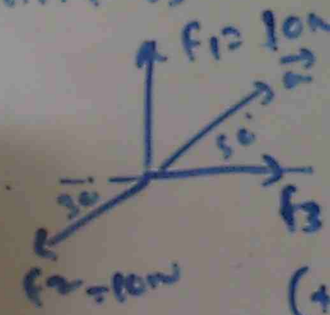
SLIDE (1) → (13)

Q6 → Q11

FORCE = MASS × ACCELERATION

$F = m \times a$

ph 2 KG TIM IS ACCELERATED AT 3 m/s^2 IN THE DIRECTION SHOWN BY $\vec{a}$ OVER A FRACTIONLESS HORIZONTAL SURFACE. THE ACCELERATION IS CAUSED BY THREE FORCES WHAT IS THIRD FORCE?



$F_{NET} = m\vec{a}$

$= 2 \times 3 = 6$ N

$\vec{F} +$

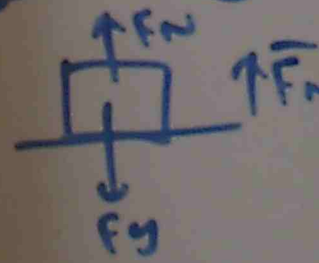
$(+F_3) + (-F_1\cos 30) = 6\cos 50$

$F_3 - 10 \times 0.866 = 6\cos 50$

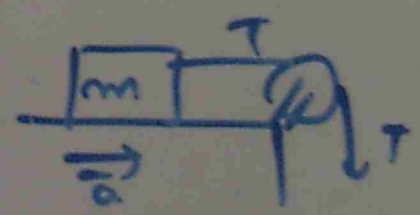
$F_3 = 12.5$N



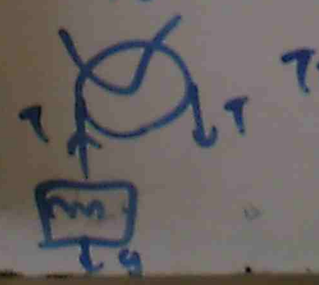
$a_N = \dfrac{m_1 g - m_2 g}{m_1 + m_2}$



$\uparrow F_N = F_y \downarrow$

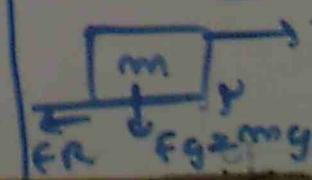


$T = ma$



$T = mg$

FRICTION

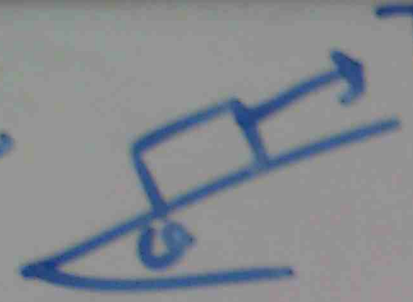


$T = mg\mu$

$F_R = F_g \times \mu$

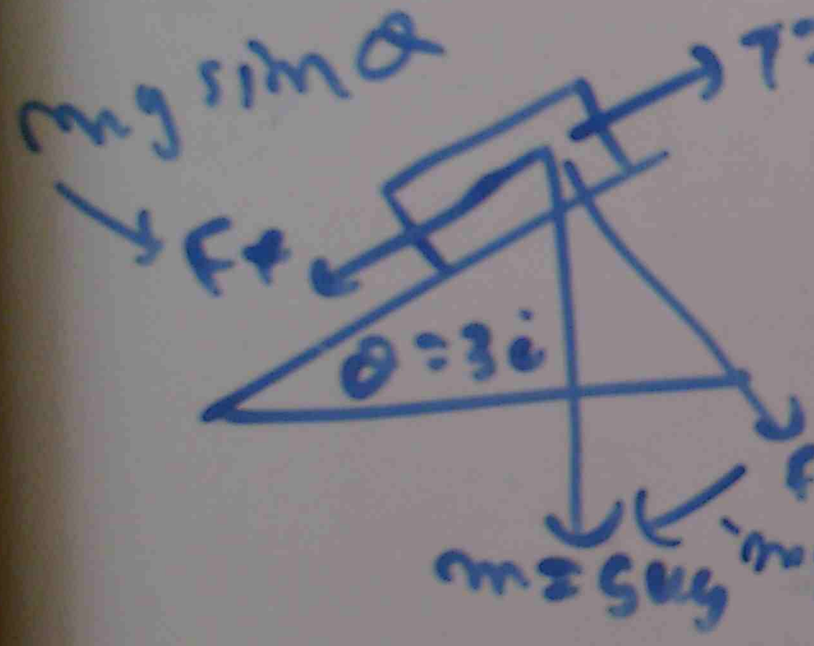
$= mg\mu$

ph



A CORD pulls on a Box moves along a FRICTIONLESS-PLANE $\theta = 30°$, $m = 5kg$

$T = 25N$ FIND ACCELERATION



FRICTIONAL FORCE $= \mu F_g$

$F_x = mg \sin 30$

$= 5 \times 9.8 \times 0.5$

$= 24.5N$

$F_{NET} = T - F_x$

$= 25 - 24.5 = 0.5N$

$a = \frac{\text{NET FORCE}}{\text{MASS}} = \frac{0.5N}{5kg} = 0.1 m/s^2$

---

(3) FORCE + ACCELERATION

SLIDE 1 ⟶ 4 @ 11 ⟶ 13

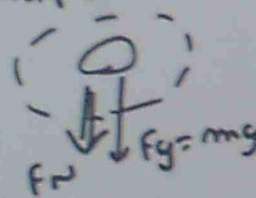
UNIFORM CIRCULAR MOTION



$a = \frac{v^2}{R}$

a = CENTRIPETAL ACCELERATION
v = VELOCITY
R = RADIUS OF MOTION

CENTRIPETAL FORCE :) $F = ma = m\frac{v^2}{R}$



$-F_N - mg = m(-\frac{v^2}{R})$

(4) CIRCULAR MOTION
SLIDE 1 → 9, @ 14 → 18

Pb THE CIRCUS PERFORMER IS RIDING A BICYCLE IN THE LOOP WITH RADIUS R = 2.7m. WHAT IS THE LEAST SPEED AT THE TOP of LOOP AND FORCE.



m = 20 kg

$F = m\frac{v^2}{R} = \frac{20 \times 5.1^2}{2.7} = 192N$

$-F_N - mg = m(-\frac{v^2}{R})$, AT THE TOP, $F_N = 0$

$-0 - mg = m(-\frac{v^2}{R}) \rightarrow v^2 = gR \rightarrow v = \sqrt{gR}$

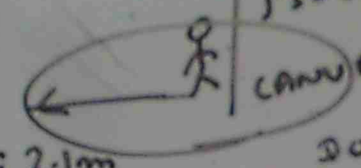
$v = \sqrt{9.81 \times 2.7} = 5.1 m/s$

Pb SUPPOSE THAT THE COEFFICIENT OF STATIC FRICTION μ_S BETWEEN THE RIDER'S CLOTHING AND THE CANVAS IS 0.4 AND THE CYLINDER RADIUS "R" IS 2.1m.

(a) WHAT MINIMUM SPEED (V) MUST THE CYLINDER AND THE RIDER HAVE IF THE RIDER IS NOT TO FAIL WHEN THE FLOOR DROP?

(b) IF THE RIDER'S MASS IS 49kg, WHAT IS THE MAGNITUDE of CENTRIPETAL FORCE?

(a)



$\mu_S = 0.4$ $f_N = \frac{mg}{\mu_S}$

$-f_N - mg = m(-\frac{v^2}{R})$

R = 2.1m

DO NOT FALL $\mu f_N = mg$

$-F_N = -m(\frac{v^2}{R})$ | $\frac{g}{\mu_S} = \frac{v^2}{R}$

$-\frac{mg}{\mu_S} = -m\frac{v^2}{R}$ | $\therefore v = \sqrt{\frac{gR}{\mu_S}} = \sqrt{\frac{9.81 \times 2.1}{0.4}} = 7.2 m/s$

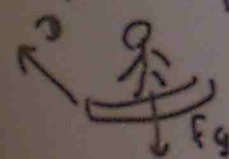
(b) $F_N = m\frac{v^2}{R} = 49 \times \frac{7.2^2}{2.1} = 1200N$

DRAG FORCE AND TERMINAL SPEED



D = DRAG FORCE
Cp: DRAG COEFFICIENT
A = EFFECTIVE C.S.A

v = VELOCITY



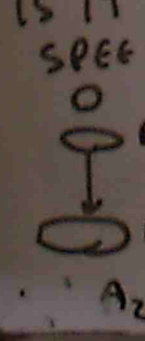
$D - F_g = ma$

IF $a = 0$ (MOVING AT CONSTANT VELOCITY)

$D - F_g = m \times 0 \rightarrow D = F_g$

$\frac{1}{2} C_p A v^2 = F_g \rightarrow v = \sqrt{\frac{2F_g}{C_p A}}$

Pb IF A FALLING CAT REACHES A FIRST TERMINAL SPEED OF 97 km/hr WHILE IT IS TUCKED IN AND THEN STRATCHES OUT, DOUBLING A, HOW FAST IS IT FALLING WHEN IT REACHES A NEW TERMINAL SPEED?



$v = \sqrt{\frac{2F_g}{C_p A}}$

$v_1 = \sqrt{\frac{2F_g}{C_p A_1}}$

$v_2 = \sqrt{\frac{2F_g}{C_p A_2}}$

$\frac{v_1}{v_2} = \sqrt{\frac{\frac{2F_g}{C_p A_1}}{\frac{2F_g}{C_p A_2}}}$

$= \sqrt{\frac{2F_g}{C_p A_1} \cdot \frac{C_p 2A_1}{2F_g}}$

$\frac{97}{v_2} = \sqrt{2}$

$v_2 = 69 km/h$

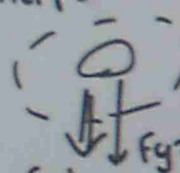
UNIFORM CIRCULAR MOTION



$a = \frac{v^2}{R}$

a = CENTRIPETAL ACCELERATION
v = VELOCITY
R = RADIUS OF MOTION

CENTRIPETAL FORCE :) $F = ma = m\frac{v^2}{R}$



$-F_N - mg = m(-\frac{v^2}{R})$

(4) CIRCULAR MOTION
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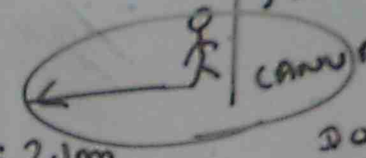

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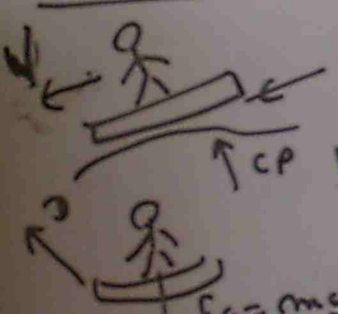
DRAG FORCE AND TERMINAL SPEED



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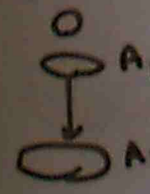


$A_2 = 2A_1$

$v = \sqrt{\frac{2F_g}{C_p A}}$

$v_1 = \sqrt{\frac{2F_g}{C_p A_1}}$

$v_2 = \sqrt{\frac{2F_g}{C_p A_2}}$

$\frac{v_1}{v_2} = \sqrt{\frac{\frac{2F_g}{C_p A_1}}{\frac{2F_g}{C_p A_2}}}$

$= \sqrt{\frac{2F_g}{C_p A_1} \times \frac{C_p 2A_1}{2F_g}}$

$\frac{97}{v_2} = \sqrt{2}$

$v_2 = 69$ km/hr

ENERGY

KINETIC ENERGY | POTENTIAL ENERGY

KINETIC ENERGY

STATE OF MOTION OF AN OBJECT.

$KE = \frac{1}{2} mv^2$ — m = MASS (KG), V = VELOCITY (m/s)

KE (UNIT) JOULES

Pb A LOCOMOTIVE IS MOVING AT $0.25\ m/s^2$ ACCELERATION AND IT IS WEIGHED 1.2×10^6 N. WHAT IS KINETIC ENERGY? IT MOVES FOR 3.2×10^3 m

$v^2 = u_0^2 + 2as \rightarrow v^2 = 0^2 + 2\times0.25\times3.2\times10^3$

$v = \sqrt{2\times0.25\times3.2\times10^3} = 40.8\ m/s$

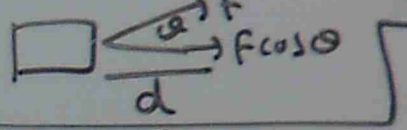
$F = mg \rightarrow 1.2\times10^6 = m\times9.81 \rightarrow m = 1.22\times10^3\ kg$

$KE = \frac{1}{2}mv^2 = \frac{1}{2}\times1.22\times10^3\times(40.8)^2 = 2\times10^8\ J$

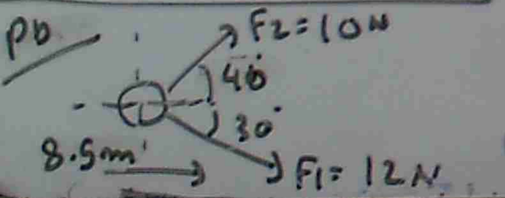
WORK

WORK ('W') IS ENERGY TRANSFORMED (OR) FROM AN OBJECT BY MEANS OF A FORCE ACTING ON THE OBJECT - ENERGY TRANSFORMED TO THE OBJECT IS POSITIVE WORK, AND ENERGY TRANSFORMED FROM THE OBJECT IS NEGATIVE WORK.

$W = F\cos\theta \times d$ (J)



Pb



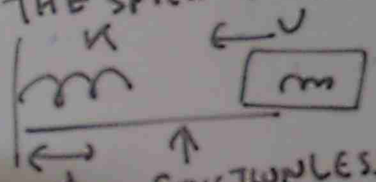
$W_1 = F_1\cos\theta_1 d_1 = 12\cos30\times8.5 = 88.33J$

$W_2 = F_2\cos\theta_2 d_2 = 10\cos40\times8.5 = 63.11\ J$

$W = W_1 + W_2 = 88.33 + 63.11 = 153\ J$

$W = \frac{1}{2}mv^2 = KE$

Pb A CANNISTER OF MASS $m = 0.4$ kg SLIDES ACROSS A HORIZONTAL FRICTIONLESS COUNTER WITH SPEED $V = 0.5$ m/s. IT THEN RUNS INTO AND COMPRESSES A SPRING OF SPRING CONSTANT $K = 750$ N/m. CALCULATE THE DISTANCE THE SPRING IS COMPRESSED



$K_f - K_i = -\frac{1}{2}kd^2$ (FINAL KE, INITIAL KE)

$KE = \frac{1}{2}mv^2$

$V_f = 0,\ V_i = 0.5$ m/s

$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = -\frac{1}{2}\times750\times d^2$

$\frac{1}{2}m0^2 - \frac{1}{2}m(0.5)^2 = -\frac{1}{2}\times750\times d^2$

$-\frac{1}{2}\times0.4\times0.5^2 = -\frac{1}{2}\times750\times d^2$

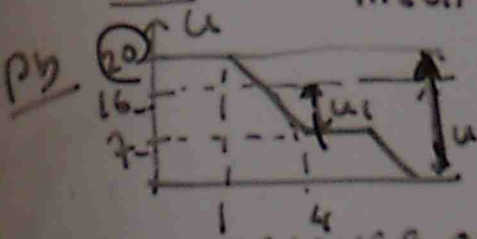
$d = \sqrt{\frac{0.4\times0.5^2}{750}} = 1.2\times10^{-2}\ m = 1.2$ cm

POTENTIAL ENERGY

PE = POTENTIAL ENERGY = mgh

CONSERVATION OF MECHANICAL ENERGY

$E_{MECH} = K + U$ | E_{MECH} - MECHANICAL ENERGY; K = KINETIC ENERGY; U = POTENTIAL ENERGY

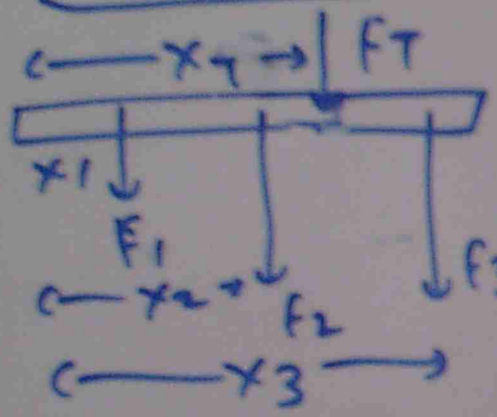


Pb CALCULATE THE FORCE FOR GIVEN ENERGY CHANGE GRAPH

$FORCE = \frac{CHANGE\ OF\ ENERGY}{CHANGE\ OF\ DISTANCE} = \frac{20-9}{1-4} = -4.3$ N

(5) ENERGY >LIDEC1) → (4) Q19 → 23

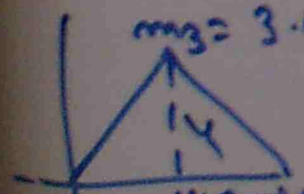
CENTRE OF MASS AND LINEAR MOMENTUM



$$X_T = \frac{F_1X_1 + F_2X_2 + F_3X_3}{F_1 + F_2 + F_3}$$

$$X_T = \frac{\Sigma FX}{\Sigma F}$$

Pa THREE PARTICLES OF MASSES $m_1 = 1.2\,kg$, $m_2 = 2.5kg$ AND $m_3 = 3.4kg$ FORM AN EQUILATERIAL TRIANGLE OF EDGE 140cm FIND CENTRE OF MASS



$$X_T = \frac{m_1X_1 + m_2X_2 + m_3X_3}{m_1 + m_2 + m_3} = \frac{1.2\times 0 + 2.5\times 140 + 3.4\times 70}{1.2 + 2.5 + 3.4}$$

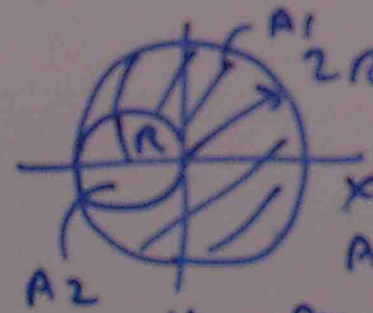
$$X_T = 83cm$$

$$Y = \sqrt{140^2 - 70^2} = 120$$

$$Y_T = \frac{m_1Y_1 + m_2Y_2 + m_3Y_3}{m_1 + m_2 + m_3} = \frac{1.2\times 0 + 2.5\times 0 + 3.4\times 120}{1.2 + 2.5 + 3.4}$$

$$= 58cm$$

Pb THE FIGURE SHOWS A UNIFORM METAL PLATE "P" of '2R' FROM WHICH A DISK OF RADIUS "R" HAS BEEN STAMPED OUT. LOCATE CENTRE OF MASS



$A_1 = \pi\,(\text{RADIUS})^2$

$m_1 = \pi(2R)^2 \times \rho = \pi 4R^2\rho$

$X_1 = 0\,,\ Y_1 = 0$

$A_2 = \pi(R)^2 = \pi R^2$

$m_2 = A_2\rho = \pi R^2\rho$ | $X_2 = -R$, $Y_2 = 0$

$$\bar{X}_T = \frac{m_1X_1 - m_2X_2}{m_1 - m_2} = \frac{\pi 4R^2\rho\times 0 - \pi R^2\rho(-R)}{\pi 4R^2\rho - \pi R^2\rho} = \frac{R}{3}$$

$$\bar{Y}_T = \frac{m_1Y_1 - m_2Y_2}{m_1 - m_2} = \frac{\pi 4R^2\rho\,.0 - \pi R^2\rho\times 0}{\pi 4R^2\rho - \pi R^2\rho} = 0$$

CENTRE OF MASS $R/3, 0$

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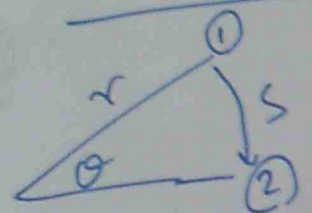
(6) CENTRE OF MASS SLIDE 1 → 6 | Q24 → 26.

ROTATION



r = RADIUS, S = ANGULAR PATH

1 REVOLUTION = 360° = 2π RADIAN

1 RADIAN ⟶ $\frac{1}{2\pi}$ = 0.159 REVOLUTION

ANGULAR VELOCITY = $\omega = \frac{\Delta\theta}{\Delta t} = \frac{\theta_2 - \theta_1}{t_2 - t_1}$

$\omega_2 = \omega_1 + \alpha \Delta t$ α = ANGULAR ACCELERATION RAD/s²

$\alpha = \frac{\omega_2 - \omega_1}{\Delta t}$ / ANGULAR DISPLACEMENT $S = \omega_1 t + \frac{1}{2}\alpha t^2$

Pb THE ANGULAR POSITION $\theta(t)$ of A REFERENCE LINE ON THE DISK IS GIVEN BY

$\theta = -1 - 0.6t + 0.25t^2$

(a) GRAPH THE ANGULAR POSITION of THE DISK VERSUS TIME (-3 TO 5.4 sec)

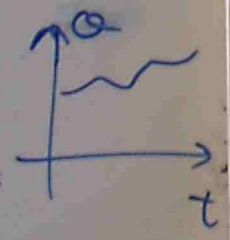
(b) AT WHAT TIME DOES $\theta(t)$ REACH MINIMUM VALUE? WHAT IS THE MINIMUM VALUE?

(a) $\theta(t) = -1 - 0.6t + 0.25t^2$

$\theta(-3) = -1 - 0.6(-3) + 0.25(-3)^2 =$

$\theta(-2) = -1 - 0.6(-2) + 0.25(-2)^2$

$\theta(5.4) = -1 - 0.6(5.4) + 0.25(5.4)^2 =$



(b) MINIMUM $\frac{d\theta}{dt} = 0$

$\frac{d}{dt}(-1 - 0.6t + 0.25t^2) = -0.6 + 0.5t = 0$

$\therefore 0.5t = 0.6 \rightarrow t = \frac{0.6}{0.5} = 1.2$ sec

$\theta = -1 - 0.6t + 0.25t^2 = -1 - 0.6 \times 1.2 + 0.25 \times (1.2)^2$

$= -1.36$ RAD

π RAD ⟶ 180°

-1.36 RAD ⟶ ? $= 180 \times \frac{-1.36}{3.1416} = -77.9°$

Pb A GRIND STONE ROTATES AT A CONSTANT ANGULAR ACCELERATION $\alpha = 0.35$ RAD/s². AT TIME $t = 0$. IT HAS ANGULAR VELOCITY $\omega_0 = -4.6$ RAD/s AND A REFERENCE LINE ON IT IS HORIZONTAL AT THE ANGULAR POSITION $\theta_0 = 0$

(a) AT WHAT TIME AFTER $t = 0$, IS THE REFERENCE LINE AT ANGULAR POSITION $\theta = 5$ REV

(b) DESCRIBE THE ROTATION BETWEEN $t = 0$ & $t = 32$ sec

(c) AT WHAT TIME "t", DOES THE GRIND STONE MOMENTARILY STOP?

(a) $\theta_0 = 0$, $\theta = 5$ REV $= 5 \times 2\pi$ RAD $= 10\pi$

$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \rightarrow 10\pi = (-4.6)t + \frac{1}{2} \times 0.35 \times t^2$

$0.175t^2 - 4.6t - 31.4 = 0$

$Ax^2 + Bx + C = 0$

$x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$

$t = \frac{-(-4.6) \pm \sqrt{(4.6)^2 - 4 \times 0.175 \times (-31.4)}}{2 \times 0.175}$

(b) $t = 0 \longrightarrow t = 32$

$\alpha = -0.35$ RAD/s²

$t = 32$ sec

(c) $\omega_0 = -4.6$

$\omega = 0$ $t = ?$

$t = \frac{\omega - \omega_0}{\alpha} = \frac{0 - (-4.6)}{0.35} = 13$ sec

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(6) CENTRE OF MASS & LINEAR MOMENTUM

SLIDE (7) ⟶ (11) Q27 ⟶ Q28

RELATING THE LINEAR AND ANGULAR VARIABLES

DISPLACEMENT $S = \theta r$

S = LINEAR DISPLACEMENT, θ = ANGULAR DISPLACEMENT, r = RADIUS

THE SPEED $\frac{ds}{dt} = r\frac{d\theta}{dt}$, $V = \omega r$ | V = LINEAR VELOCITY, ω = ANGULAR VELOCITY, r = RADIUS OF CURVATURE (or)

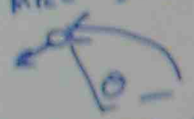


$T = \frac{2\pi r}{v}$

$T = \frac{2\pi}{\omega}$

T = TORQUE | α = ANGULAR ACCELERATION $\frac{dv}{dt} = r\frac{d\omega}{dt} \Rightarrow a_T = r\alpha$ | $a_r = \frac{v^2}{r} = \omega^2 r$ (ACCELERATION)

Pb THE COACH ROACH RIDES THE RIM OF A ROTATING MERRY GO AROUND. IF THE ANGULAR SPEED IS CONSTANT DOES THE COACH ROACH HAVE (a) RADIAL ACCELERATION? (b) TANGENTIAL ACCELERATION? WHAT ANGLE θ_P SHOULD THE ARC SUBTEND SO THAT a IS 4g AT POINT 'P'?



(a) $a_T = \frac{dv}{dt} = r\frac{d\omega}{dt}$

ANGULAR SPEED CONSTANT

$\frac{d\omega}{dt} = 0 \rightarrow a_T = r\frac{d\omega}{dt} = r \times 0 = 0$ (b) NO TANGENTIAL ACCELERATION

$a_r = \omega^2 r$ (a) IT HAS RADIAL ACCELERATION

$\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$, $\alpha = \frac{a_t}{r}$ $\omega_0 = 0$, $\theta_0 = 0$

$\omega^2 = 2\alpha\theta$, BUT $\alpha = \frac{a_t}{r}$ $\therefore \omega^2 = 2\frac{a_t}{r}\theta$

$\therefore a_r = \omega^2 r \rightarrow \omega^2 = \frac{a_r}{r} \rightarrow \frac{a_r}{r} = \frac{2a_t}{r}\theta$

$a_r = 2a_t\theta$

$a = \sqrt{a_t^2 + a_r^2}$

$a = \sqrt{a_t^2 + (2a_t\theta)^2}$

$a^2 = a_t^2 + (2a_t\theta)^2$

$(2a_t\theta)^2 = a^2 - a_t^2$

$2a_t\theta = \sqrt{a^2 - a_t^2}$

$\theta = \frac{1}{2a_t}\sqrt{a^2 - a_t^2}$

$= \frac{1}{2}\sqrt{\frac{a^2}{a_t^2} - \frac{a_t^2}{a_t^2}}$

$\theta = \frac{1}{2}\sqrt{\frac{a^2}{a_t^2} - 1}$

$a = 4g$ (GIVEN) $\therefore a_t = g$

$\theta_P = \frac{1}{2}\sqrt{\frac{(4g)^2}{g^2} - 1} = 1.94$ RAD

$= 1.94 \times \frac{180}{\pi} = 111°$

KINETIC ENERGY OF ROTATION



K = KINETIC ENERGY

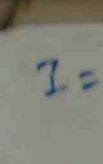
$K = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \frac{1}{2}m_3v_3^2$

$= \sum \frac{1}{2}m_iv_i^2 = \sum \frac{1}{2}m_i(\omega r_i)^2 = \frac{1}{2}\sum m_i r_i^2\omega^2$

ROTATIONAL INERTIA $(I) = \sum m_i r_i^2$

$K = \frac{1}{2}I\omega^2$

$I = \int r^2 dm$





$I = mR^2$



$I = \frac{1}{2}mR^2$



$I = \frac{1}{12}mL^2$



$I = \frac{2}{5}mR^2$



$I = \frac{1}{2}m(R_1^2 + R_2^2)$

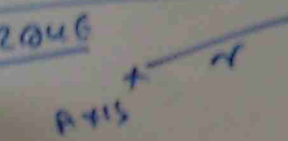


$I = \frac{1}{2}mR^2$



$I = \frac{1}{12}m(a^2 + b^2)$

TORQUE



TORQUE = FORCE × DISTANCE

$\tau = F \times r$

$\tau = I\alpha$

$\tau = mr^2\alpha$

Pb



FIGURE SHOWS A UNIFORM DISK WITH MASS $m = 2.5kg$, $R = 20cm$

A BLOCK OF $m = 1.2kg$ HANGS FROM A MASSLESS CORD. FIND ACCELERATION OF FALLING BLOCK.

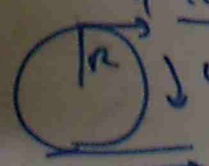
$T = m \times R$, $T - mg = ma$, $a = \frac{T - mg}{m} = \frac{mR - mg}{m}$

$a = \frac{2.5 \times \frac{20}{100} - 1.2 \times 9.81}{1.2} = -9.39\ m/s^2$

(7) LINEAR AND ANGULAR VARIABLES

SLIDE (2) → (10) ⊙29 → ⊙30

TORQUE & EQUILIBRIUM



$V = \omega \times R$

KINETIC ENERGY $(K) = \frac{1}{2}I\omega^2$

I = MOMENT OF INERTIA

ω = ANGULAR VELOCITY RAD/S

(1) POLYNOMIALS

$3x^{15} + 7.6x^8 - 4x^2$ (DEGREE 15)

$5x + 3$ (DEGREE 1)

$4x^3$ (DEGREE 3)

Pb $(2x^3 - 4x + 1)(3x^3 - x^2 - 2)$

$2x^3 - 4x + 1$

$3x^3 - x^2 - 2$

$6x^6 - 12x^4 + 3x^3$

$-2x^5 + 4x^3 - x^2$

$-4x^3 + 8x - 2$

$6x^6 - 2x^5 - 12x^4 + 3x^3 - x^2 + 8x - 2$

FACTORIZATION

$6 = 2 \times 3$, $12 = 4 \times 3$

Pb $x^2 + 4x + 3 = (x+3)(x+1)$

$x \times x = x^2$

$3 \times 1 = 3$

$x + 3x = 4x$

Pb $(x+9)(x-7) = 83$

$x^2 + 7x - 7x - 49 = 83$

$x^2 = 83 + 49 = 132$

$x = \sqrt{132}$

Pb $\frac{2t-3}{25} = \frac{4}{2t-3}$

$(2t-3)^2 = 100 \rightarrow$

$2t - 3 = \sqrt{100}$

$2t - 3 = 10$

$t = 13/2$

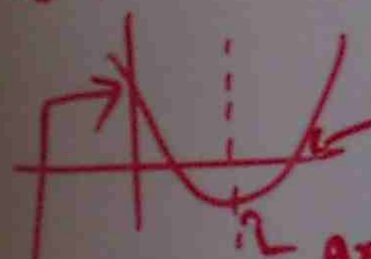
FUNCTIONS & THEIR GRAPHS

Pb IF $g(x) = 2 - 3x$, EVALUATE $g(-2)$

$g(-2) = 2 - 3(-2) = 8$

Pb $y = 2x^2 - 12x + 3$

COMPARE $Ax^2 + Bx + C$ $\quad A = 2,\ B = -12,\ C = 3$



AXIS OF SYMMETRY X VALUE $= \frac{-B}{2A} = \frac{-(-12)}{2 \times 2} = 3$

Y VALUE: $2(3)^2 - 12 \times 3 + 3 = -5$

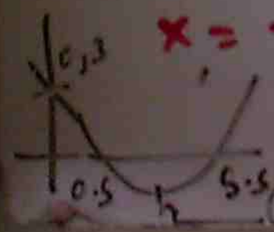
$\therefore$ AXIS OF SYMMETRY = 3, −5

Y-AXIS CROSSING PT, $X = 0 \rightarrow y = 2(0)^2 - 12(0) + 3 = 3 \quad \therefore (0, 3)$

X-AXIS CROSSING PT, $y = 0$

$2x^2 - 12x + 3 = 0$

$x = \frac{-(-12) \pm \sqrt{(-12)^2 - 4 \times 2 \times 3}}{2 \times 2} = 5.5$ (OR) 0.5



GRAPH | (1) POWER INDEX + GRAPH

SLIDE 1 → 14, 21 → 2 Q16

INTEGRATION of TRIGO function

$\int \sin x\,dx = -\cos x + C$

$\int \cos x\,dx = \sin x + C$

$\int \tan x\,dx = \ln \cos x + C$

$\int \cot x\,dx = \ln \sin x + C$

$\int \sec^2 x\,dx = \tan x + C$

$\int \operatorname{cosec}^2 x\,dx = \cot x + C$

$\cos 2x = 2\cos^2 x - 1 = 1 - 2\sin^2 x$

Ph $\int \sin^2 3x\,dx = ?$

$\cos 2x = 1 - 2\sin^2 x$

$\cos 6x = 1 - 2\sin^2 3x$

$\therefore 2\sin^2 3x = 1 - \cos 6x$

$\sin^2 3x = \dfrac{1-\cos 6x}{2}$

$\int \sin^2 3x\,dx = \int \dfrac{1-\cos 6x}{2}\,dx$

$= \frac{1}{2}\int dx - \frac{1}{2}\int \cos 6x\,dx$

$= \frac{x}{2} - \frac{1}{2}\int \cos 6x \dfrac{d6x}{6}$

$= \frac{x}{2} - \frac{1}{12}\int \cos 6x\,d6x$

$= \frac{x}{2} - \frac{1}{12}\sin 6x + C$

$\sin A\cos B = \frac{1}{2}[\sin(A+B) + \sin(A-B)]$

$\cos A\sin B = \frac{1}{2}[\sin(A+B) - \sin(A-B)]$

$\cos A\cos B = \frac{1}{2}[\cos(A+B) + \cos(A-B)]$

$\sin A\sin B = \frac{1}{2}[\cos(A-B) - \cos(A+B)]$

Ph $\int \sin 3x \cos 7x\,dx$

$\sin 3x\cos 7x = \frac{1}{2}[\sin(3x+7x) + \sin(3x-7x)]$

$= \frac{1}{2}[\sin 10x + \sin(-4x)]$

$= \frac{1}{2}[\sin 10x - \sin 4x]$

$\int \sin 3x\cos 7x\,dx = \int \frac{1}{2}[\sin 10x - \sin 4x]\,dx$

$= \frac{1}{2}\int \sin 10x\,dx - \frac{1}{2}\int \sin 4x\,dx$

$= \frac{1}{2}\int \sin 10x \dfrac{d10x}{10} - \frac{1}{2}\int \dfrac{\sin 4x\,d4x}{4}$

$= \frac{1}{20}(-)\cos 10x - \frac{1}{8}(-)\cos 4x = -\frac{1}{20}\cos 10x + \frac{1}{8}\cos 4x$

DEFINITE INTEGRAL

$$\int_a^b f(x)\,dx = F(b) - F(a)$$

Pb $\int_2^4 x^2\,dx = \left[\frac{x^{2+1}}{2+1}\right]_2^4 = \left[\frac{x^3}{3}\right]_2^4$

$$= \frac{4^3 - 2^3}{3} = \frac{64-8}{3} = \frac{48}{3} = 16$$

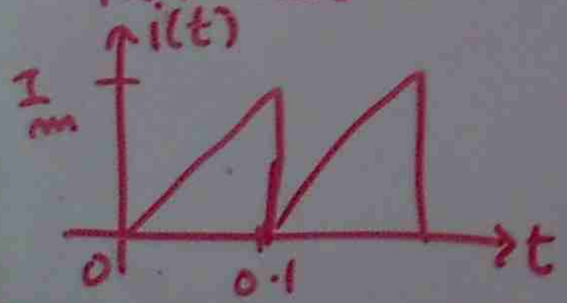
(11) INTEGRATION

SLIDE (1) ⟶ (20)

@ 88 ⟶ @ 102

(12) INTEGRATION APPLICATION -ELECTRICAL

AVERAGE VALUE



$$I_{AVG} = \frac{1}{T}\int_0^T i(t)\,dt$$

$$i(t) = \frac{I_m}{T}\,t$$

$$I_{AVG} = \frac{1}{T}\int_0^T \frac{I_m}{T}\,t\,dt$$

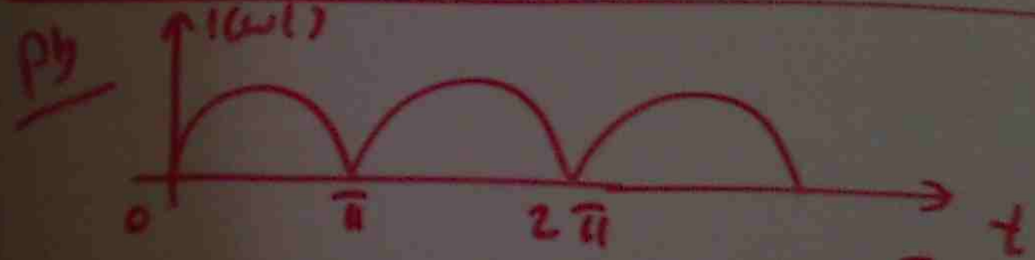
$$= \frac{I_m}{T^2}\int_0^T t\,dt$$

$$= \frac{I_m}{T^2}\left[\frac{t^2}{2}\right]_0^T$$

$$= \frac{I_m}{T^2}\left[\frac{T^2-0}{2}\right] = \frac{I_m}{T^2}\times\frac{T^2}{2}$$

$$= \frac{I_m}{2}$$

Pb



$i(\omega t) = I_m \sin \omega t$, $T = \frac{\pi}{\omega}$

$$I_{AVG} = \frac{1}{T}\int_0^{\omega T} i(\omega t)\,dt$$

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T [i(t)]^2\,dt}$$

$$I_{AVG} = \frac{1}{\pi/\omega} \int_0^{\frac{\pi}{\omega}\times\omega} I_m \sin\omega t \, dt$$

$$= \frac{\omega}{\pi} \int_0^{\pi} I_m \sin\omega t \frac{d\omega t}{\omega}$$

$$= \frac{1}{\pi} \int_0^{\pi} I_m \sin\omega t \, d\omega t$$

$$= \frac{I_m}{\pi} \left[\int_0^{\pi} \sin\omega t \, d\omega t \right]$$

$$= \frac{I_m}{\pi} \left[-\cos\omega t \right]_0^{\pi}$$

$$= -\frac{I_m}{\pi} \left[\cos\omega t \right]_0^{\pi}$$

$$= -\frac{I_m}{\pi} \left[\cos\pi - \cos 0 \right]$$

$$\frac{I_m}{\pi}(-)\left[-1-1\right]$$

$$= \frac{2I_m}{\pi} = 0.636 I_m$$

RMS VALUE OF Δ WAVE

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T \left(\frac{I_m t}{T}\right)^2 dt}$$

$$= \sqrt{\frac{1}{T}\int_0^T \frac{I_m^2 t^2}{T^2} dt}$$

$$= \sqrt{\frac{I_m^2}{T^3}\int_0^T t^2 dt}$$

$$= \sqrt{\frac{I_m^2}{T^3}\left[\frac{t^3}{3}\right]_0^T} = \sqrt{\frac{I_m^2}{3T^3}\times T^3}$$

$$= \frac{I_m}{\sqrt{3}}$$

(12) INTEGRATION APPLICATIONS
– ELECTRICAL

SLIDE (1) ⟶ (18)
Q103 ⟶ Q110

FURTHER STUDY (OPTIONAL)

PART of MATHS (2) E026/E027
ADVANCED MATHS

(13) DIFFERENTIAL EQUATION

SLIDE (1) ⟶ (9)
Q111 ⟶ Q114

(14) RL-RC 2nd ORDER

SLIDE 1 ⟶ 6
Q115 ⟶ Q116

(15) STATISTICS & DATA COLLECTION

SLIDE (1) ⟶ (21)
Q117 ⟶ Q128

(16) STATISTICS + PROBABILITY

SLIDE (1) ⟶ (13)
Q129 ⟶ Q132

(17) PROBABILITY DISTRIBUTION

SLIDE (1) ⟶ (13)
Q133 ⟶ Q137

NON LINEAR EMPIRICAL EQUATIONS

CONVERSION TO LINEAR EQUATION

$y = ax^2 + bx$ ← NON LINEAR

$\frac{y}{x} = ax + b$ ← LINEAR (DIVIDE BY x)

Pb THE FOLLOWING VALUES OF x & y ARE BELIEVED TO SATISFY THE EQUATION $y = ax^2 + bx$. FIND A LINEAR EQUATION THAT SUITS THIS INFORMATION AND SO EVALUATE a & b.

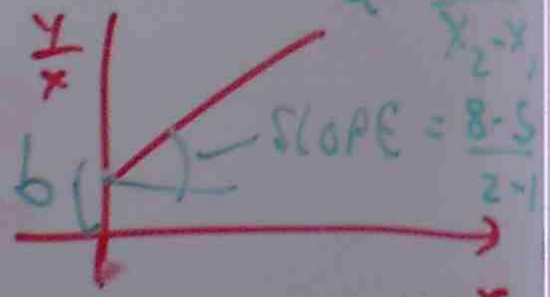
x	1	2	3	4	5
y	5	16	34	57	84

$y = Ax^2 + Bx$

$\frac{y}{x} = Ax + b$

x	1	2	3	4	5
$\frac{y}{x}$	$\frac{5}{1}$	$\frac{16}{2}$	$\frac{34}{3}$	$\frac{57}{4}$	$\frac{84}{5}$
	5	8	11.3	14.3	16.8

$q = \frac{y_2 - y_1}{x_2 - x_1}$



USE OF LOGARITHM TO PRODUCE A LINEAR EQUATION

$y = kx^n$

$\log y = \log k x^n$

$\log y = \log k + \log x^n$

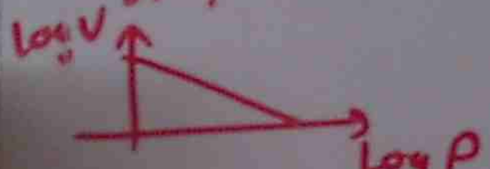
$= \log k + n \log x$

GRADIENT

y = VERTICAL INTERCEPT × X

p	135	110	25	63	47
v	3.69	4.25	5.24	6.5	7.8

$\log v$	0.567	0.628	0.719	0.813	0.792
$\log p$	2.13	2.04	1.93	1.8	1.67



$\log mN = \log m + \log N$

$\log \frac{m}{N} = \log m - \log N$

$\log A^m = m \log A$

$\log_a^N = \frac{\log N}{\log a}$

(2) LOGARITHMS & EXPONENTIAL EQUATION

$\log_a^M = N \rightarrow M = a^N$

Pb $\log_3^{81} = ?$ $\log_3^{81} = x \rightarrow 81 = 3^x \rightarrow 3^4 = 3^x$

$\therefore x = 4$

Pb AN AMPLIFIER HAS IN PUT POWER 1.7×10^{-3} WATT OUT PUT POWER 5.8 WATT. FIND POWER GAIN

GAIN $(dB) = 10 \log \frac{P_2}{P_1} = 10 \log \frac{5.8}{1.7 \times 10^{-3}} = 35.3$

Pb solve $\log_{10} \frac{K}{K-x} = t$

$\frac{K}{K-x} = 10^t$

$\frac{K}{10^t} = K - x$

$\therefore x = K - \frac{K}{10^t}$

$x = K\left(\frac{10^t - 1}{10^t}\right)$

(2) LOGARTHMIC GRAPH

SLIDE 1 → 12, Q 18 → 25

(3) CIRCULAR FUNCTION & TRIGO
SLIDE 1 → 3
Q 18 → Q 23

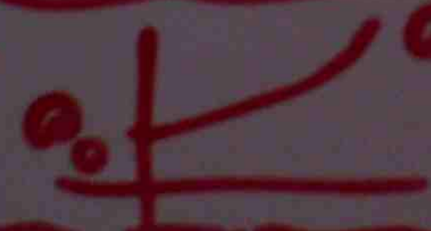
COMPOUND INTEREST / EXPONENTIAL GROWTH & DECAY

$$A = P\left(1 + \frac{r}{100}\right)^n$$

A = TOTAL AMOUNT
P = PRINCIPAL
r = ANNUAL INTEREST
n = NO. OF YEAR

EXPONENTIAL FUNCTION

$Y = e^x$



$Q = Q_0 e^{kt}$



$Q = Q_0 e^{-kt}$

PERIOD (T) = $\frac{2\pi}{\omega}$

PHASE SHIFT = $\frac{\phi}{\omega}$

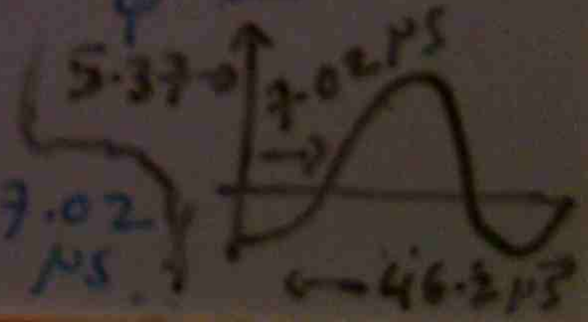
$180^\circ \longrightarrow \pi$ RADIAN

Pb SKETCH $5.37 \sin(136 \times 10^3 t - 0.955)$ mA

$\omega = 2\pi f =$ ϕ

$T = \frac{2\pi}{\omega} = \frac{2 \times 3.1416}{136 \times 10^3} = 46.2\,\mu s$

PHASE SHIFT = $\frac{\phi}{\omega} = \frac{0.955}{136 \times 10^3} = 7.02\,\mu s$



(2) LOGARTHMIC GRAPH

SLIDE 1 → 12, Q 18 → 25

(3) CIRCULAR FUNCTION & TRIGO
SLIDE 1 → 3
Q 18 → Q 23

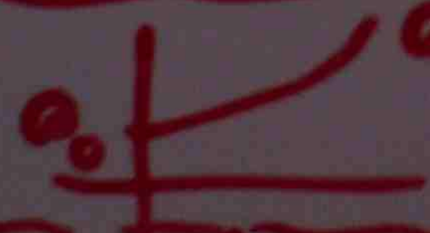
COMPOUND INTEREST / EXPONENTIAL GROWTH & DECAY

$$A = P\left(1 + \frac{r}{100}\right)^n$$

A = TOTAL AMOUNT
P = PRINCIPAL
r = ANNUAL INTEREST
n = NO. OF YEAR

EXPONENTIAL FUNCTION

$Y = e^x$



$Q = Q_0 e^{kt}$



$Q = Q_0 e^{-kt}$

PERIOD $(T) = \frac{2\pi}{\omega}$

PHASE SHIFT $= \frac{\phi}{\omega}$

$180^\circ \longrightarrow \pi$ RADIAN

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$\omega = 2\pi f =$ ϕ

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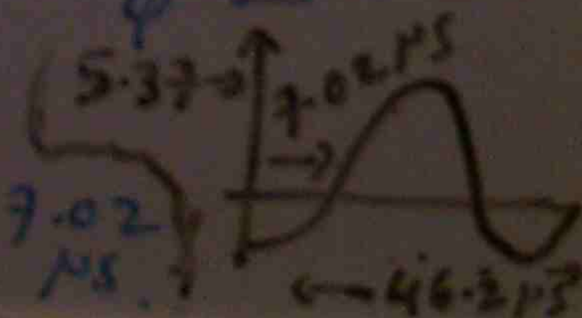
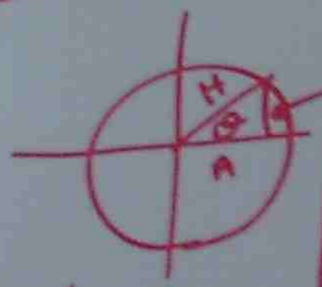
PHASE SHIFT $= \frac{\phi}{\omega} = \frac{0.955}{136 \times 10^3} = 7.02\,\mu s$

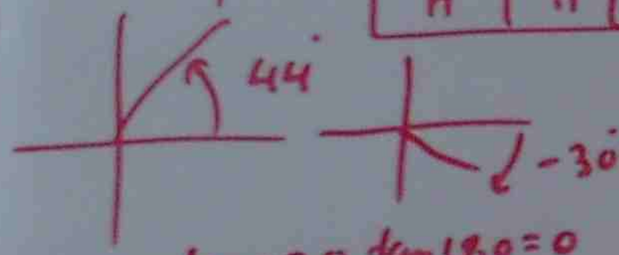


(3)/(4) CIRCULAR FUNCTION & TRIGO

$\sin\theta = \frac{\text{OPPOSITE SIDE}}{\text{HYPOTENUSE}}$



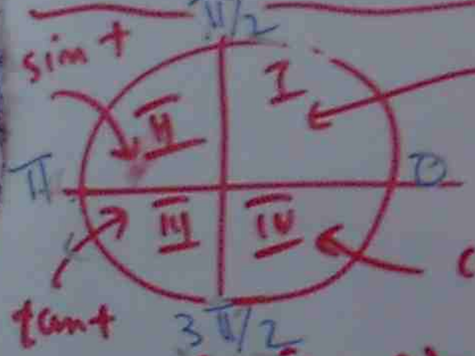
sin	cos	tan	cot	sec	cosec
O	A	O	A	H	H
H	H	A	O	A	O



$\tan 0 = 0$, $\tan 180 = 0$

$\tan 90 = \infty$, $\tan 270 = \infty$

$\cos 0 = 1$	$\sin 0 = 0$
$\cos 90 = 0$	$\sin 90 = 1$
$\cos 180 = -1$	$\sin 180 = 0$
$\cos 270 = 0$	$\sin 270 = -1$



SUPPLEMENTARY ANGLE

$\sin(180-\theta) = \sin\theta$

$\cos(180-\theta) = -\cos\theta$

$\tan(180-\theta) = -\tan\theta$

$\sin(90-\theta) = \cos\theta$

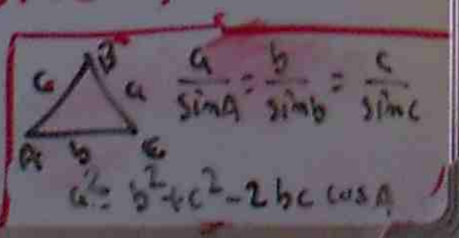
$\cos(90-\theta) = \sin\theta$

$\sec\theta = \frac{1}{\cos\theta}$, $\operatorname{cosec}\theta = \frac{1}{\sin\theta}$, $\tan\theta = \frac{1}{\cot\theta}$

SINE GRAPH



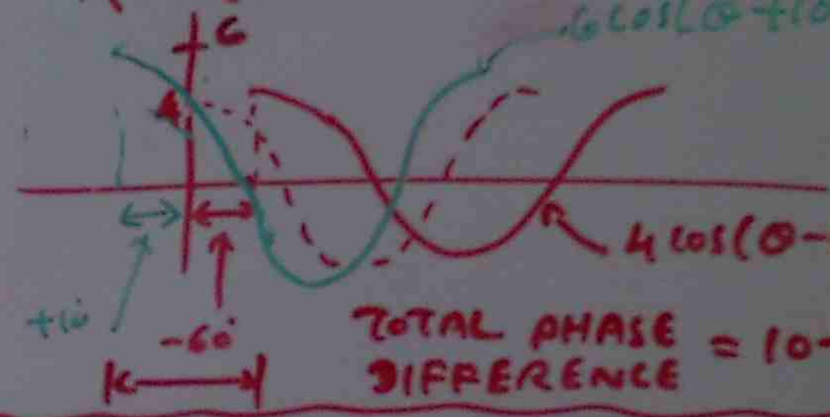
COS GRAPH



$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$

$a^2 = b^2 + c^2 - 2bc\cos A$

Ph FIND THE PHASE DIFFERENCE BETWEEN $4\cos(\theta-60)$ & $6\cos(\theta+10)$



TOTAL PHASE DIFFERENCE $= 10 + 60 = 70°$

Ph FIND PERIOD & ANGULAR VELOCITY 30 MHz

$f = 30\times10^6$ Hz $\quad T = \frac{1}{f} = \frac{1}{30\times10^6} = 10^{-6}\times 0.033 = 0.033\ \mu s$

$\omega = 2\pi f = 2\times3.14\times30\times10^6 = 188.4\times10^6$ RAD/S

Ph FIND FREQUENCY & ANGULAR VELOCITY of 2 sec

$f = \frac{1}{T} = \frac{1}{2} = 0.5$ Hz $\quad \omega = 2\pi f = 2\times3.14\times0.5 = 3.14$ RAD/S

(3) CIRCULAR FUNCTION & TRIGO

SLIDE 1 → 6, Q 18 → Q 23

(4) CIRCULAR FUNCTION & TRIGO

SLIDE 1 → 12, Q 24 → Q 31

(5) TRIGONOMETRIC IDENTITIES

$\sin^2\theta + \cos^2\theta = 1$

$\sec^2\theta = 1 + \tan^2\theta$

$\operatorname{cosec}^2\theta = 1 + \cot^2\theta$

$\tan\theta = \dfrac{\sin\theta}{\cos\theta}$

$\cot\theta = \dfrac{\cos\theta}{\sin\theta}$

$\dfrac{1}{\operatorname{cosec}\theta} = \sin\theta$

$\dfrac{1}{\sec\theta} = \cos\theta$

$\dfrac{1}{\cot\theta} = \tan\theta$

$\cot\theta = \dfrac{\cos\theta}{\sin\theta}$

Pb PROVE THAT $\operatorname{cosec} x - \sin x = \cos x \cot x$

$\operatorname{cosec} x - \sin x$

$\dfrac{1}{\sin x} - \sin x$

$\dfrac{1 - \sin^2 x}{\sin x} = \dfrac{\cos^2 x}{\sin x}$

$= \cos x \dfrac{\cos x}{\sin x} = \cos x \cot x$

$\sin(\alpha+\beta) = \sin\alpha\cos\beta + \cos\alpha\sin\beta$

$\sin(\alpha-\beta) = \sin\alpha\cos\beta - \cos\alpha\sin\beta$

$\cos(\alpha+\beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$

$\cos(\alpha-\beta) = \cos\alpha\cos\beta + \sin\alpha\sin\beta$

Pb EXPRESS $\dfrac{\sin(A+B)}{\cos(A-B)}$ IN TERM of $\tan A, \tan B$

$\sin A\cos B + \cos A\sin B$

$\cos A\cos B + \sin A\sin B$

DIVIDE BY $\cos A\cos B$

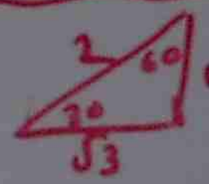
$\dfrac{\dfrac{\sin A\cos B + \cos A\sin B}{\cos A\cos B}}{\dfrac{\cos A\cos B + \sin A\sin B}{\cos A\cos B}}$

$\dfrac{\sin A\cos B}{\cos A\cos B} + \dfrac{\cos A\sin B}{\cos A\cos B}$

$\dfrac{\cos A\cos B}{\cos A\cos B} + \dfrac{\sin A\sin B}{\cos A\cos B}$

$\dfrac{\tan A + \tan B}{1 + \tan A\tan B}$

$\sin 2A = 2\sin A\cos A$



$\sin 30 = \dfrac{1}{2}$

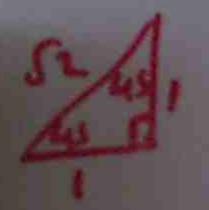
$\cos 30 = \sqrt{3}/2$

$\tan 30 = 1/\sqrt{3}$

$\sin 60 = \sqrt{3}/2$

$\cos 60 = 1/2$

$\tan 60 = \sqrt{3}$



$\sin 45 = 1/\sqrt{2}$

$\cos 45 = 1/\sqrt{2}$

$\tan 45 = 1$

Pb FIND THE EXACT VALUE of $\sin 15$

$\sin 15 = \sin(45-30) = \sin 45\cos 30 - \cos 45\sin 30$

$= \dfrac{1}{\sqrt{2}} \times \sqrt{3}/2 - \dfrac{1}{\sqrt{2}} \times \dfrac{1}{2}$

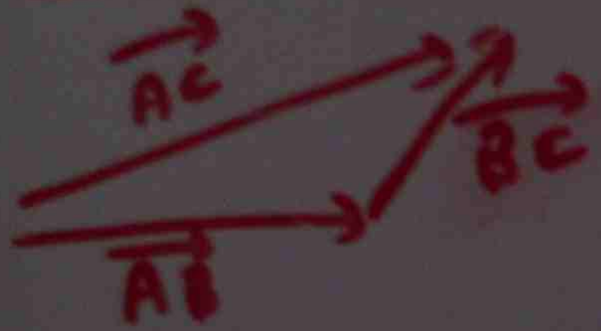
$= \dfrac{\sqrt{3}-1}{2\sqrt{2}}$

(5) TRIGONOMETRIC IDENTITIES

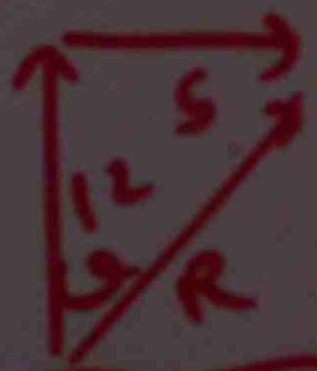
SLIDE 1 ⟶ 8

Q 32 ⟶ Q 47

(6) VECTOR

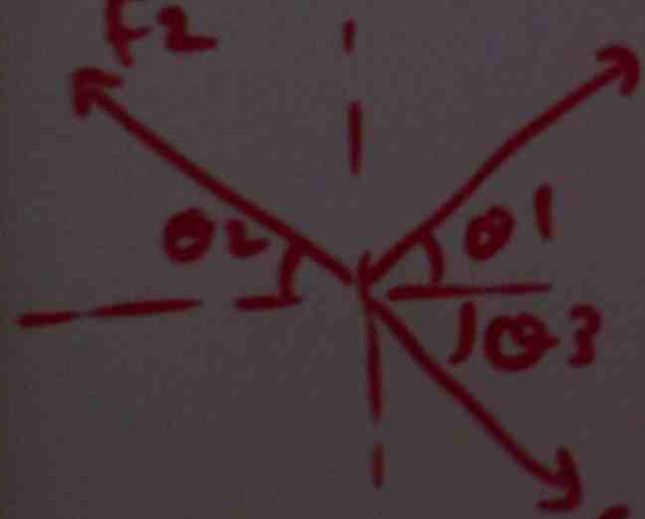


Q) IF A BODY MOVES 12 km NORTH & 5 km EAST FIND TOTAL DISPLACEMENT



$R = \sqrt{12^2 + 5^2} = 13$

$\theta = \tan^{-1}\frac{5}{12} = 22.6$



(6) VECTOR
SLIDE 1 → 12
@ 48 → @ 54

$\vec{F}_{1x} = F_1 \cos\theta_1$

$\uparrow F_{1y} = F_1 \sin\theta_1$

$\leftarrow F_{2x} = F_2 \cos\theta_2$

$\uparrow F_{2y} = F_2 \sin\theta_2$

$\vec{F}_{3x} = F_3 \cos\theta_3$

$\downarrow F_{3y} = F_3 \sin\theta_3$

$R = \sqrt{F_x^2 + F_y^2}$

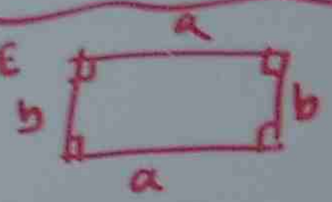
$\tan\theta = \frac{F_y}{F_x}$

$F_x = \vec{F}_{1x} + (-\overleftarrow{F}_{2x}) + (\vec{F}_{3x}) \rightarrow +$

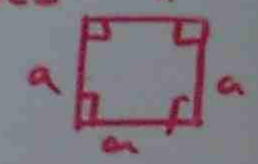
$F_y = \uparrow F_{1y} + (F_{2y})\uparrow + (-F_{2y})\downarrow \quad \uparrow +$

(7) MENSURATION + AREA

RECTANGLE

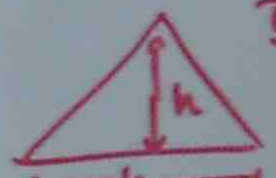


SQUARE

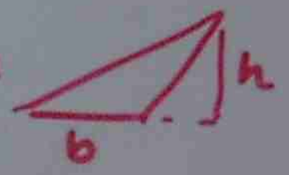


AREA OF RECTANGLE / SQUARE = BASE × HEIGHT
= a × b / a × a

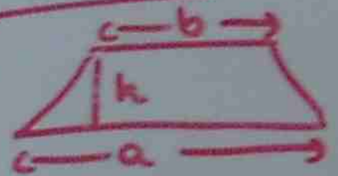
TRIANGLE



AREA = $\frac{1}{2} \times b \times h$



TRIPIZIUM



AREA = $\frac{1}{2} \times h (a + b)$

CIRCLE



AREA = $\frac{\pi D^2}{4}$ D = DIAMETER, R = RADIUS

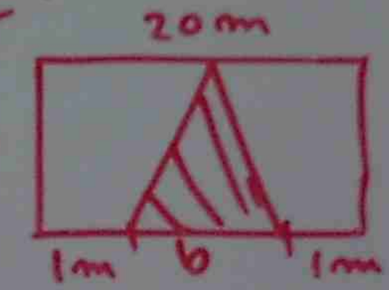
$D = 2R$

CIRCUMFERENCE = πD (OR) $2\pi R$



VOLUME = AREA × LENGTH
= $\frac{1}{2} b h \times l$

Pb FIND THE AREA OF SHADING



$b = 20 - (1+1) = 18$

$A = \frac{1}{2} b h = \frac{1}{2} \times 18 \times 5$

$= 45 m^2$

Pb FIND THE SHADED AREA



DIAMETER = 2m

AREA = $40 \times 30 = 1200 m^2$

AREA = $\frac{\pi}{4} D^2 = \frac{\pi}{4} \times 2^2 = 3.1416$

$\therefore$ NET AREA = $1200 - 3.1416 = 1196.85 m^2$

Pb FIND x

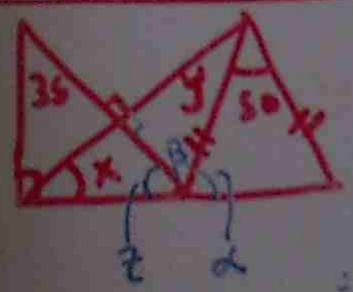


$\alpha = 180 - (35 + 90) = 65^\circ$

$y = 180 - (2\alpha) = 180 - 2 \times 65 = 50^\circ$

$\therefore x = 90 - y = 90 - 50 = 40^\circ$

Pb



$z = 180 - (90 + 35) = 65^\circ$

$\alpha = \frac{(180 - 50)}{2} = 65^\circ$

$\beta = 180 - (z + \alpha) = 180 - (65 + 65) = 50^\circ$

$\therefore y = 180 - (90 + \beta) = 180 - (90 + 50) = 40^\circ$

(7) AREA, SLIDE (1) → (14) Qs 55 → 63

(8) (9) DIFFERENTIATION

$y = x^n$, $\frac{dy}{dx} = n x^{n-1} \frac{dx}{dx} = n x^{n-1}$

$y = u^n$, $\frac{dy}{dx} = n u^{n-1} \frac{du}{dx}$

$y = \sin\theta \rightarrow \frac{dy}{d\theta} = \frac{d\sin\theta}{d\theta} = \cos\theta$

$y = \sin 3\theta \rightarrow \frac{dy}{d\theta} = \frac{d\sin 3\theta}{d\theta} = \cos 3\theta \frac{d3\theta}{d\theta}$

$= 3\cos 3\theta$

$y = \cos 3\theta \rightarrow \frac{dy}{d\theta} = \frac{d\cos 3\theta}{d\theta} = -\sin 3\theta \frac{d3\theta}{d\theta}$

$= -3\sin 3\theta$

pb $y = 5x^3 + 6x^2 + 7$ DIFFERENTIATE

$\frac{dy}{dx} = \frac{d}{dx} 5x^3 + \frac{d}{dx} 6x^2 + \frac{d7}{dx}$

$= 5 \times 3 x^{3-1} + 6 \times 2 x^{2-1} + 0 = 15x^2 + 12x$

pb $y = \sin x + \cos x$, DIFFERENTIATE

$\frac{dy}{dx} = \frac{d}{dx}\sin x + \frac{d}{dx}\cos x$

$= \cos x - \sin x$

$y = u.v$

$\frac{dy}{dx} = \frac{d}{dx} u.v = u\frac{dv}{dx} + v\frac{du}{dx}$

pb $y = (x+1)^2 (x+3)^3$, DIFFERENTIATE

$y = (x+1)^2 (x+3)^3$

$\frac{dy}{dx} = (x+1)^2 \frac{d}{dx}(x+3)^3 + (x+3)^3 \frac{d}{dx}(x+1)^2$

$= (x+1)^2 \times 3(x+3)^{3-1} \frac{d}{dx}(x+3)$

$+ (x+3)^3 \times 2(x+1)^{2-1} \frac{d}{dx}(x+1)$

$= 3(x+1)^2 (x+3)^2 \left(\frac{dx}{dx} + 0\right) + 2(x+3)^3 (x+1)\left(\frac{dx}{dx} + 0\right)$

$= 3(x+1)^2 (x+3)^2 + 2(x+3)^3 (x+1)$

$y = \frac{u}{v} \rightarrow \frac{dy}{dx} = \frac{v\frac{du}{dx} - u\frac{dv}{dx}}{v^2}$

pb DIFFERENTIATE $\frac{x}{x+1}$

$\frac{dy}{dx} = \frac{(x+1)\frac{dx}{dx} - x\frac{d}{dx}(x+1)}{(x+1)^2}$

$= \frac{(x+1) - x}{(x+1)^2} = \frac{1}{(x+1)^2}$

$\frac{d}{d\theta}\tan\theta = \sec^2\theta$ | $\frac{d}{d\theta}\sec\theta = \sec\theta\tan\theta$

$\frac{d}{d\theta}\cot\theta = -\operatorname{cosec}^2\theta$ | $\frac{d}{d\theta}\operatorname{cosec}\theta = -\operatorname{cosec}\theta\cot\theta$

$y = e^u \rightarrow \frac{dy}{dx} = e^u \frac{du}{dx}$

$y = \ln u \rightarrow \frac{dy}{dx} = \frac{1}{u}\frac{du}{dx}$

Pb DIFFERENTIATE $y = \log_e x^2$

$\frac{dy}{dx} = \frac{d}{dx}\ln x^2 = \frac{1}{x^2}\frac{dx^2}{dx} = \frac{1}{x^2} \times 2x^{2-1}\frac{dx}{dx}$

$= \frac{2x}{x^2} = \frac{2}{x}$

SUCCESSIVE DIFFERENTIATION

$y = x^3 + 3x^2 + 4$ FIND $\frac{dy}{dx}, \frac{d^2y}{dx^2}, \frac{d^3y}{dx^3}$

$\frac{dy}{dx} = \frac{d}{dx}(x^3 + 3x^2 + 4)$

$= \frac{d}{dx}x^3 + \frac{d}{dx}3x^2 + \frac{d4}{dx} = 3x^{3-1} + 3\times 2x^{2-1} + 0$

$= 3x^2 + 6x$

$\frac{d^2y}{dx^2} = \frac{d}{dx}(3x^2 + 6x) = \frac{d}{dx}3x^2 + \frac{d}{dx}6x$

$= 3\times 2x^{2-1}\frac{dx}{dx} + 6\frac{dx}{dx}$

$= 6x + 6$

$\frac{d^3y}{dx^2} = \frac{d}{dx}(6x + 6) = \frac{d6x}{dx} + \frac{d6}{dx} = 6\frac{dx}{dx} + 0$

$= 6$

DIFFERENTIATION OF IMPLICIT FUNCTIONS

Pb DIFFERENTIATE $x^2 + y^2 = 4$

$\frac{d(x^2+y^2)}{dx} = \frac{d4}{dx} \rightarrow \frac{dx^2}{dx} + \frac{dy^2}{dx} = 0$

$2x^{2-1}\frac{dx}{dx} + 2y^{2-1}\frac{dy}{dx} = 0$

$2x + 2y\frac{dy}{dx} = 0$

$2y\frac{dy}{dx} = -2x$

$\frac{dy}{dx} = -\frac{2x}{2y} = -\frac{x}{y}$

(8) DIFFERENTIATION
SLIDE 1 → 2
Q67 → Q68

(9) SUCCESSIVE DIFFERENTIATION
SLIDE 1 → 12.
Q69 → Q80

(10) DIFFERENTIATION
SLIDE (1) → (13) Q81 → 87

(11) INTEGRATION

$$\int u^n du = \frac{u^{n+1}}{n+1} + c$$

$$\int \frac{1}{u} du = \ln u + c$$

Ex $\int x^{\frac{1}{5}} dx = \frac{x^{\frac{1}{5}+1}}{\frac{1}{5}+1} + c = \frac{x^{\frac{6}{5}}}{\frac{6}{5}} + c = \frac{5}{6} x^{\frac{6}{5}} + c$

$$\int e^u du = e^u + c$$

Ex INTEGRATE $\frac{e^{ax}}{e^{ax}+a}$

$d(e^{ax}+a) = de^{ax} + da$

$= e^{ax} dax + 0$

$d(e^{ax}+a) = e^{ax} \times a\, dx$

$dx = \frac{1}{ae^{ax}} d(e^{ax}+a)$

$\int \frac{e^{ax}}{e^{ax}+a} dx$

$\int \frac{e^{ax}}{e^{ax}+a} \frac{1}{ae^{ax}} d(e^{ax}+a)$

$\frac{1}{a} \int \frac{1}{e^{ax}+a} d(e^{ax}+a)$

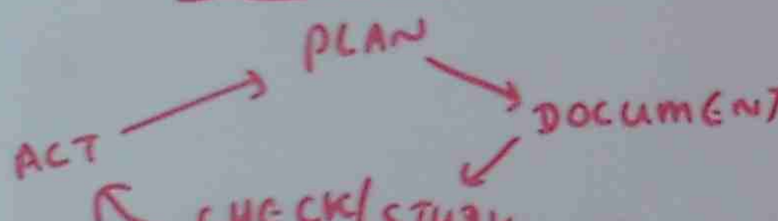
$\frac{1}{a} \ln(e^{ax}+a)$

G064 + 9070

(1) PROJECT MANAGEMENT + PLANNING

- SYMATICALLY INCORPORATING THE VOICE OF CUSTOMER, CREATING THE DISCIPLINE WAY OF THINKING, PRITORISING EFFORTS, RESOLVING TRADE OFFS
- GOAL ORIENTED, MEASURABLE OUTPUT

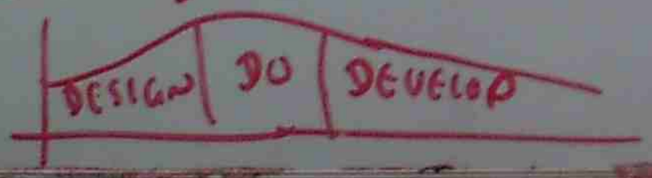
CYCLE OF PROJECT MANAGEMENT

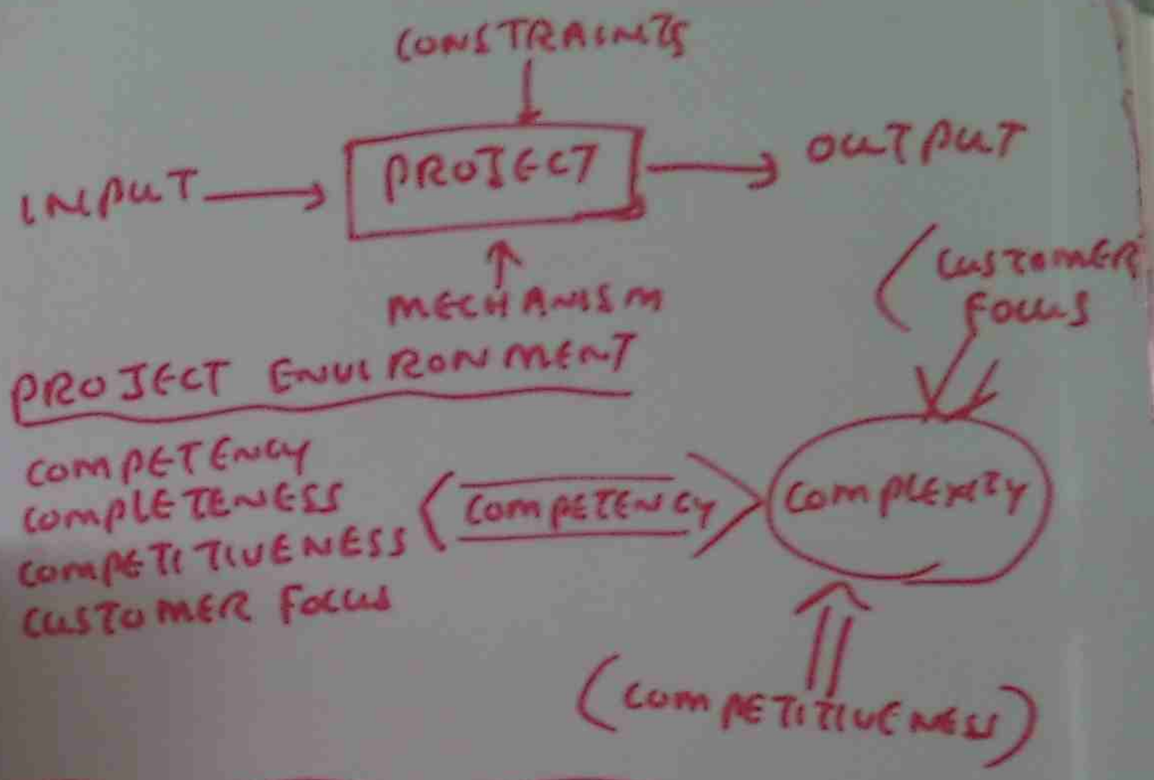


STAGES IN PROJECT LIFE CYCLE

DESIGN IT, DO IT, DEVELOP IT.

CONCEPTUALISATION, ANALYSIS, PROPOSAL JUSTIFICATION, AGREEMENT, START UP EXECUTION, COMPLETION, HAND OVER, CHECK, ACT.





TOPOLOGY OF PROJECT

STRATEGIC, SYSTEM, OPERATIONAL

PROJECT MANAGEMENT VS LINE MANAGEMENT

STRATEGY & PROJECT MANAGEMENT

- CONSIDERATION OF THE PROCESSES THAT THE OUTCOME OF IT IS ASSESSED



CONTRACT BID WORK

GENERAL CONTRACTOR, BONDING — CRITICAL

CONTRACT. ⟶ LEGAL CONSIDERATION,
DOCUMENTATION, ARBITRATION

BIDDING — CHECK LIST, PROJECT NAME, BID DATE
FINANCIAL INFORMATION.
LIST OF BIDDERS, CHANGE ORDER

---

(10) U.G CABLE INSTALLATION + CONTRACT
BID WORK

SPECIFICATION FOR LAYING OF U.G CABLE UP TO
22 KV, INSTALLATION OF CONDUITS, SWITCHES

SLIDE 1 ⟶ 12, @ 47 → @ 50

GO69+GO70

PROJECT STRUCTURE

ORGANIZATION OF PEOPLE - TAKE ADVANTAGE OF BRINGING TOGETHER INDIVIDUALS FROM DIFFERENT SPECIALIZATIONS.

ORGANIZATION SIZE INCREASED - THE DEGREE OF SPECIALISATION OF INDIVIDUAL INCREASES

- RESEARCH DEVELOPMENT, MARKETING, ENGINEERING, MANUFACTURING, SALE





THE NATURE OF WORK ORGANIZATION

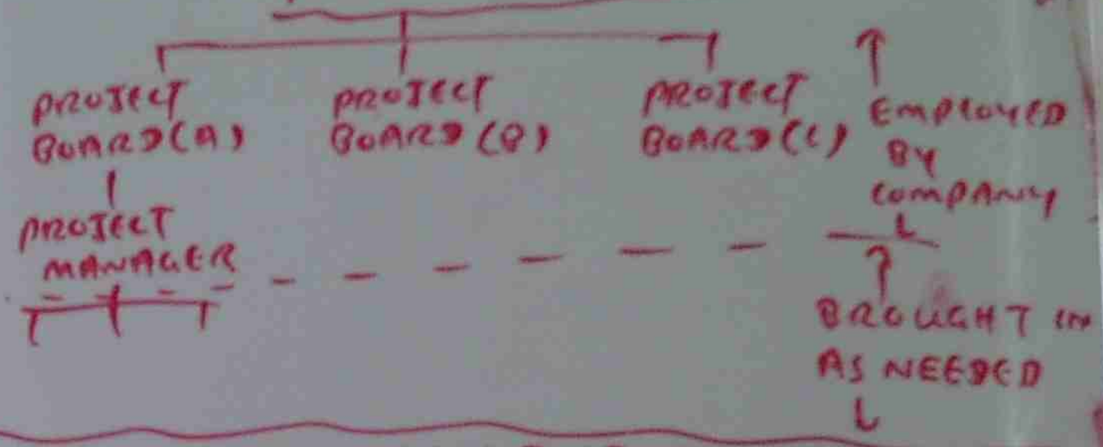
- DEFINE RESPONSIBILITY AND AUTHORITY
- OUTLINE REPORTING ARRANGEMENT
- DETERMINE THE MANAGEMENT OVERHEAD COST
- FUNCTION THEY PERFORM
- DETERMINE ONE GROUP OF STAKE HOLDERS IN PROJECT ACTIVITIES

EXPENSION OF ORGANIZATION - LESS INTEGRATION

GEOGRAPHICAL SEPARATION

DETAILED ADMINISTRATIVE → INTEGRATION PROCEDURES

PROJECT ORGANIZATION



PLANNING STAGE - ARCHITECT, STRUCTURAL ENGINEER, QUANTITY SURVEYOR, LEGAL ADVISORS

EXECUTION STAGE - CONTRACTORS

PROJECT IS COMPLETED, TEAM IS DISBANDED

ADVANTAGES / DISADVANTAGES

MATRIX MANAGEMENT

- MORE THAN ONE ORIENTATION TO ACTIVITIES
- THE NEED TO PROCESS SIMULTANEOUSLY
- SHARE RESOURCES
- CROSS FUNCTION PROJECT TEAM.

EFFECTIVE TEAM WORK

- CLEAR, ELEVATING GOAL
- PROVIDE RESULT DRIVEN STRUCTURE
- UNIFIED COMMITMENT
- FOSTER A COLLABORATIVE CLIMATE
- STANDARDS OF EXCELLENCE

DIS INTEGRATION ⟷ INTEGRATION

NO AGREEMENT	GROUP
BREAK DOWN	THINKING
GROUP APPROACH	GROUP PROCESS

EFFECTIVE MEETING

- CONFIRM PURPOSE
- PREPARATION
- CONSTRUCTIVE DEBATE

GOGY + GOTO

ANALYZING PLANS

ANALYZING ⇄ TIME PLAN, COST PLAN, QUALITY PLAN } RISK & CONTINGENCY, STRATEGIC INVESTMENT STRATEGIES

CRASHING

HOW ALL (OR) PART OF THE PROJECT COULD BE CARRIED OUT IN LESS TIME

NUMBER OF WAYS TO SHORTEN ACTIVITIES

INCENTIVE, ADDITIONAL RESOURCES, PARALLEL ACTIVITIES, REDUCED LEVEL OF TECHNOLOGY CHANGE

CHALLENGES

CALCULATING MINIMUM COST SCHEDULE

$$\text{COST/UNIT TIME TO CRASH EACH ACTIVITY} = \frac{C_c - C_n}{t_n - t_c}$$

C_c - CRASHED COST
C_n - NORMAL COST
t_n - NORMAL TIME
t_c - CRASH TIME

ANALYZING COST PLAN

THE OF PROJECT BEING CONSIDERED TIME SPAN

PAY BACK ANALYSIS | DISCOUNTED CASH FLOW, INTERNAL RATE OF RETURN

CASH FLOWS of COST & BENEFIT

PAY BACK - LIFE CYCLE COST OF ITEM, TIME VALUE OF MONEY

$$\text{PRESENT VALUE (P.V)} = \frac{C_n}{(1+i)^n}$$

$$\text{FUTURE VALUE} = C(1+i)^n$$

C_n: FUTURE VALUE OF INVESTMENTS IN n YEAR
i = DISCOUNTING RATE

NET PRESENT VALUE = PRESENT VALUE OF BENEFIT − PRESENT VALUE OF COST

P11/ IF A PROJECT REQUIRES THE EXPENDITURE OF $100000 NOW AND WILL YIELD $200000 IN 6 YEARS, FIND NET PRESENT VALUE. 10% DISCOUNT RATE

$$\text{P.V of BENEFIT} = \frac{C_n}{(1+i)^n} = \frac{200,000}{(1+\frac{10}{100})^6} = 112800$$

P.V OF COST = 100,000

N.P.V = 112800 − 100,000 = $12800 } SHOULD BE CARRIED OUT

RISK & CONTINGENCY

- PROJECT WILL FAIL COMPLETELY
- PROJECT WILL BE COMPROMISED ON TIME, COST (OR) BOTH
- THE LIKELIHOOD OF A PARTICULAR UNDESIRABLE EVENTS HAPPENING
- THE SEVERITY OF THE EFFECT ON THE PROJECT BY THESE EVENTS

FORMAL USE OF RISK ANALYSIS TECHNIQUES

- COMPANY POLICY, CLIENT

RISK ANALYSIS TECHNIQUES

PERT, CATASTROPHE THEORY, GAME THEORY
DECISION TREE, MULTIPLE CRITERIA DECISION MODEL
EXPECTED VALUE, SENSITIVITY ANALYSIS
MONTE-CARLO SIMULATION

(a) PROJECT STRUCTURE
SLIDE (1) → (9)
Q 26 → Q 33

(b) TEAM EFFECTIVENESS
SLIDE (1) → (9)
Q 34 → Q 38

E071 - INSURANCE

COMPREHENSIVE - GENERAL LIABILITY POLICY

MANAGEMENT SUCCESSION - INVESTMENTS, CONTRACTOR'S ASSETS & RISKS,

INVESTMENTS - REAL ESTATE, RENTAL PROPERTIES, STOCK BONDS SHARE

BIDDING TACTICS - UNDERCUT TECHNIQUE, THE BAIT & SWITCH TECHNIQUE, OUT OF TOWN FAKE, OUTRIGHT DECEPTION.

(G) TELECOMMUNICATION + INSURANCE

COMPONENTS of TELECOM: SYSTEM, IMPORTANT FACTS IN WRITING TELECOM: SPECIFICATIONS, COAXIAL CABLE, COMPONENTS, END-OFFICE SWITCHING ACCESSORIES, INTERNATIONAL TELECOM: STANDARD, POCKET SWITCHING, DIGITAL TRANSMISSION & SWITCHING.

SLIDE 1→11, 022→024

E071 - INSURANCE

COMPREHENSIVE - GENERAL LIABILITY POLICY

MANAGEMENT SUCCESSION - INVESTMENTS, CONTRACTOR'S ASSETS & RISKS,

INVESTMENTS - REAL ESTATE, RENTAL PROPERTIES, STOCK BONDS SHARE

BIDDING TACTICS - UNDERCUT TECHNIQUE, THE BAIT & SWITCH TECHNIQUE, OUT OF TOWN FAKE, OUTRIGHT DECEPTION.

(6) TELECOMMUNICATION + INSURANCE

COMPONENTS of TELECOM: SYSTEM, IMPORTANT FACTS IN WRITING TELECOM: SPECIFICATIONS, COAXIAL CABLE, COMPONENTS, END-OFFICE SWITCHING ACCESSORIES, INTERNATIONAL TELECOM: STANDARD, POCKET SWITCHING, DIGITAL TRANSMISSION & SWITCHING.

SUBG I → II, 022 → 024

GOGG+GOTO- MODELLING THE PROJECT SYSTEM

- ROUGH OVERVIEW, REVISION, ITERATION

SUB PROJECTS
NUMERICAL ANALYSIS
EXPERIENCE
PROJECT OWNER
CUSTOMER

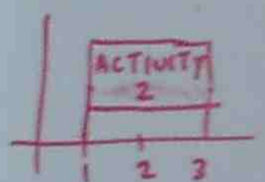
INPUTS → OUTPUT TO

APPROVAL PROCESS

REFINEMENT

REVISION

PLANNING SEQUENCE



ACTIVITY	FINISH
START	2/2/10
END	2/11/10

PROJECT PLAN, GRAPHICAL FORM

CARRY OUT LITERATURE REVIEW	xxxx							
ARRANGE TASKS		xx						
PREPARE QUESTIONNAIRES			xxx					
REVIEW QUESTIONNAIRES				xxx				
DELIVER QUESTIONNAIRES					xx			
ANALYZE RESULT						x		
WRITE UP							x	
HAND IN DATE								x

GANTT CHART

	FEB	MARCH	APRIL
LITERATURE	→		
ANALYZE		→	

SCHEDULE
FORWARD
BACKWARD

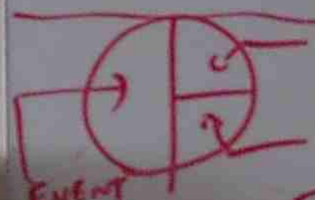
GANTT CHART FOR SIMPLE PROJECTS

ACTIVITY ON ARROW DIAGRAM

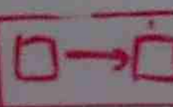
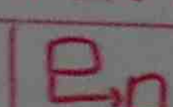
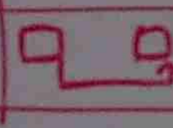
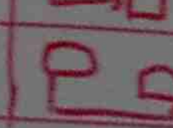


PLANNING SEQUENCE

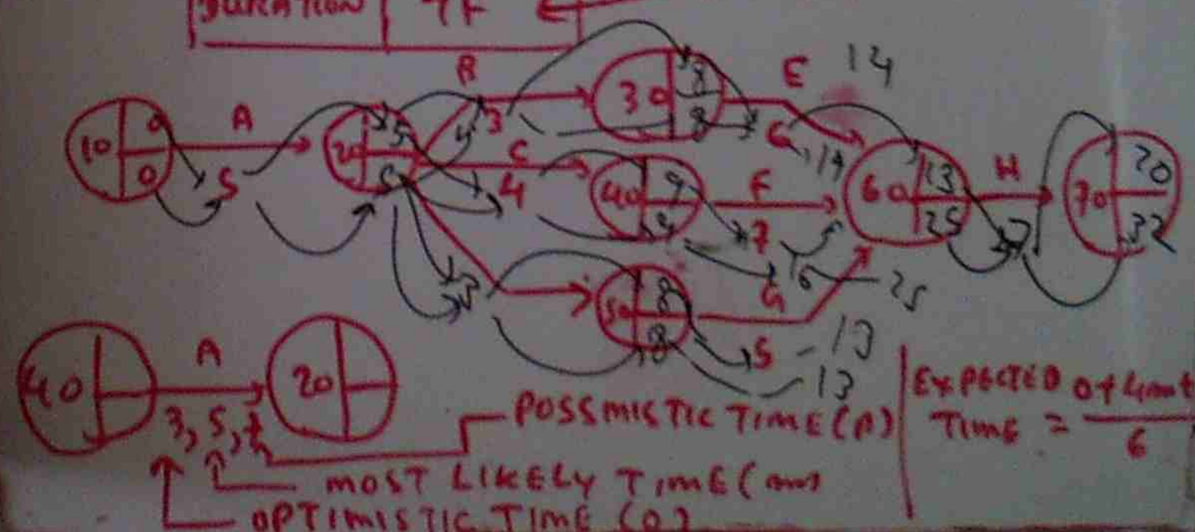
- IDENTIFY CONSTITUENT ACTIVITIES
- DETERMINE THEIR SEQUENCES
- ESTIMATE TIME FOR EACH



4 WAYS IN WHICH ACTIVITIES CAN LINK

FINISH TO START		START TO START	
FINISH TO FINISH		START TO FINISH	

EARLIEST START TIME → EST | LST ← LATEST START TIME
ACTIVITY DESCRIPTION
DURATION | TF ← TOTAL FLOAT



EXPECTED TIME = $\frac{O+4m+P}{6}$

TOP-DOWN COSTING

CERTAIN AMOUNT IS ALLOCATED TO THE PROJECT. THEN IT IS SPLIT BETWEEN SUB PROJECTS

GROUND UP COSTING

THE ESTIMATE OF EACH LEVEL IN THE WORK BREAKDOWN STRUCTURE ARE COMPILED AND ADDED TOGETHER

ACTIVITY LEVEL COST

TIME, MATERIAL, CAPITAL EQUIPMENTS, INDIRECT EXPENSES, OVER HEADS

INPUT OF PROJECT

DIRECT WORK MEASUREMENT, WORK SAMPLING
SYNTHETIC ESTIMATION

PRICE = DIRECT MATERIAL + DIRECT LABOUR + PROJECT OVERHEAD + GENERAL OVER-HEAD + PROFIT

REVENUE = DIRECT MATERIAL + DIRECT LABOUR + PROJECT OVERHEAD + GENERAL OVERHEAD

COST + PROFIT = PRICE
PRICE − PROFIT = COST
PRICE − COST = PROFIT

REVENUE ALLOCATION

- ALLOCATE TO DIFFERENT PARTS OF PROJECT
- UNIFORMLY CENTRALISED
- ALLOCATION TO TASK TO PROJECT

⑥ ACTIVITY LINK

SLIDE (1) → (13)
Ø22 → Ø27

E071 - PAPER WORK

KEY FACTORS IN PROCESSING PAPERWORK SMOOTHLY

- HAVING ENOUGH INFORMATION
- GETTING INFORMATION WHEN NEEDED
- HAVING ENOUGH PEOPLE TO HANDLE THE WORK

PURCHASE ORDER − P.O FILE / VENDOR / JOB FOLDER

BILLING → JOB FOLDER / CUSTOMER /
TIME CARD → PAY ROLL / JOB FOLDER
INCOMING INVOICE → JOB FOLDER / BOOKKEEPER
INCOMING STATEMENT → PAID FILE / RETURN WITH PAYMENT

PURCHASE ORDER FORMAT

BOOKKEEPER → ACCOUNT PAYABLE / ACCOUNT RECEIVABLE
BILLING

SERVICE ORDER FORMAT

CUTTING COST

BUYING QUALITY MATERIAL MORE CHEAPLY MAKING IT EASIER FOR SUPPLIER

BID PRICING

LABOUR PRODUCTIVITY

- MORE EFFICIENT INSTALLATION TECHNIQUE
- INCREASE WORKER MOTIVATION

DIVISION OF TASKS

BY AREA / BY TYPE

CONSULT INSTALLATION
INSTALLATION SCHEDULE

TOP-DOWN COSTING

CERTAIN AMOUNT IS ALLOCATED TO THE PROJECT. THEN IT IS SPLIT BETWEEN SUB PROJECTS

GROUND UP COSTING

THE ESTIMATE OF EACH LEVEL IN THE WORK BREAKDOWN STRUCTURE ARE COMPILED AND ADDED TOGETHER

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- INCREASE WORKER MOTIVATION

DIVISION OF TASKS

BY AREA / BY TYPE (CONSULT INSTALLATION / INSTALLATION SCHEDULE

PRICE = DIRECT MATERIAL + PROJECT OVERHEAD + GENERAL OVER + PROFIT

BOOKKEEPER → ACCOUNT

BILL IN

(7) DOMESTIC ELECTRICAL INSTALLATION + PAPER WORK

- SPECIFICATION FOR DOMESTIC ELECTRICAL INSTALLATION
- ELECTRICAL REGULATION FOR WIRING

SLIDE (1) ⟶ (12) @ 30 → @ 3.3

YN THETIC ESTIMATION

PRICE = DIRECT MATERIAL + PROJECT OVERHEAD + GENERAL OVER + PROFIT

BOOKKEEPER → ACCOUNT BILL IN

(7) DOMESTIC ELECTRICAL INSTALLATION + PAPER WORK

- SPECIFICATION FOR DOMESTIC ELECTRICAL INSTALLATION
- ELECTRICAL REGULATION FOR WIRING

SLIDE (1) ⟶ (12) @ 30 → @ 33

CHANGE CONTROL

CHANGE REQUEST - EVALUATING
- COST & BENEFIT, THE PRIORITY ATTACHED TO CHANGE, THE EFFECT OF CHANGE ON OTHER PROCESSES, THE EFFECT ON OTHER ASSUMPTION

CHANGE CONTROL SYSTEM

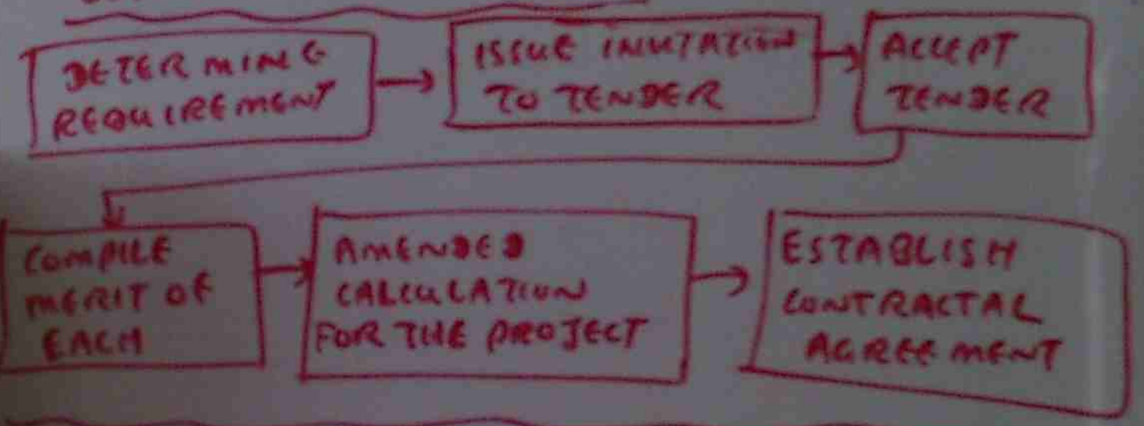


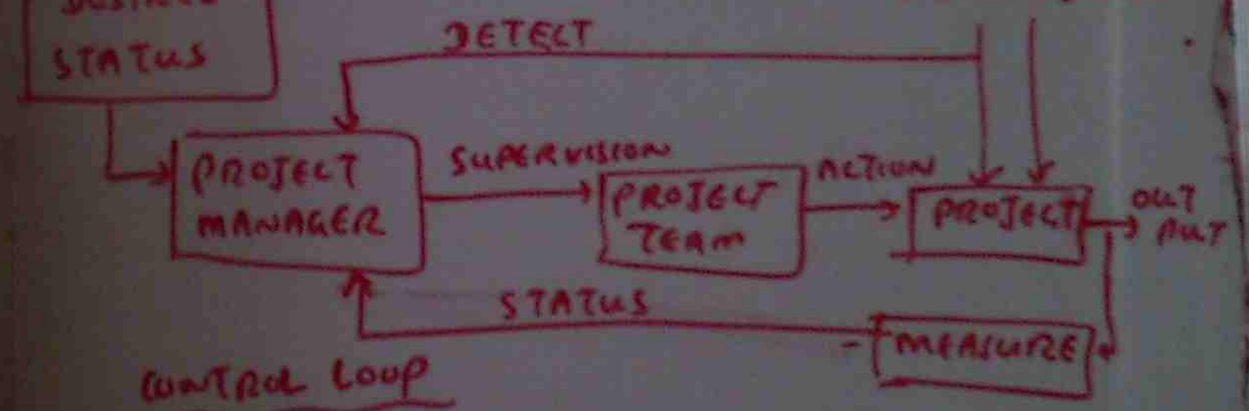
TRADE OFF

RIGHT QUALITY, QUANTITY, PRICE, PRACTICE
RIGHT TIME, PLACE, SUPPLIER

QUALITY IS DETERMINED BY INITIAL SUPPLY OF GOODS, PRIOR REPUTATION, CERTIFICATION, ASSESSMENT

ESTABLISHMENT OF CONTRACT





PREPARING QUALITY MANUAL

DOCUMENT CHANGE

REQUEST CHANGE

CHECK IMPACT ON QUALITY SYSTEM

APPROVE CHANGE

ISSUE NEW PROCEDURES & AMENDMENT RECORDS

DOCUMENT APPROVAL ISSUE

RECEIVE NEW PROCEDURES & AMENDMENT RECORD

DESTROY OLD PROCEDURES

COMMUNICATE CHANGE TO ALL PEOPLE

RETAIN THE APPROPRIATE PROCEDURES

MANAGEMENT LEADERSHIP

MANAGEMENT HAS A POSITIVE ROLE TO PLAY IN THE ACHIEVEMENT OF PROJECT GOALS

MANAGEMENT - TECHNICAL DISCIPLINE OF APPLYING & ADMINISTERING AUTHORITY

LEADERSHIP - THE QUALITY OF OBTAING RESULTS FROM OTHER PERSONAL INFLUENCE

PROJECT MANAGER'S ROLE

PLANNING, ORGANISING, DIRECTING, CONTROLLING MOTIVATION,

FORMAL EDUCATION & TRAINING

INFORMAL EDUCATION & TRAINING

RETURN OF TASK

INDIVIDUAL MOTIVATION OF TEAM MEMBER

PERSONALITY

EXPERIENCE

INDIVIDUAL SKILL & ATTITUDE

ORGANIZATIONAL STRUCTURE

INDIVIDUAL PROJECT MANAGER

ORGANISATIONAL CULTURE

MANAGEMENT STYLE

TEST OF MANAGEMENT EFFECTIVENESS

INFLUENCE ON OUT COME

(14) MANAGEMENT THINKING

SLIDE (1) → (8)

Q63 → Q71

SCIENTIFIC MANAGEMENT

- SCIENTIFIC STUDY, MATCHING SKILL TO TASK TRAINING, REWARD

MANAGEMENT LEADERSHIP

QUALITY, FUNCTION OF GROUP APPROACH, LEADERSHIP BEHAVIOUR STYLE, SITUATION TRANSFORMATIONAL

(11) CHANGE CONTROL

SLIDE (1) → (8)

Q50 → Q55

(13) MANAGEMENT LEADERSHIP

SLIDE 1 → 8 | Q61 → Q67

E671 - JOB ACCOUNTING

SECTIONAL SYSTEM

SECTION(1) - SITE WORK - TEMPORARY POWER
SECTION(2) - INTERIOR RACE WAY
SECTION(3) - DISTRIBUTION EQUIPMENT
SECTION(4) - WIRE
SECTION(5) - LIGHT FIXTURE
SECTION(6) - TRIM OUT

SECTION(7) - SPECIAL SYSTEM
OTHER

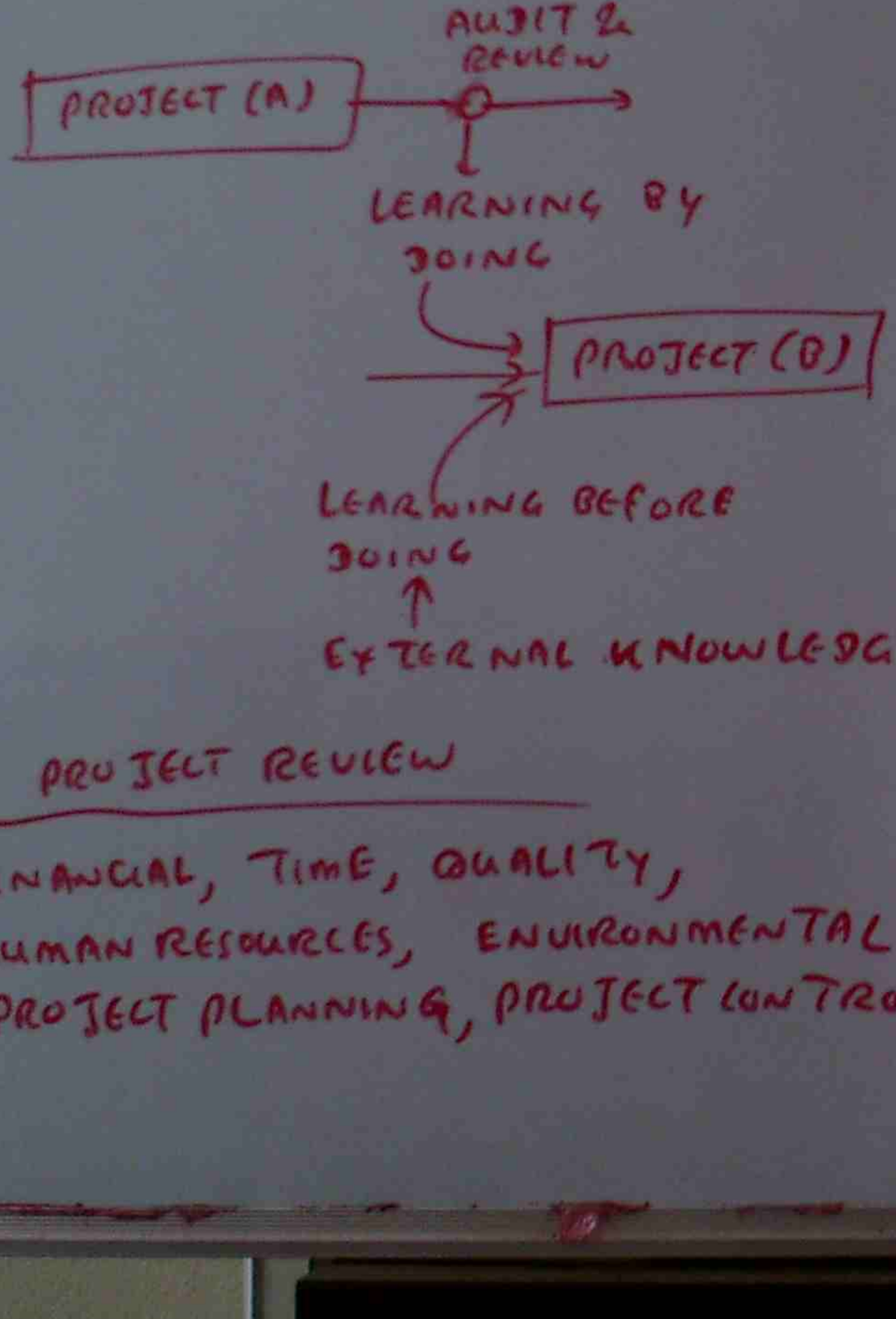
JOB REVIEW SHEET, TIME CARD

JOB SCHEDULE - COMPOSITE SCHEDULE, CASH FLOW SCHEDULE
OFFICE MANAGEMENT, LIST OF RESPONSIBILITIES
RESPONSIBILITIES OF - PRESIDENT / OWNER, ESTIMATOR
SUPERINTENT, BOOKKEEPER, SECRETARY / RECEPTIONIST
JOB MANAGEMENT / JOB PLANNING

(a) DESIGN STANDARD FOR ON LINE & JOB ACCOUNTING
SLIDE (1) → (14), @ 41 → @ 46

DEVELOPMENT OF MANAGEMENT THINKING

- LEARNING BEFORE DOING
- LEARNING BY DOING



PROJECT REVIEW

FINANCIAL, TIME, QUALITY, HUMAN RESOURCES, ENVIRONMENTAL PROJECT PLANNING, PROJECT CONTROL

(14) DEVELOPMENT OF MANAGEMENT THINKING

SLIDE 1 ⟶ 8

@68 ⟶ @71

E071

(8) PULLING THE CABLE IN TO CONDUIT MANAGEMENT PLANNING

FORMULA, RADII REQUIREMENT, CONCRETE WORK SPECIFICATION SPECIFICATION FOR CABLE PULLING

SLIDE 1 ⟶ 20

@ 34 ⟶ @40

(11) H.V OH LINE PROTECTION + JOB SCHEDULE

PROTECTION SYSTEM FOR 11/22KV FEEDER PROTECTION OF L.V OH WORK PROTECTION CO-ORDINATION

SLIDE (1) ⟶ (12), @ 51 ⟶ @60

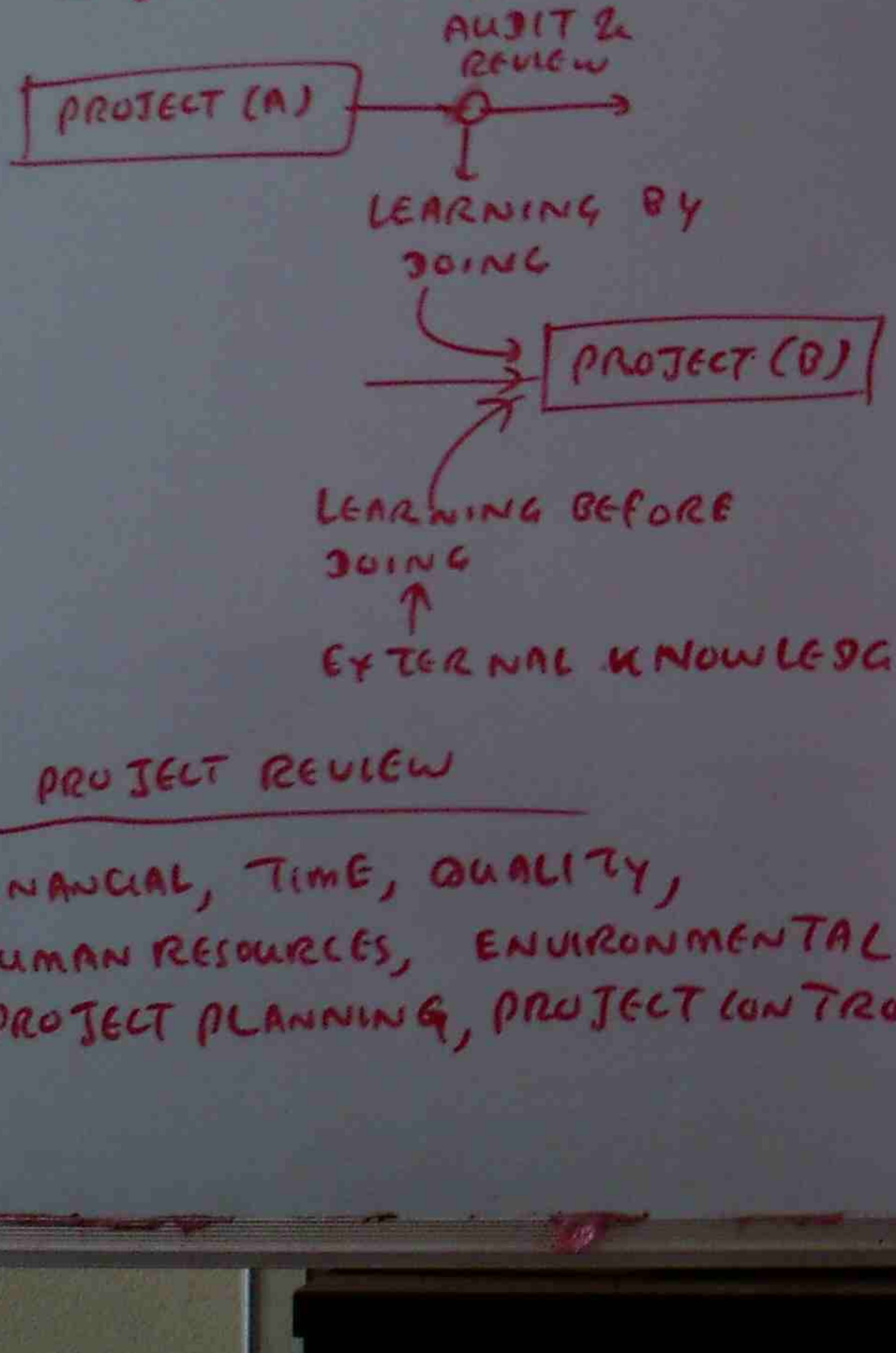
(12) MECHANICAL SWITCHES + ESTIMATOR

TYPE OF SWITCHES, RELAY SYMBOL TYPES OF RELAYS

SLIDE (1) ⟶ (14), @61 ⟶ @69

DEVELOPMENT OF MANAGEMENT THINKING

- LEARNING BEFORE DOING
- LEARNING BY DOING



PROJECT REVIEW

FINANCIAL, TIME, QUALITY, HUMAN RESOURCES, ENVIRONMENTAL PROJECT PLANNING, PROJECT CONTROL

(14) DEVELOPMENT OF MANAGEMENT THINKING

SLIDE 1 ⟶ 8

@68 ⟶ @71

E071

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SLIDE 1 ⟶ 20

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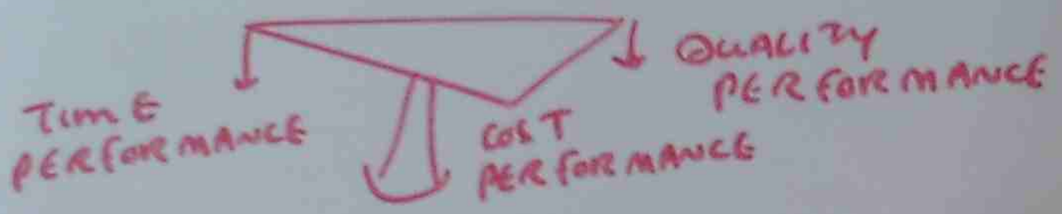
SLIDE (1) ⟶ (14), @61 ⟶ @69

TRADE OFFS IN PROJECT MANAGEMENT



SUCCESS

- RESULTS ACHIEVED MEET THE STATED NEEDS / WITH IN GIVEN CONSTRAINT / MINIMUM COST / BENEFIT TO TEAM / BENEFIT TO ALL STAKE HOLDERS

FAILURE

OVER TIME, OVER BUDGET, OUT PUT DOES NOT MEET THE NEEDS

SATISFACTION = PERCEPTION — EXPECTATION

RESPONSIVENESS, COMMUNICATION, COMPETENCY / PROFESSIONALISM, COURTESY ACCESSIBILITY

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(1) PROJECT MANAGEMENT INTRODUCTION

SLIDE (1) → (10), Ø1 → Ø7

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(2) STRATEGIES IN PROJECT MANAGEMENT

SLIDE (1) → (4), Ø8 → Ø10

(E071)

(1) NSW ELECTRICAL SERVICE RULE CONTENTS SLIDE (1) → (5), Ø1

ELECTRICAL CONTRACTING

SUPPLY & DEMAND, MARKET PLACE DETERMINES PROFITABILITY,

- GETTING WORK, DOING WORK
- MARKETING

QUESTIONS FOR SALE & MARKETING CONSISTING OF MARKET FIGURE, LONG TERM FORECAST, COMPETITORS, STRENGTH / WEAKNESS, DIFFERENT MARKET CUSTOMER FOCUS, PROFIT TYPE, REQUIRED ITEMS ETC

- ANALYZING THE MARKET PLACE
- TRENDS IN MARKET PLACE

CHOOSING THE MARKET SEGMENT

- MOST PROFITABLE TYPE OF WORK
- AMOUNT OF WORK
- TYPE OF WORK
- TYPE OF COMPETITATOR
- DIFFERENT TYPES OF WORK

PLANNING - CONTRACTING

ASSET, LIABILITIES, MARKET FORECAST, CUSTOMER
PROFITABLE TYPE OF WORK
SYSTEM OF OPERATION

CONTROL, ORGANIZE, FLOW OF PAPER WORK
PLANNING PURCHASING, ASSURE TO HAVE
DONE, OPERATION GOES AS PLAN
LEADERSHIP + EMPLOYEES + MOTIVATION

PLANNING BUDGET

STATE OF AFFAIRS, OVER HEAD AND PROFIT
PERCENTAGE, MARKET PLACEMENT
SCHEDULE
(1) PROJECT SPECIALIZATION
SLIDE 6, Q. 2 + Q 3

(2) H.V CONDUCTORS
SLIDE (1) → (3)
Q 4 + Q 5

(2) H.V CONDUCTORS / SALE / MARKETING

AUSTRALIAN STANDARD FOR 11KV OH CONDUCTOR, CONSTRUCTION, CLEARANCE REQUIREMENT, POLE ACCESSORIES, PROTECTION DEVICES ON POLE, INSULATOR SURGE ARRESTERS, H.V CABLES, AUSTRALIAN STANDARD FOR OH LINE CONSTRUCTION.

(2) H.V CONDUCTORS, SALE, MARKETING

SLIDE (1) → (14)

Q4 → Q10

GOGG + GOTO

MODELLING THE PROJECT SYSTEM
OVER VIEW MODEL

TO CONSIDER THE FORM IN WHICH OBJECTIVES ARE OFTEN PRESENTED TO THE PROJECT AND THAT IN WHICH THE ANALYZED PLAN WILL NEED TO BE DELIVERED

BRIEF

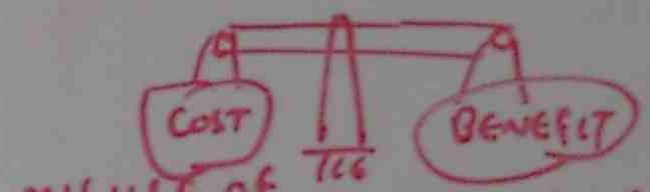
- VERY PRECISE
- AREAS THAT ARE NOT SO PRECISE NEED TO BE IDENTIFIED
- OPEN BRIEF

PROPOSAL

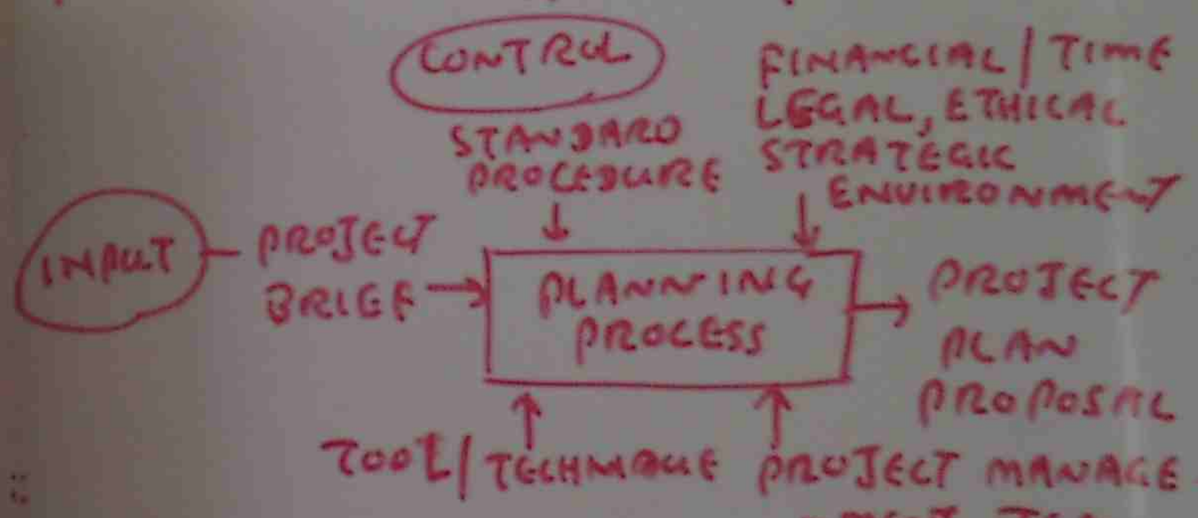
- WHO IS THE PROPOSAL FOR?
- WHY IS THE PROPOSAL BEING REQUESTED?

PROJECT → INTERNAL CUSTOMER → CONSISTENSY WITH ORGANIZATION'S GOAL
PROJECT → EXTERNAL CUSTOMER → PAY FOR PROJECT

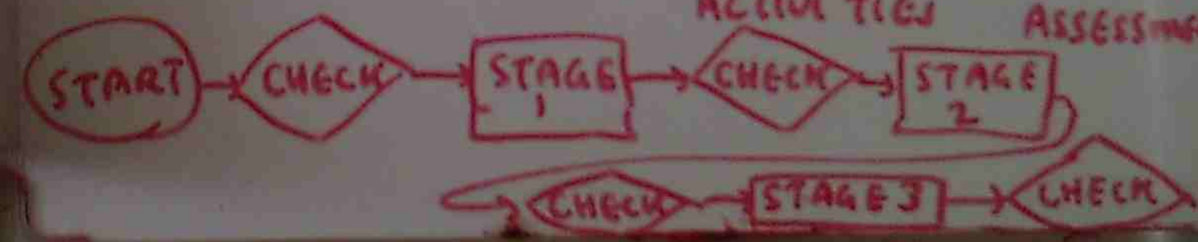
- APPROPRIATE RESULT
- COMPETITIVE BID
- WHAT WOULD BE INVOLVED
- ORGANIZATIONAL POLICY TO CONSIDER THE SUPPLIER



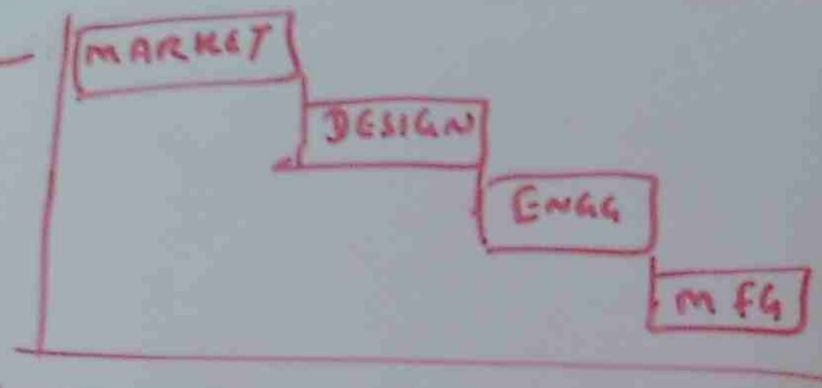
BALANCING COST & BENEFIT ←



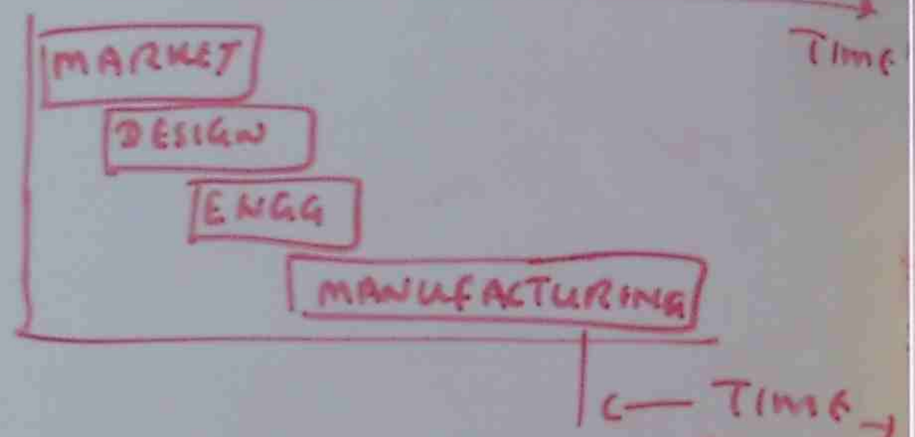
BREAK DOWN ACTIVITIES → DETERMINE LOGICAL SEQUENCE → INPUT TO SUBSEQUENT MANAGEMENT ACTIVITIES → FRAME WORK FOR ASSESSMENT



WESTERN



JAPAN



(3) STRATEGY OBJECTIVE

SLIDE (1) ⟶ (2)

Ø11 ⟶ Ø12

(4) CUSTOMER REQUIREMENTS

SLIDE (1) ⟶ (4)

Ø13 ⟶ Ø15

E071 - JOB PLANNING

PRE-JOB PLANNING

INSURANCE, STORAGE, JOB SCHEDULE, ENOUGH WORKERS, PAYMENT PROCESSING CASH FLOW PROBLEM, CHANGE ORDER, PERCENTAGE OF OVER HEAD & PROFIT, PAYMENT FROM GENERAL CONTRACTOR, MATERIALS FOR FIRST JOB, JOB FOREMAN CONSTRUCTION, ELECTRICAL, TELECOM: ETC

INSTRUCTING WORKERS, RE DESIGN

PURCHASING

- CORRECT MATERIALS LIST
- BREAK MATERIALS LIST IN TO SECTIONS
- GIVE THE COPIES of MATERIALS LIST TO SUPPLIER
- ISSUE PURCHASE ORDER

PURCHASE ORDER FORM

- GETTING SUBMITTED, DELIVERY SCHEDULE AVOIDING BACK ORDER.

MATERIALS HANDLING / TOOL STORAGE

JOB DESCRIPTION/ UNDERSTANDING / RIGHT TOOL MATERIAL

(E071)

(3) LINE INFRASTRUCTURE + MATERIALS STORAGE

SLIDE 1 → 7, Q11 → Q12

(4) MECHANICAL FITTING + LIGHT FIXTURE + PURCHASING

SLIDE (1) → (9)

Q13 → Q16

(5) HAZARDS IDENTIFICATIONS + RESIDENTIAL ELECTRICAL CONTRACTS

SLIDE (1) → (20)

Q17 → Q 21

(E071)

(3) LINE INFRASTRUCTURE + MATERIALS STORAGE

SLIDE 1 → 7, Q11 → Q12

(4) MECHANICAL FITTING + LIGHT FIXTURE + PURCHASING

SLIDE (1) → (9)

Q13 → Q16

(5) HAZARDS IDENTIFICATIONS + RESIDENTIAL ELECTRICAL CONTRACTS

SLIDE (1) → (20)

Q17 → Q 21

GOOD & GOOD PROBLEM SOLVING & DECISION MAKING

PROBLEM. THE GAP BETWEEN AN ACTUAL SITUATION AND THE REQUIRED (OR) EXPECTED SITUATION

NATURE OF PROBLEM

REQUIRING IMMEDIATE ACTION
RESPONSE TO CRISIS
EMERGING PROBLEMS
RESPONSE TO OPPORTUNITY
STRATEGY FORMULATION

RESPONSE → INSTINCTIVE, TO REMOVE THE SOURCE OF POTENTIAL DANGER

DECISION - POOR DECISION MAKING

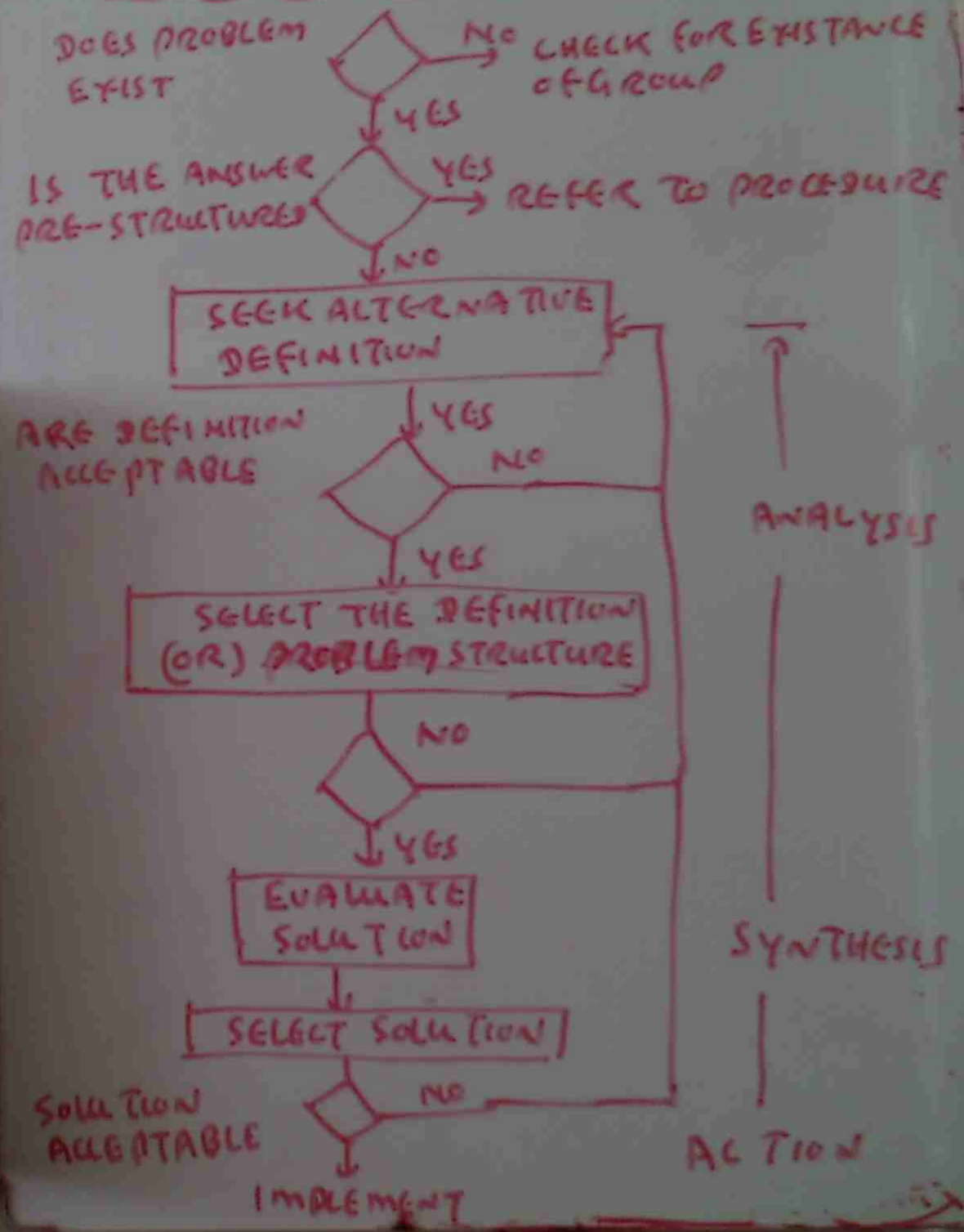
MODEL - DESCRIPTIVE, MATHEMATICAL
STATIC, IN/OUT SYSTEM
DYNAMIC PREDICTIVE MODEL

CAUSE EFFECT ANALYSIS
DECISION FRAMEWORK / DECISION SUPPORT MODEL

FORECAST | JUSTIFICATION | FOLLOW UP

(12) PROBLEM SOLVING DECISION MAKING | SLIDE (1) → (7) } 256 → 260.

SYSTEMIC PROBLEM SOLVING



GO69+GO70 CONTROL OF PROJECT

ROLE OF PROJECT MANAGER

PLANNING, ORGANIZING, DIRECTING, CONTROLLING

ACTIVITIES → FEED BACK CONTROL → OUT PUT → INPUT

INSTABLE / STABLE

QUALITY

MANAGEMENT RESPONSIBILITY, ESTABLISH & MAINTAIN QUALITY SYSTEM, REVIEWING CUSTOMER CONTACT DECISION PROCESS, DOCUMENT CONTROL.

QUALITY SYSTEM DOCUMENTATION

STATEMENT OF AIM!
↓
SYSTEM DESCRIPTION!
↓
PROCEDURE DESCRIPTION!
↓
TECHNICAL REFERENCE/MANUAL

QUALITY SYSTEM

ESTABLISH THE REASON, TRAIN THE PEOPLE, CREATE DOCUMENTATION, INTERNAL AUDIT,

ELEMENT of QUALITY COST

PREVENTION, APPRAISAL, FAILURE

CONTROL COST, PRECAUTION

PROJECT INFORMATION SYSTEM _ MEASURE / RECORD / ANALYZE ACT

COST VARIANCE = ACTUAL COST of PERFORMANCE _ BUDGETED COST (BCWP)

ESTIMATED PROJECT = TOTAL BUDGET – COST VARIANCE

(10) CONTROL of PROJECT

SLIDE 1 → 10 | 045 → 049

E071 – MAINTENANCE & SPECIALIST WORK

GETTING WORK, DOING THE WORK,

MAINTENANCE

PERFORM BY NEED BASIS, SPECIAL TOOL + EQUIPMENT TRAINED ELECTRICIANS.

MAINTENANCE BY CONTRACT

SPECIALITY WORK

- SPECIAL TYPE OF INSTALLATION, SPECIAL SERVICE TO SPECIFIC TYPE OF CUSTOMERS
- TELEPHONE, FIRE ALARM, T.V, LIGHTNING PROTECTION, LIFT

DESIGN & BUILD WORK

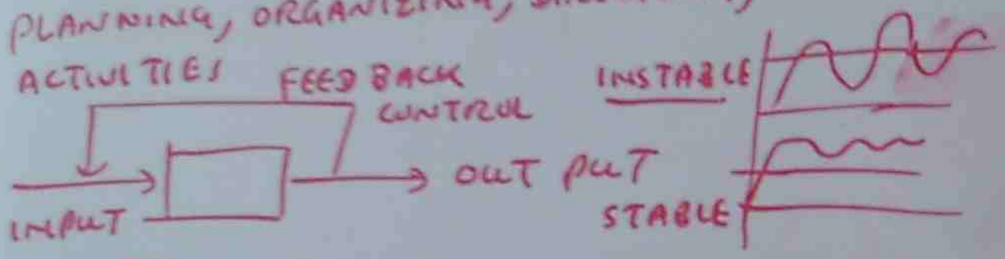
AMOUNT COMPETITION, ACCEPTABLE PACKAGE OF PRICE CO-OPERATION

- GREAT DEAL of TRUST TO CUSTOMER, FIRST CLASS MANNER IN INSTALLATION, COURTESY, CUSTOMER'S INTEREST

G069+G070 CONTROL OF PROJECT

ROLE of PROJECT MANAGER

PLANNING, ORGANIZING, DIRECTING, CONTROLLING ACTIVITIES



QUALITY

MANAGEMENT RESPONSIBILITY, ESTABLISH & MAINTAIN QUALITY SYSTEM, REVIEWING CUSTOMER CONTACT DECISION PROCESS, DOCUMENT CONTROL.

QUALITY SYSTEM DOCUMENTATION

STATEMENT OF AIM

↓

SYSTEM DESCRIPTION

↓

PROCEDURE DESCRIPTION

↓

TECHNICAL REFERENCE/MANUAL

QUALITY SYSTEM

ESTABLISH THE REASON, TRAIN THE PEOPLE, CREATE DOCUMENTATION, INTERNAL AUDIT,

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PROJECT INFORMATION SYSTEM _ MEASURE / RECORD / ANALYZE ACT

COST VARIANCE = ACTUAL COST of PERFORMANCE _ BUDGETED COST (BCWP)

ESTIMATED PROJECT = TOTAL BUDGET – COST VARIANCE

(10) CONTROL of PROJECT

SLIDE 1 ⟶ 10 | 045 ⟶ 049

E071 – MAINTENANCE & SPECIALIST WORK

GETTING WORK, DOING THE WORK,

MAINTENANCE

PERFORM BY NEED BASIS, SPECIAL TOOL + EQUIPMENT TRAINED ELECTRICIANS.

MAINTENANCE BY CONTRACT

SPECIALITY WORK

- SPECIAL TYPE OF INSTALLATION, SPECIAL SERVICE TO SPECIFIC TYPE OF CUSTOMERS
- TELEPHONE, FIRE ALARM, T.V, LIGHTNING PROTECTION, LIFT

DESIGN & BUILD WORK

AMOUNT COMPETITION, ACCEPTABLE PACKAGE OF PRICE CO-OPERATION

- GREAT DEAL OF TRUST TO CUSTOMER, FIRST CLASS MANNER IN INSTALLATION, COURTESY, CUSTOMER'S INTEREST
-

EOO1- OCCUPATIONAL HEALTH & SAFETY

NSW- OCCUPATIONAL HEALTH & SAFETY ACT (1983)
AS1270- HEARING PROTECTION DEVICES
AS 1318- PHYSICAL HAZARDS COLOUR CODING
AS 1336- INDUSTRIAL EYE PROTECTION
AS 2210- SAFETY FOOT WEAR

PRIMARY AIM of OHS ACT

TO PREVENT INJURY, DISABILITY & LONGTERM HEALTH PROBLEMS ASSOCIATED WITH PERSONS IN WORK PLACE

EMPLOYER HAS THE RESPONSIBILITY OF ENSURING HEALTH & SAFETY of EMPLOYEES

OHS COMMITTEE

- REPRESENTATIVES of EMPLOYEES
- OHS REVIEW, RESOLVE OHS PROBLEMS
  ACCIDENT RECORDING SYSTEM DEVELOPMENT
  MONITOR PROCEDURES FOR ENSURING THE PROPER USE OF PROTECTIVE EQUIPMENTS
- INSPECT WORK PLACE
- ACCESS TO WORK PLACE SAFETY INFORMATION
- RECOMMEND OHS TRAINING

INJURY EMPLOYEE- DISABILITY, LOSS OF INCOME
EMPLOYER- WORKER COMPENSATION COST
COMMUNITY- HIGHER TAXATION

EMPLOYER

- SAFE OPERATION OF EQUIPMENT
- SAFE USE/ HANDLING OF SUBSTANCES
- PROVIDE SAFETY INFORMATION
- SAFE WORK PLACE

HOUSE KEEPING - CLEAN, TIDY, ORDERLY WORKSHOP

EMERGENCIES- CHEMICAL/ FIRE/ ACCIDENT EXPLOSION, GAS

PERSONAL PROTECTIVE EQUIPMENTS

PROTECTIVE GEAR, EYE PROTECTION, FOOT WEAR HEAD PROTECTION, FACE COVER

FIRE FIGHT/ INFORM/ RETURN/ EVACUATE

MANUAL LIFTING

PLAN, ASSESS THE BEST WAY, SECURE GRIP, (KNEEL), KEEP THE LOAD CLOSE TO BODY A TEAM LIFT

INDUSTRIAL CHEMICAL CAN ENTER

(1) INGESTION, INHALATION (2) SKIN (3) EYE

DANGEROUS SUBSTANCE

CLASS, SUBSIDIARY, PRODUCT NAME, CHEMICAL NAME FIRST AID PROCEDURE, MANUFACTURER/ SUPPLIER

HEAT STRESS, EXCESSIVE VIBRATION - EXCESSIVE NOISE

MINIMUM GRIP/ REGULAR BREAK/ AWAY FROM BODY VENTILATION, EAR PLUG

PROTECTING WORK PLACE HAZARD

CLOTHING, WALK IN DESIGNATED LANE, NO PRACTICAL JOKE, DO NOT TREAD ON LOOSELY STACKED MATERIAL, DO NOT STAND / WALK UNDER OVERHEAD LOAD, DO NOT APPROACH SCAFFOLDING, CAREFUL FOR SLIPPERY, TAKE CARE OF MACHINE PARTS, FAMILIARIZE WITH CONTROL
NO LOOSED HANDLED HANDTOOLS.
NOT TO ADJUST ELECTRICAL EQUIPMENTS

USE OF ELECTRICITY IN WORK PLACE

DETEORIATION OF INSULATION, CONTACT WITH LIVE PARTS,
PROTECTION - DOUBLE INSULATION, ISOLATING TRANSFORMER, EARTH LEAKAGE CIRCUIT BREAKER, SAFETY SWITCH
ELECTRICITY HAZARDS - SHOCK / HEAT / INDUCTION
CHECK TOOL, CORDS FOR CRACK, NEVER CARRY THE TOOL BY IT'S LEAD
- SAFETY INTER LOCK / RCD

RESCUE
- SWITCH OFF CB
- REMOVE THE VICTIM FROM LIVE WIRE (USE INSULATION / DRY CLOTH)

ARTIFICIAL RESUSCIATION
NO ATTEMPT TO RESCUE IF VOLTAGE IS MORE THAN 1000V

E002 / E005 - ASSEMBLY, FIT & SECURE EQUIPMENT

FITTING - SCREW, NAIL
- BOLT & NUT

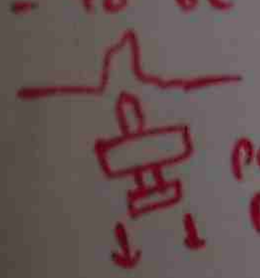
DRILLING HOLE - USE DRILL BIT SMALLER DIAMETER THAN REQUIRED HOLE.
FOR LARGE HOLE, DRILL A PILOT HOLE

O/H ASSEMBLY

CHEMICAL ANCHOR / INJECTION ANCHOR
MASONARY NAIL FOR CONCRETE FIXING
- DO NOT DRIVE NAIL IN TO MORTAR JOINT
- ONLY ONE NAIL INTO ONE BRICK

EQUIPMENTS / TOOL - HAMMER (POWER PNEUMATIC,

PURPOSE OF FIXING
- TO HOLD THE PARTS OF JOINTS TOGETHER,
- TO BE STRONG TO CARRY WEIGHT



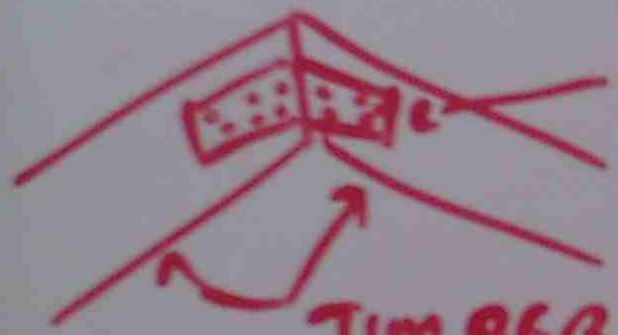
DRILL
ROTARY, HAND
ELECTRIC
PNUEMATIC

FOLLOWING THE SETTING INSTRUCTION FOR DRIE

GRINDER, FITING - CHARACTERISTICS, SIZE WEIGHT
(CORROSION, OXIDATION)

MECHANICAL FIXING IN TIMBER BASE

NAIL - SHAPE & SIZE DEPENDS ON APPLICATION
WOOD SCREW, USE OF NAIL PUNCH PLATE



NAIL PLATE
TIMBER FASTENER, BOLT, NUT

SHAFT - TOOTHED CONNECTOR, SPLIT RING CONNECTOR
SHEAR PLATE CONNECTOR



FASTENERS

CORRGUATED

E002	SLIDE (1) → 4
E005	@22 → @32

(4) FIXING ACCESSORIES

SLIDE (1) → (14)
@33 → @46

MECHANICAL FIXINGS IN METAL BASE

BOLT, NUT, HANGER, BRACKET

SOLDERING | WELDING,

(1) OHS + MANUAL HANDLING
SLIDE (1) → (7)
@1 → @9

(2) SAFETY + ASSEMBLY
SLIDE (1) → (10)
@10 → @21

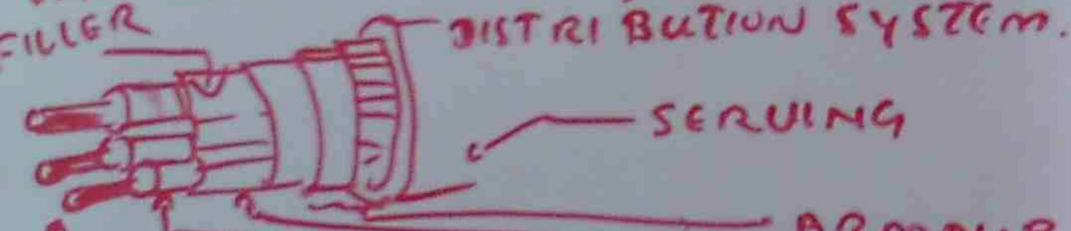
E002
SLIDE (5) → (N
@16 → @21

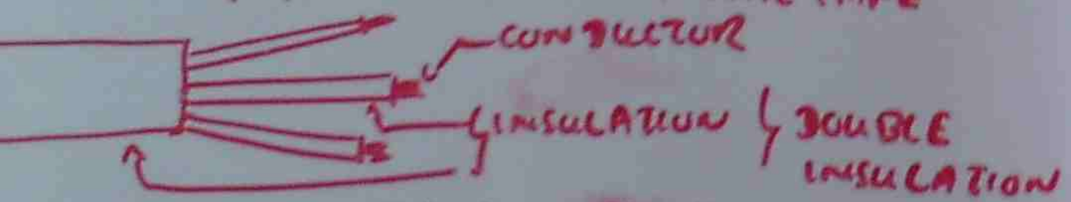
BASIC ELECTRICAL WIRING (E008)

IDENTIFICATION OF CABLE & CABLE CORE

SINGLE CORE - RED (OR) BLACK
TWO CORE - RED AND BLACK (OR) RED AND WHITE
THREE CORE - RED, WHITE, BLUE
FOUR CORE - RED, WHITE, BLUE, BLACK
FLEXIBLE CORD - GREEN/YELLOW - EARTH
BROWN - ACTIVE
LIGHT BLUE - NEUTRAL

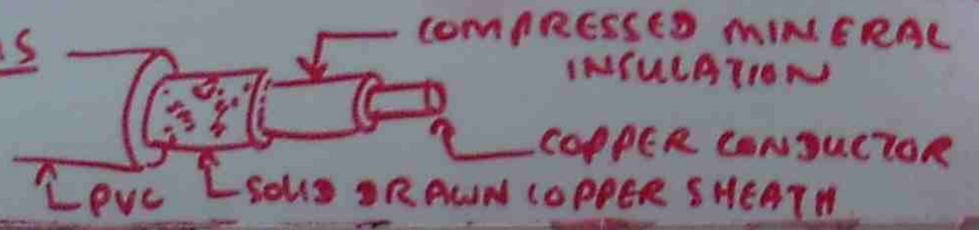
BARE CONDUCTOR - COPPER, ALUMINIUM
FILLER
DISTRIBUTION SYSTEM.





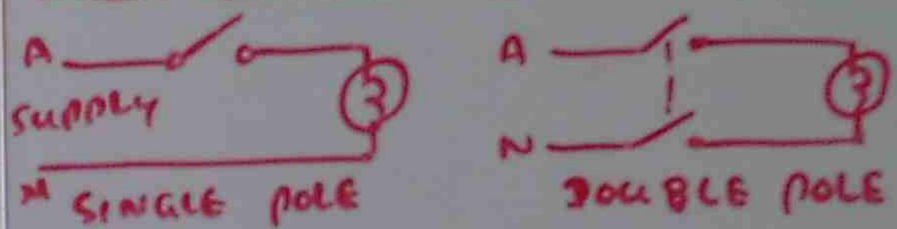
TPS - THERMO PLASTIC SHEATH CABLE

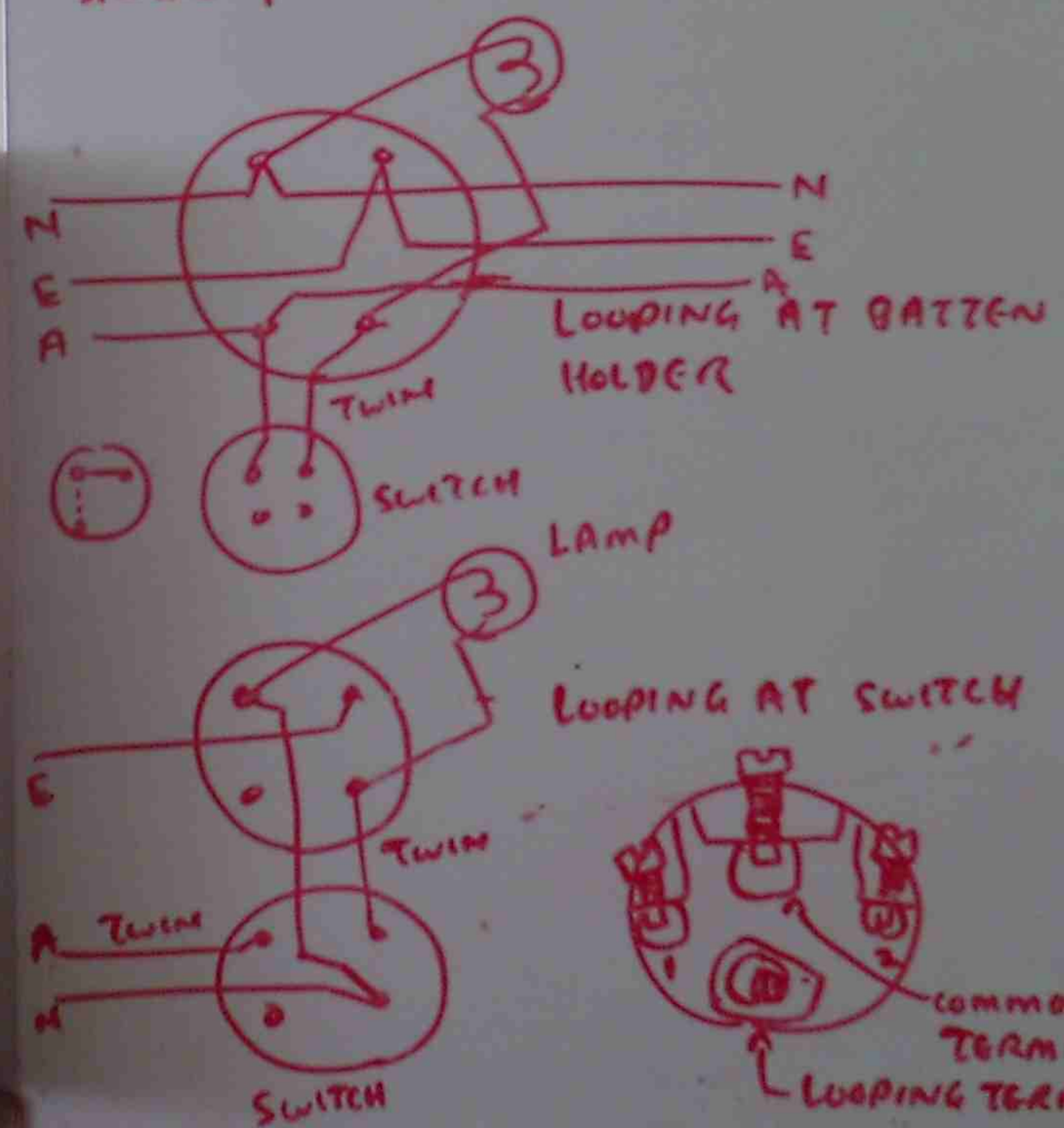
MIMS



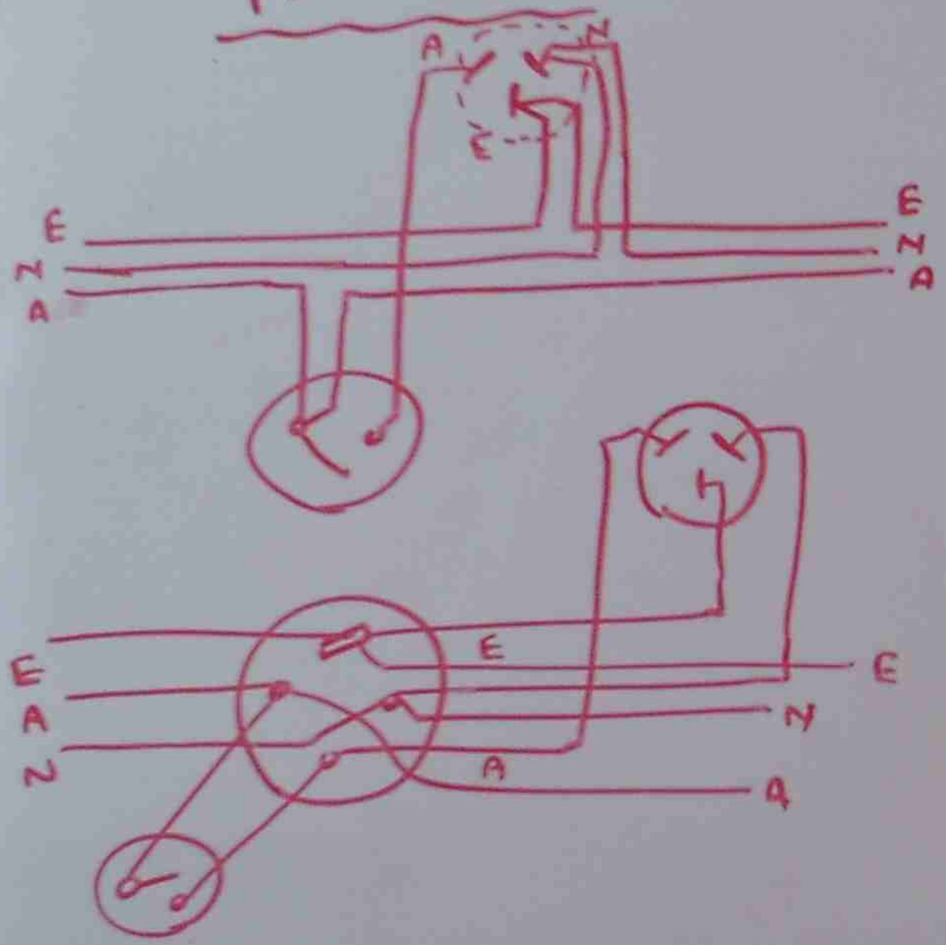
MIMS - UP TO 1100°C APPLICATIONS

CONTROL OF LIGHTING CIRCUITS

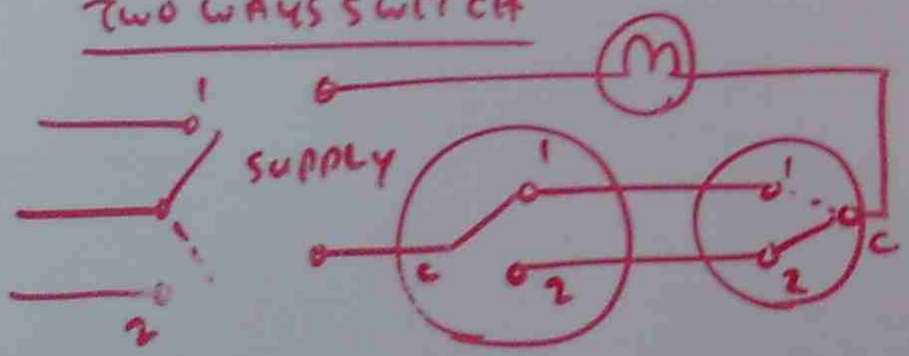


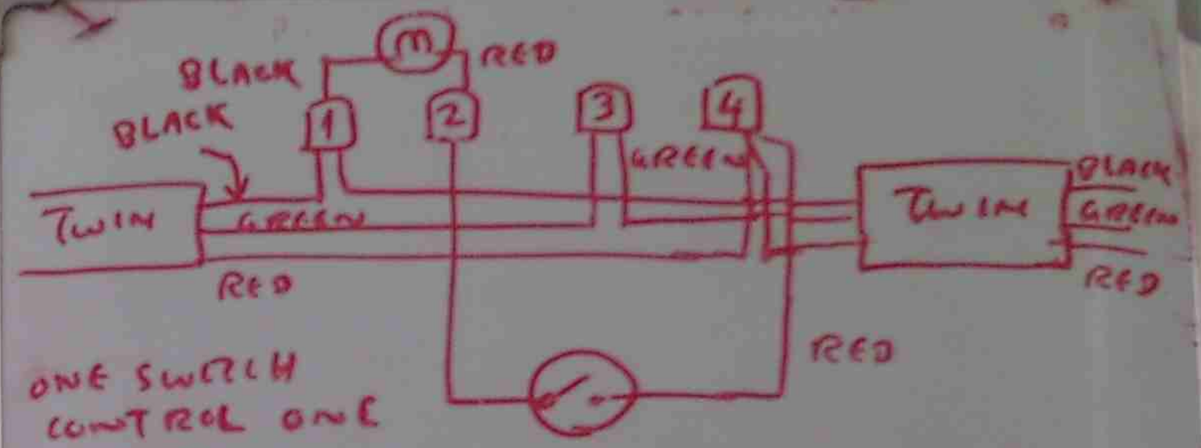


POWER OUTLET



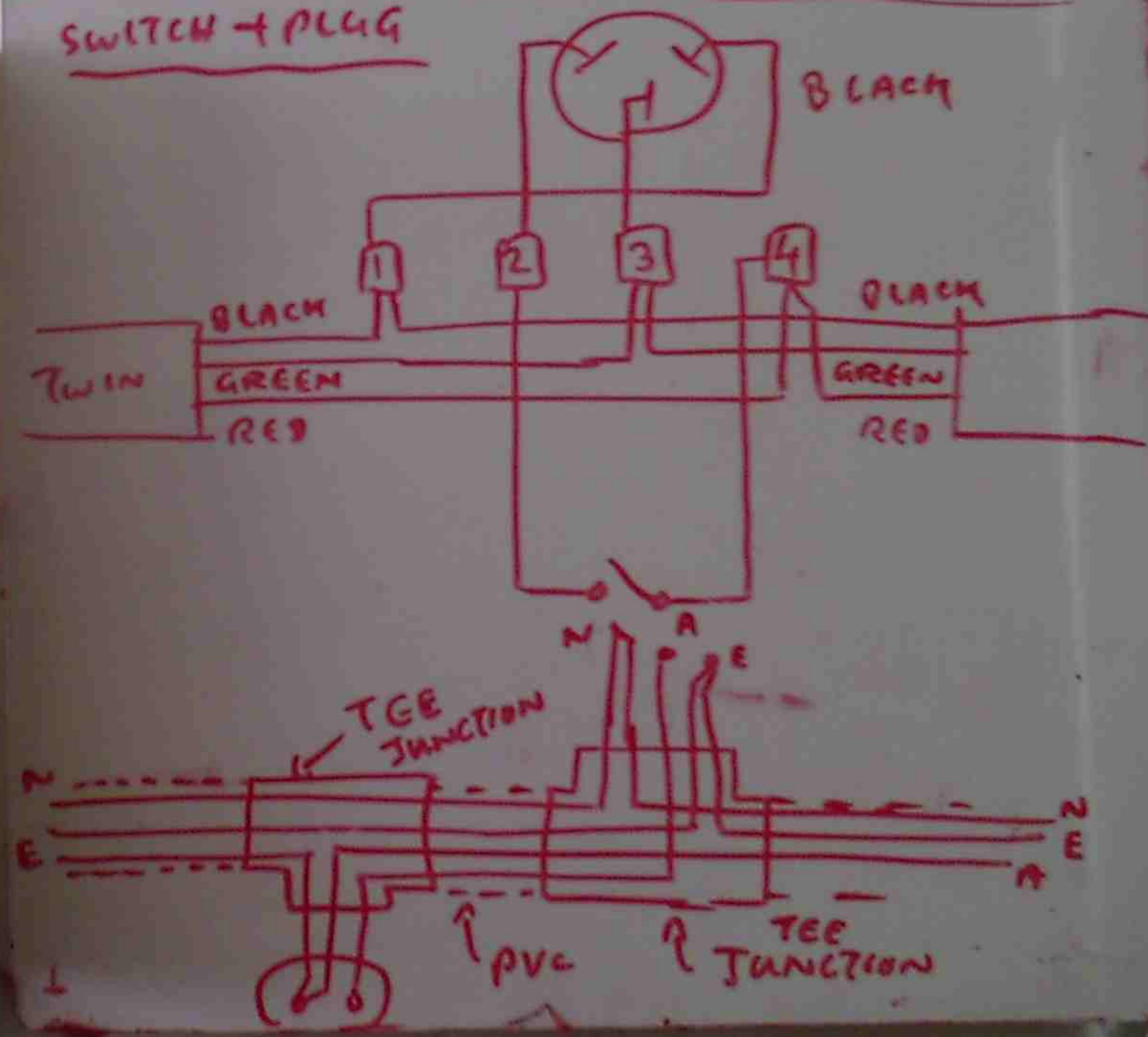
TWO WAYS SWITCH





ONE SWITCH CONTROL ONE LIGHT

SWITCH + PLUG



E008

⑤ FIXED ELECTRICAL WIRING + HOME CIRCUIT SIMPLIFICATION

SLIDE (1) ⟶ (17)

Q47 → Q54

⑥ WIRING CIRCUIT + 2WAYS SWITCHING

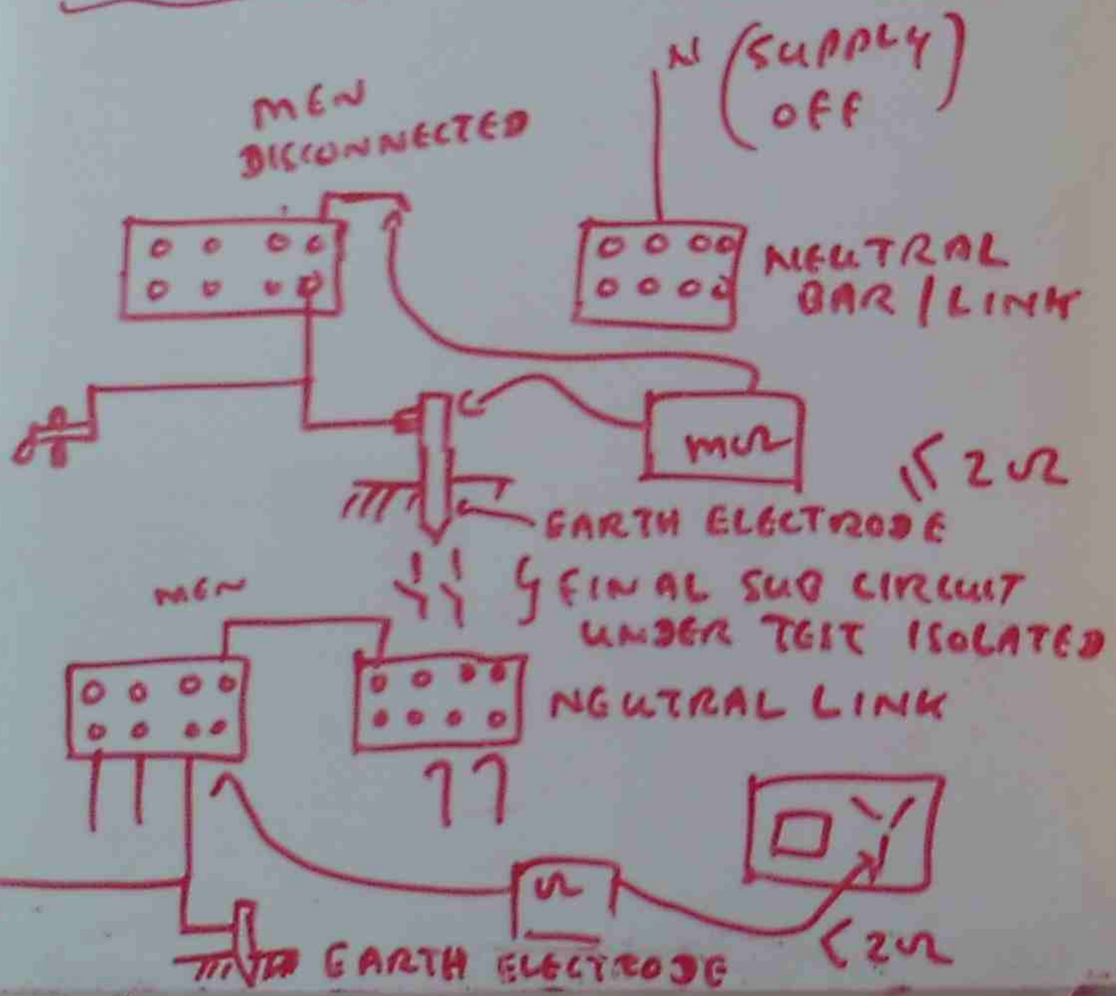
SLIDE (1) ⟶ (10)

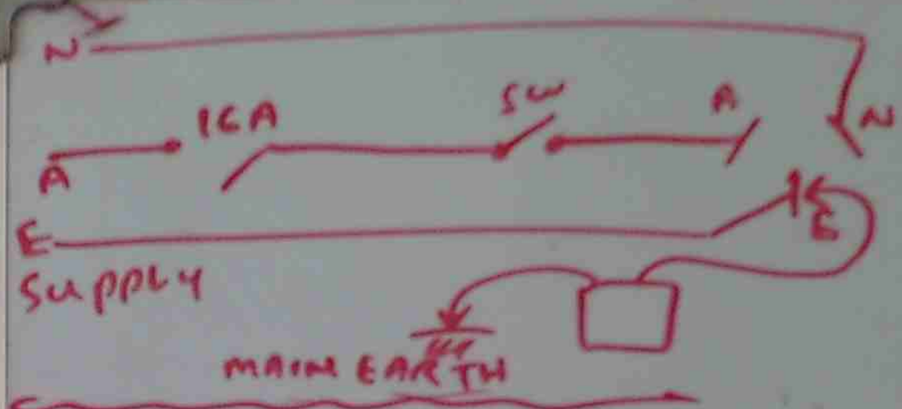
Q55 ⟶ Q59

ELECTRICAL INSTALLATION SAFETY TESTING (E033)

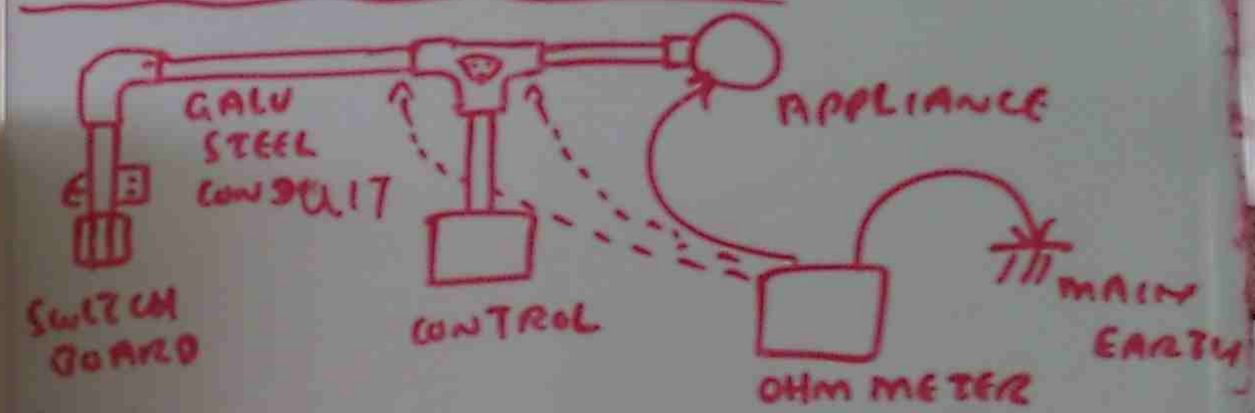
TESTING TECHNIQUE (1) EARTHING SYSTEM
TESTING TECHNIQUE (2) INSULATION RESISTANCE
TESTING TECHNIQUE (3) POLARITY TEST

TESTING TECHNIQUE (1) EARTHING SYSTEM

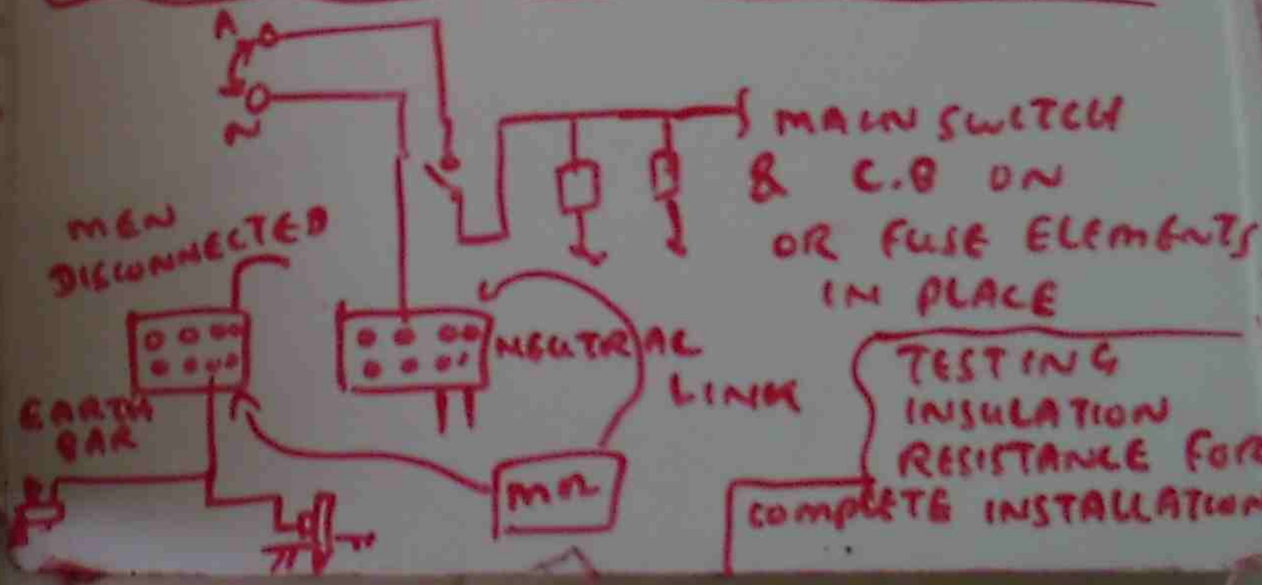


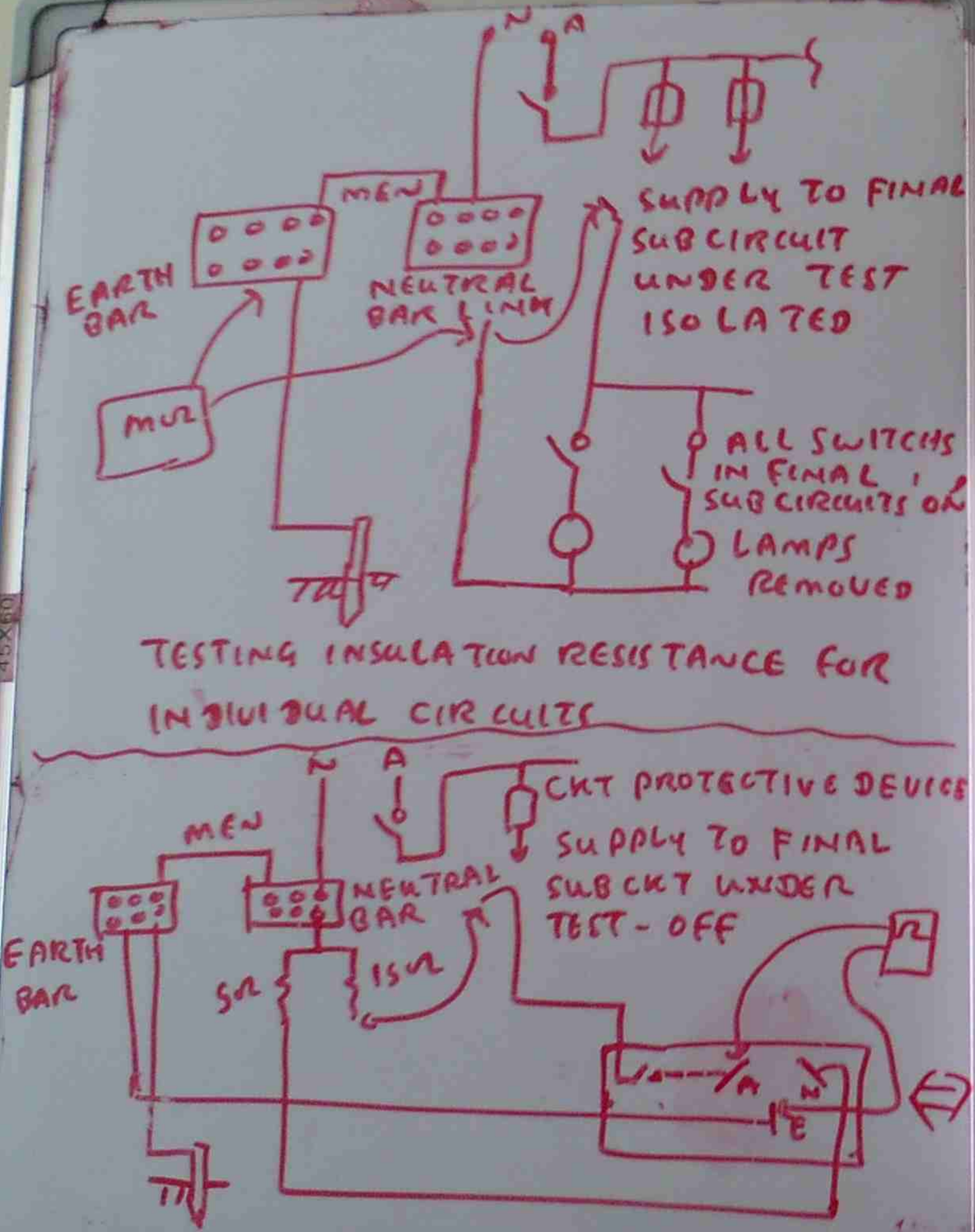


TESTING EARTH CONTINUITY



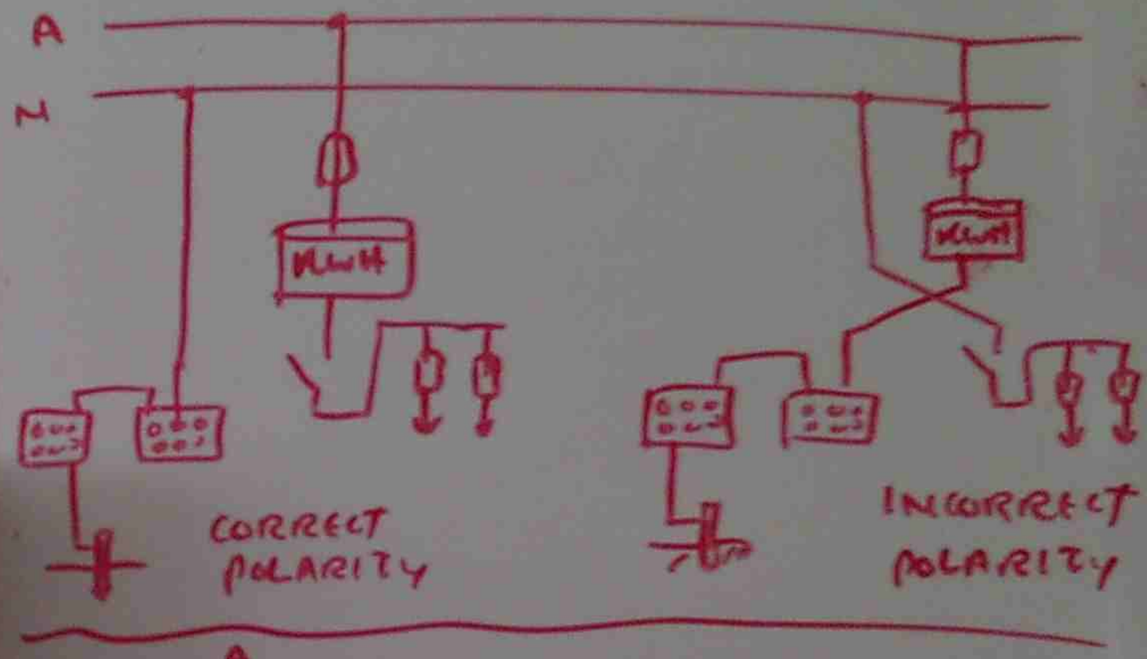
TECHNIQUE (2) INSULATION RESISTANCE

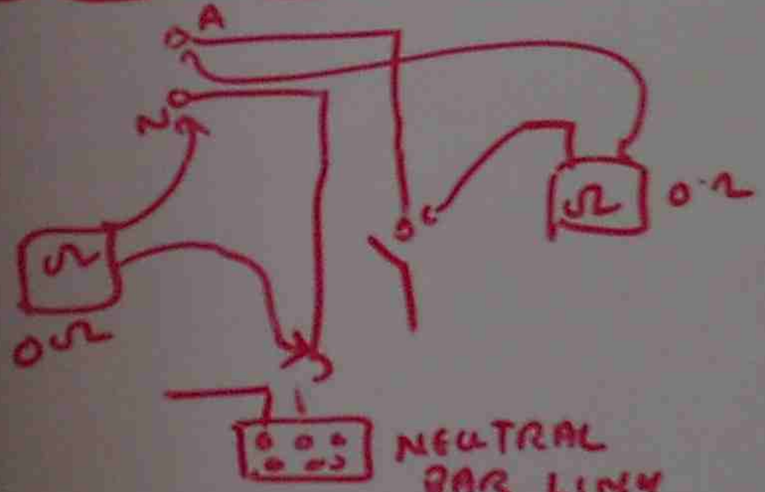




TESTING INSULATION RESISTANCE FOR INDIVIDUAL CIRCUITS

TESTING TECHNIQUE (3) POLARITY





TESTING THE POLARITY OF CONSUMER MAIN PRIOR TO CONNECTIO

TEST POINT	SWITCH OFF	SWITCH ON
A / N	∝	20Ω
A / E	∝	15Ω
E / N	5Ω	5Ω

FIG 3

(1) ELECTRICAL SAFETY TEST

SLIDE (1) → (16)

$Q_{60} \rightarrow Q_{66}$

MAIN

NEUTRAL LINK

EARTH BAR

SW

N

E

LAMP REMOVED

SUPPLY

FUSE

LINK

ELCB

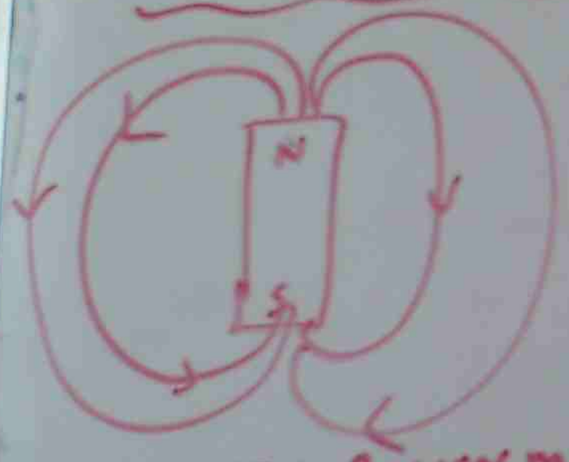
GOOD

MAGNETISM + ELECTROMAGNET

MAGNETISM

THE ABILITY TO ATTRACT IRON

MAGNETIC FIELD of PERMANENT MAGNET



A MAGNET CONSISTS of A NORTH & SOUTH POLES WITH MAGNETIC LINES

MAGNETIC & NON MAGNETIC MATERIALS

TOOL - PERMANENT MAGNET

SOFT IRON - TEMPORARY MAGNET

MAGNETIC ACTION



WHEN A PIECE of SOFT IRON IS PLACED IN A MAGNETIC FIELD,

(1) LINES of FLUX PASSES THE SOFT IRON

(2) SOFT IRON BECOMES MAGNET

MAGNETIC SHIELD

LINES of FLUX TO PASS THROUGH IRON RATHER THAN AIR

ELECTRO MAGNETISM



MAGNETIC FIELDS AROUND TYPES of POLES

MAGNETO MOTIVE FORCE = AMP x TURNS

= I x N

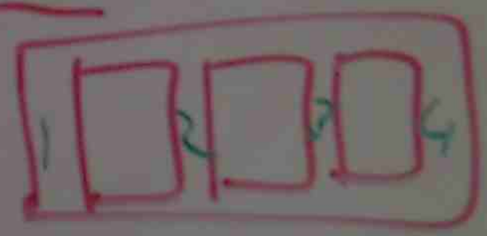
APPLICATIONS of ELECTRO MAGNET

SOLENOID, CONTACTORS, RELAYS

MAGNETIC CIRCUIT

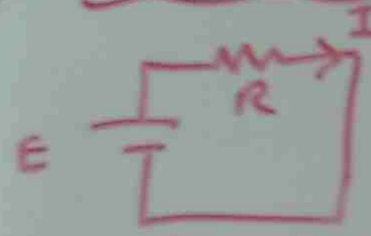


SERIES CIRCUIT



PARALLEL CIRCUIT

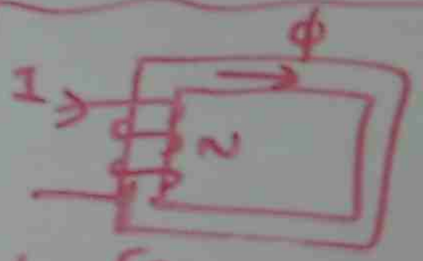
ELECTRIC CIRCUIT



$I = \frac{E}{R}$ E: VOLTAGE I: CURRENT R: RESISTANCE

$R = \frac{\rho L}{A}$

MAGNETIC CIRCUIT



$\phi = \frac{F_m}{R_m}$

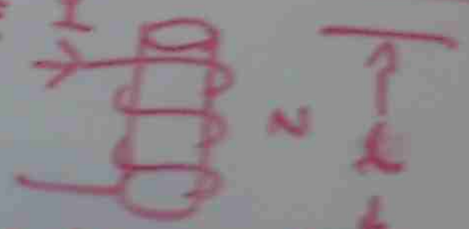
F_m: MAGNETO MOTIVE FORCE $N \times I$

R_m: RELUCTANCE

ϕ: FLUX (wb)

$R_m = \frac{l}{\mu A}$

MAGNETIZING FORCE

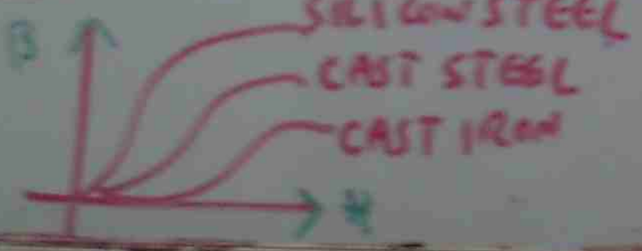


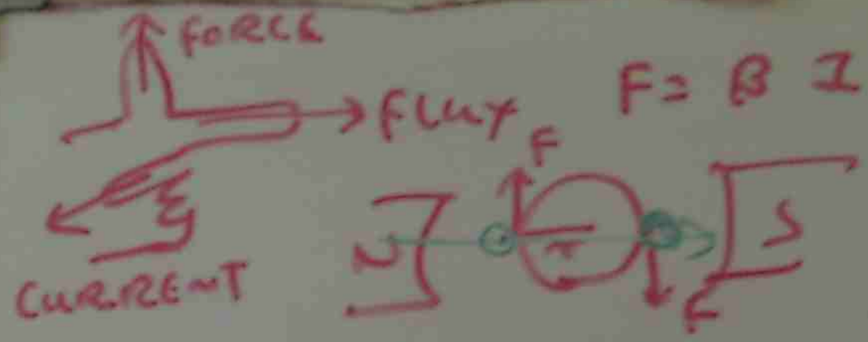
$H = \frac{F_m}{l}$

$\mu_0 = 4\pi \times 10^{-7}$, $\mu = \mu_0 \times \mu_r$



FLUX DENSITY $B = \frac{\phi}{A}$ → $\frac{\text{FLUX}}{\text{C.S.A}}$



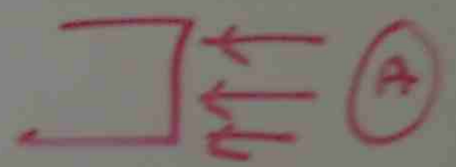


$F = B I L$

TORQUE = FORCE × RADIUS = $F \times r$

$T = (BIL) \times r$

$F = \frac{B^2 A}{2\mu_0}$



Pb A PLUNGER BRAKE ELECTRO MAGNET OPERATES AT FLUX DENSITY 1.2 TESLA. C.S.A = 0.04 m^2, RELUCTANCE = 12000 A-T/wb. No. of TURNS = 1000, FIND CURRENT.

$B = \frac{\phi}{A} \Rightarrow \phi = B \times A = 1.2 \times 0.04 = 0.048$ wb

$\phi = \frac{F_m}{R_m} \rightarrow F_m = \phi \times R_m = 0.048 \times 12000$

$NI = 0.048 \times 12000$

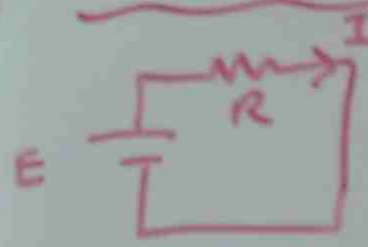
$1000\, I = 0.048 \times 12000 \rightarrow I = 0.576$ Amp

(i) MAGNETISM + ELECTROMAGNETICS

SLIDE (1) → (11)

Q 1 → 817

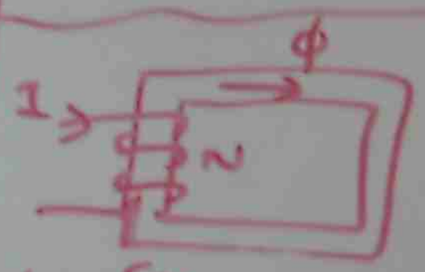
ELECTRIC CIRCUIT



$I = \frac{E}{R}$ E = VOLTAGE, I = CURRENT, R = RESISTANCE

$R = \frac{\rho L}{A}$

MAGNETIC CIRCUIT



$\phi = \frac{Fm}{Rm}$

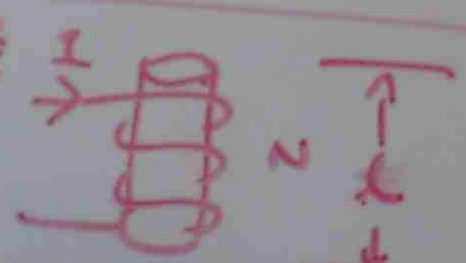
Fm = MAGNETO MOTIVE FORCE $N \times I$

Rm = RELUCTANCE

ϕ = FLUX (wb)

$Rm = \frac{l}{\mu A}$

MAGNETIZING FORCE



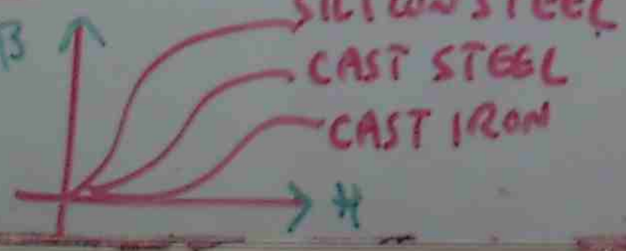
$H = \frac{Fm}{l}$

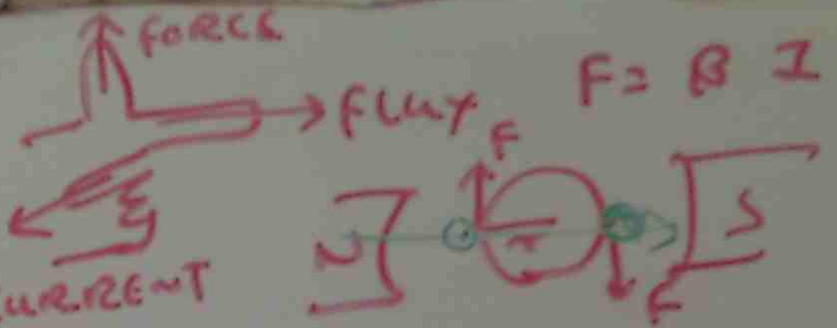
$\mu_0 = 4\pi \times 10^{-7}$, $\mu = \mu_0 \times \mu_r$



FLUX DENSITY = $\frac{\phi}{A}$ = $\frac{\text{FLUX}}{\text{C.S.A}}$

B



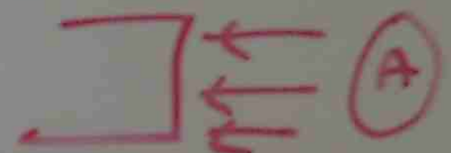


$F = B I L$

TORQUE = FORCE × RADIUS = $F \times r$

$T = (B I L) \times r$

$F = \frac{B^2 A}{2\mu_0}$



Ex A PLUNGER BRAKE ELECTRO MAGNET OPERATES AT FLUX DENSITY 12 TESLA. C.S.A = 0.04 m^2, RELUCTANCE = 12000 A-T/wb, NO. OF TURNS = 1000, FIND CURRENT.

$B = \frac{\phi}{A} \Rightarrow \phi = B \times A = 12 \times 0.04 = 0.048$ wb

$\phi = \frac{Fm}{Rm} \rightarrow Fm = \phi \times Rm = 0.048 \times 12000$

$NI = 0.048 \times 12000$

$1000\ I = 0.048 \times 12000 \rightarrow I = 0.576$ Amp

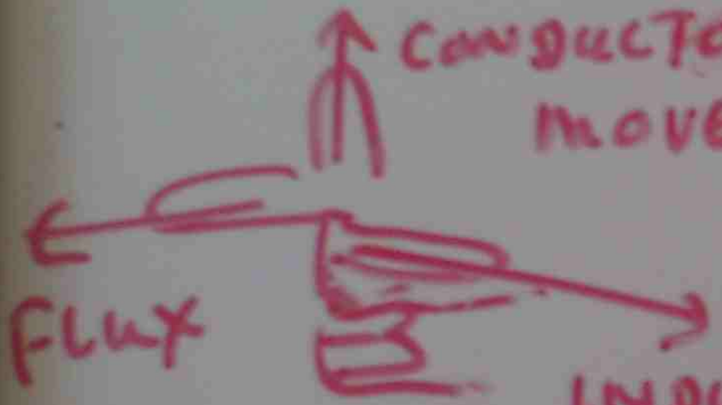
(1) MAGNETISM + ELECTROMAGNETICS

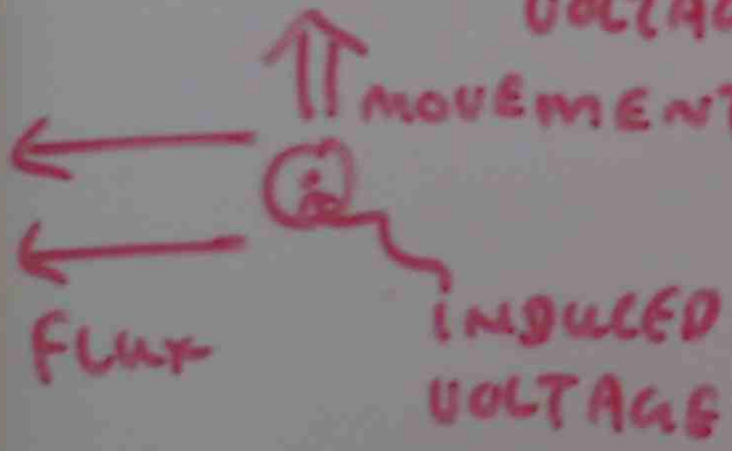
SLIDE (1) → (11)

Q 1 → 8 17

(2) ELECTROMAGNETIC INDUCTION

SLIDE
1 → 10
@ 12 → 25.

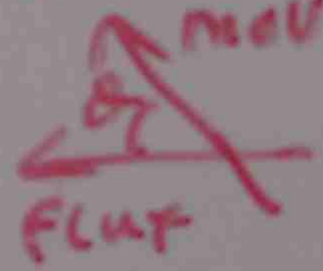




INDUCED VOLTAGE

$e = BLU \sin\theta$

B = FLUX DENSITY
L = LENGTH, V = VELOCITY



VOLTAGE GENERATED IN CONDUCTOR DUE TO FLUX CHANGE

$$V = N\frac{d\phi}{dt}$$



Pb WHAT IS VELOCITY OF CONDUCTOR
150mm LONG, MOVING RIGHT ANGLE, FLUX DENSITY 0.4T, INDUCED VOLTAGE 4V

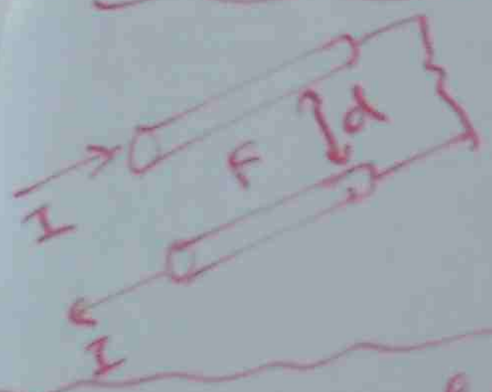
$e = BLU\sin\theta$

$4 = 0.4 \times \frac{150}{1000} \times V \times \sin 90$

$V = 3.3$ m/s

③ INDUCTOR / ④ RELAY

CALCULATION OF FORCE BETWEEN TWO CURRENT CARRYING CONDUCTORS



$$F = \frac{2\times10^{-7} I}{d} \quad N/m$$

$$e_1 = N_1 \frac{d\phi}{dt}$$

e_1 } N_1 { e_2 N_2

$$e_2 = N_2 \frac{d\phi}{dt}$$

Pb A TRANSFORMER HAS 50T ON PRIMARY & 600T ON SECONDARY. IF FLUX 0.25wb IS INDUCED IN 5ms, CALCULATE THE VOLTAGE IN EACH COIL

$$e_1 = N_1 \frac{d\phi}{dt} = 50 \times \frac{0.25}{5\times10^{-3}} = 2500V$$

$$e_2 = N_2 \frac{d\phi}{dt} = \frac{600 \times 0.25}{5\times10^{-3}} = 30,000V$$

RELAY



PRACTICAL APPLICATION OF ELECTRO-MAGNET

GENERATOR, MOTOR, TRANSFORMER MOTOR, RELAY COIL

CONDUCTION OF ELECTROMAGNETIC CU



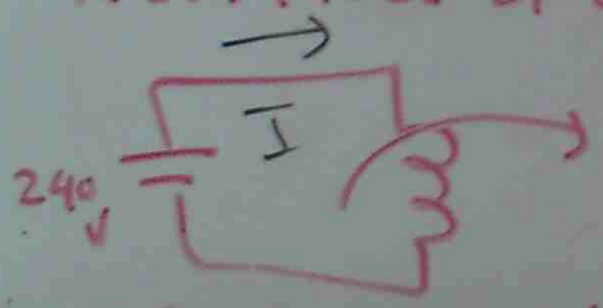
Pb/ A CONDUCTOR IS REVOLVING AT 1000 RPM, VOLTAGE INDUCED IS 200V. WHAT IS THE VOLTAGE AT 500 RPM

1000 RPM ⟶ 200V

500 RPM ⟶ ?

$200 \times \frac{500}{1000} = 100V$

Pb/ A 240V COIL 5000T PROVIDES MAGNETIZING FORCE 4000 A-T/m THE MAGNETIC CKT IS 200mm LONG. C.S.A 500 SQ-mm. FIND RESISTANCE of coil



V = 240V
N = 5000T
H = 4000 A-T/m
L = 200mm

$NI = HL$

$5000 \times I = 4000 \times \frac{200}{1000}$

$I = 0.16$ AMP

$R = \frac{V}{I} = \frac{240}{0.16} = 1500\ \Omega$

(2) ELECTRO MAGNETIC INDUCTION

SLIDE (1) → (9)

Q18 → Q25

(3) INDUCTOR

SLIDE (1) → (4)

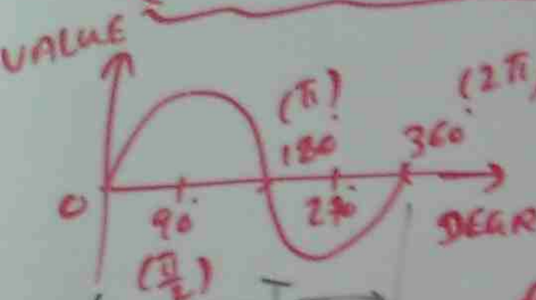
Q26 → Q29

(4) RELAY

SLIDE (1) → (2)

Q22 → Q(30)

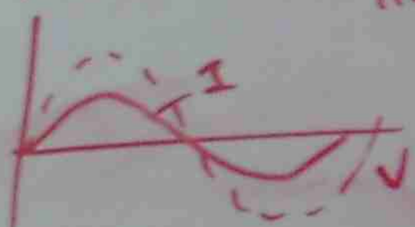
(G002) SINE WAVE & IT'S VALUE



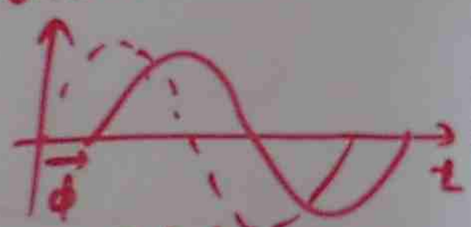
INSTANTANEOUS VALUE = PEAK VALUE × sin θ

R.M.S VALUE = $\frac{\text{PEAK VALUE}}{\sqrt{2}} = 0.707 \times \text{PEAK VALUE}$

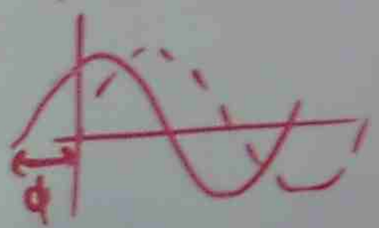
FREQUENCY = $\frac{1}{\text{TIME}}$



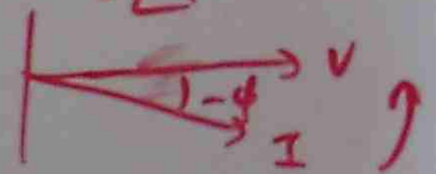
$I \angle 0$

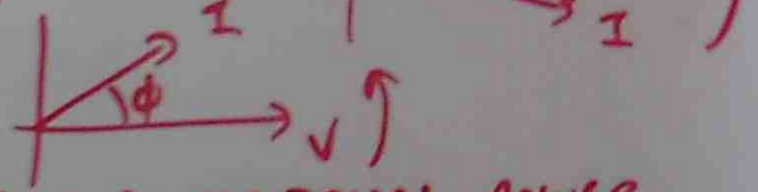


$I \angle -\phi$

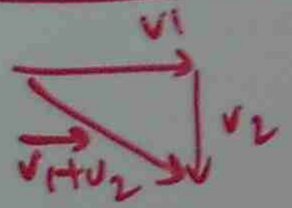


$I \angle +\phi$





PHASOR ADDITION



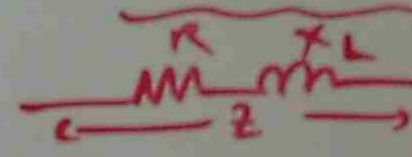
ELECTRICAL POWER

$P = V I \cos\phi$

$P = I^2 R$

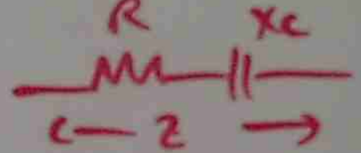
$P = \frac{V^2}{R}$

SERIES AC CIRCUIT



$Z = \sqrt{R^2 + X_L^2} \angle \tan^{-1}\frac{X}{R}$

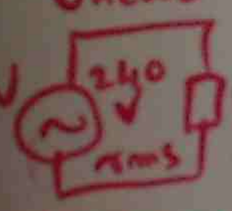
$X = 2\pi f L$ } L = INDUCTANCE (H), f = FREQUENCY (Ω)



$Z = \sqrt{R^2 + X_c^2} \angle -\tan^{-1}\frac{X_c}{R}$

$X_c = \frac{1}{2\pi f C}$ } C = CAPACITANCE (F)

Pa A SINE WAVE VOLTAGE OF 240V RMS IS APPLIED TO A RESISTIVE CIRCUIT OF 60Ω. CALCULATE (a) RMS VALUE OF CURRENT (b) MAXIMUM VALUE OF CURRENT



(a) $I = \frac{V}{R} = \frac{240}{60} = 4\text{A (RMS)}$

(b) $I_{MAX} = \sqrt{2}\, I_{RMS} = 1.4142 \times 4 = 5.65\text{ A}$

Pb A COIL OF NEGLIGIBLE RESISTANCE DRAWS A CURRENT OF 0.2 Amp (RMS) WHEN CONNECTED TO 240V, 50Hz. (a) DETERMINE COIL INDUCTIVE REACTANCE (b) COIL INDUCTANCE (c) DRAW VOLTAGE CURRENT PHASOR DIAGRAM.



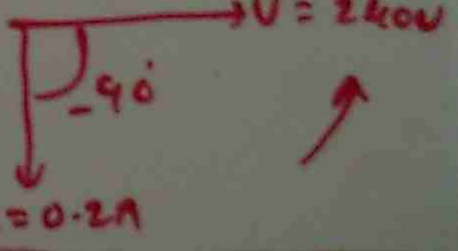
(a) $X_L = \frac{V}{I} = \frac{240}{0.2} = 1200\Omega$

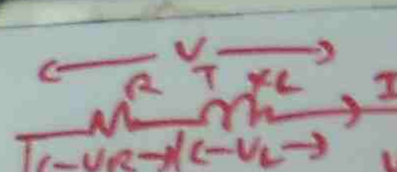
(b) $X_L = 2\pi f L$

$L = \frac{X_L}{2\pi f}$

$L = \frac{1200}{2 \times 3.1416 \times 50} = 3.81\text{ H}$

(c)

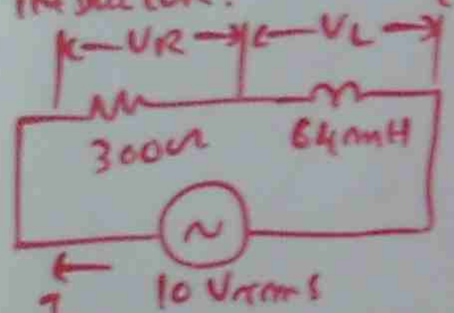




$V_T = \sqrt{V_R^2 + V_L^2}$

$V_R = I \times R$, $V_L = I X_L$

Pb A 64 mH INDUCTOR IS CONNECTED IN SERIES WITH A 300Ω RESISTOR TO A 1000Hz A.C CURRENT VOLTAGE OF 10 Vrms FIND (a) THE IMPEDANCE (b) THE PHASE ANGLE (c) THE CURRENT (d) THE POTENTIAL DROP ACROSS RESISTOR (e) THE POTENTIAL DROP ACROSS INDUCTOR.



(a) $X_L = 2\pi f L = 2 \times 3.1416 \times 1000 \times 64 \times 10^{-3}$

$= 400\Omega$

$Z = \sqrt{R^2 + X_L^2} \angle \tan^{-1} \frac{X_L}{R}$

$= \sqrt{300^2 + 400^2} \angle \tan^{-1} \frac{400}{300}$

$= 500 \angle 53.2^\circ \Omega$

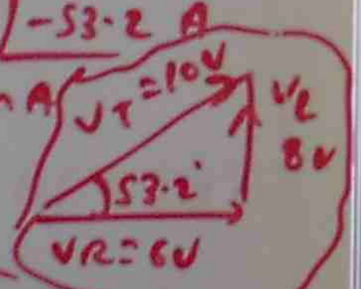
(b) PHASE ANGLE = 53.2°

(c) $I = \frac{V}{Z} = \frac{10 \angle 0}{500 \angle 53.2} = 0.02 \angle -53.2$ A

$= 20$ mA

(d) $V_R = I \times R = 0.02 \times 300 = 6$V

(e) $V_L = I X_L = 0.02 \times 400 = 8$V



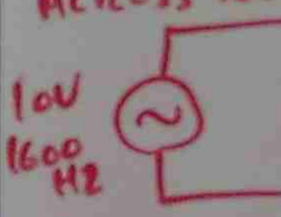
FIND THE CURRENT IN THE CIRCUIT WHEN AN AC VOLTAGE 10 Vrms AT 1000 Hz IS APPLIED TO 2μF CAPACITOR

$X_C = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.1416 \times 1000 \times 10^{-6} \times 2} = 79.5\Omega$

$I = \frac{V}{X_C}$

$= \frac{10}{79.5} = 0.125$ A

Pb A 1μF CAPACITOR IS CONNECTED IN SERIES WITH 200Ω RESISTOR TO 10V rms 1600Hz SUPPLY. FIND (a) THE IMPEDANCE (b) THE PHASE ANGLE (c) THE CURRENT (d) P.D ACROSS RESISTOR (e) P.D ACROSS CAPACITOR.



$X_C = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.1416 \times 1600 \times 1 \times 10^{-6}}$

$= 100\Omega$

$Z = \sqrt{R^2 + X_C^2} \angle -\tan^{-1} \frac{X_C}{R}$

(a) $Z = \sqrt{200^2 + 100^2} \angle -\tan^{-1} \frac{100}{200} = 223.6 \angle -26.5\Omega$

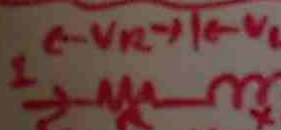
(b) $\phi = -26.5^\circ$

(c) $I = \frac{V}{Z} = \frac{10 \angle 0}{223.6 \angle -26.5} = 0.0448 \angle 26.5$ Amp

(d) $V_R = I \times R = 0.0448 \times 200 = 9$V

(e) $V_C = I \times X_C = 0.0448 \times 100 = 4.48$V

RESISTANCE, CAPACITANCE AND INDUCTANCE IN SERIES



$V_R = IR$

$V_L = I X_L$

$V_C = I X_C$

$V_T = \sqrt{V_R^2 + (V_L - V_C)^2}$

$\tan\phi = \frac{X_L - X_C}{R}$

$X_L > X_C$

$I = \frac{V}{Z \angle \phi} = I = \frac{V}{Z} \angle -\phi$

LAGGING

$Z = R + j(X_L - X_C)$, $X_L > X_C$

$Z = R - j(X_C - X_L)$, $X_C > X_L$

$\tan\phi = \frac{X_C - X_L}{R}$

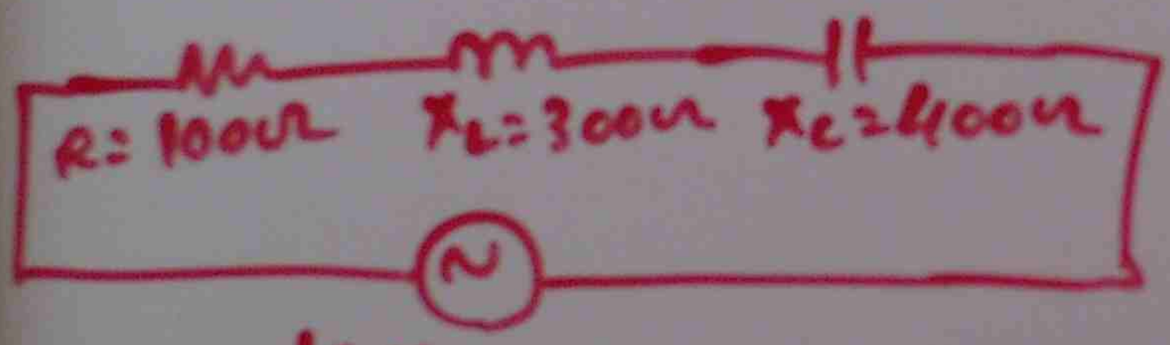
$X_C > X_L$

$I = \frac{V}{Z \angle \phi} = \frac{V}{Z} \angle +\phi$

LEADING

$PF = \cos\phi$

Pb A SERIES CIRCUIT IS CONNECTED TO A 10V rms AC SUPPLY. THE CIRCUIT HAS RESISTANCE 100Ω. INDUCTIVE REACTANCE 300Ω, CAPACITIVE REACTANCE 400Ω. FIND (a) IMPEDANCE (b) CURRENT (c) PHASE ANGLE (d) VOLTAGE DROP ACROSS RESISTOR (e) VOLTAGE DROP ACROSS INDUCTOR (f) VOLTAGE DROP ACROSS CAPACITOR.



(a)

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \angle \tan^{-1}\frac{X_L - X_C}{R}$$

$$= \sqrt{100^2 + (300-400)^2} \angle \tan^{-1}\frac{300-400}{100}$$

$$= 141 \angle -45^\circ \ \Omega$$

(b) $I = \frac{V}{Z} = \frac{10}{141} = 0.071\ A$

(c) $\phi = 45^\circ$

(d) $V_R = IR = 0.071 \times 100$
$= 7.1\ V$

(e) $V_L = IX_L = 0.071 \times 300$
$= 21.3\ V$

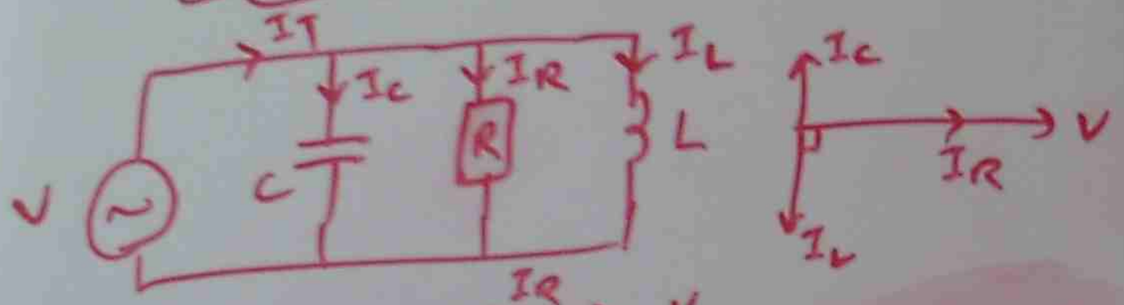
(f) $V_C = IX_C = 0.071 \times 400$
$= 28.4\ V$

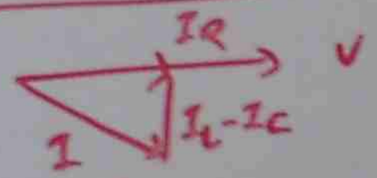
(1) 3ϕ AC CIRCUIT BASIC

SLIDE (1) → (14)

Q1 → Q15

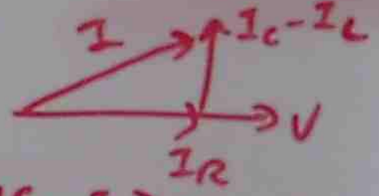
RESISTANCE, INDUCTANCE AND CAPACITANCE IN PARALLEL





IF $I_L > I_C$

LAGGING



IF $I_C > I_L$

LEADING

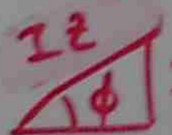
$$I = \sqrt{I_R^2 + (I_L - I_C)^2}$$

PHASE ANGLE $\tan\phi = \dfrac{I_L - I_C}{I_R}$

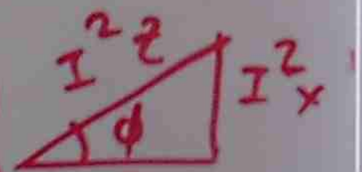
POWER IN A PARALLEL CIRCUIT



IMPEDANCE TRIANGLE



VOLTAGE TRIANGLE



POWER TRIANGLE

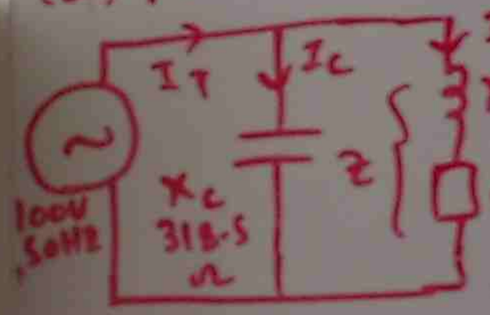
I^2R = ACTIVE POWER (WATT)

I^2X = REACTIVE POWER (VAR)

I^2Z = APPARENT POWER (V.A)

Q4 THE FOLLOWING IS A DIAGRAM OF A PARALLEL CIRCUIT WITH A SUPPLY VOLTAGE 100V-RMS AT 50HZ. DRAW A PHASOR DIAGRAM FOR THE CIRCUIT AND USE IT TO DETERMINE THE FOLLOWINGS

(a) TOTAL CIRCUIT CURRENT
(b) TOTAL CIRCUIT IMPEDANCE
(c) PHASE ANGLE BETWEEN CIRCUIT CURRENT & APPLIED VOLTAGE
(d) POWER FACTOR OF CIRCUIT.



$$Z = \sqrt{R^2 + X_L^2} \angle \tan^{-1}\frac{X_L}{R}$$

$$= \sqrt{100^2 + 94.2^2} \angle \tan^{-1}\frac{94.2}{100}$$

$$= 137.38 \angle 43.29^\circ$$

$$I_L = \frac{V}{Z} = \frac{100}{137.38 \angle 43.29} = 0.7278 \angle -43.29^\circ$$

$$I_C = \frac{V}{X_C} = \frac{100}{318.5 \angle 90} = 0.314 \angle -90^\circ$$

$$I_T = \bar{I}_L + \bar{I}_C = 0.7278(\cos(-43.29) + j\sin(-43.29)$$
$$+ 0.314(\cos(-90) + j\sin(-90$$

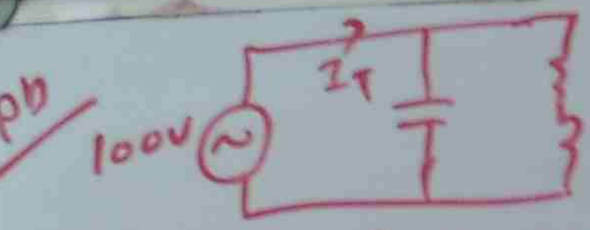
$$= 0.7278(0.7278 - j0.685) - j0.314$$

$$= 0.531 - j0.5 - j0.314 = 0.531 - j0.814$$

(a) $I_T = \sqrt{0.531^2 + 0.814^2} \angle -\tan^{-1}\frac{0.814}{0.531} = 0.971 \angle -56.8$

(b) $Z_T = \frac{V}{I_T} = \frac{100}{0.971} = 103\Omega$ | $\phi = 56.86$ | PF = cos 56.86 = 0.54

Pb



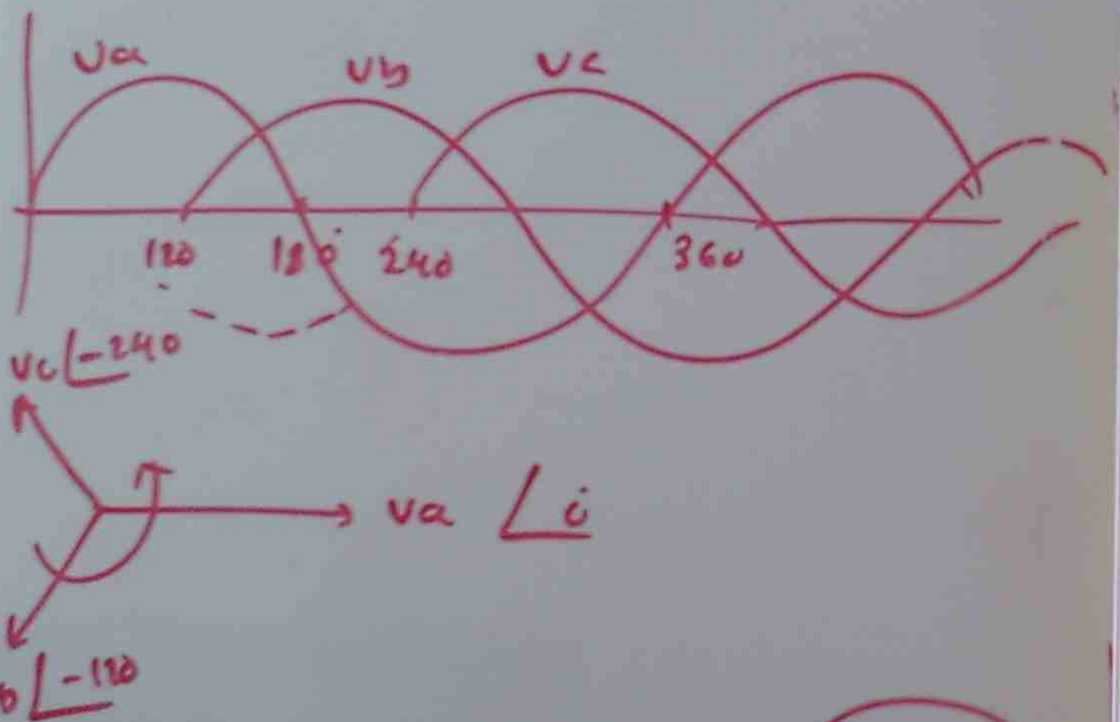
$I_T = 0.471$ A

PF = 0.54

FIND TOTAL POWER

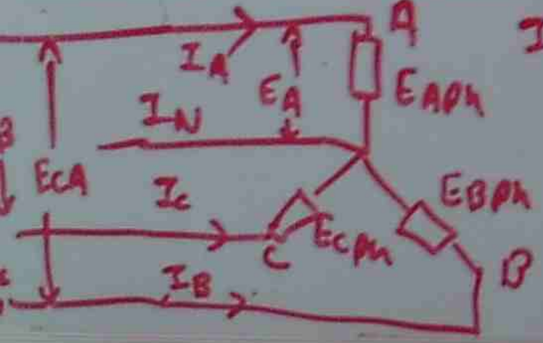
$P = VI\cos\phi = 100 \times 0.471 \times 0.54 = 52.43W$

THREE PHASE CIRCUIT



THREE PHASE CONNECTION

STAR

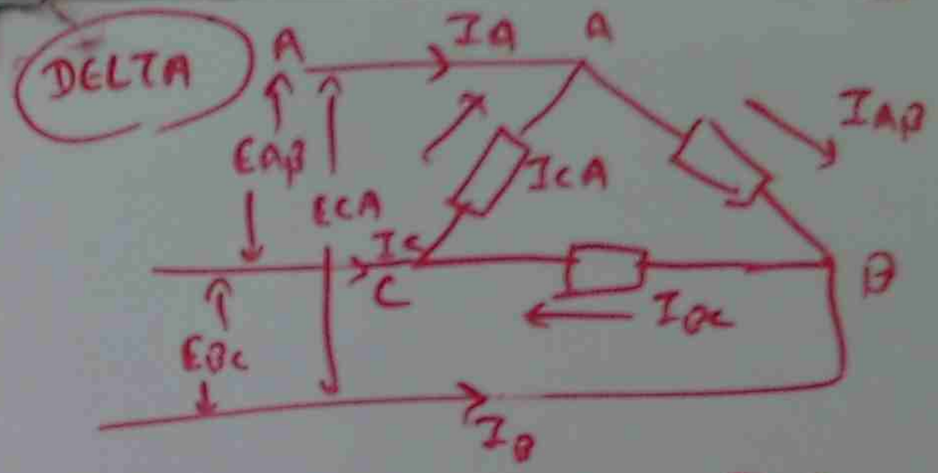


$I_A = I_B = I_C = I_{Ph}$

$E_{AB} = E_{BC} = E_{CA} = \sqrt{3}\, E_{APh}$

$= \sqrt{3}\, E_{BPh} = \sqrt{3} E_{CPh}$

DELTA



BALANCE

$I_A = I_B = I_C = \sqrt{3}\, I_{AB} = \sqrt{3}\, I_{BC} = \sqrt{3}\, I_{CA}$

LINE CURRENT = $\sqrt{3}$ PHASE CURRENT

POWER: $\sqrt{3}\, E\, I \cos\phi$

Pb THE PHASE VOLTAGE & CURRENT IN 3ϕ STAR PHASE VOLTAGE ARE 240V & 50A. FIND LINE VOLTAGE, LINE CURRENT

$V_L = \sqrt{3}\, V_p = 1.7321 \times 240 = 415V$ RMS

$I_L = I_p = 50A$

Pb A DELTA CONNECTED LOAD TAKES A LIN CURRENT 40A AND LINE VOLTAGE 41 FIND (a) PHASE CURRENT (b) PHASE VOLTA

$I_p = \dfrac{I_L}{\sqrt{3}} = \dfrac{40}{1.732} = 23.1$ A

$V_p = V_L = 415V$

Pb 3φ 415V, 37.3 KW Δ CONNECTED ALTERNATOR HAS EFFICIENCY 90% AND P.F 0.88 LAGGING. FIND (a) LINE CURRENT (b) PHASE CURRENT

$$\text{INPUT POWER} = \frac{\text{OUT PUT}}{\text{EFFICIENCY}} = \frac{37.3\times10^3}{0.9}$$

$$\sqrt{3}\,E\,I\cos\phi = \frac{37.3\times10^3}{0.9}$$

$$I = \frac{37.3\times10^3}{\sqrt{3}\,E\cos\phi\times0.9} = \frac{37300}{1.7321\times415\times0.88\times0.9}$$

$$I_{LINE} = 65.5\,A$$

$$\text{PHASE CURRENT} = \frac{I_L}{\sqrt{3}} = \frac{65.5}{1.7321} = 37.8\,A$$

(6) APPARENT, REAL, REACTIVE POWER
SLIDE 1 → 4
Q 1 → Q 3

(7) 3φ VOLTAGE
SLIDE 1 → 6
Q 4 → 5

(8) Δ & Δ LOAD
SLIDE 1 → 16
Q 6 → Q 12

ELECTRICAL INSTALLATION PROTECTION

METHOD - ZIP (www.1790817794-zoomshare.com G003+G004

MECHANICAL HAZARD 4.2.1.1 → 4.2

PROTECTION AGAINST DIRECT CONTACT 1.4.31

PROTECTION BY INSULATION 1.7.3.3

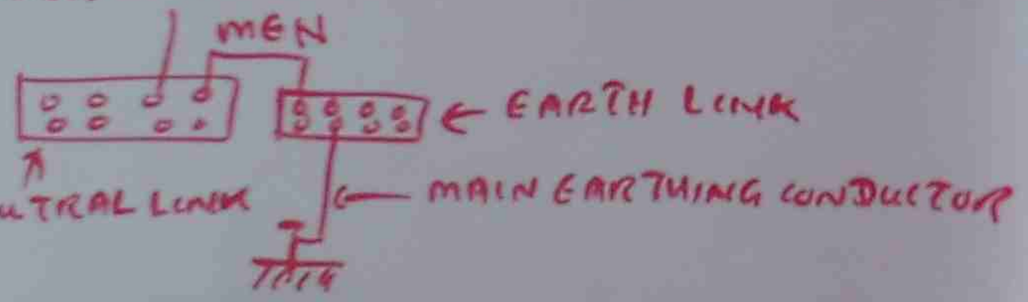
PROTECTION BY BARRIER 1.7.3.4

PROTECTION BY OBSTACLES 1.7.3.5

EARTHED - 1.4.40, EARTHED SITUATION 1.4.41

MAIN EARTHING CONDUCTOR - 5.6.3

MULTIPLE EARTHED NEUTRAL MEN 5.3



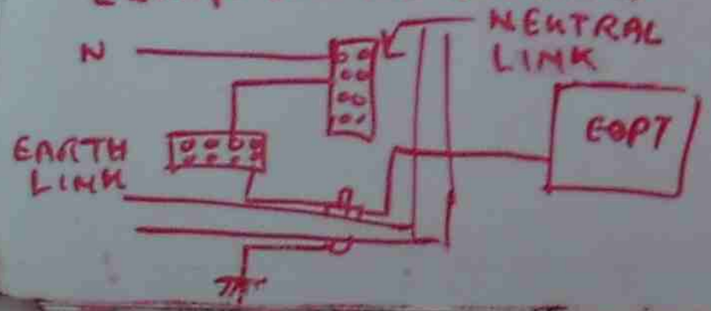
PROTECTIVE EARTHING CONDUCTOR - 5.6.7

FUNCTIONAL EARTH CONDUCTOR - 5.2.3

EARTHING TERM 1.4.50,

EARTHING ELECTRICAL EQUIPMENTS 5.7

EQUIPOTENTIAL BONDING - 5.8



OVER CURRENT 1.4.65

PROTECTION AGAINST OVER CURRENT 2.4.3

OVERLOAD PROTECTION DEVICES

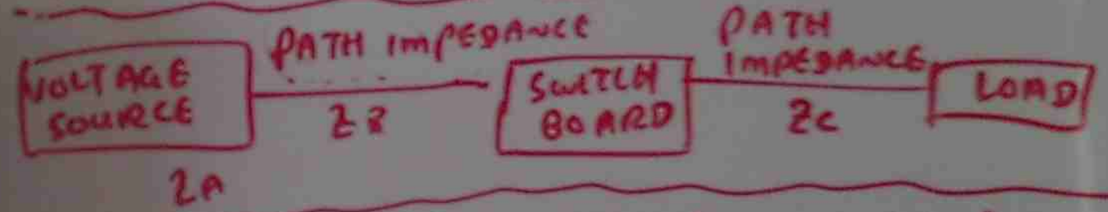
BI METALLIC STRIP, THERMISTOR

SHORT CIRCUIT CURRENT 1.4.36

SHORT CIRCUIT CURRENT PROTECTION

↳ CALCULATION / MEASUREMENT

CALCULATION OF PROSPECTIVE FAULT CURRENT



Pb GIVEN SUPPLY TRANSFORMER IS 400V 500KVA IMPEDANCE 5%. CALCULATE FAULT CURRENT

$I_{SH} = \frac{I_{FL}}{\frac{\%\ IMPEDANCE}{100}}$

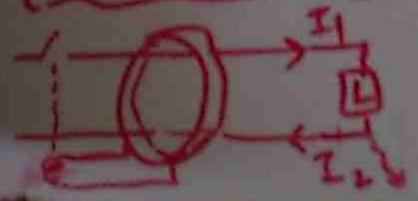
$I_{FL} = \frac{KVA \times 10^3}{\sqrt{3} \times V} = \frac{500 \times 10^3}{1.7321 \times 400}$

$I_{FL} = 721\ A$

$I_{SH} = \frac{721}{\frac{5}{100}} = \frac{72100}{5} = 14420\ Amp$

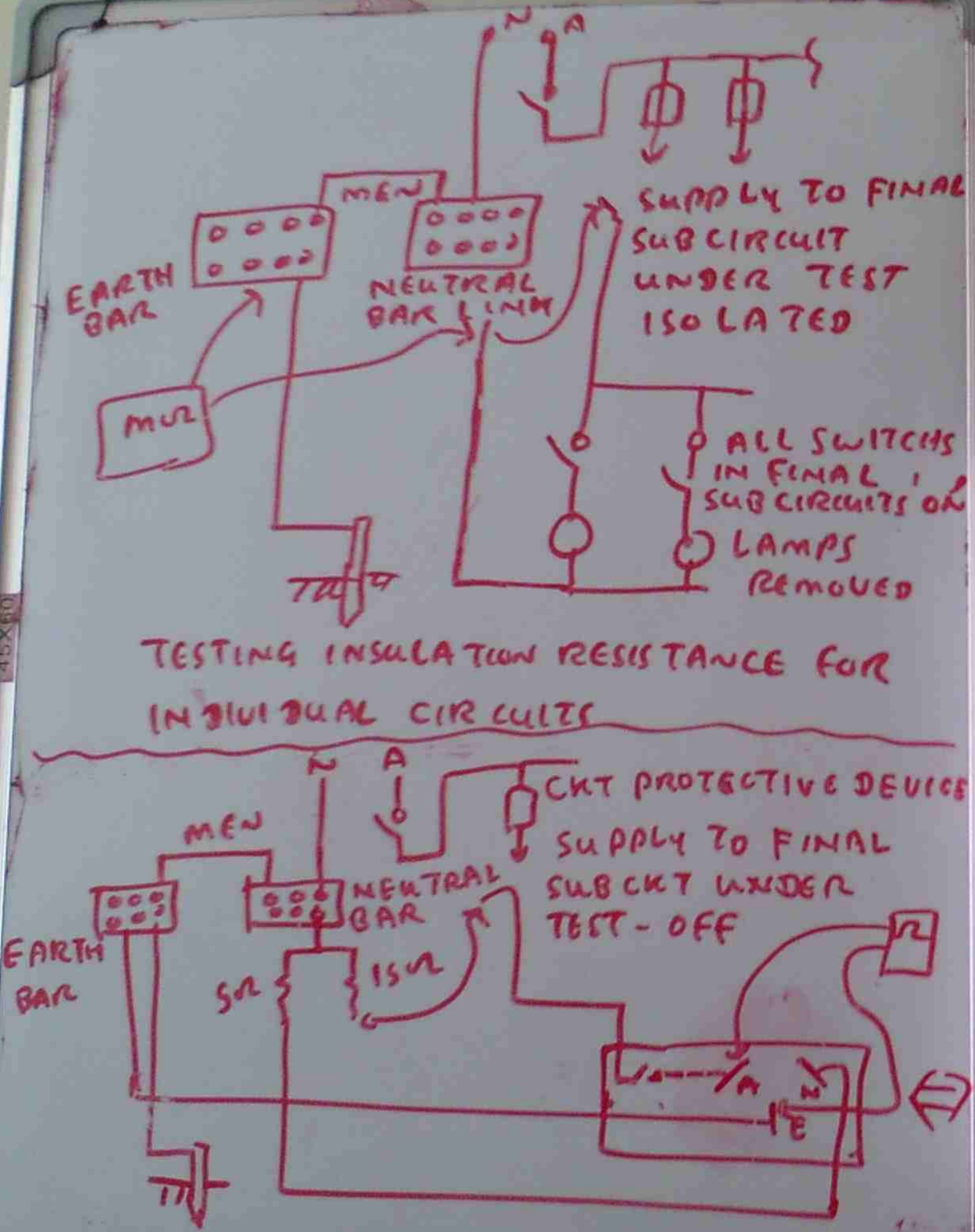
UNDER VOLTAGE PROTECTION - 2.7.1

RCD - RESIDUAL CURRENT DEVICE



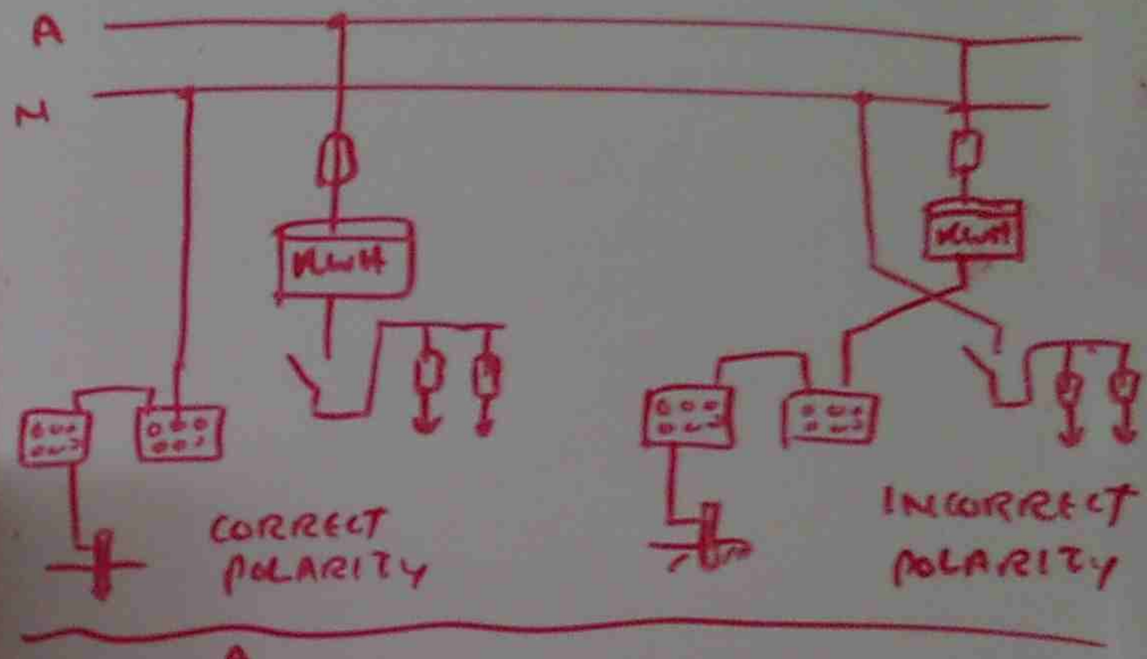
- ELECTRO-MECHANICAL TYPE
- ELECTRONIC TYPE
- TIME DELAY TYPE

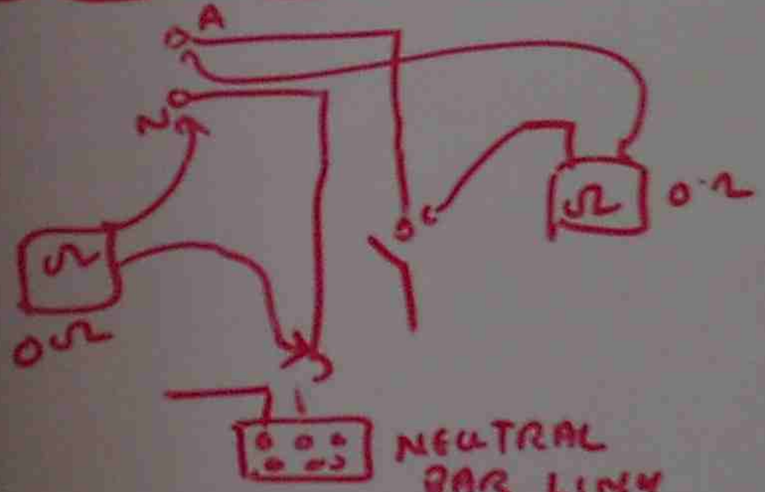
CLASS I, II, III



TESTING INSULATION RESISTANCE FOR INDIVIDUAL CIRCUITS

TESTING TECHNIQUE (3) POLARITY





TESTING THE POLARITY OF CONSUMER MAIN PRIOR TO CONNECTIO

TEST POINT	SWITCH OFF	SWITCH ON
A / N	∝	20Ω
A / E	∝	15Ω
E / N	5Ω	5Ω

FIG 3

(1) ELECTRICAL SAFETY TEST

SLIDE (1) → (16)

$Q_{60} \rightarrow Q_{66}$

MAIN

NEUTRAL LINK

EARTH BAR

SW

N

E

LAMP REMOVED

SUPPLY

FUSE

LINK

ELCB

ELECTRICAL INSTALLATION SAFETY TESTING

THE FINAL OUTCOME OF TESTING AND CHECKING AN INSTALLATION IS TO ENSURE THAT THE FOLLOWING APPLY

- THAT THE EARTHING SYSTEM IS COMPLETE AND CONTINUOUS. IT'S RESISTANCE IS ADEQUATELY LOW
- THAT THE INSTALLATION RESISTANCE BETWEEN ALL LIVE PARTS AND THE EARTH IS ADEQUATE AND SUFFICIENTLY HIGH TO MEET THE REQUIREMENT OF REGULATION
- THAT THE ACTIVE, NEUTRAL AND EARTHING CONDUCTORS ARE CONNECTED TO THE CORRECT TERMINALS THROUGHOUT THE INSTALLATION
- THAT ALL CIRCUITS ARE CONNECTED CORRECTLY TO ENSURE THAT THERE ARE NO INTER CONNECTIONS OF LIVE CONDUCTORS BETWEEN DIFFERENT CIRCUITS (OR) SHORT CIRCUIT BETWEEN CONDUCTORS
- THAT THE SWITCH BOARD EQUIPMENT IS MARKED CORRECTLY
- THAT INSTALLATION OPERATES AS INTENDED

TESTING

- CONTINUITY TESTING
- DEAD TESTING
- LIVE TESTING

TESTING DEVICES

- VISUAL INDICATOR < TEST LAMP, VOLTMETER, AMMETER, MULTIMETER
- INSULATION RESISTANCE TESTER
- RCD TESTER

TESTING SAFELY

DEAD TESTING IS SAFER THAN LIVE TESTING

RISK FACTORS IN TESTING

FLASH OVER VOLTAGE | BURN | SPARK
CONFINED AREA ⟶ MORE RISK
EXPLOSION BY HYDROGEN GAS
CHEMICAL BURNS

THE RISK OF ELECTRIC SHOCK IS USUALLY MINIMAL IN TESTING ON ELV SYSTEM.

GOOD GENERAL NOTE(2)

G008 GENERAL NOTE (2)

DETECTING THE VOLTAGE

TEST LEADS- ADEQUATELY INSULATED

PROTECT TEST BULB FROM MECHANICAL DAMAGE

WHENEVER THE TESTING DEVICE IS USED, TEST FOR IT'S CORRECT FUNCTIONING BEFORE THE TEST AND AGAINST AFTER THE TEST

- VISUAL CHECK BEFORE TEST

TECHNIQUE (1) EARTHING SYSTEM

TECHNIQUE (2) INSULATION RESISTANCE

TECHNIQUE (3) POLARITY

WATCH CIRCUIT TESTING VIDEO

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G003 + G004 + G007

(4) CIRCUIT TESTING

SLIDE (1) → (18), Q26 → Q34

(5) CIRCUIT TESTING (2)

SLIDE (1) → (16), Q35 → Q39

G008 + G009

AC MACHINE

- VIDEO OF G043 + G045 - BASIC PRINCIPLE OF AC MOTOR (www.advanced diploma electrical-zoomshare-com UNDER G043 + G045

- www.1790817794-zoomshare-com G008 | G008 E Trade 1. ZIP

- www.advanced diploma electrical -zoomshare-com G008 + G009

(1) AC MACHINE

SLIDE (1) → (12), Q1 → Q9

AC MOTOR CONTROL

- VIDEO OF G043 + G045 - MOTOR CONTROL VIDEO OF E029 | G012

- www.1790817794.zoomshare.com G008/ E Trade 1. ZIP { G009. ZIP

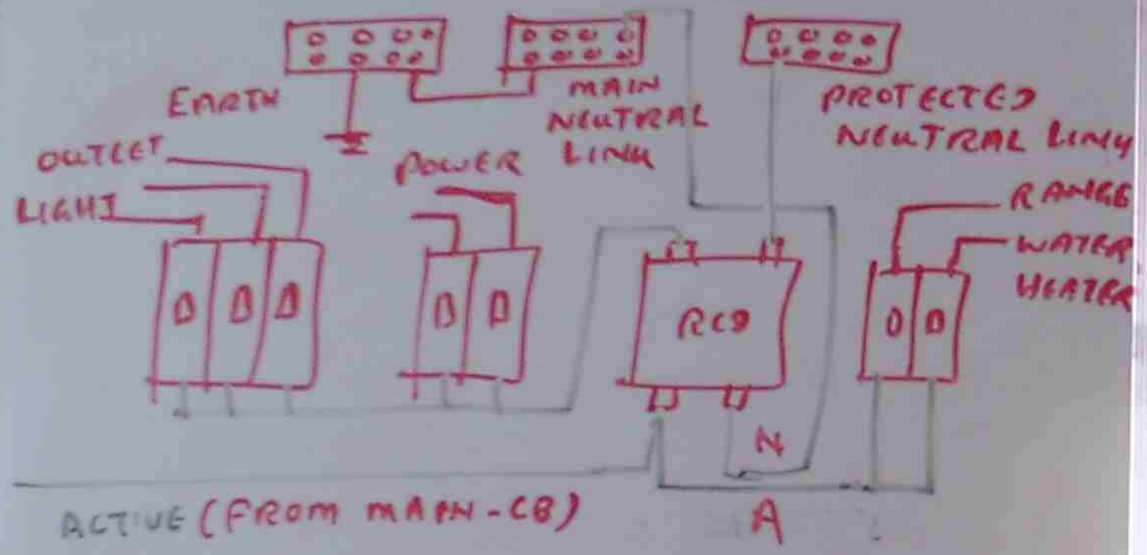
- www.advanced diploma electrical -zoomshare-com

(2) AC MOTOR CONTROL

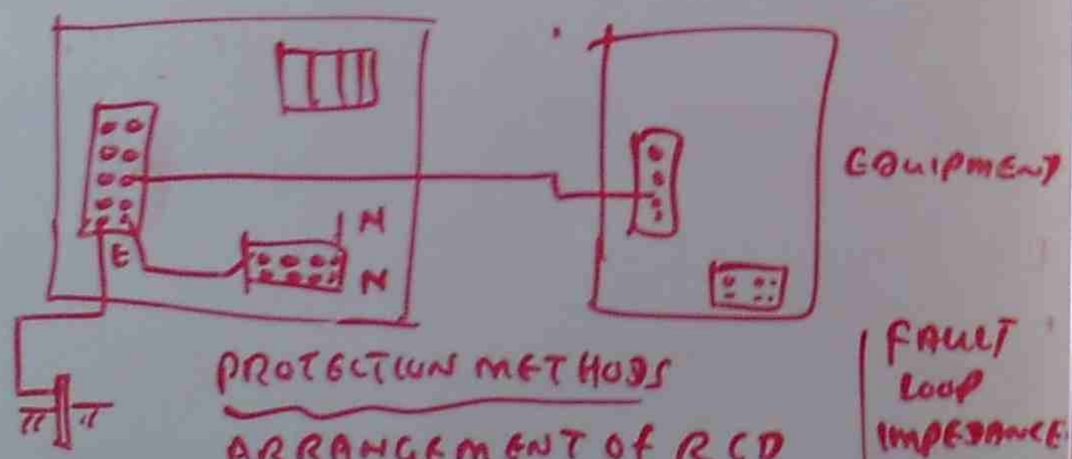
SLIDE (1) → (18)

Q10 → Q20

RCD - 2.5.3.1 RCD CONNECTION



G003 + G004 | ELECTRICAL SYSTEM SAFETY 1
(www.17408 17744.zoomshare.com) .ZIP
G003 + G004
EARTHING SYSTEM + EARTHING ARRANGEMENT



PROTECTION METHODS
ARRANGEMENT of RCD
ELECTRICAL INSTALLATION DESIGN
- VOLTAGE DROP $Vd = \frac{Vd \, L \, I}{1000}$
FAULT LOOP IMPEDANCE

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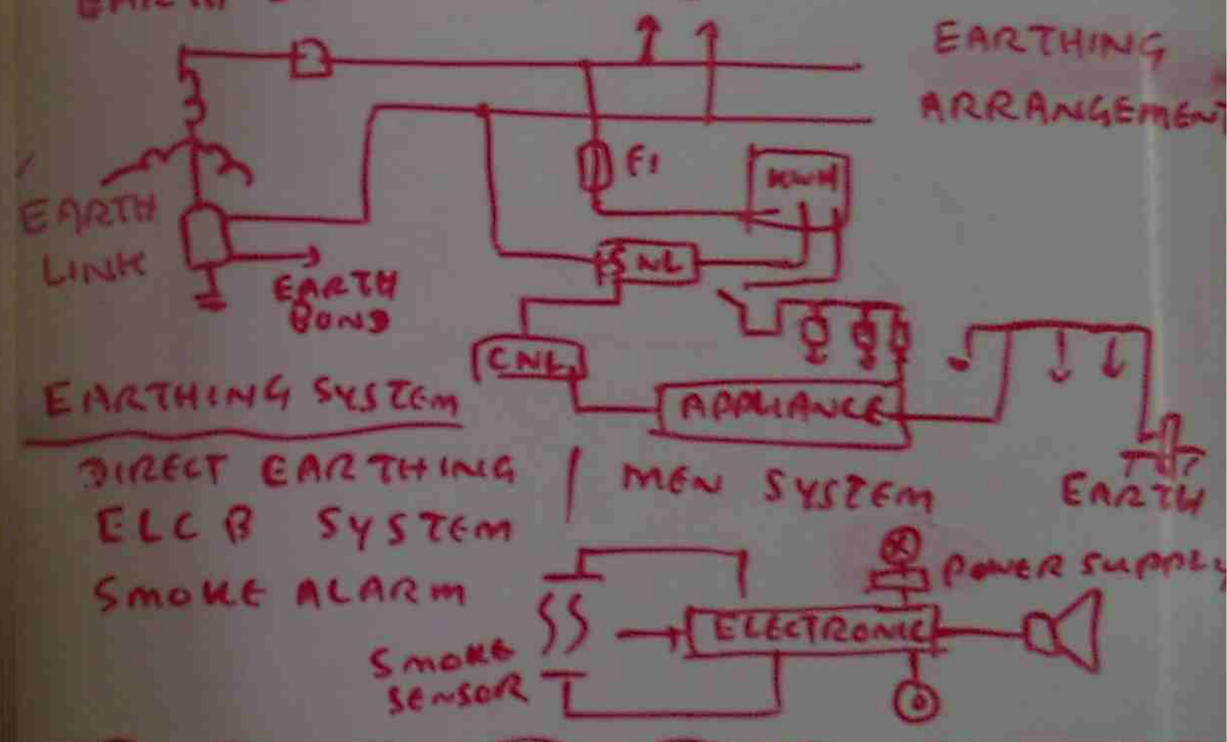
G003 + G004 / FIRE PROTECTION - HEATING - TESTING EARTHING - ZIP

EARTH FAULT - CAUSE of EARTH FAULT,
PROTECTION AGAINST OVER LOAD, INSTALLING
THE EARTHING SYSTEM,
SUPPLEMENTARY SYSTEM OF EARTH SYSTEM

ISOLATION OF LIVE PARTS,
(USE OF ALL INSULATED / DOUBLE INSULATED EQUIPMENT
ISOLATION TRANSFORMER
EARTH LEAKAGE DEVICES



G008 LIGHTING PART (1) + (2)

APPLICATION, HIGH PRESSURE SODIUM LAMP
LIGHTING CONTROL MULTI POSITION / AUTOMATIC
. ELECTRONIC LIGHT DIMMER

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G003 + G004 → G003 + G004 - GENERAL WIRING - ZIP

WATER HEATER - MAX. OPERATING PRESSURE
CAPACITY (L), SUPPLY VOLTAGE, PH,
POWER INPUT

COOKING APPLIANCES SUPPLY VOLTAGE / NO. OF PHASES
POWER INPUT

MOTOR FULL LOAD SPEED, POWER OUTPUT, NO. OF PHASE
SUPPLY VOLTAGE

RECONNECTING CIRCUIT CABLING TO APPLIANCES

LOCATION OF SWITCH BOARD, PROHIBITED / RESTRICTED
LOCATION, EQUIPMENTS ON SWITCH BOARD

TPI CABLE IN NON METALLIC ENCLOSURE -
RIGID P.V.C, FLEXIBLE PVC, CORRUGATED PVC

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G003 + G004 - CABLE CIRCUIT PROTECTION & ACCESSORIES - ZIP

SUITABLE SYSTEM TYPE OF BUILDING /	OPEN WIRING AERIAL / U-G	WIRE CABLE TRAY / LADDER CABLE DUCT / GUTWAY

LING EARTHING SYSTEM

ELECTRICAL HEATING

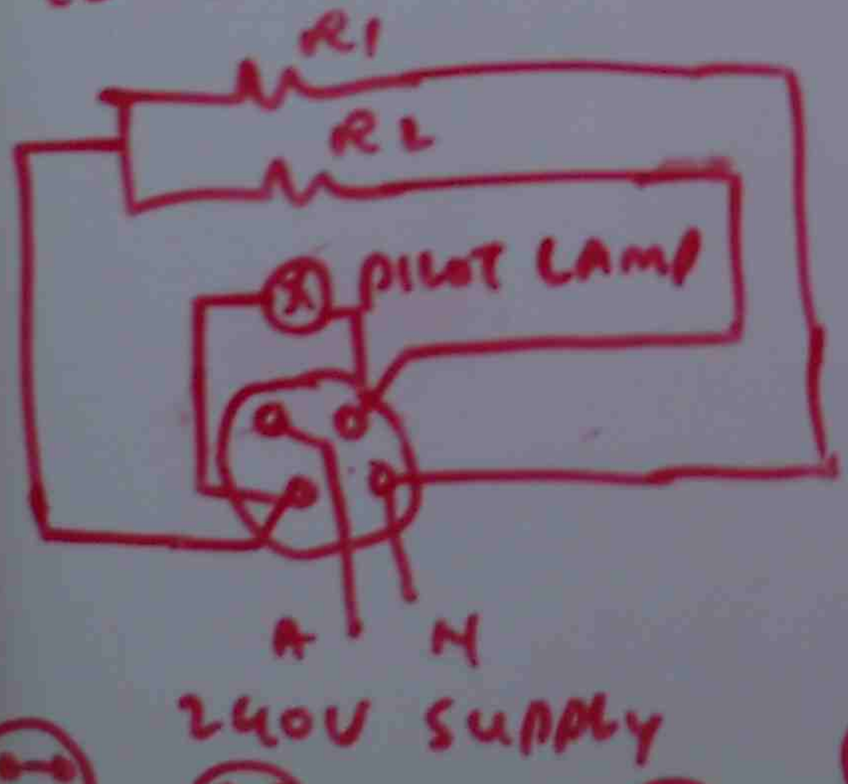
BOILER - SIDE FED, ELECTRODE TYPE, MAIN PRESSURE

INSTANTANEOUS, STORAGE

HEAT TRANSFER - RADIATION, CONVECTION CONDUCTION

WATER AND SPACE HEATING INSTALLATION

DUTY CYCLE, INDEPENDENT SWITCH, AUTOMATIC CONTROL



THERMOSTATIC CONTROL

BIMETAL, EXPANDING TUBE

VAPOUR PRESSURE

WATER HEATING

INSTANTANEOUS

STORAGE

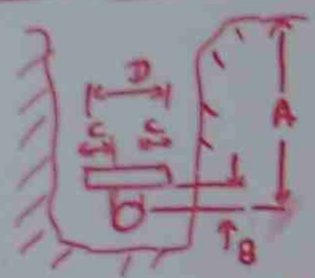
CONTINUOUS

CONTROLLED LOAD

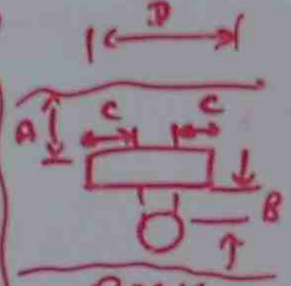
UNDERGROUND WIRING



CATEGORY (A)
NO FURTHER MECHANICAL PROTECTION
AS 2053



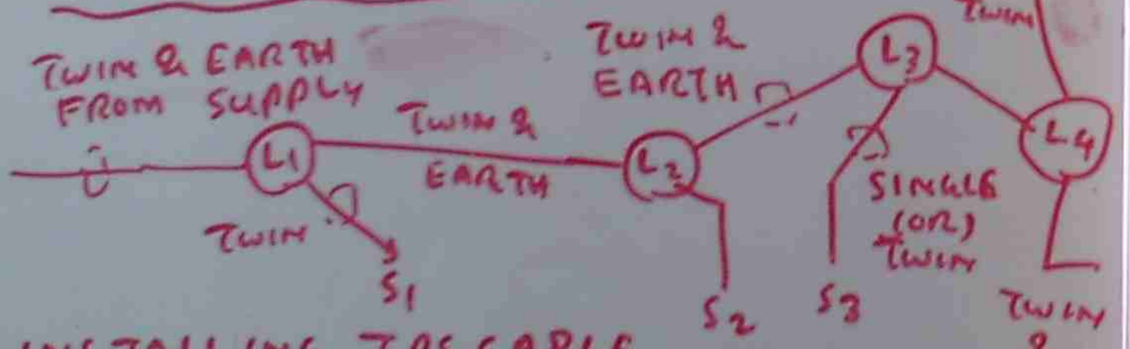
A - LAYING DEPTH ACCORDANCE WITH TABLE
B - 175mm
C - 40mm
D > 150 mm
CATEGORY (B)



ROCK
CATEGORY (C)

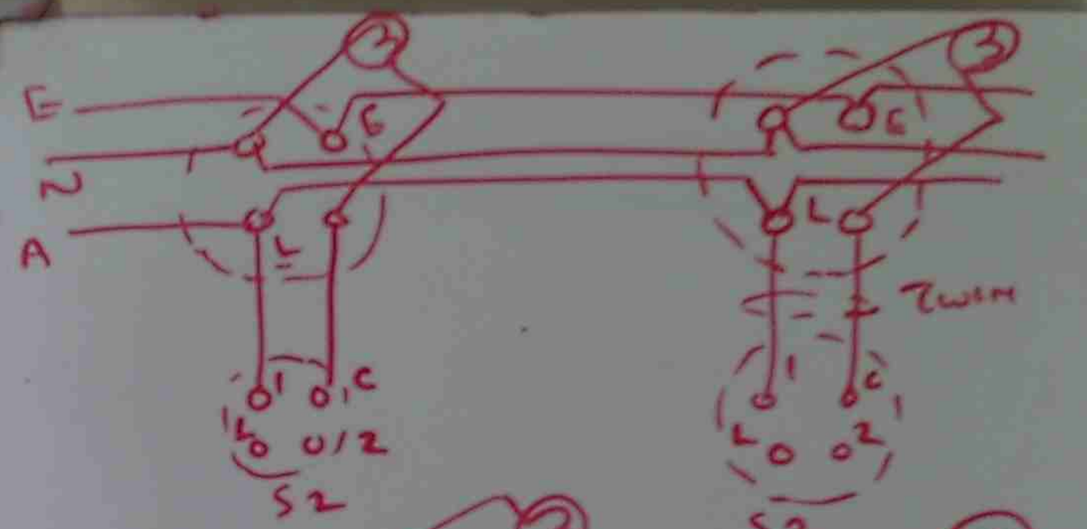
UNDER CARPET POWER WIRING - FINAL SUB CIRCUIT

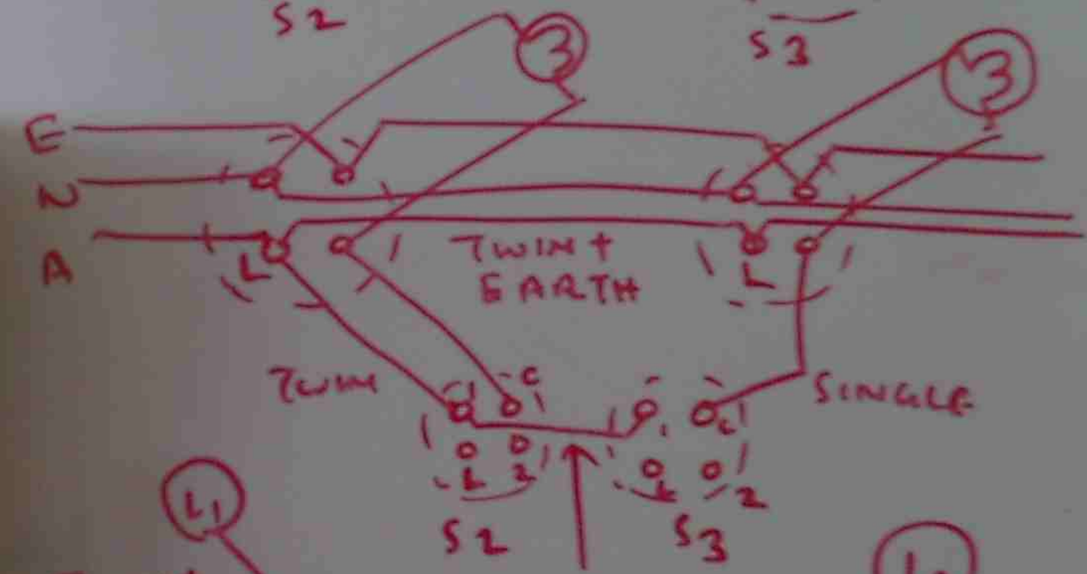
TPS WIRING SYSTEM

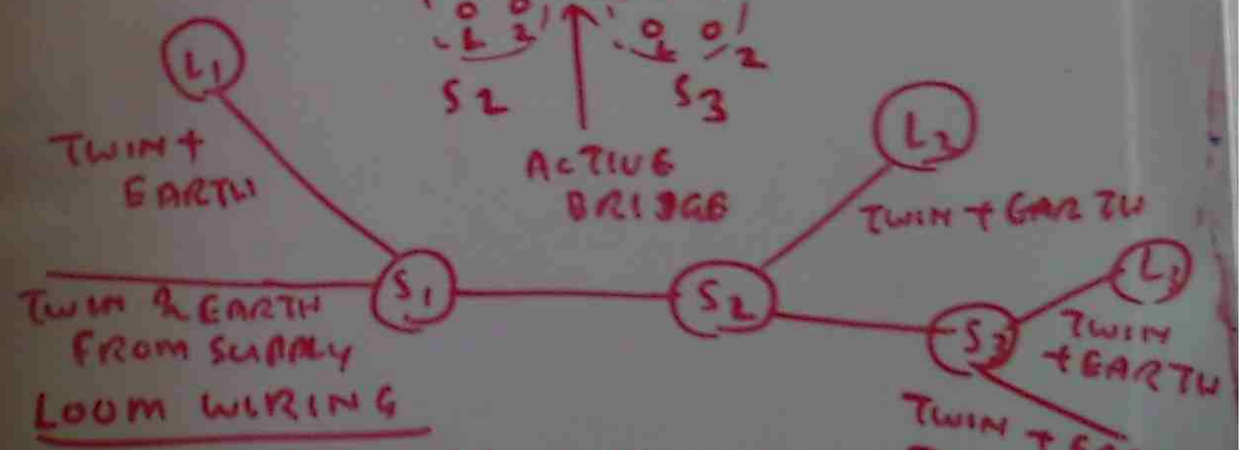


INSTALLING TPS CABLE

1. CABLE RUN SHOULD BE PLANNED
2. METAL PIN CLIPS ARE USED WHERE IT IS LIKELY TO BE DISTURBED
3. ALL CABLES ARE FIXED & SECURED
4. FINAL TESTING







LOOM WIRING

TPS CABLES ARE INSTALLED IN THE SPACE BETWEEN THE UNDERSIDE OF CONCRETE FLOOR SLAB (OR) FALSE (OR) SUSPENDED STRUCTURE

- CABLE SELECTION

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STUDY OPTION (1)
G003 + G004 + G007 PART (1)

(1) BASIC WIRING CIRCUIT + WIRING RULE
SLIDE (1) → (8) { Q1 → Q6

(2) WATER HEATER + SWITCH BOARD WIRING + RCD
SLIDE (1) → (11) { Q7 → Q14

(3) EARTHING/WIRING SYSTEM + SAFETY TEST
SLIDE (1) → (3) { Q15 → Q17

(4) CABLE INSTALLATION
SLIDE (1) → (22) { Q18 → Q33

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GOO3+ GOO4

GOO8 GENERAL NOTE (1) { ZONE 0, 1, 2

EXPLOSION TECHNIQUES

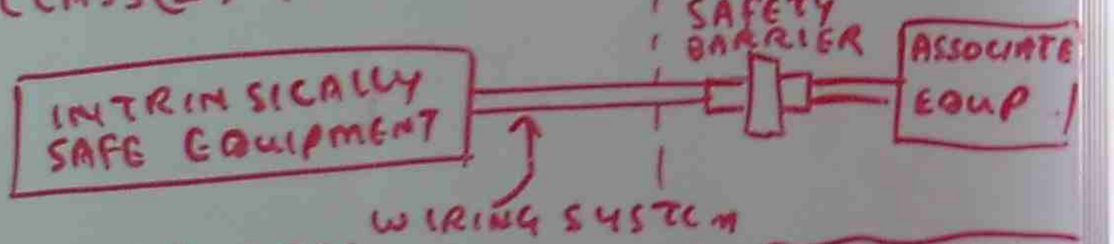
EXCLUSION, EXPLOSION CONTAINMENT, ENERGY LIMITATION, DILUTION, AVOIDANCE OF IGNITION SOURCE

EXAMPLE OF PROTECTION

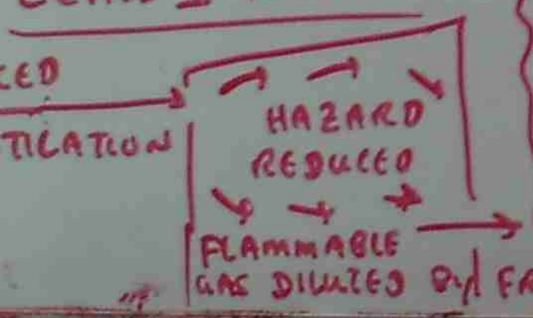
NON SPARKING AS2380-9 (Ex n)
OIL IMMERSION (Ex o), SAND FILLED (Ex q)
FLAME PROOF ENCLOSURE AS2380.2 (Ex d)
VENTILATION AS1482 (Ex v) ETC
INCREASED SAFETY AS2380.6 (Ex e)

SELECTION OF EQUIPMENTS AS2381.1

CLASS (I) PROTECTION



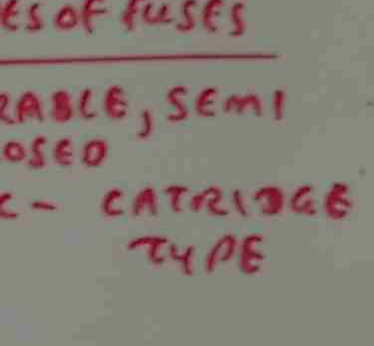
CLASS II AREA



NOT PERMITTED

OPEN WIRING, LOW PRESSURE SODIUM, VAPOUR LAMP, AERIAL BARE CONDUCTOR, BUSWAY TRUNKING

- PROTECTION OF FLAME PATH FROM MECHANICAL DAMAGE
- CABLE ENTRY / CABLE GLAND
- GENERAL EQUIPMENT MODIFICATION & MAINTENANCE



TYPES OF FUSES

- REWIRABLE, SEMI ENCLOSED
- HRC - CATRIDGE TYPE

BASIC PROTECTION PRINCIPLE

- THE FUSE (OR) CB SHOULD BE CAPABLE OF CARRYING IT'S RATED CURRENT CONTINUOUSLY WITHOUT OVER HEATING (OR) DETEORIATION.
- THE PROTECTION MUST OPEN THE CIRCUIT BEFORE THE DAMAGE CAUSED BY FAULT CURRENT CAN OCCUR
- PROTECTION MUST BE DISCRIMINATIVE

OVER LOAD AND SHORT CIRCUIT PROTECTION

OVER LOAD $H \propto I^2 t$

SHORT CIRCUIT $I_{FL} \times \frac{100}{5}$

CIRCUIT BREAKER - MAGNETIC CIRCUIT BREAKER (MCB)

GOOD GENERAL NOTE (1)

PROTECTION AGAINST OVER LOAD
- FUSE, CIRCUIT BREAKER

EARTH FAULT

CAUSE OF ACTIVE TO EARTH FAULT

- ON THE SUPPLY SYSTEM TO INSTALLATION
- ON AN ADJACENT INSTALLATION
- IN WIRING (OR) ACCESSORIES
- WITHIN APPLIANCES
- IN LUMINAIRES (OR) SWITCH BOARDS

REVERSE POLARITY OF SUPPLY,
OPEN CIRCUIT ON SUPPLY NEUTRAL
EARTHING TERMS — AS3000
INSTALLING EARTHING SYSTEM
SUPPLEMENTARY SYSTEM OF EARTH PROTECTION

PROTECTION IS ACHIEVED BY THE ACTION OF THE CIRCUIT BREAKER IN TRIPPING OUT.

TYPES OF TRIPPING ELEMENTS

THERMAL, MAGNETIC, THERMAL-MAGNETIC ELECTRONIC

FAULT CURRENT LIMITER

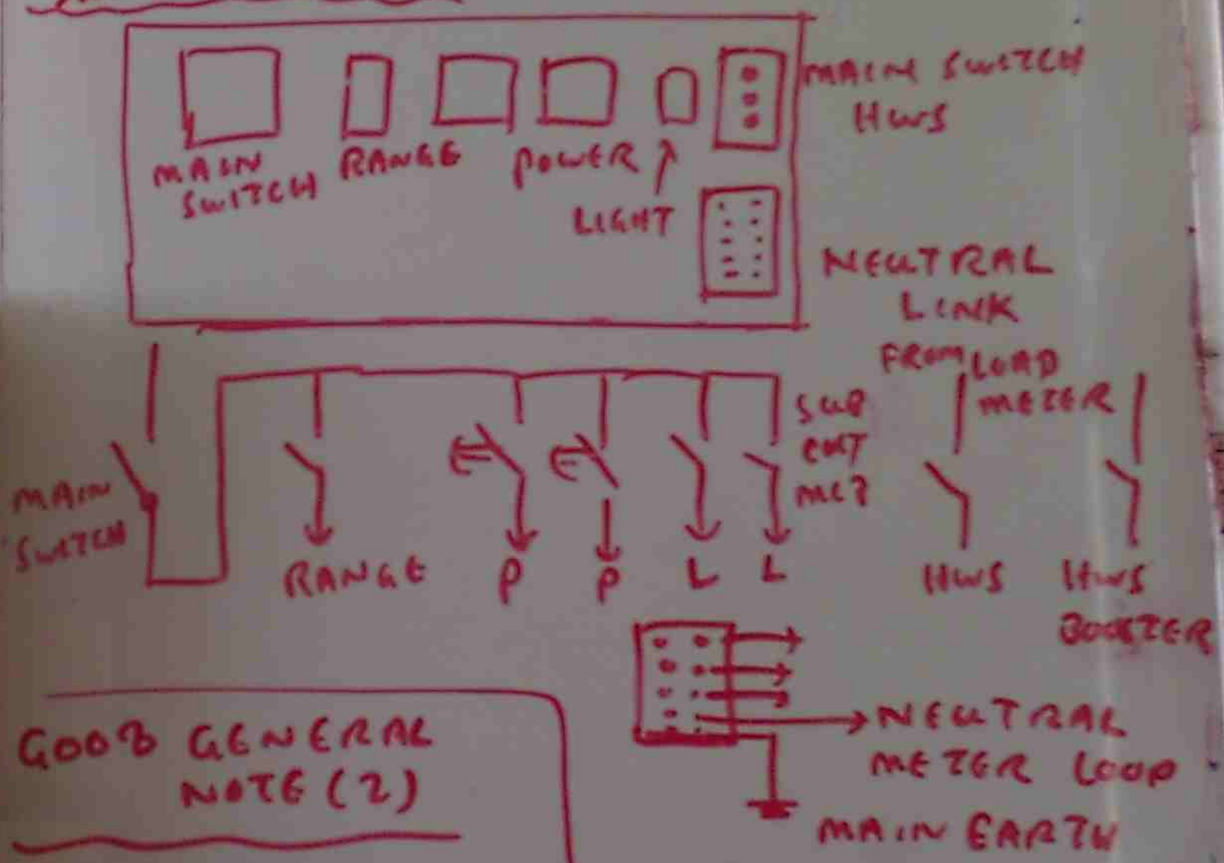
VOLTAGE SURGE & TRANSIENT — INTERNAL (SWITCHING), EXTERNAL

VALVE TYPE | EXPULSION TYPE (SURGE DIVERTER)

MOTOR PROTECTION.

PROTECTION FROM ENVIRONMENT
PROTECTION FROM OVER HEATING

SWITCH BOARD



GOOD GENERAL NOTE (2)

SWITCH BOARD FOR NON DOMESTIC INSTALLATION

AS 3439.1 – 1993 - LOW VOLTAGE SWITCH GEAR AND CONTROL GEAR ASSEMBLY

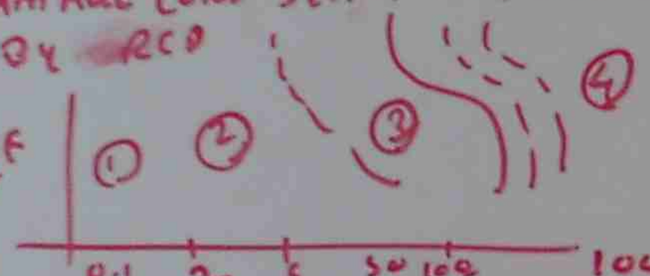
LOCATION | ACCESS
FIRE | SHOCK HAZARD
MOUNTING OF EQUIPMENT
NEUTRAL LINK RATING

MARKING
WIRING OF SWITCH BOARD
CONTROL | LAYOUT

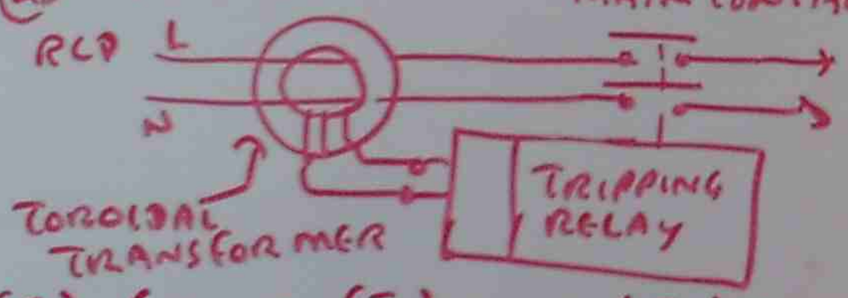
G008- GENERAL NOTE (2)

DEVELOPMENT OF RESIDUAL CURRENT PROTECTION

PROTECTION AGAINST LEAKAGE CURRENT LIKELY TO CAUSE DAMAGE (OR) START A FIRE CAN BE PROVIDED BY RCD



(1)- NO EFFECT
(2) NO HARMFUL
(3) MUSCULAR CONTRACTION, BREATHING DIFFICULTIES, VENTRICULAR FIRKILLATION
(4) FATAL

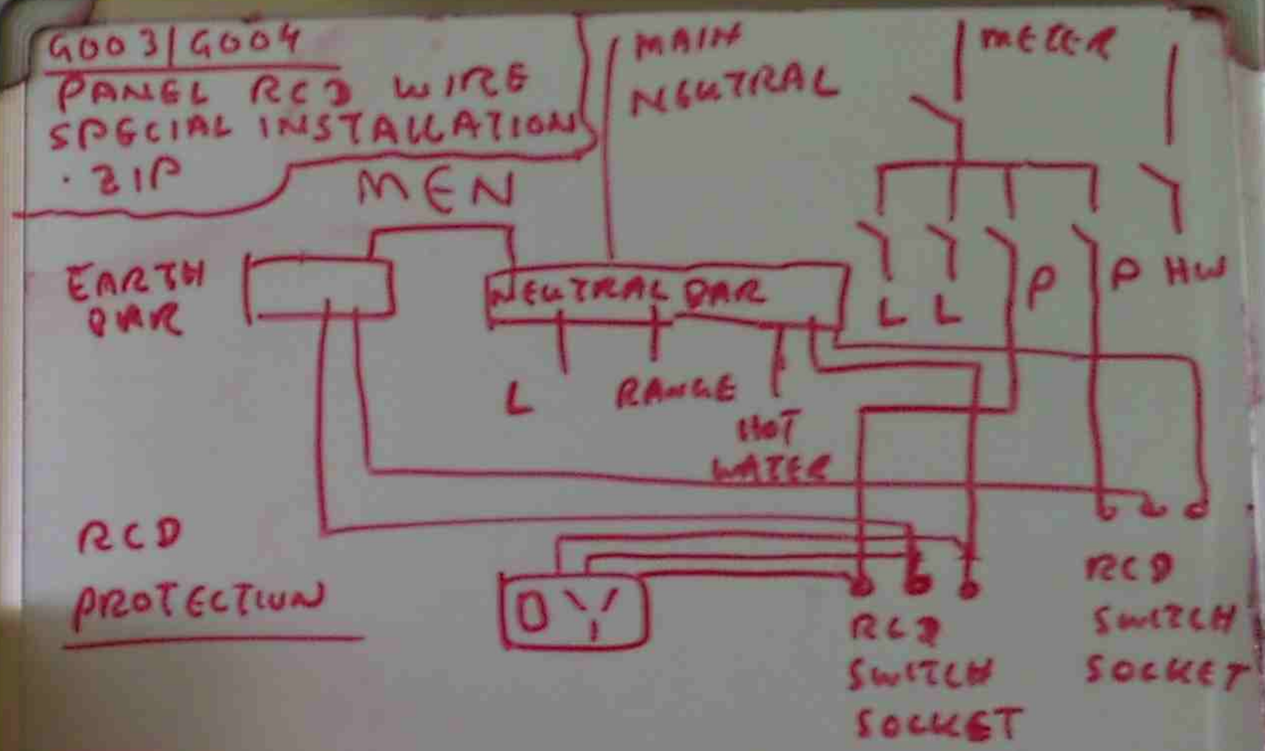


(I) < 10mA, (II) 10mA < I < 30mA
(III) 30mA < I < 300mA (IV) 30 mA < I < 300 mA

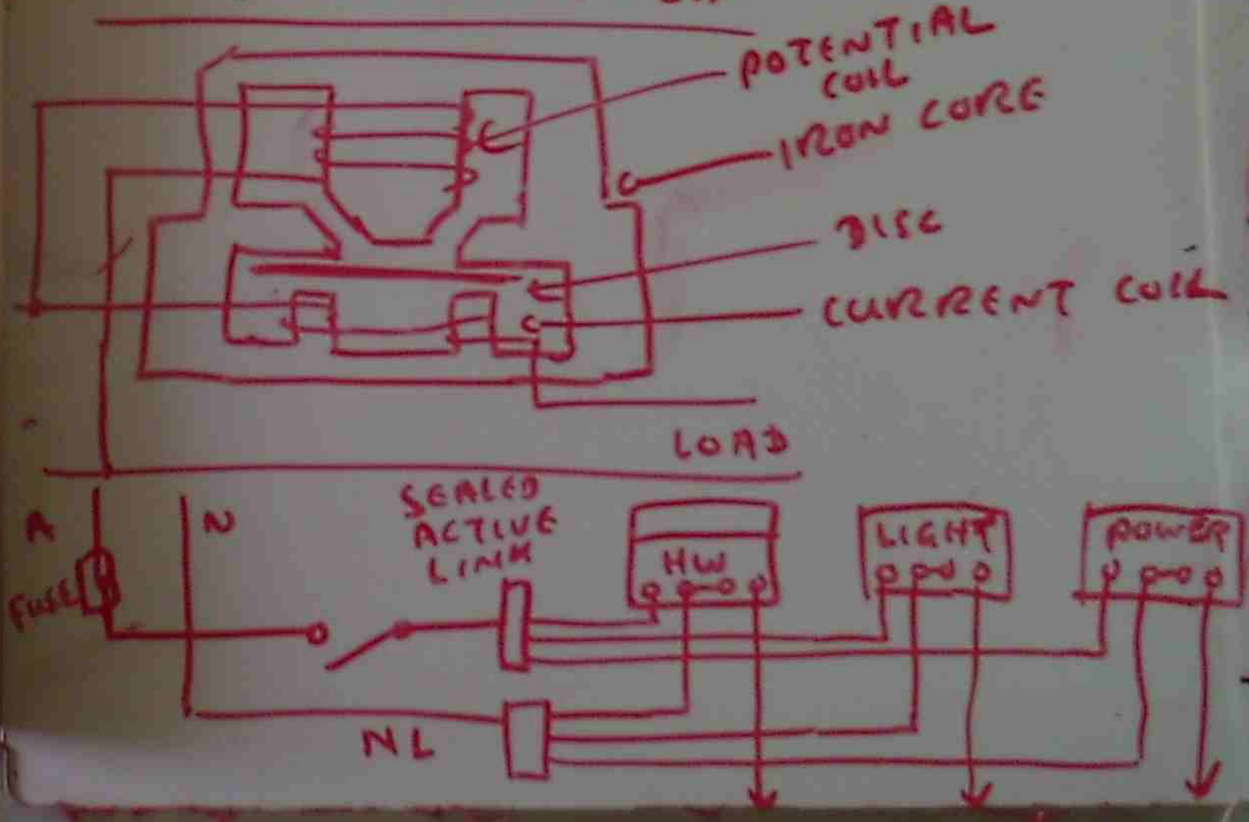
CLASS L - 1φ PORTABLE HOUSE HOLD — SELECTIVE TRIPPING TIME DELAY
CLASS H - INDUSTRIAL USE

NUISANCE TRIPPING — STANDING LEAK CURRENT
— ELECTRICAL DISTURBANCE
— INSTALLATION FAULT

G003/G004
PANEL RCD WIRE SPECIAL INSTALLATION .ZIP



G005/ METERING .ZIP



G003+G004/ PANEL RCD WIRE SPECIAL INSTALLATION - ZIP

SWITCH BOARD LOCATION & ACCESS

- EACH OCCUPIER MUST HAVE READY ACCESS TO MAIN SWITCH
- SWITCH BOARD SHOULD NOT BE LOCATED IN BATH ROOM.
- KITCHEN / LAUNDRY (ENCLOSED IN A CUP BOARD)
- WELL VENTILATED
- MUST NOT BE INSTALLED WITHIN 1.2m ABOVE THE GROUND.
- THE ENCLOSURE (OR) SHEATH OF CONDUCTORS MUST CONTINUE IN TO THE SWITCH BOARD SURROUND TO LEAVE NO EXPOSED WIRING
- NO EXPOSED PARTS UNLESS PROTECTED BY AN ENCLOSING CASE
- AT LEAST 25 mm CLEARANCE BETWEEN R TYPE FUSE BODIES
- 12mm FROM EDGE
- FUSE & CB MUST BE ARRANGED SO THAT A PERSON LOOKING AT THE SWITCH BOARD CAN SEE THEM INSTANTLY
- NO FUSE (OR) CB AT THE BACK.

- NEUTRAL LINK - 40 mm² CSA 3mm THICK
- MARKING
- WIRING MUST BE RUN AT THE BACK OF THE SWITCH BOARD
- SUFFICIENT SPACE BEHIND THE PANEL TO PERMIT THE MANIPULATION OF WIRING

1 KA FOR REWIRABLE FUSE
1.5KA FOR PLUG IN CB
8KA FOR MCB

- MAXIMUM NO OF MAIN SWITCH PERMISSIBLE - SIX

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G003+G004+G007 Part 1

(5) EARTH FAULT HAZARDOUS AREA

SLIDE (1) → (15)
@ 34 → @ 50

(6) PROTECTION MECHANISM

SLIDE (1) → (29)
@ 51 → @ 71

CABLE SELECTION + MAXIMUM DEMAND

- STUDY 4007 CABLE SELECTION + MAXIMUM DEMAND TOPICS (www.advanced diploma electrical -zoomshare.com (4007)

- www-17908 17744. zoomshare.com
  4003 + 4004

4003+4004- CABLE CKT PROT E ACCESSORIES -ZIP
- CABLE SELECTION BACKGROUND NOTES

4003+4004 | HAZARD LIGHTING PANEL-ZIP

$E = \frac{F}{A}$ F= TOTAL FLUX, E= ILLUMINANCE LUX
A= WORKING PLANE AREA

ILLUMINANCE CALCULATION, LUMINAIRES, MAINTENANCE
EMERGENCY LIGHTING, AUTOMATIC CONTROL, DIMMER

4003+4004+4007 PART(2)-(7) RCD CABLE SELECTION
SLIDE(1→5) @ 72

G007

AS 3000 OVERVIEW

WIRING RULE

PART(1) SCOPE
APPLICATION
FUNDAMENTAL PRINCIPLE

PART(2) INSTALLATION PRACTICE

STRUCTURE

SECTION (1)
SCOPE, APPLICATION
REFERENCE DOCUMENT
DESIGN OF ELECTRICAL INSTALLATION, SELECTION AND INSTALLATION OF EQUIPMENT, VERIFICATION MEAN OF COMPLIANCE

↑
REGULATORY ISSUE

THE ACT, THE REGULATION
OTHER REGULATION
THE STANDARD

SECTION(2)→(8)
GENERAL ARRANGEMENT
CONTROL
PROTECTION
INSTALLATION
OF APPLIANCES AND ACCESSORIES
EARTHING, ARRANGEMENT
/CONDUCTOR
DAMPING
SPECIFICAL
VERIFICATION

APPENDIX
REF
CKT
PROTECTION
SURGE PROTECTIO-N

SECTION (1) – STRUCTURE, PROTECTION
ADDITIONAL PROTECTION, COMPLIANCE

SECTION(2) - GENERAL ARRANGEMENT, CONTROL OF INSTALLATION, FAULT PROTECTION PROTECTION AGAINST OVER LOAD, UNDER VOLTAGE SWITCH BOARD PROTECTION COMMON REQUIREMENT, MAIN SWITCH FUNCTIONAL SWITCH, RELIABILITY, FUSE TIME CURRENT CURVE, GENERAL DISCRIMINATION RCD

SECTION(3) SELECTION AND INSTALLATION OF WIRING SYSTEM, TYPE, CONDUCTOR SIZE, VOLTAGE DROP, ELECTRICAL CONNECTION, IDENTIFICATION, MAXIMUM DEMAND, MEN SUPPORT FITING, ACRIAL, UNDERGROUND EARTHING

SECTION(4) SELECTION AND INSTALLATION OF APPLIANCES AND ACCESSORIES, SOCKET OUTLET SMOKE DETECTOR, HEATER, CONVERTOR, MOTOR TRANSFORMER, BATTERIES

SECTION (5) EARTHING

SECTION(6) DAMP SITUATION, WATER FOUNTAIN SOCKET OUTLET, PROTECTION

SECTION (7) SPECIAL INSTALLATION
GENERATION, GRID CONNECTION, BONDING

SECTION(8)
VERIFICATION
COMPLIANCE

MAXIMUM DEMAND CALCULATION

pb① DETERMINE THE MAXIMUM DEMAND OF A SINGLE DOMESTIC ELECTRICAL INSTALLATION SUPPLIED AT SINGLE PHASE WITH THE FOLLOWING LOADS

a { 24 LIGHTING POINTS
10m OF LIGHTING TRACK
9 - 10A SINGLE SOCKET OUTLET } c
8 - 10A DOUBLE SOCKET OUTLET }
1 - 50W EXHAUST FAN
1 - 15A SOCKET OUTLET ← d
1 - 10KW RANGE ← e
1 - 1000W STRIP HEATER ← c
1 - 4.8 KW WATER HEATER ← f
1 - 3 KW TENNIS COURT LIGHTING ← b

24 LIGHTING POINTS

(a) TABLE C1, LOAD GROUP A(i) - LIGHT = 24 Pt
LIGHTING TRACK → FOOT NOTE (d) →
2 Pt/m × 10m = 20 Pt
EXHAUST FAN (NOT INCLUDED IN OTHER GROUP) = 1 Pt
45 Pt

TABLE C1, A(i)
FIRST 20 Pt = 3A
2nd 20 Pt = 2A
45-40 = 5 3rd 20Pt = 2A
7A

LOAD(i) = 7A //

(b) 3 KW TENNIS COURT LIGHTING → OUTDOOR LIGHTING
EXCEEDING 1000W
TABLE (A)(ii) 75% OF CONNECTED LOAD
(b) → 0.75 × 12.5 = 9.4A
$\frac{3000}{240} = 12.5A$ //

(c) NOT EXCEED 10A { 9 × 10A SINGLE SOCKET OUTLET = 9 Pt
8 × 10A DOUBLE SOCKET OUTLET = 16 Pt (8×2)
LOAD GROUP B(i) STRIP HEATER = 1 Pt
26 Pt

10A FOR 1 → 20 Pt + 5A FOR ADDITIONAL 20 Pt
TOTAL 26 Pt → 10 + 5 = 15A //

(d) 15A SOCKET OUTLET
LOAD GROUP B(ii) → 1 × 15A SOCKET OUTLET = 10A //

(e) 10 KW RANGE
LOAD GROUP (C) → 50% CONNECTED LOAD
$\therefore 0.5 \times \frac{10 \times 10^3}{240} = 20.8A$ //

(f) 4.8 KW WATER HEATER - STORAGE WATER HEATER
LOAD GROUP (E) - FULL LOAD = $\frac{4.8 \times 10^3}{240} = 20A$ //

TOTAL MAXIMUM DEMAND = (a)+(b)+(c)+(d)+(e)+(f) = 7 + 4.4 + 15 + 10 + 20.8 + 20 = 82.2

Pb(2) FOR 3φ LOAD

EQUIPMENT	LOAD GROUP	COLUMN	RED	WHITE	BLUE
LIGHT, SOCKET RANGE, HEATER AIR CON:					

Pb(3) 3φ SUPPLY FOR TOTAL LIVING UNITS

INDIVIDUAL UNITS / PHASE = $\frac{\text{TOTAL UNITS}}{3}$

EQUIPMENT	LOAD GROUP	COL:	CAL:	RESULT
LIGHT, RANGE SOCKET OUTLET HEATER				

TABLE (C_1) , MOTOR - TABLE (C_2)

(1) SCOPE MAXIMUM DEMAND	(2) MAXIMUM DEMAND FOR 3φ	(3) MAX DEMAND CALCULATION
SLIDE (1) → (8) / @1 → @5	SLIDE 1 → 3, @6	SLIDE (1) → (4) / @7

CABLE SELECTION

$$V_d = \frac{V_c \times L \times I}{1000}$$

V_c (mV/A-m), L = LENGTH OF CABLE (m)

V_d - VOLTAGE DROP (V) I = MAXIMUM DEMAND CURRENT

TABLE

C.S.A	75°C	90°C
	V_c (mV/A-m) 3φ	V_c (mV/A-m) 3φ

1φ VOLTAGE DROP = 3φ VOLTAGE DROP × √3

$$1\phi\ V_c = \frac{3\phi\ V_c}{0.866}$$

$$3\phi\ V_c = 0.866 \times 1\phi\ V_c$$

TABLE 40 → 50, VOLTAGE DROP of CABLE, C.S.A, TEMP

COPPER

INSULATED SHEATH

SINGLE CORE | TREFOIL - TABLE 40
SINGLE CORE | TOUCHING (FLAT/ENCL) - TABLE 41

MULTI CORE - TABLE (42)

ALUMINIUM

SINGLE CORE - TREFOIL → TABLE (43)
CONDUIT
SINGLE CORE - FLAT / TOUCHING - TABLE (44)
MULTICORE → TABLE (45)

FLEXIBLE

SINGLE CORE - TREFOIL → TABLE (46)
(CONDUIT)
MULTI CORE → TABLE (47)

MIMS

SINGLE CORE + MULTI CORE → TREFOIL - TABLE (48)

AERIAL

COPPER + INSULATED - TABLE (49)
ALUMINIUM → TABLE (50)

Pb DETERMINE THE MAXIMUM ROUTE LENGTH OF 6 mm² BARE COPPER AERIAL SINGLE PHASE CONSUMER MAIN WITH MAXIMUM DEMAND of 80A AND PERMISSIBLE DROP of 4.3V

TABLE (49)

75C

6 mm² → 6.71 (3φ V_c)

$$1\phi\ V_c = \frac{6.71}{0.866} = 7.14$$

$$V_d = \frac{V_c I L}{1000}$$

$$4.3 = \frac{7.14 \times L \times 80}{1000}$$

$$L = \frac{4.3 \times 1000}{7.14 \times 80} = 6.94\ m$$

pb/ DETERMINE THE CABLE SIZE FOR A SINGLE PHASE FINAL SUB CIRCUIT TO BE ADDED TO THE FOLLOWING NON-DOMESTIC INSTALLATIONS.

CONSUMER MAIN

NO. OF PHASE = 3, ROUTE LENGTH - 45m
MAXIMUM DEMAND - 300A
CABLE SIZE - 185mm², VJS INSULATED COPPER CABLE ENCLOSED IN CONDUIT

SUB MAIN

NO. of PHASE = 3, ROUTE LENGTH = 50m
MAXIMUM DEMAND = 75A
CABLE SIZE = 25mm², VJS INSULATED COPPER CABLE ENCLOSED IN CONDUIT

FINAL SUB CIRCUIT

NO. OF PHASES = 1, ROUTE LENGTH = 50m
MAXIMUM DEMAND = 35A
CABLE SIZE - MULTICORE VJS - SHEATHED CABLE UNENCLOSED IN AIR

5% of 415V = $\frac{5}{100} \times 415 = 20.75V$ (3φ Vd)

$\frac{20.75}{\sqrt{3}} = 12V$ (1φ Vd)

3φ + 1φ ⇒ TOTAL Vd − (3φ Vd MAIN + 3φ Vd SUB MAIN) = FINAL SUB CKT

FINAL SUB CKT 3φ Vd / $\sqrt{3}$ = FINAL SUB CKT 1φ Vd

CONSUMER MAIN

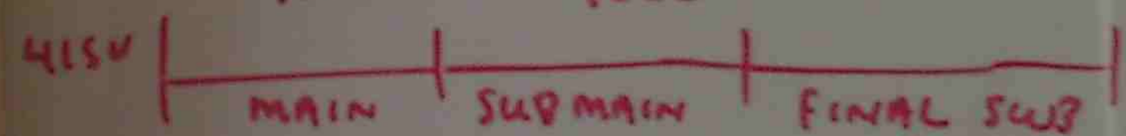
COPPER CABLE ENCLOSED IN CONDUIT - TABLE 41
Vjs - 75°C (75°C), 185mm² → 0.277 ← Vc

$Vd = \frac{Vc\ L\ I}{1000} = \frac{0.277 \times 45 \times 300}{1000} = 3.73V$

SUB MAIN

COPPER ENCLOSED IN CONDUIT - TABLE 41
25mm² → 1.55 ← Vc

$Vd = \frac{Vc\ L\ I}{1000} = \frac{1.55 \times 50 \times 75}{1000} = 5.81V$



FINAL SUB CKT 3φ Vd = TOTAL Vd − (3φ Vd MAIN + 3φ Vd SUB MAIN)
= 20.75 − (3.73 + 5.81)
= 11.21 V

FINAL SUB CKT 1φ Vd = $\frac{11.21}{1.7321} = 6.47V$

$Vd = \frac{Vc\ L\ I}{1000}$

$6.47 = \frac{Vc \times 50 \times 35}{1000}$

1φ Vc = 3.69V { 3φ Vc = 3.69 × 0.866 = 2.92

{ MULTI CORE UNENCLOSED IN AIR TABLE 42
75°C 2.43 { 2.92 { 3.86
16mm² 10mm²
CSA = 16mm²

(4) CABLE SELECTION

SLIDE 1 → 11

Q 8 → Q 9

(5) THREE PHASE VOLTAGE DROP

SLIDE 1 → 6

Q 10 → Q 14

CABLE SIZE → CURRENT RATING → DERATING FACTOR FOR MULTI CKT

	INSTALLATION METHOD	TABLE	column
SHEATHED V75, V90 Cu/AL CABLE	UN ENCLOSED IN AIR TABLE 2(1)	3,4,6,7,9,10 12,13	2,3,4,5 6,7
MIMS	ENCLOSED IN CONDUIT TABLE 2(2)	3,4,6,7,9,10 12,13	8,9,10,11 12,13
SINGLE CORE - T-18 MULTI CORE - T-19	DIRECT BURIED TABLE 2(3)	3,4,6,7, 9,10 12,13	14,15, 12,13
FLEXIBLE - T-17 PTCC FLEX: - T-15	BURIED UG ENCL TABLE 2(4)	3,4,6,7,9,10 12,13	16,17,14 15,18,19

CABLE FLEX WRD - T-16 → DERATED CURRENT SIZE OF CABLE ← DGRATING 22, 23, 24

22
25
26

NOTE

(i) SINGLE CIRCUIT, ONLY ONE CKT - NO DERATING

(ii) X, XE, R-EB, RCPE, RHF
R-CSB INSULATION - TABLE 4, 7, 11, 13

(iii) V, HFI, TP → TABLE 3, 6, 9, 12

(iv) RHE, RE, XHF 110 → TABLE 5, 8, 10, 14
INSULATION

(v) SURROUNDED BY THERMAL → ENCLOSED
INSULATION

(vi) IN AIR → SPACED FROM WALL

(vii) FREE AIR → SUPPORTED BY CANTERY

DERATING FACTOR

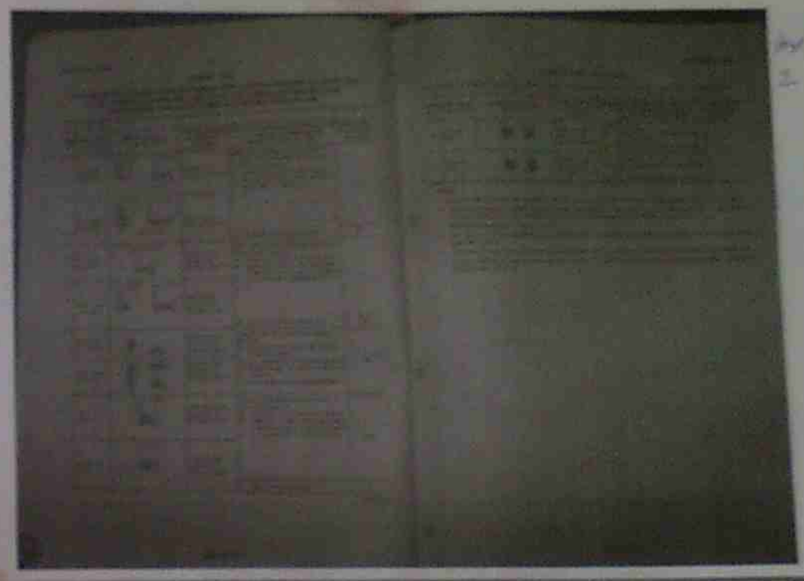
CONDITION → TYPE OF CABLE (ROW NO. OF TABLE 2(1), 2(2) 2(3), 2(4)) → TABLE 10 → 30 TO SELECT SIZE, CSA

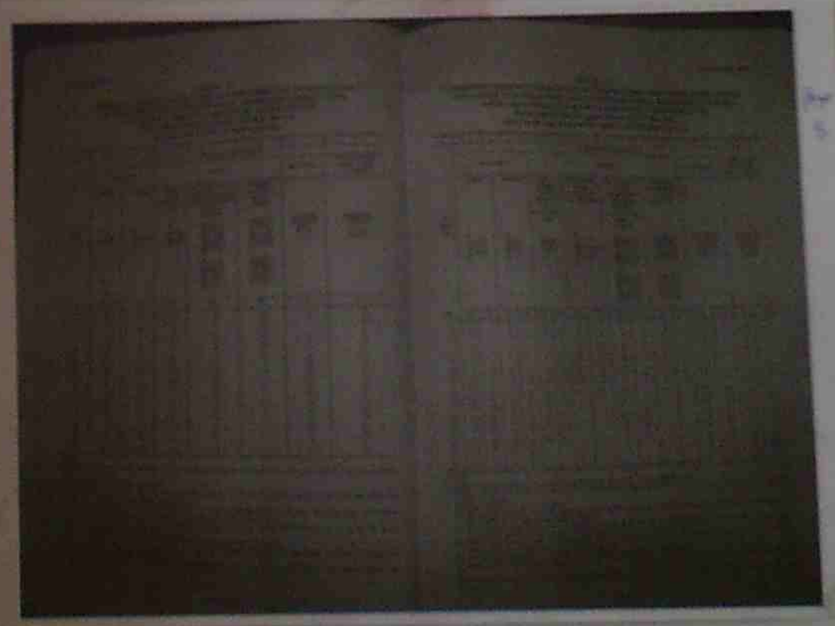
(1) THE MAXIMUM DEMAND OF CURRENT OF THE CONSUMER IN A NON DOMESTIC INSTALLATION IS CALCULATED TO BE 290 A. THE SELECTED CABLE IS 4 CORE NON ARMOURED V90 INSULATED AND SHEATHED, CIRCULAR CABLE WITH COPPER CONDUCTOR.
THE INSTALLATION IS CLIPPED DIRECTLY TO INTERNAL WALL, OPEN TO AIR AND PROTECTED BY CIRCUIT BREAKER

(1) FIRST SEE TABLE 2(1)
NO. OF CONDUCT, 4 CORE → 3CORE
ROW (13)

TABLE (1) →

TABLE (12)
↓
COLUMN 4





COL 4
↓
325A → 185 mm²
↑
CONDUCTOR SIZE

(1) FIRST SEE TABLE 2 (1)

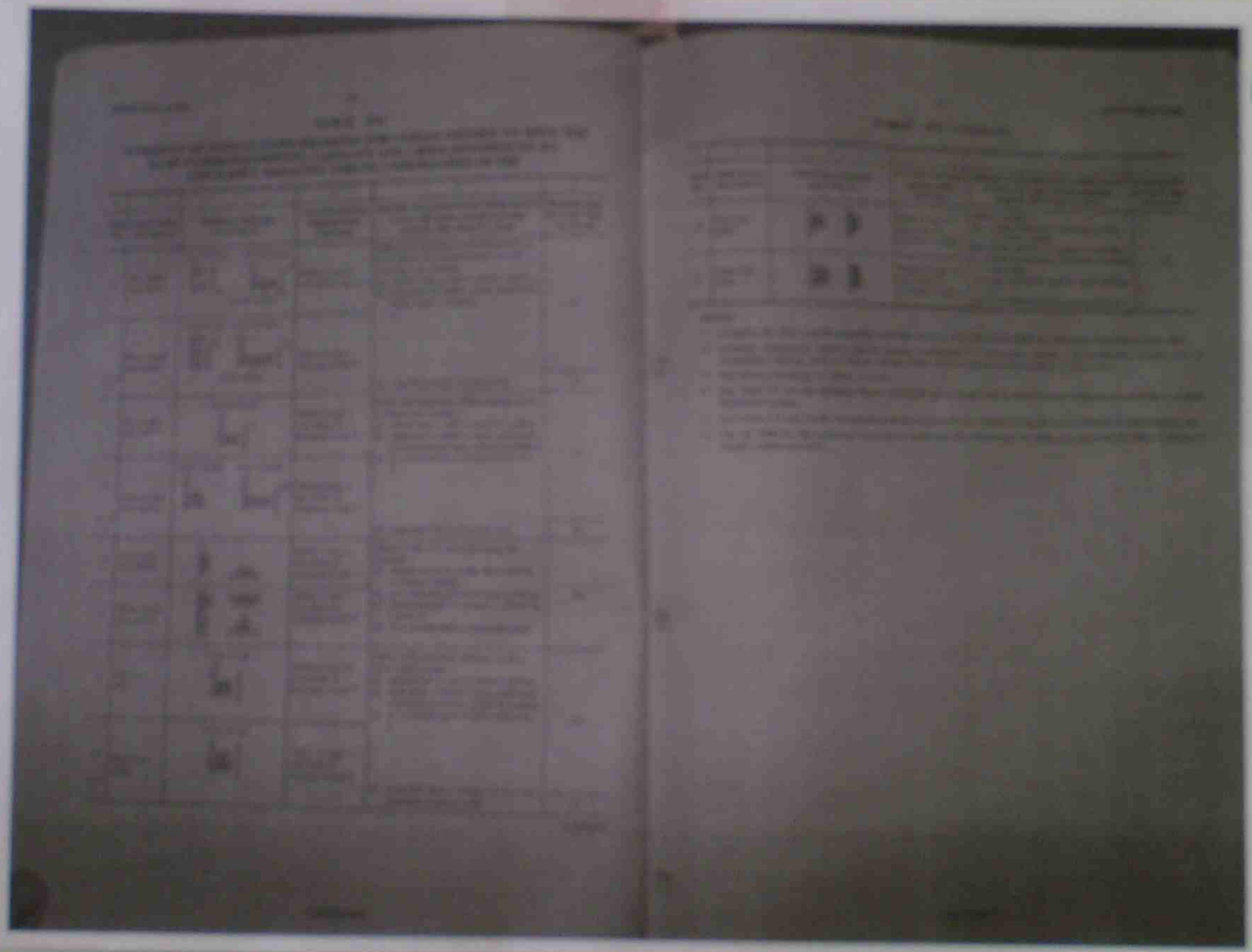
NO. OF CONDUIT, 4 CORE → 3 CORE

ROW (13)

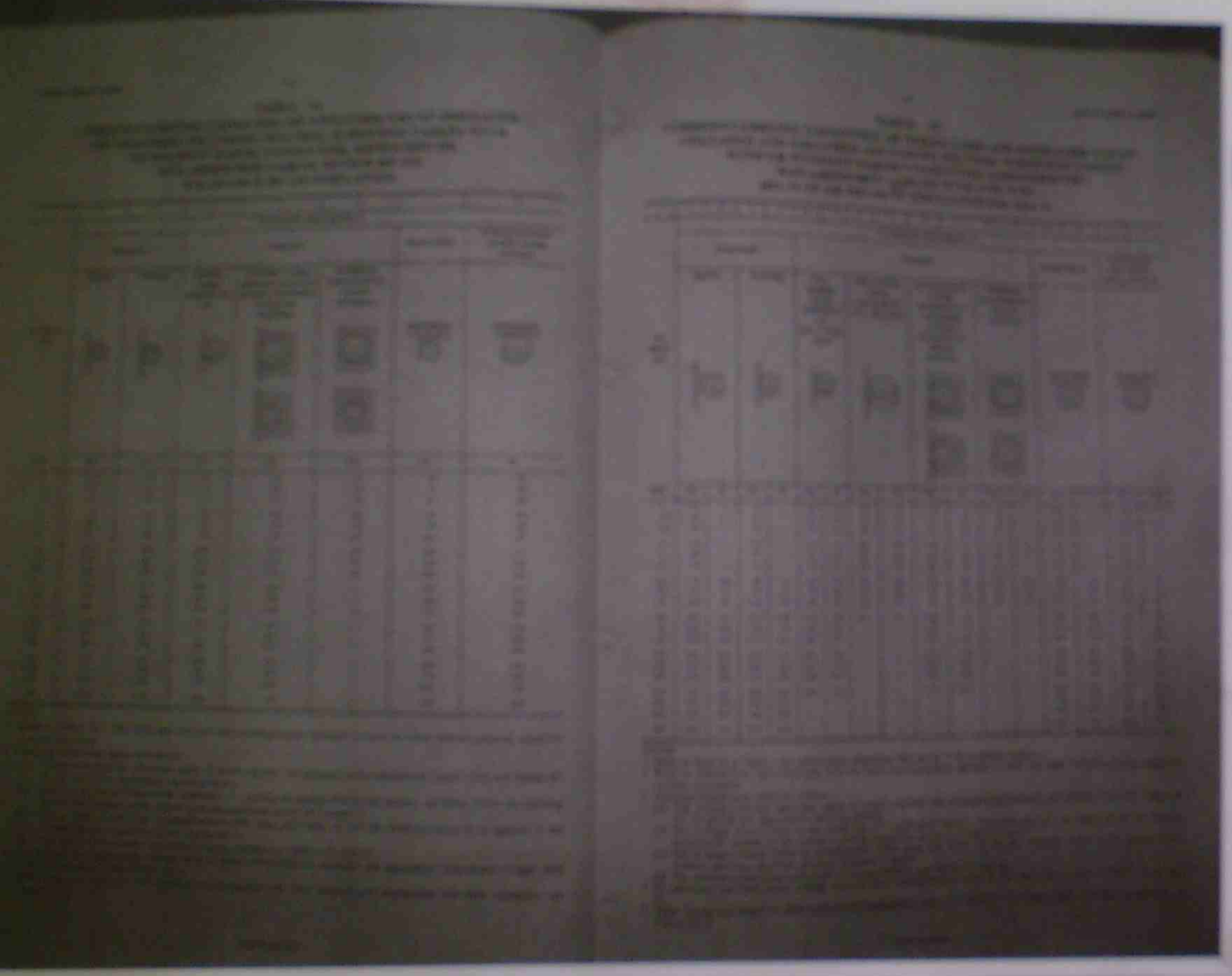
TABLE (1) →

TABLE (12)

↓



COLUMN 4



COL 4

↓

185 ← 325A

mm^2

↑

CONDUCTOR SIZE

Pg 4 CIRCUITS CONSISTING OF 3 CORE VQ0 CIRCULAR NON ARMOURED INSULATED AND SHEATHED COPPER CONDUCTOR CABLES ARE BUNCHED TOGETHER IN CLOSED THROUGHING THE THROUGHING IS FIXED TO AN INTERNAL WALL IN HORIZONTAL POSITION OPEN TO AIR. EACH CIRCUIT IS TO CARRY 54 Amp WHEN PROTECTED BY CIRCUIT BREAKER.

THROUGHING - ENCLOSED → TABLE 2(2)

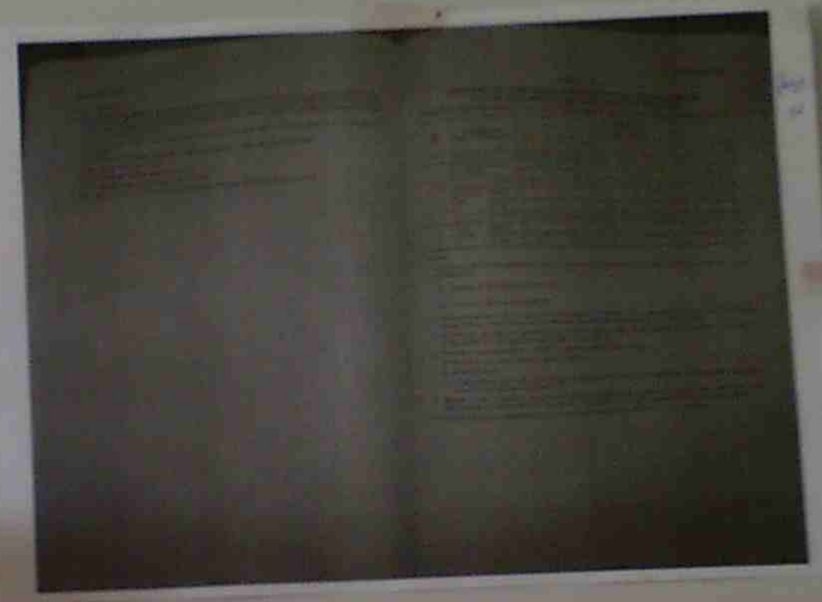
3 CORE - BUNCHED FIXED TO INTERNAL WALL - ITEM (8) → IN A WALL

↓

DERATING TABLE (22)

↳ TABLE (12) COLUMN (6 → 9)

DERATING TABLE (22), 4 CIRCUITS COLUMN (7)



$$\text{DERATED CURRENT CAPACITY} = \frac{\text{GIVEN CURRENT}}{\text{DERATED FACTOR}}$$

$$= \frac{54}{0.65} = 83\text{A}$$

TABLE (12)

CSA	COL 6
35 mm²	83A

DERATED MAXIMUM DEMAND FOR HRC FUSE PROTECTION

P11 A FACTORY INSTALLATION HAS A 3φ 400V SUPPLY WHICH HAS A MULTIPLE EARTHED NEUTRAL CONNECTION. THE GREATEST PORTION OF MAXIMUM DEMAND CURRENT 180A IS BALANCED OVER 3φ. THE ACTIVE CONDUCTORS ARE 3 SINGLE CORE, NON ARMOURED V90 INSULATED AND SHEATHED CIRCULAR CABLE WITH COPPER CONDUCTORS. INSTALLATION OF THE CABLES PLACES THEM IN RIGID THERMOPLASTIC CONDUIT, BURIED IN THE GROUND AT 500 mm DEPTH WHERE AMBIENT SOIL TEMPERATURE IS 25°C. THE CABLES ARE PROTECTED BY C.B. DETERMINE THE MINIMUM CONDUCTOR SIZE FOR THE NEUTRAL CONDUCTORS.

BURIED IN GROUND WITH WIRING ENCLOSURE (RIGID THERMOPLASTICS)

↓

TABLE (4.) → TABLE 27/28(2)
FOR DEPTH — FOR ENCLOSURE

TABLE 28(2)

SINGLE CORE, 500mm → SINGLE CORE DERATING FACTOR = 1

CURRENT = $\frac{180A}{DF=1}$ = 180 A

→ 3 SINGLE CORE → TABLE 6/7 COL 16/17

FOR V90 → 6 COL 16/17

→ COPPER 180A → SIZE 70mm²

FOR $I_{NEUTRAL} = \frac{180}{3} = 60A$

AS 3.5.2 (b)

TABLE 6, COL 16 → 16A → 10mm²

DERATED MAXIMUM DEMAND FOR HRC FUSE PROTECTION

P11 A FACTORY INSTALLATION HAS A 3φ 400V SUPPLY WHICH HAS A MULTIPLE EARTHED NEUTRAL CONNECTION. THE GREATEST PORTION OF MAXIMUM DEMAND CURRENT 180A IS BALANCED OVER 3φ. THE ACTIVE CONDUCTORS ARE 3 SINGLE CORE, NON ARMOURED V90 INSULATED AND SHEATHED CIRCULAR CABLE WITH COPPER CONDUCTORS. INSTALLATION OF THE CABLES PLACES THEM IN RIGID THERMOPLASTIC CONDUIT, BURIED IN THE GROUND AT 500 mm DEPTH WHERE AMBIENT SOIL TEMPERATURE IS 25°C. THE CABLES ARE PROTECTED BY C.B. DETERMINE THE MINIMUM CONDUCTOR SIZE FOR THE NEUTRAL CONDUCTORS.

BURIED IN GROUND WITH WIRING ENCLOSURE (RIGID THERMOPLASTICS)

TABLE (4) → TABLE 27/28(2)
FOR DEPTH — FOR ENCLOSURE

TABLE 28(2)

SINGLE CORE, 500 mm → SINGLE CORE

CURRENT = $\frac{180A}{DF=1}$ = 180 A DERATING FACTOR = 1

→ 3 SINGLE CORES → TABLE 6/7 COL 16/17

FOR V90 → 6 COL 16/17

→ COPPER 180A → SIZE 70 mm²

FOR $I_{NEUTRAL} = \frac{180}{3} = 60A$

AS 3.5.2 (6)

TABLE 6, COL 16 → 160A

→ 70 mm²

FINAL SUB CIRCUIT
FAULT LOOP IMPEDANCE

pb A FINAL SUB CIRCUIT SUPPLIES A LOAD CONSISTING OF A RANGE IN A DOMESTIC INSTALLATION AND IS PROTECTED BY 32 A TYPE (C) CB. DETERMINE THE MAXIMUM INTERNAL FAULT LOOP IMPEDANCE OF FINAL SUB CIRCUIT BASED ON 230V WHEN SUPPLY IS UNAVAILABLE

TABLE B 4.1 32A → TYPE(C)
NO LOAD 80%
0.96 × 0.8 = 0.768Ω

Pb A FINAL SUB CIRCUIT SUPPLIES A LOAD CONSISTING OF IS A SOCKET OUTLET & IS PROTECTED BY 25A HRC FUSE.
DETERMINE THE MAXIMUM INTERNAL FAULT LOOP IMPEDANCE OF FINAL SUB CIRCUIT BASED ON 230V WHEN SUPPLY IS UNAVAILABLE IS 0.4Ω

HRC FUSE 25A → 1.64 × 0.8 = 1.31Ω

FAULT CURRENT

ACTIVE → SWITCH

EARTH → EARTH LINK → NEUTRAL LINK → NEUTRAL

USE AS 3000 AND AS/NZS 3008

CSA mm²	CABLE TYPE	INSTALLATION	CURRENT	TABLE COLUMN
2.5	2 CORE m MS	SERVICE DUCT	1404	14 / 3
185	3 SINGLE CORE V75 SHEATH	SINGLE CKT DUCTED IN U.G DUCT	520	T.2(1) I 3 T4 C14
35	2 CORE FLEXI PTFE	UNENCLOSED IN AIR	265	T13 COL2
2.5	SINGLE CORE 5D1	6 CKT GROUP IN FREE AIR	16A	T2(1) I3 T6, C4

6003 + 6004 + 6007 PART (2)

(1) CABLE SELECTION

SLIDE (1) ⟶ (17)

Q1 ⟶ Q4

(2) DERATING FACTOR

SLIDE (1) ⟶ (15)

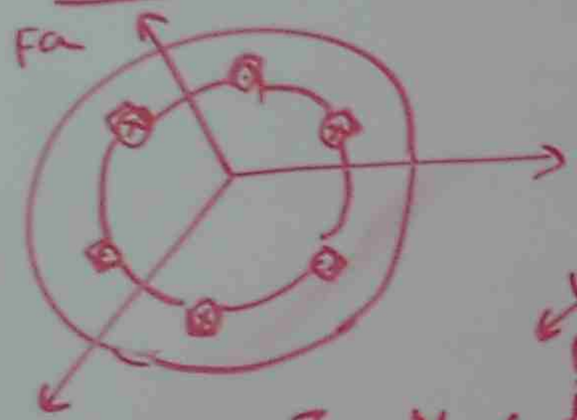
Q 5 ⟶ Q 13

(3) FINAL SUB CIRCUIT, FAULT LOOP IMPEDANCE RCD

SLIDE (1) ⟶ (10)

Q 14 ⟶ Q 25

(1) AC MACHINE INTRODUCTION

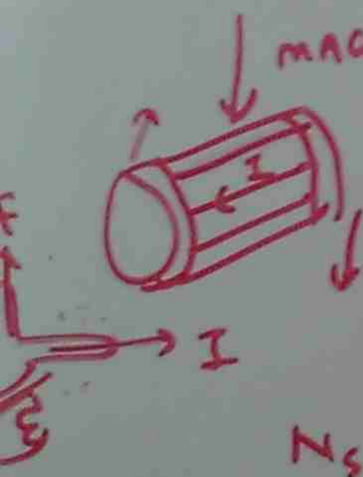


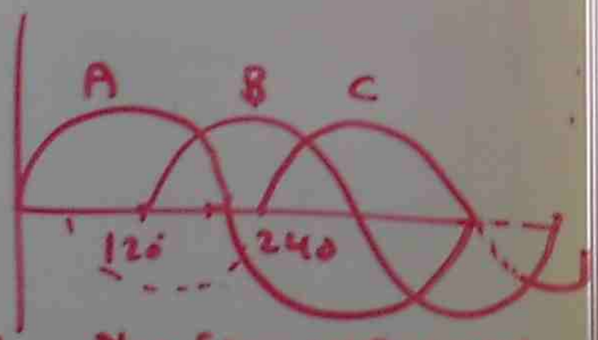
$$f_a = \frac{I_m N}{2}\left(e^{j\omega t} + e^{-j\omega t}\right) e^{j0}$$

$$f_b = \frac{I_m N}{2}\left(e^{j\omega t} + e^{-j\omega t}\right) e^{j(\omega t - \frac{4\pi}{3})}$$

$$f_c = \frac{I_m N}{2}\left(e^{j\omega t} + e^{-j\omega t}\right) e^{j(\omega t + \frac{4\pi}{3})}$$

$$F = 3\,\frac{I_m N}{2}\, e^{j\omega t}$$





$$N_s = \frac{120 f}{P}$$

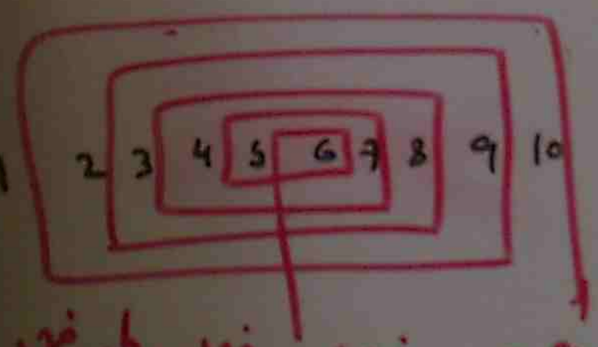
N_s = SYNCHRONOUS SPEED
f = FREQUENCY
P = NO. OF POLES

- THE REVOLVING FIELD CREATED BY THE STATOR CUTS ACROSS THE ROTOR BARS AND INDUCED VOLTAGES IN ALL OF THEM.
- BECAUSE THE ROTOR BARS ARE SHORT CIRCUITED BY END RINGS, THE VOLTAGE CAUSES A LARGE CURRENT TO FLOW.
- THE CURRENT CARRYING CONDUCTORS IN THE PATH OF FLUX CREATED BY THE STATOR, THEY ALL EXPERIENCE A STRONG MECHANICAL FORCE

DESIGN 3φ 4 POLES 36 SLOT 50HZ WINDING

$$\text{COIL SPAN} = \frac{\text{NO. OF SLOT}}{\text{NO. OF POLE}} = \frac{36}{4} = 9$$

1 (+9) 10 (+9) 20 (+9) 30 (+9) $40 - \frac{36}{4}$

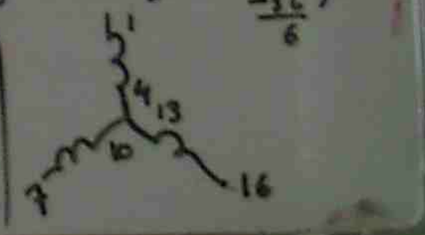


1 → 10, 11 → 20, 21 → 30, 31 → 4 (+6)
7 → 16, 17 → 26, 27 → 36, 1 → 10 (+6)
13 → 22, 23 → 33, 33 → $\frac{42}{-36}$, 7 → 16 $\frac{}{6}$



180° → 9 SLOT

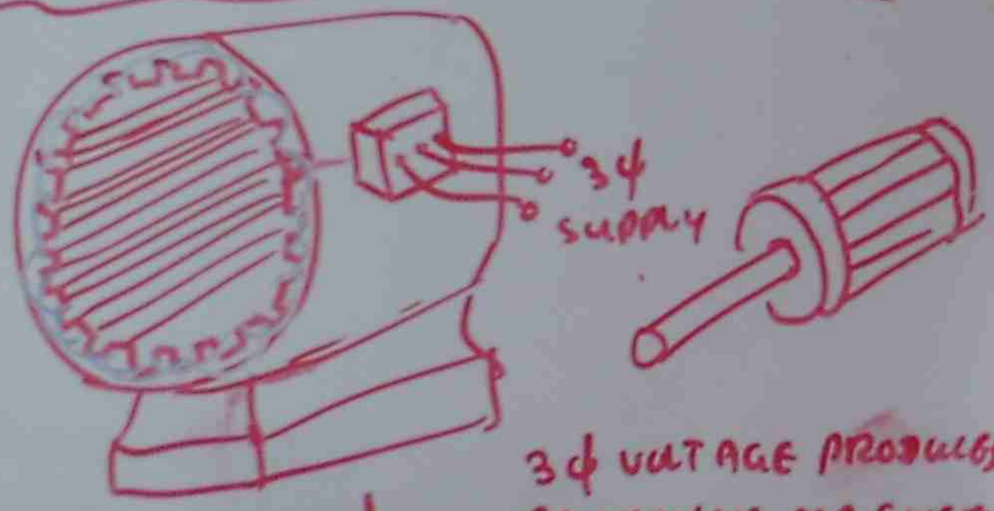
120° → $? = 9 \times \frac{120}{180} = 6$



REVERSING 3C MOTOR

REVERSE THE CONNECTION OF FIELD WINDING.

SQUIRREL CAGE INDUCTION MOTOR



3φ VOLTAGE PRODUCES REVOLVING MAGNETIC FIELD.



FIELD CUTS ROTOR BARS INDUCED CURRENT IN ROTOR BARS

ROTOR BAR REVOLVING FIELD INTERACTS WITH SUPPLY FIELD. MOTOR REVOLVES

$N_S = \frac{120f}{P}$



P = 4 POLES

REVERSING 3φ MOTOR - REVERSE THE CONNECTION OF ANY TWO TERMINALS

SLIP: $\frac{N_S - N_r}{N_S}$ /

PD CALCULATE THE SPEED IN RPM OF 2 POLES 25 HZ MOTOR

$N_S = \frac{120f}{P} = \frac{120 \times 25}{2} = 1500$ RPM

PD THE MEASURED SPEED OF 3φ 415V 50HZ 2 POLE MOTOR IS 2700 RPM. CALCULATE SLIP & % SLIP

$N_S = \frac{120f}{P} = \frac{120 \times 50}{2} = 3000$ RPM

$SLIP = \frac{N_S - N_r}{N_S} = \frac{3000 - 2700}{3000} = \frac{300}{3000} = 0.1$

% SLIP = 10%

STARTING CURRENT — 2-5 → 6 TIMES FULL LOAD CURRENT

REDUCED VOLTAGE STARTER IS REQUIRED TO REDUCE CURRENT AT STARTING

(S) MULTI PHASE SYSTEM, AC - DC MOTOR INDUCTION MOTOR

SLIDE 1 → 16 @ 51 → @ 66

G008 GENERAL NOTE (2)

DETECTING THE VOLTAGE

TEST LEADS - ADEQUATELY INSULATED

PROTECT TEST BULB FROM MECHANICAL DAMAGE

WHENEVER THE TESTING DEVICE IS USED, TEST FOR IT'S CORRECT FUNCTIONING BEFORE THE TEST AND AGAINST AFTER THE TEST

- VISUAL CHECK BEFORE TEST

TECHNIQUE (1) EARTHING SYSTEM

TECHNIQUE (2) INSULATION RESISTANCE

TECHNIQUE (3) POLARITY

WATCH CIRCUIT TESTING VIDEO

www.advanced diploma electrical -zoomshare.com

G003 + G004 + G007

(4) CIRCUIT TESTING

SLIDE (1) → (18), Q26 → Q34

(5) CIRCUIT TESTING (2)

SLIDE (1) → (16), Q35 → Q39

G008 + G009

AC MACHINE

- VIDEO OF G043 + G045 - BASIC PRINCIPLE OF AC MOTOR (www.advanced diploma electrical-zoomshare.com UNDER G043 + G045

- www.1790817794-zoomshare.com G008 | G008 E Trade 1. ZIP

- www.advanced diploma electrical -zoomshare.com G008 + G009

(1) AC MACHINE

SLIDE (1) → (12), Q1 → Q9

AC MOTOR CONTROL

- VIDEO OF G043 + G045 - MOTOR CONTROL VIDEO OF E029 | G012

www.1790817794.zoomshare.com G008/ E Trade 1. ZIP { G009. ZIP

- www.advanced diploma electrical -zoomshare.com

(2) AC MOTOR CONTROL

SLIDE (1) → (18)

Q10 → Q20

SYNCHRONOUS MACHINE + DC MACHINE + TRANSFORMER

VIDEO OF 0044- DC MACHINE PRINCIPLE
VIDEO OF 0040- TRANSFORMER PRINCIPLE

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(3) SYNCHRONOUS MACHINE
+ DC MACHINE TRANSFORMER

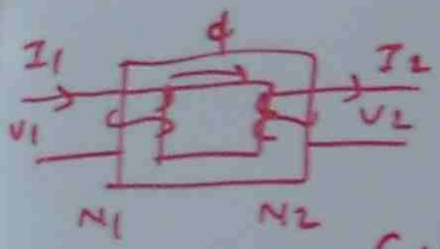
PAGE 1 → 7 - SYNCHRONOUS MACHINE Q1 → Q6
PAGE 8 → 15 DC MACHINE Q 12 → Q13
PAGE 16 → 32 TRANSFORMER
EXERCISE PAGE 20 → 31

(1) POWER TRANSFORMER RATING

TRANSFORMER RATING

VOLTAGE RATING | CURRENT RATING | V.A RATING

$$\text{RATED CURRENT} = \frac{\text{V.A RATING}}{\text{VOLTAGE RATING}}$$



$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a$$

TURN RATIO

N = NO. OF TURNS
ϕ = FLUX (Wb)
f = FREQUENCY

$E_{RMS} = 4.44\, f N \phi_{MAX}$ (VOLT)

$\phi = B \times A$

B = FLUX DENSITY (T)
A = C.S.A (m^2)

$$\%\ \text{VOLTAGE REGULATION} = \frac{V_{\text{NO LOAD}} - V_{\text{FULL LOAD}}}{V_{\text{FULL LOAD}}} \times 100$$



$N \times I = H \times l$

$N \times I = \sum H l$

l = LENGTH OF MAGNETIC CIRCUIT

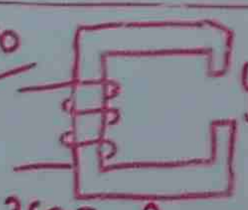
H = MAGNETIZING FORCE

$B = \mu \times H$ (μ = PERMEABILITY)

$\mu = \mu_0 \times \mu_r$

$\mu_0 = 4\pi \times 10^{-7}$

P10



N = 350 T $\hat{L}$ CORE LENGTH

B = 1.105 T 1250mm

CALCULATE CURRENT

μ_r STEEL = 1800

$NI = HL = H_{IRON} L_{IRON} + H_{AIR\ GAP} L_{AIR\ GAP}$

$$350 \times I = \frac{B}{\mu_0 \mu_r} L_{IRON} + \frac{B}{\mu_0} L_{AIR\ GAP}$$

$$350 \times I = \frac{1.105}{4\pi \times 10^{-7} \times 1800} \times \frac{1250}{1000} + \frac{1.105}{4\pi \times 10^{-7}} \times \frac{0.15}{1000}$$

$I = 2.1\ A$

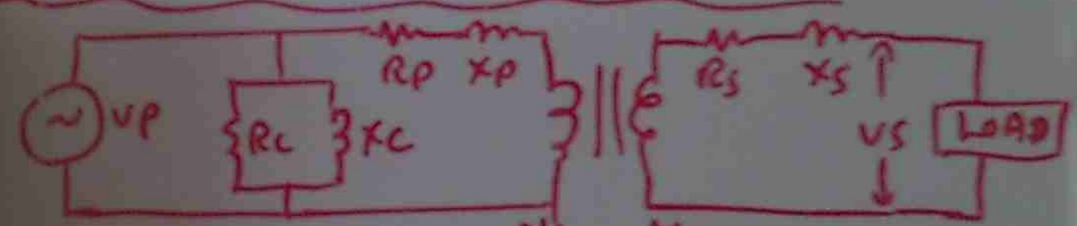
(2) LOSSES IN TRANSFORMER

TOTAL LOSSES

IRON LOSS | COPPER LOSS (PRIMARY, SECONDARY)

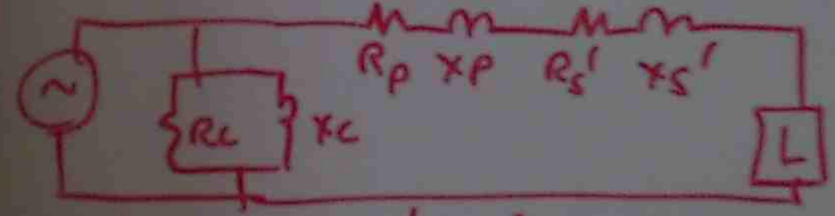
IRON LOSS: EDDY CURRENT LOSS | HYSTERESIS LOSS

TRANSFORMER EQUIVALENT CIRCUIT



$$\frac{R_P}{R_S} = \frac{X_P}{X_S} = a^2$$

$$a = \frac{N_1}{N_2}$$

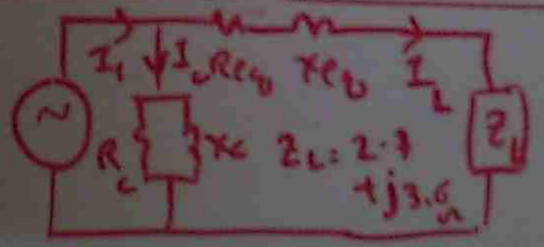


$R_S' = a^2 R_S$, $X_S' = a^2 X_S$

$R_e = R_P + R_S' = R_P + a^2 R_S$

$X_e = X_P + X_S' = X_P + a^2 X_S$

P9



$R_{eB} = 0.3\ \Omega$

$X_{eB} = 0.4\ \Omega$

$R_C = 200\ \Omega$

$X_C = 200\ \Omega$

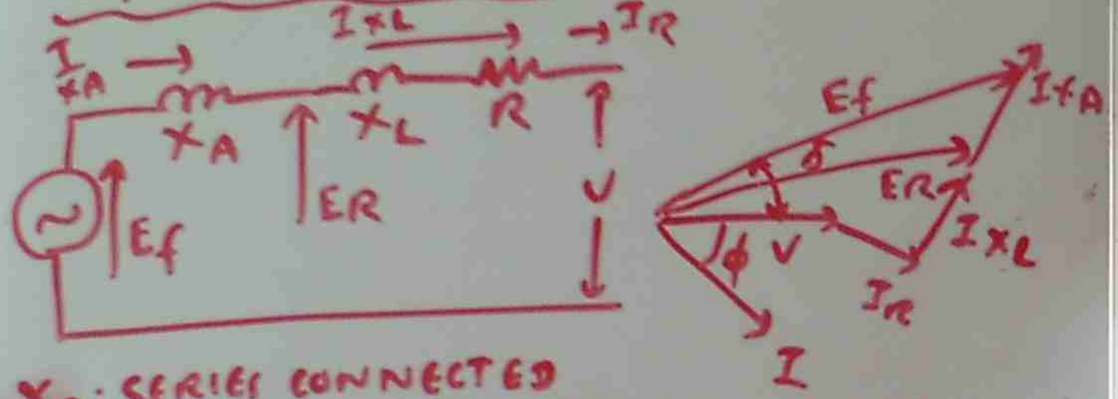
$V = 200\ V$

FIND
I_L
I_C,
I
COPPER LOSS

IRON LOSS

SYNCHRONOUS MACHINES

SYNCHRONOUS GENERATOR



X_A: SERIES CONNECTED REACTANCE OF VOLTAGE WINDING

X_L - LEAKAGE REACTANCE OF VOLTAGE WINDING

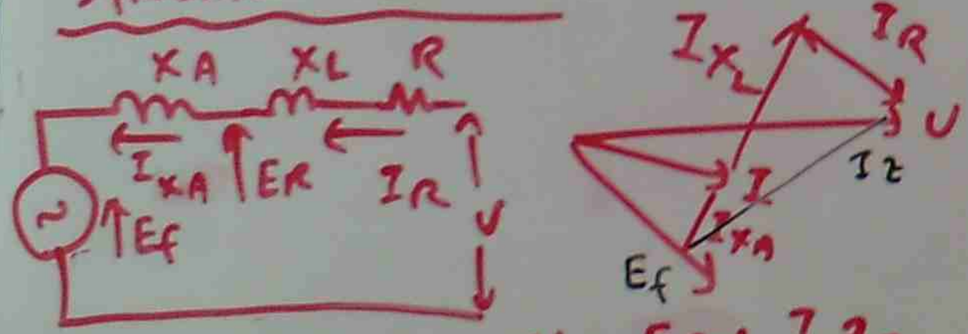
R - RESISTANCE OF VOLTAGE WINDING

V - TERMINAL VOLTAGE, E_f - GENERATED VOLTAGE

$$E_f = V + I Z_s = V + I (R + j(X_L + X_A))$$

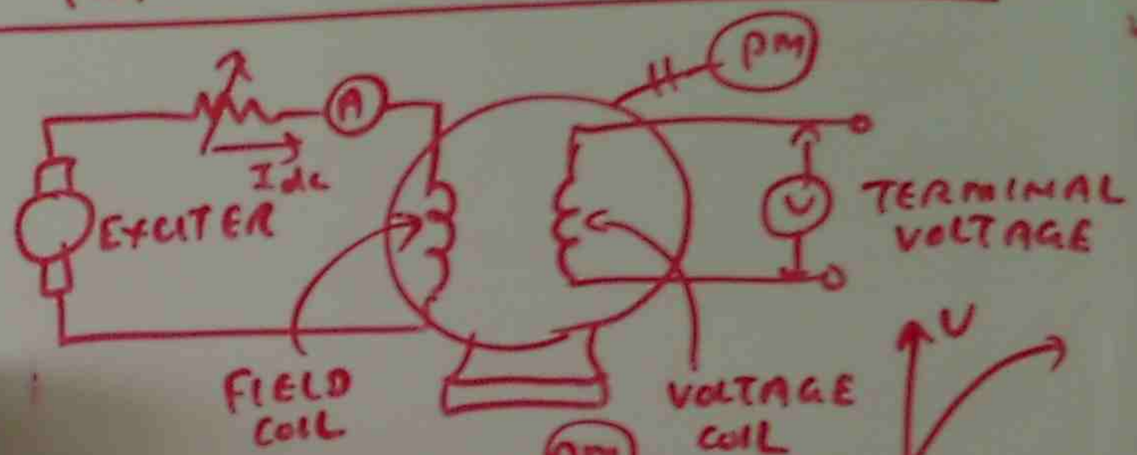
$$Z_s = R + j(X_L + X_A)$$

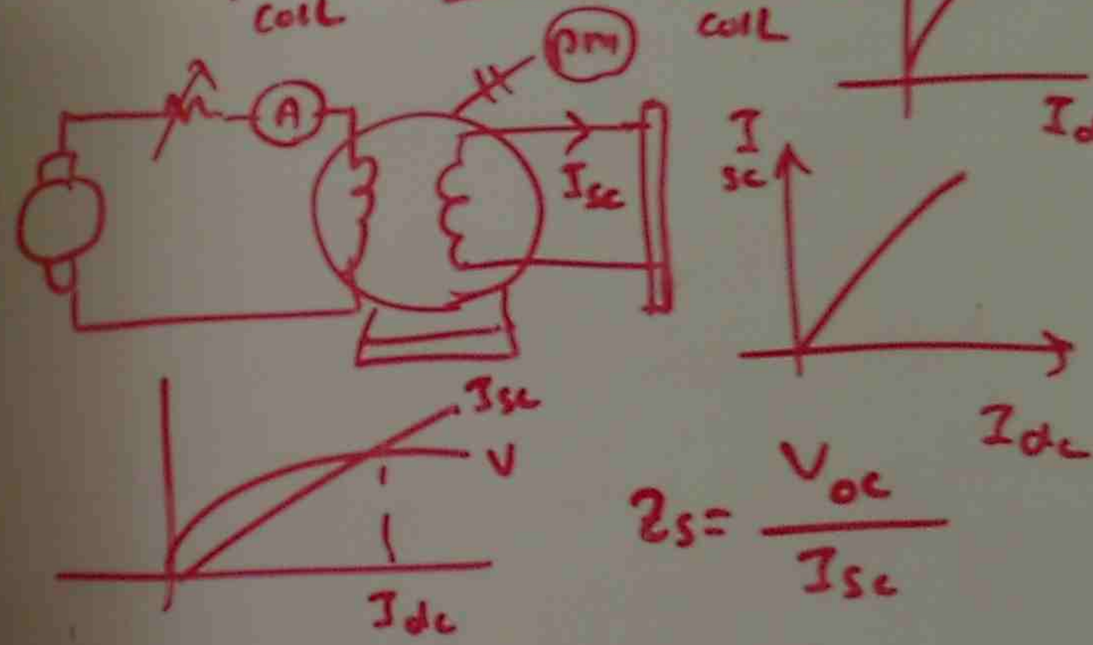
SYNCHRONOUS MOTOR



$$V = E_f + I Z_s$$

DETERMINATION of SYNCHRONOUS IMPEDANCE





$$Z_s = \frac{V_{oc}}{I_{sc}}$$

$$Z_s = \frac{E_f - V}{I}$$

$$\text{VOLTAGE REGULATION} = \frac{E_f - V}{V} \times 100\ \%$$

SYNCHRONOUS MACHINE + DC MACHINE + TRANSFORMER

VIDEO of 4044- DC MACHINE PRINCIPLE
VIDEO of 4040- TRANSFORMER PRINCIPLE

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(3) SYNCHRONOUS MACHINE
+ DC MACHINE TRANSFORMER

PAGE 1 → 7 - SYNCHRONOUS MACHINE Q1 → Q6
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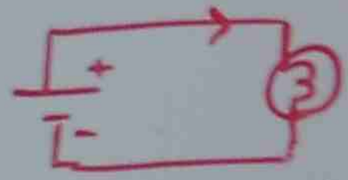
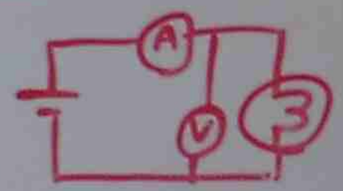
PAGE 16 → 32 TRANSFORMER
EXERCISE PAGE 20 → 31

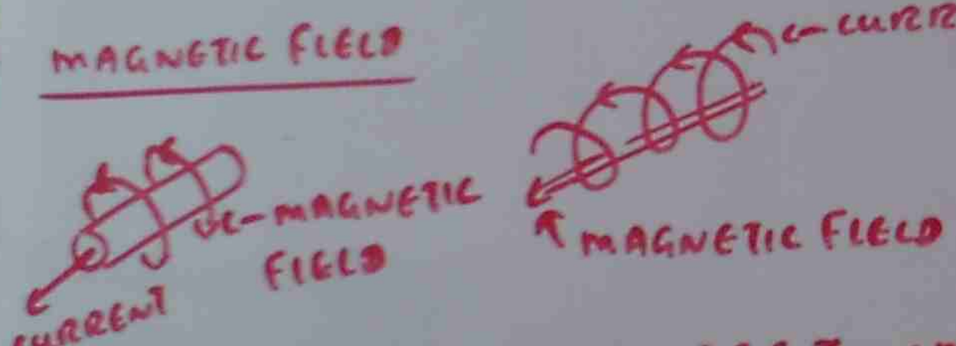
GOI2 ELECTRICAL FUNDAMENTAL

(1) ELECTRICAL COMPONENTS + ENERGY & POWER





MAGNETIC FIELD



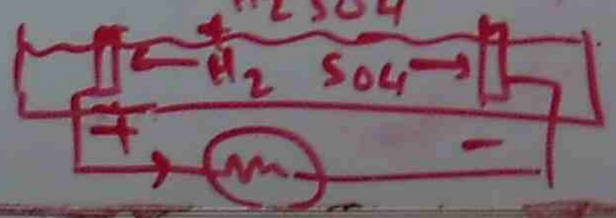
MAGNETIC EFFECT → CURRENT → MAGNETIC FLUX

PIEZO ELECTRIC EFFECT → MOVEMENT → ELECTRIC

CHEMICAL EFFECT → CHEMICAL REACTION
↳ ELECTRIC CURRENT FLOW

HEAT EFFECT → ELECTRICITY → HEATING

BATTERY – LEAD / LEAD PER OXIDE
– H_2SO_4



ELECTRICAL COMPONENTS

RESISTOR, INDUCTOR, CAPACITOR, SEMI CONDUCTOR

WORK = FORCE × DISTANCE (JOULE)

POWER = $\frac{\text{WORK}}{\text{TIME}}$

ELECTRICAL POWER = VOLTAGE × CURRENT = $\frac{(\text{VOLTAGE})^2}{\text{RESISTANCE}}$
$= (\text{CURRENT})^2 \times \text{RESISTANCE}$

ELECTRICAL ENERGY = POWER × TIME

JOULES = WATT × SEC

KWH = KILOWATT × HR

Pa A MOTOR CONSUMES 10 KW POWER WHEN CONNECTED TO 250V. CALCULATE CURRENT

$P = V \times I \rightarrow I = \frac{P}{V} = \frac{10 \times 10^3}{250} = \frac{10,000}{250} = 40A$

Pb A RESISTANCE 10Ω IS CONNECTED TO 90V DC SUPPLY (a) FIND CURRENT (b) POWER

(a) $IR = V \rightarrow I = \frac{V}{R} = \frac{90}{10} = 9A$

(b) $P = I^2R = 9^2 \times 10 = 810W$

(1) ELECTRICAL COMPONENTS + ENERGY & POWER

SLIDE 1 → 16, Q1 → Q17

(2) INDUSTRIAL ELECTRICAL APPLICATION

- MAGNETIC – MOTOR / TRANSFORMER
- HEATING – INDUSTRIAL OVEN
- CHEMICAL – BATTERY PLANT
- SENSORS IN BUILDING – FIRE ALARM, SMOKE ALARM

AMPLIFIER

AMPLIFY INPUT SIGNAL / CURRENT / POWER

$dB(V) = 20 \log \frac{V_2}{V_1}$, $dB(I) = 20 \log \frac{I_2}{I_1}$

$dB(P) = 10 \log \frac{P_2}{P_1}$

$I_1 \; V_1 \xrightarrow{P_1} \boxed{\text{AMPLIFIER}} \rightarrow I_2 \; V_2 \; P_2$

POWER GENERATION

DRIVING FORCE → MOVEMENT OF CONDUCTOR ⇒ OUTPUT ELECTRICAL POWER

↑ DC FIELD EXCITATION (MAGNETISATION)

$\text{EFFICIENCY} = \frac{\text{OUTPUT}}{\text{INPUT}} \times 100$

ENERGY CONVERSION

HYDRO STATION → POTENTIAL ENERGY → ELECTRICAL

CAR ENGINE → HEAT → MECHANICAL

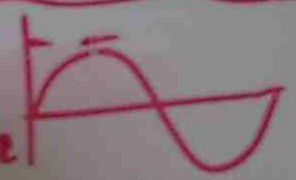
GENERATOR → MECHANICAL → ELECTRICAL

Pb A POWER STATION IS SUPPLYING 1MW AT 10K V, FIND (a) CURRENT (b) IF LINE IMPEDANCE IS 0.1Ω/km FOR 200km FIND LINE DROP.

(a) $P = V \times I \rightarrow I = \frac{P}{V} = \frac{1 \times 10^6}{10 \times 10^3} = 100\,A$

(b) $V = I \times Z = 100 \times 0.1 \times 200 = 100 \times 20 = 2000\,V$

Pb



$f = 100\,Hz$

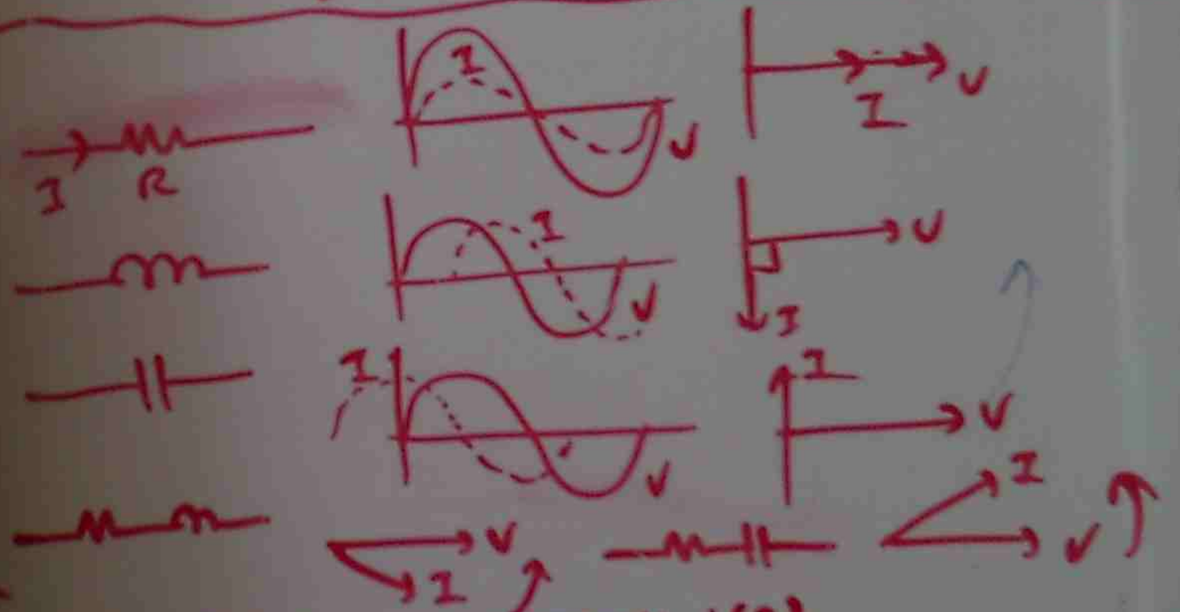
$\bar{V}$ ↑ 100V ↓

FIND (a) V_{MAX} (b) V_{rms} (c) T

(a) $V_{MAX} = 100V$

(b) $V_{rms} = \frac{\bar{V}_{MAX}}{\sqrt{2}} = \frac{100}{\sqrt{2}} = 90.7\,V$

(c) $T = \frac{1}{f} = \frac{1}{100} = 0.01\,sec$



(2) INDUSTRIAL ELECTRICAL APPLICATION

SLIDE(1) → (6) | Q18 → Q22

(3) SLIDE (1) → 12

Q23 → Q37

(4) TRANSFORMER, VOLTAGE REGULATION INDUCTANCE, CAPACITANCE, POWER, P.F



$V_1 = N_1 \frac{d\phi}{dt}$, $V_2 = N_2 \frac{d\phi}{dt}$

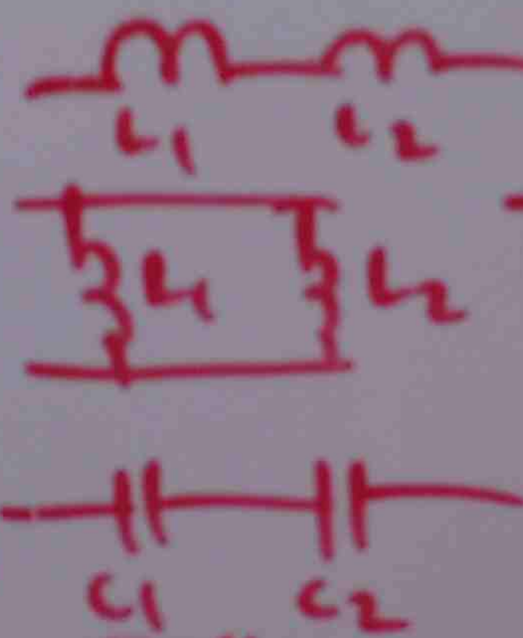
$\frac{V_1}{V_2} = \frac{N_1}{N_2}$, $\frac{I_2}{I_1} = \frac{N_1}{N_2}$

VOLTAGE REGULATION $= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

$PF = \cos\theta$

$P = V + I \cos\theta$

(4) SLIDE 1 → 15
Q 38 → Q 50



$= L_T = L_1 + L_2$

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2}$

$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$



$C_T = C_1 + C_2$

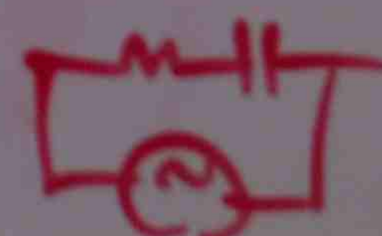


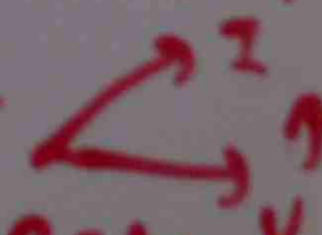
$PF = 1$





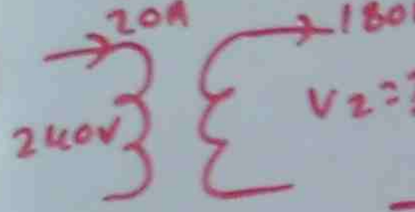
PF-LAG





PF LEAD

Pb A WELDER NEEDS TO HAVE 180A OUTPUT & IS CONNECTED TO 240A, 20A SUPPLY. WHAT IS TURN RATIO. FIND THE VOLTAGE APPLIED TO ELECTRODE



$I_1 = 20A$, $I_2 = 180A$

$V_1 = 240V$, $V_2 = ?$

$$\frac{I_2}{I_1} = a = \frac{180}{20} = 9$$

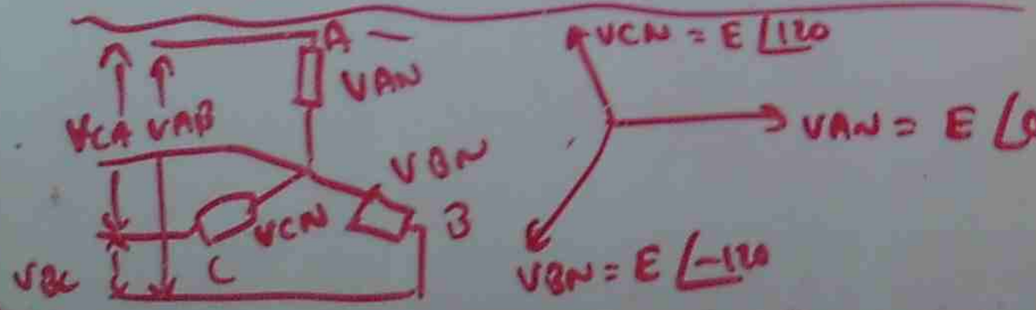
$$\frac{V_1}{V_2} = a \rightarrow \frac{240}{V_2} = 9 \quad V_2 = \frac{240}{9} = 26.6V$$

Pb FOR SUPPLY VOLTAGE 240V, 4KW LOAD CALCULATE CURRENT FOR $\phi = 60°$

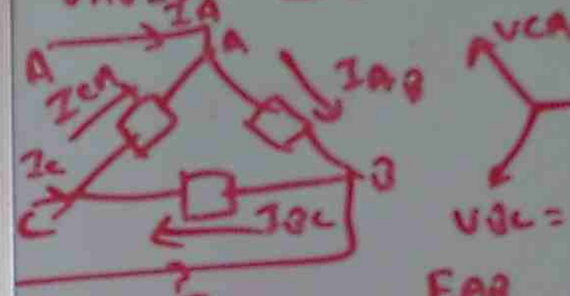
$$P = VI\cos\theta \rightarrow I = \frac{P}{V\cos\theta} = \frac{4000}{240 \times \cos\theta}$$

$$I = \frac{4000}{240 \times \frac{1}{2}} = \frac{4000}{120} = 33.3\ A$$

(5) MULTIPHASE SYSTEM, AC DC MOTOR INDUCTION MOTOR



$V_{AB} = \sqrt{3}E\angle 30$, $V_{BC} = \sqrt{3}E\angle -90$ $V_{CA} = \sqrt{3}E\angle 150$

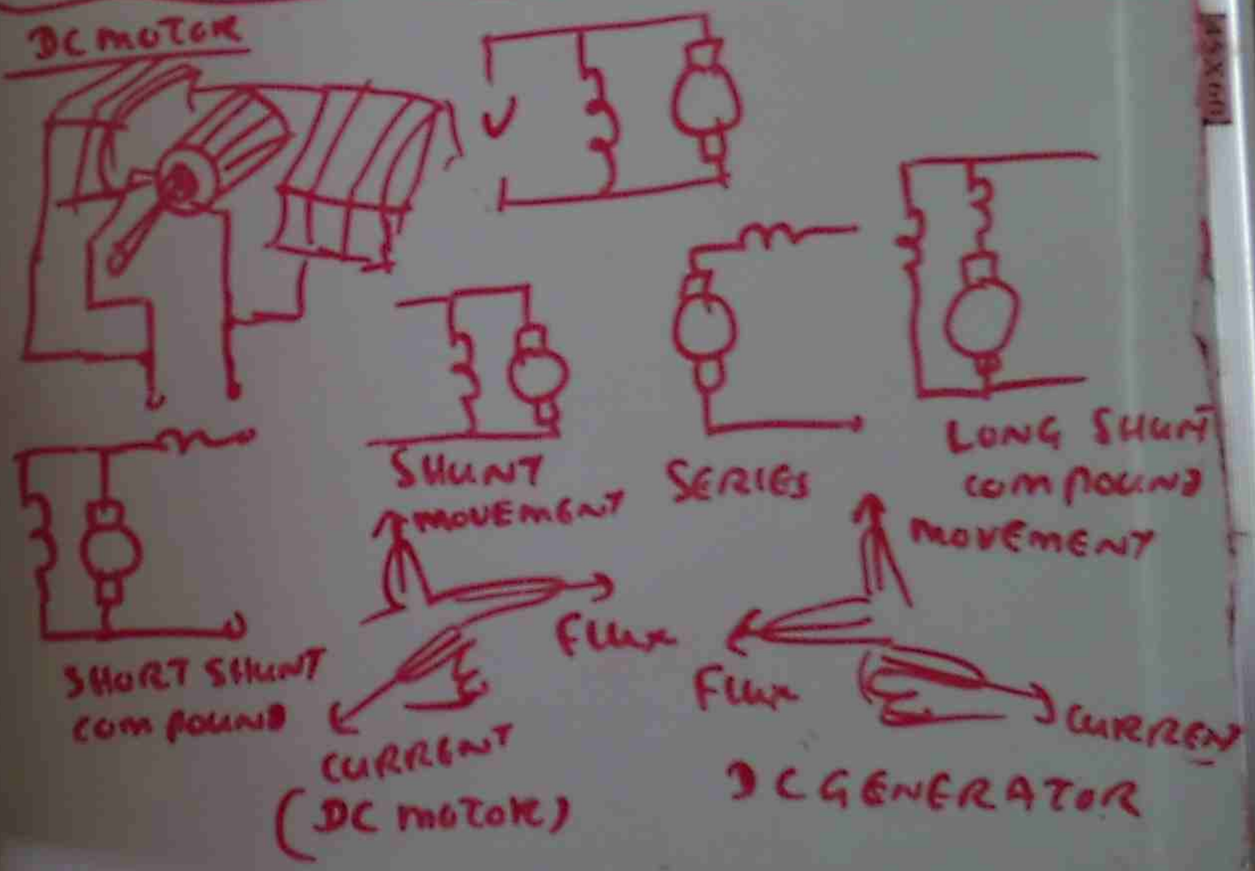


$$I_{AB} = \frac{E_{AB}}{Z_{AB}}, \quad I_{BC} = \frac{E_{BC}}{Z_{BC}}, \quad I_{CA} = \frac{E_{CA}}{Z_{CA}}$$

$I_A = I_{AB} - I_{CA}$, $I_B = I_{BC} - I_{AB}$, $I_C = I_{CA} - I_{BC}$

FOR BALANCED $I_A = I_B = I_C = \sqrt{3}\ I_{PH}$

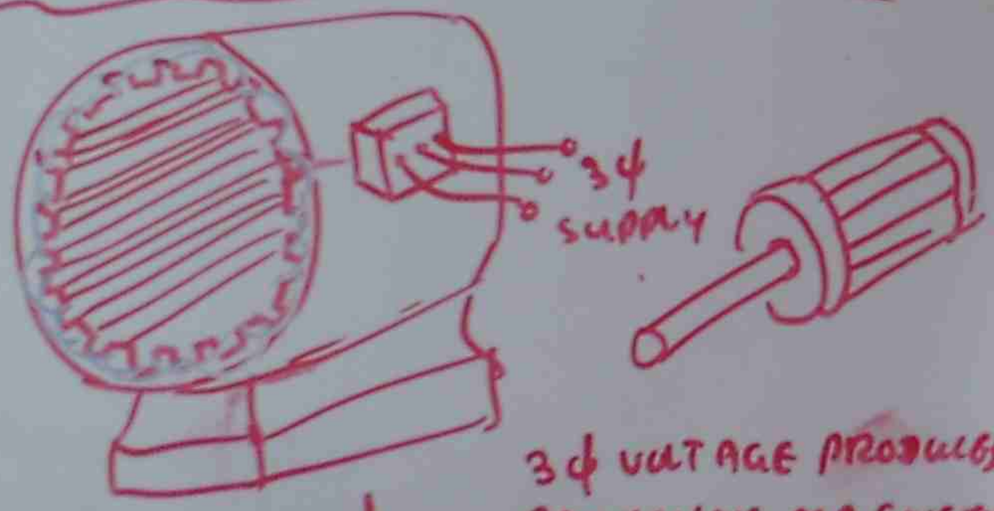
DC MOTOR



REVERSING 3C MOTOR

REVERSE THE CONNECTION OF FIELD WINDING.

SQUIRREL CAGE INDUCTION MOTOR



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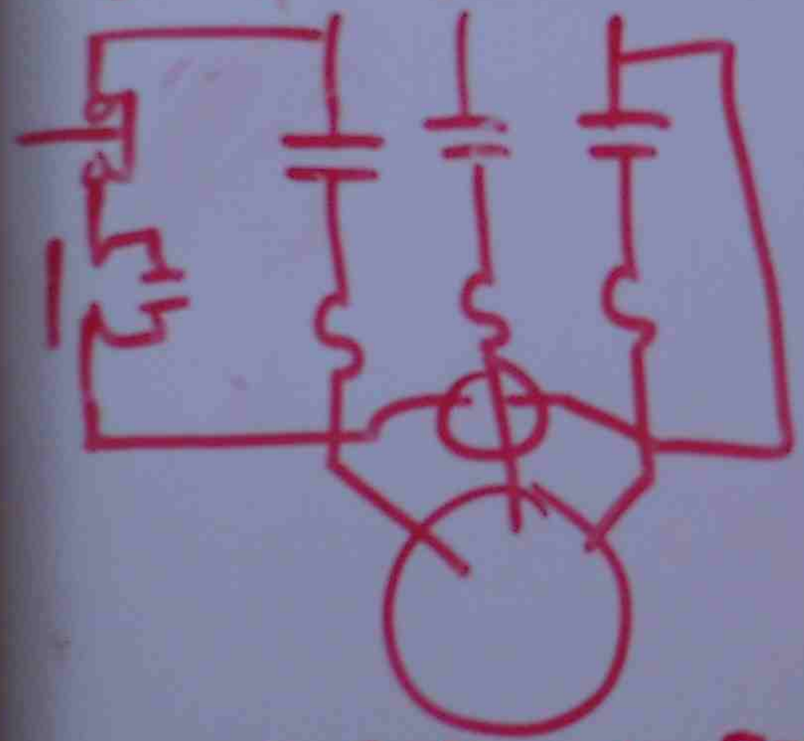
(S) MULTI PHASE SYSTEM, AC - DC MOTOR INDUCTION MOTOR

SLIDE 1 → 16 @ 51 → @ 66

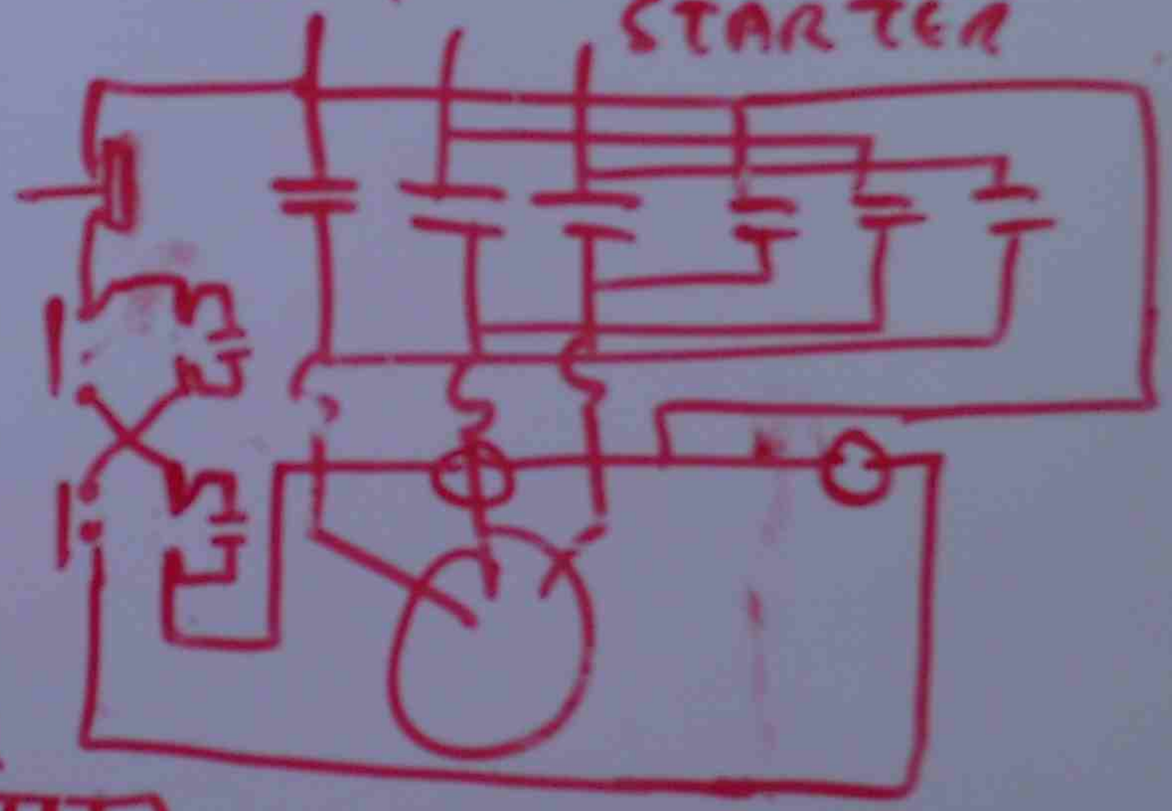
(G) MOTOR STARTING - WOUND ROTOR MOTOR

MOTOR CONSTRUCTION

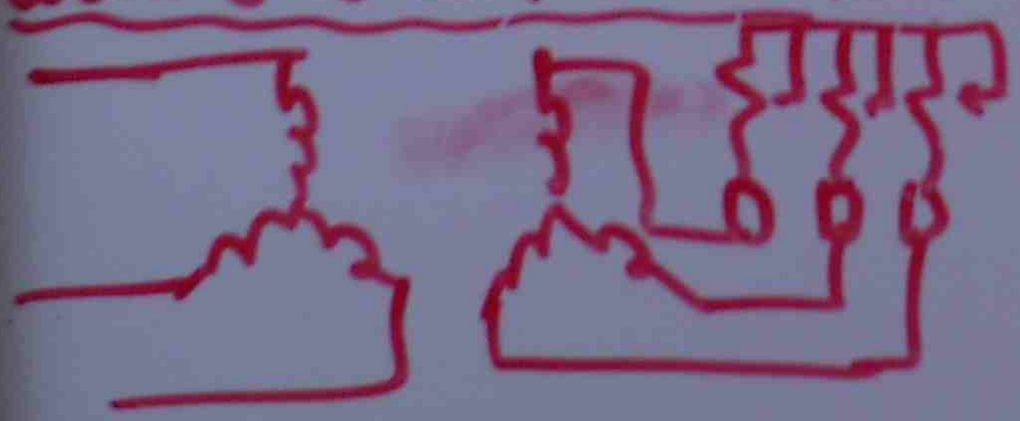
DIRECT ON LINE STARTER

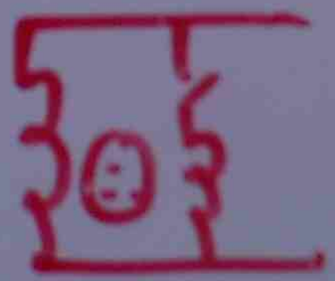


FORWARD/REVERSE STARTER



WOUND ROTOR MOTOR





SPLIT PHASE MOTOR

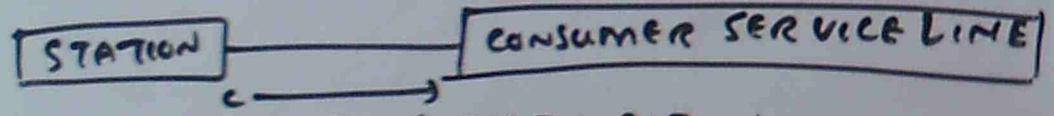
SLIDE
1 → 10
$Q_{67} \rightarrow Q_{73}$

ELECTRICAL DISTRIBUTION

EQUIPMENTS CONTAINED IN ELECTRICAL DISTRIBUTION SYSTEM

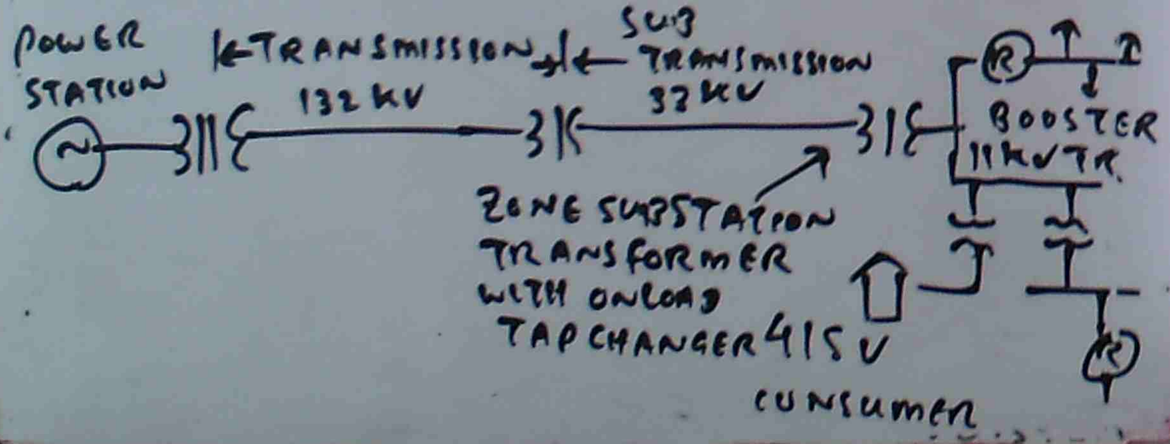
- POWER GENERATING EQUIPMENTS
- PRIMARY AND SECONDARY DISTRIBUTION SYSTEM
  - FEEDERS, TRANSFORMERS, SWITCH GEARS, STAND BY GENERATOR
- MOTOR DRIVES, HEATERS, OVEN
- ELECTRICAL & ELECTRONIC CONTROL SYSTEM
- AUXILIARY SYSTEM
- COMMUNICATION EQUIPMENTS.

LIMIT OF DISTRIBUTION

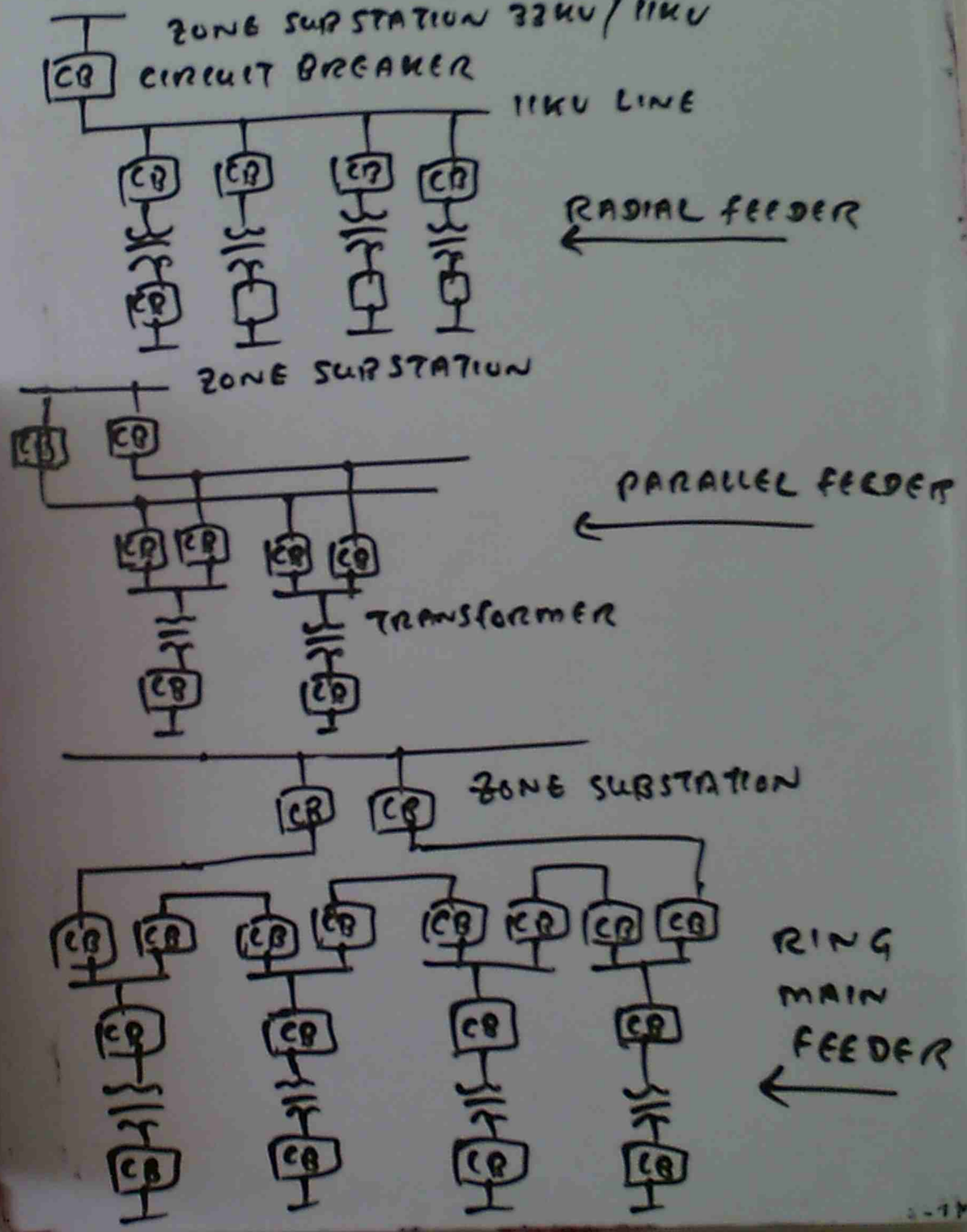


STANDARD VOLTAGES for 3ϕ SYSTEM

415V, 240V, 11KV, 22KV, 33KV, 66KV



TYPES of FEEDERS



RESERVE, SPINNING RESERVE

DIVERSITY – LOAD CHANGES DURING A PERIOD OF TIME

$$\text{DEMAND FACTOR} = \frac{\text{MAXIMUM LOAD}}{\text{TOTAL CONNECTED LOAD}}$$

$$\text{CONCIDENT FACTOR} = \frac{\text{MAXIMUM CONDINCIDENT TOTAL DEMAND OF A GROUP OF CONSUMERS}}{\text{SUM OF MAXIMUM DEMANDS OF EACH OF CONSUMERS}}$$

$$\text{UTILIZATION FACTOR} = \frac{\text{MAXIMUM DEMAND OF THE SYSTEM}}{\text{RATED CAPACITY OF THE SYSTEM}}$$

$$\text{DIVERSITY FACTOR} = \frac{\text{SUM OF MAXIMUM DEMANDS OF EACH OF THE COMPONENT LOAD}}{\text{MAXIMUM DEMAND OF THE LOAD AS WHOLE}}$$

$$\text{DIVERSITY FACTOR} = \frac{\text{SUM OF INDIVIDUAL MAXIMUM DEMANDS}}{\text{MAXIMUM DEMAND OF TRANSFORMER}}$$

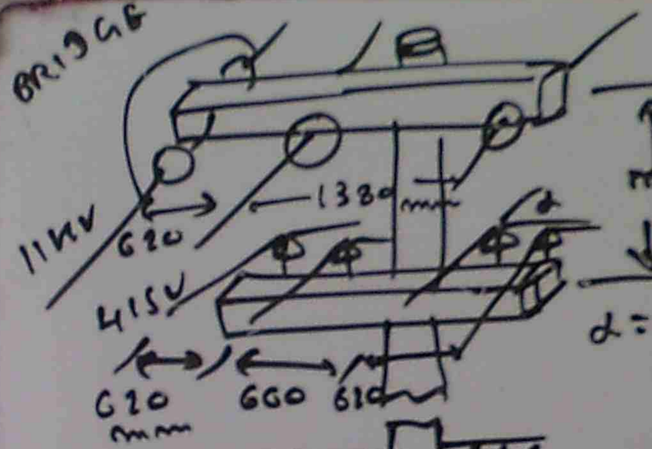
---

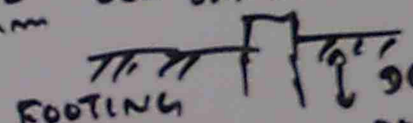
pb A TRANSFORMER SUPPLIES A GROUP OF 4 FEEDERS WHICH HAVE INDIVIDUAL MAXIMUM DEMANDS OF 2.5, 2.4, 4.3 AND 1.6 MUA. IF THE DIVERSITY FACTOR IS 1.82, DETERMINE THE MAXIMUM DEMAND ON TRANSFORMER

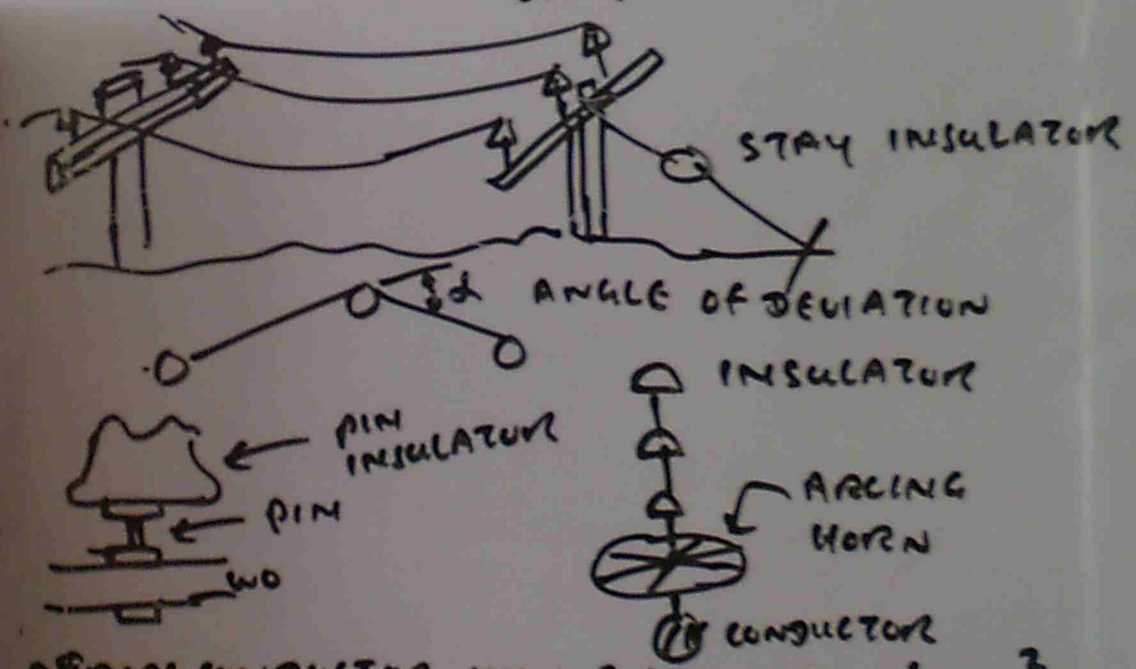
$$\text{DIVERSITY FACTOR} = \frac{\text{SUM OF INDIVIDUAL MAXIMUM DEMANDS}}{\text{MAXIMUM DEMAND OF TRANSFORMER}}$$

$$1.82 = \frac{2.5+2.4+4.3+1.6}{\text{M.D of TR}} \quad \Big| \quad \therefore \text{M.D of TR} = \frac{10.8}{1.82} = 5.93 \text{ MUA}$$

BRIDGE







AERIAL CONDUCTOR - MIN 7 STRANDS, 4mm² CSA

SIZE OF CONDUCTOR & SPAN RELATIONS OVER HEAD LINE CONDUCTORS

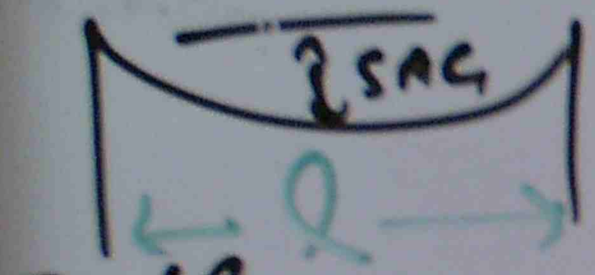
HARD DRAWN COPPER, AAC, AAAC, ACSR, GC/G2/S4/A

PROTECTION - GALVANIZING, COATING WITH ALUMINIUM

CURRENTI... - HEATING / VOLTAGE DROP / POWER LOSS

LINE INSULATOR SPECIFICATIONS | MAXIMUM TENSION

SAG OF CONDUCTOR



$$SAG = \frac{WL^2}{8T}$$

S = SAG IN METRE
L = LENGTH OF SPAN IN (m)
W = COMBINED LOAD OF WIND + CONDUCTOR WEIGHT
T - TENSION

P1) CALCULATE ALLOWABLE SAG OF 7/3.50 HARD DRAWN COPPER OVER HEAD LINE CONDUCTOR SPAN OF 150m. THE WIND LOADING IS 500 Pa. MINIMUM TENSION IS 50% OF ULTIMATE STRENGTH

ULTIMATE STRENGTH = 26600N
GRAVITATIONAL FORCE = 5.44 N/m
DIAMETER OF CONDUCTOR = 10.5 mm

WIND LOADING = DIAMETER × 1m × PRESSURE

1m $\quad W_A = \frac{10.5}{1000} \times 1 \times 500 = 5.25 \text{ N/m}$

$$W = \sqrt{W_C^2 + W_A^2} = \sqrt{5.44^2 + 5.25^2}$$

$$= 7.934 \text{ N/m}$$

$$SAG = \frac{WL^2}{8T} = \frac{7.43 \times (150)^2}{8 \times 26600 \times \frac{50}{100}} = 1.698 \text{ m}$$

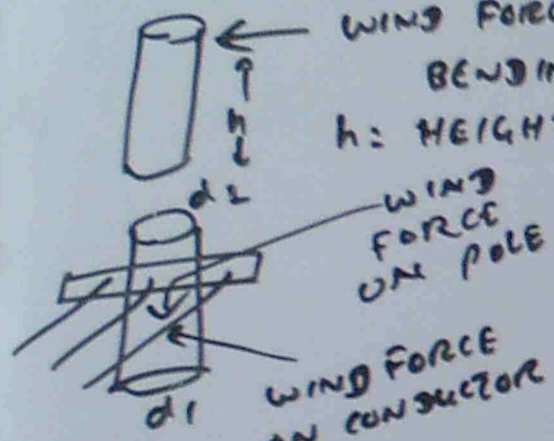
(2) SAG CALCULATION

SLIDE 1 → 3
Q2 → 3

(3) SAG CAL: ULTIMATE STRENGTH

Q4

OVER HEAD LINE MECHANICAL DESIGN



WIND FORCE (F_w)

BENDING MOMENT = $F_w \times h$

h: HEIGHT OF POLE

TOTAL BENDING MOMENT = BENDING MOMENT CAUSED BY WIND FORCE ON POLE + BENDING MOMENT CAUSED BY WIND FORCE ON CONDUCTOR

BENDING MOMENT CAUSED BY WIND FORCE ON POLE = WIND PRESSURE (Pa) $\times h^2 \times \left(\frac{d_1}{6} + \frac{d_2}{3}\right)$

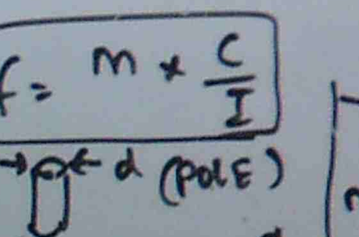
BENDING MOMENT CAUSED BY WIND FORCE ON CONDUCTOR = WIND PRESSURE $\times$ THE AREA OF CONDUCTOR SUBJECT TO WIND FOR THE WHOLE SPAN $\times$ NO. OF CONDUCTOR $\times h$

$f = \frac{m \times c}{I}$

f = MAXIMUM FIBRE STRESS

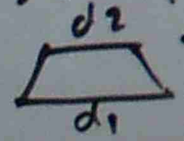
m = TOTAL BENDING MOMENT

c = DISTANCE FROM EXTREME FIBRE OF CROSS SECTION TO NEUTRAL AXIS



CONDUCTOR $c = \frac{d}{2}$

$I = \frac{\pi d^4}{64} = 0.049 d^4$



TRAPEZOIDAL SHAPE IS TO BE REPLACED BY UNIFORM C.S.A POLE

CIRCUMFERENCE OF POLE $= 3\sqrt{\frac{730 \times \text{SAFETY FACTOR} \times \text{TOTAL Bm}}{\text{ULTIMATE STRESS OF WOOD}}}$

Pb/ 12m POLE IS SET 1.83m IN GROUND WITH THREE NO 4/0 STRANDED CONDUCTORS ON A CROSS ARM WITH THE CONDUCTORS LEVEL AT THE TOP OF POLE AND 45.7m BALANCE OF HEAVY LOAD THE POLE GOT 20.32cm AT TOP AND 30.48cm AT BOTTOM. NO 4/0 CONDUCTOR HAS DIAMETER 1.34 cm AND TOTAL ICE THICKNESS 2.54 cm. WIND PRESSURE IS 196.2 Pa. SAFETY FACTOR IS TAKEN 2. CALCULATE TOTAL Bm.

TYPE OF WOOD	ULTIMATE STRESS	S.F	COST
NORTHERN WHITE CEDAR	24.4×10^6 N/m²	5	CHEAP
WESTERN RED CEDAR	38.84×10^6 N/m²	8	CHEAP
LONG LEAF YELLOW PINE	51.3×10^6 N/m²	10	MODERATE
WALLAHA	77.79×10^6 N/m²	15	EXPENSIVE

$h = 12 - 1.83 = 10.17$ m

$d = \frac{d_1 + d_2}{2} = \frac{20.32 + 30.48}{2} = 25.4$ cm

B.M WIND FORCE $= P.a \times h^2 \left(\frac{d_1}{6} + \frac{d_2}{3}\right) = 196.2 \times 10.17^2 \left(\frac{30.48}{6 \times 100} + \frac{20.32}{3 \times 100}\right)$

TOTAL DIA OF CONDUCTOR = DIA + ICE THICKNESS: $1.34 + 2.54 = 3.88$ cm $= 2404$ N-m

WIND FORCE ON CONDUCTOR = WIND P.R $\times$ AREA $\times$ NO. $\times h$ $= 196.2 \times 45.7 \times 3.88 \times 10^{-2} \times 3 \times 10.17 = 10614$ N-m

TOTAL Bm: $2404 + 10614 = 13018$ N-m | $f = \frac{mc}{I}$

IN PREVIOUS PROBLEM, CALCULATE TOTAL STRESS & SELECT TYPE OF WOOD

$$f = \frac{mc}{I} = \frac{13018 \times d/2}{0.049 \times d^4} = \frac{13018}{0.049 d^3}$$

$$= \frac{13018}{0.049 \times (25.4 \times 10^{-2})^3} = 8.095 \times 10^6 \text{ N/m}$$

S.F = 2 $\rightarrow \therefore$ WORKING STRESS $= \frac{8.095 \times 10^6}{2}$

$= 4.047 \text{ N/m}^2$

WESTERN RED CEDAR $= 4.1 \times 10^6 \text{ N/m}^2$ CHEAP (UTS 32.8×10^6)

LONG LEAF YELLOW PINE $5.13 \times 10^6 \text{ N/m}^2$ (UTS 51.3×10^6) MODERATE

BUT 4.1×10^6 IS VERY CLOSE, SELECT LONG LEAF YELLOW PINE BECAUSE (i) APPROPRIATE STRESS (ii) MODERATE COST

UNIFORM DIAMETER RULE $= \sqrt[3]{\frac{730 \times S.F \times Bm}{\text{ULTIMATE STRESS}}}$

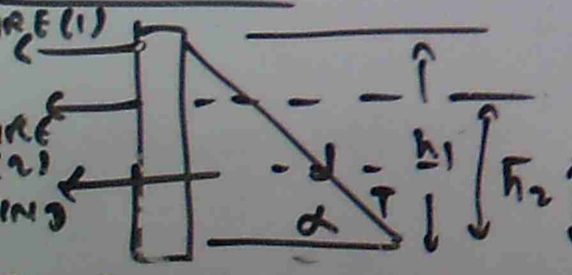
$= \sqrt[3]{\frac{730 \times 2 \times 13018}{51.3 \times 10^6}} = 0.718 \text{ m}$

DIAMETER $= \frac{0.718}{\pi}$

$= 0.228 \text{ m}$

$= 22.8 \text{ cm}$

GUY WIRE



$Bm = T\cos\alpha h_1 = W_1 \times h_1 + W_2 \times h_2 + W_{WIND} \times h_w$

CROSSARM



$I = \frac{bd^3}{12}$

$c = \frac{d}{2}$



$I = \frac{(b-a)d^3}{6} \Rightarrow \frac{I}{c} = \frac{(b-a)d^2}{6}$

$f = \frac{m}{I/c}$

LINE PLANNING

2.5 cm $\rightarrow$ 1 mm HORIZONTAL SCALE

25 cm $\rightarrow$ 1 mm VERTICAL SCALE

LINE PROFILE DRAWING



PERMISSIBLE LINE DEVIATION

RESULTANT FORCE ON PIN $= 2T \sin\frac{\alpha}{2} + W_2 l$

W_L = WIND LOAD ON CONDUCTOR = WIND PRESSURE $\times$ DIAMETER OF CONDUCTOR $\times$ 1 m LENGTH

L = SPAN LENGTH IN METRE, T = MAXIMUM TENSION IN CONDUCTOR (N)

α = ANGLE OF DEVIATION

Pb/ DETERMINE THE MAXIMUM DEVIATION ALLOWED ON 11kN PIN INSULATOR FOR 7/3.50 HARD DRAWN COPPER CONDUCTOR WITH A SPAN OF 150m. THE ULTIMATE STRENGTH 26600 N. THE LOAD IS 500 Pa. DIAMETER of CONDUCTOR 10.5mm. TENSION IN CONDUCTOR MUST NOT BE MORE THAN 50% of STRENGTH. TRANSVERSE LOADING ON PIN = 40% of ULTS.

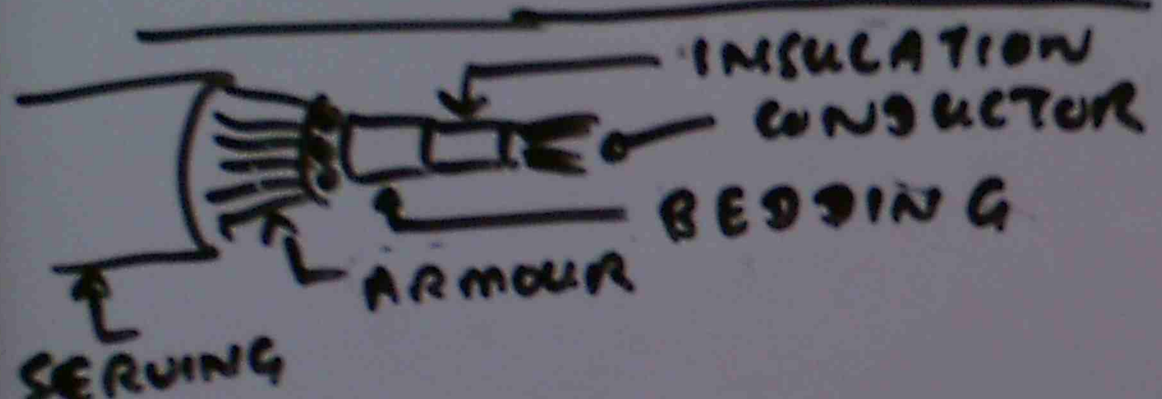
$W_L = 500 \times 10.5 \times 10^{-3} \times 150$

PIN ON LOAD $= 2T \sin\frac{\alpha}{2} + W_2 L$

$\frac{40 \times 11000}{100} = 2 \times \frac{26600}{2} \sin\frac{\alpha}{2} + 500 \times 10.5 \times 10^{-3} \times 150$

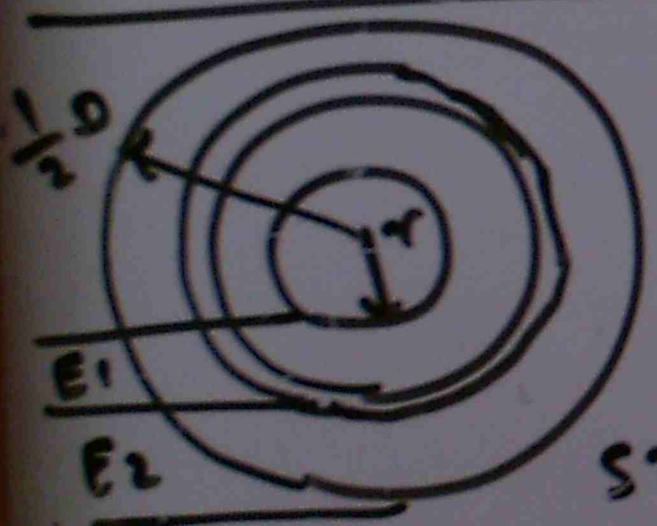
$\frac{\alpha}{2} = 7.8 \rightarrow \alpha = 15.6$

UNDER GROUND CABLE



CURRENT RATING OF CABLE

- THERMAL CAPACITY
- VOLTAGE DROP
- SHORT CIRCUIT CAPACITY



STRESS WITHOUT SHEATH

$$S_{max} = \frac{E}{\frac{1}{2} d \ln \frac{2}{d}} \quad V/mm$$

E = PEAK VOLTAGE PER PHASE $= \frac{\sqrt{2}\, E_{rms}}{\sqrt{3}}$

STRESS MAXIMUM WITH SHEATH $= \frac{S_{max \text{ WITHOUT SHEATH}}}{3\sqrt{1 + d + d^2}}$

$$E_2 = \frac{E}{1 + \frac{1}{d} + \frac{1}{d^2}}, \quad E_1 = E_2 \left(1 + \frac{1}{d}\right)$$

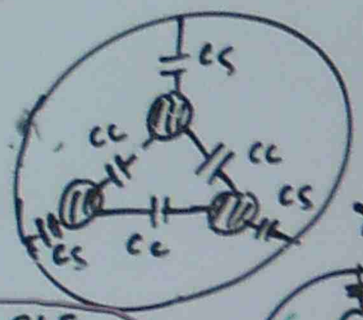
Pb A SINGLE CORE 66KV CABLE, 2 cm DIAMETER, SHEATH INSIDE DIAMETER 5.3cm. FIND MAX: STRESS

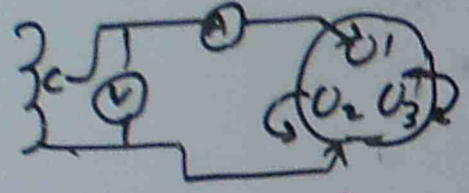
$d = 3\sqrt{\frac{D}{d}} = 3\sqrt{\frac{5.3}{2}} = 1.384$

$E = \frac{\sqrt{2} \times 66}{\sqrt{3}} = 53.3$

$E_2 = \frac{53.3}{1 + \frac{1}{1.384} + \frac{1}{1.384^2}} = 23.9$ KV

$E_1 = 23.9 \left(1 + \frac{1}{1.384}\right) = 41.1$



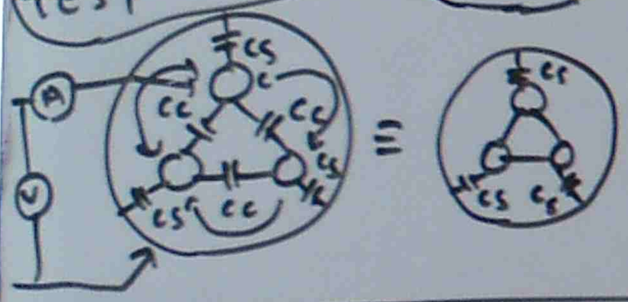


$X_c = \frac{V}{I}$, $C = \frac{1}{2\pi f X_c}$

UG CABLE CAPACITANCE TEST



$C_a = C_s + 2C_c$ — (1)



≡



$C_b = 3C_s$

U.G CABLE LAYING

DIRECT LAYING, DRAW IN, SOLID SYSTEM

CABLE JOINING.

DUCT CONSTRUCTION



MODERATE COST | ABILITY TO RADIATE HEAT - VERY GOOD | COST OF SUPPORTS VERY GOOD

Pb FIND THE INSULATION RESISTANCE PER Km OF CONDUCTOR DIAMETER 1.6 cm AND INTERNAL SHEATH DIAMETER 5.08 cm

$\rho = 6 \times 10^{14}$ Ω-cm

$$\text{INSULATION RESISTANCE} = \frac{\rho}{2\pi L} \ln\frac{D}{2r} = \frac{6\times10^{14}}{2\times3.14\times10^{2}\times R^2} \ln\frac{5.08}{1.6} = 1103 \text{ m}\Omega$$

Pb IN ABOVE PROBLEM, IF THE CABLE IS SUBJECT TO 66KV, 3φ LINE FIND DIELECTRIC LOSS

$E_{ph} = \frac{66\times10^3}{\sqrt{3}} = 38104 V$

$$\text{DIELECTRIC LOSS} = \frac{E_{ph}^2}{R_{INSULATION}} = \frac{38104^2}{1103\times10^6} = 1.316 \text{ WATT}$$

MAN HOLE COVER CONSTRUCTION

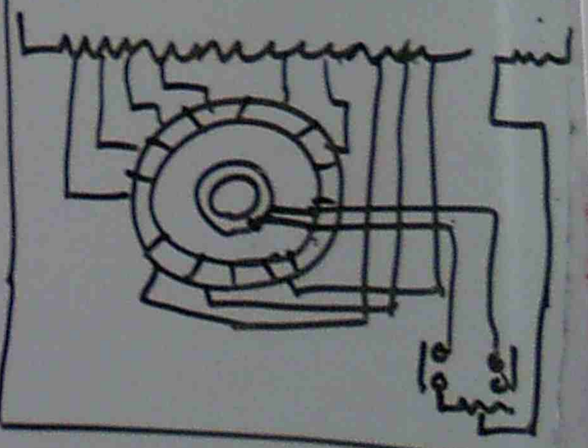
$$\text{CONCENTRATED LOAD} = \frac{\text{WHEEL LOAD}\left(1+\frac{\%\text{ IMPACT}}{100}\right)}{\text{WHEEL AREA}}$$

VOLTAGE REGULATION

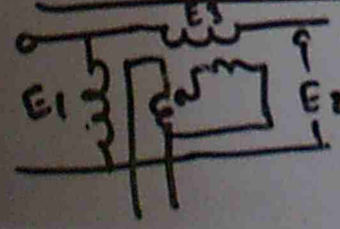
$$\text{REGULATION} = \frac{E_S - E_R}{E_R} \times 100\% = \frac{IR\cos\phi_r + IX\sin\phi_r}{E_R}$$

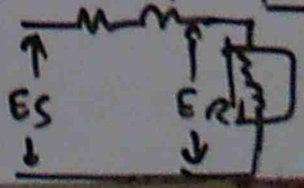
OFF LOAD TAP CHANGER

ON LOAD TAP CHANGER



BOOSTER TRANSFORMER





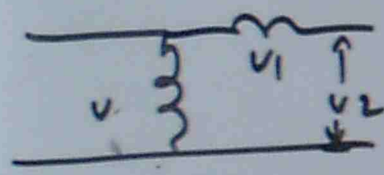
$E_S = \sqrt{(E_R\cos\phi_R + IR)^2 + (E_R\sin\phi_R + IX)^2}$ V

VOLTAGE CONTROL METHODS

- BY CONTROLLING THE SENDING END VOLTAGE
- BY CONTROLLING THE RECEIVING END VOLTAGE
- BY CONTROLLING THE CURRENT IN THE LINE
- BY CONTROLLING THE POWER FACTOR THAT IS VARYING THE POWER FACTOR

VOLTAGE CONTROL EQUIPMENT

- OFF LOAD TAP CHANGER
- ON LOAD TAP CHANGER
- BOOSTER TRANSFORMER
- MOVING COIL REGULATOR
- INDUCTION REGULATOR

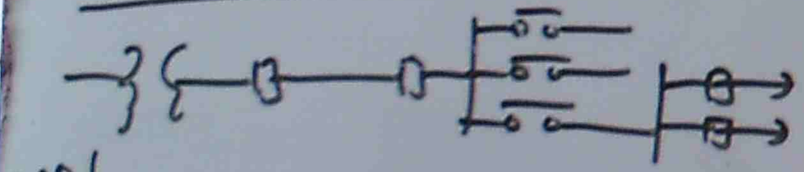


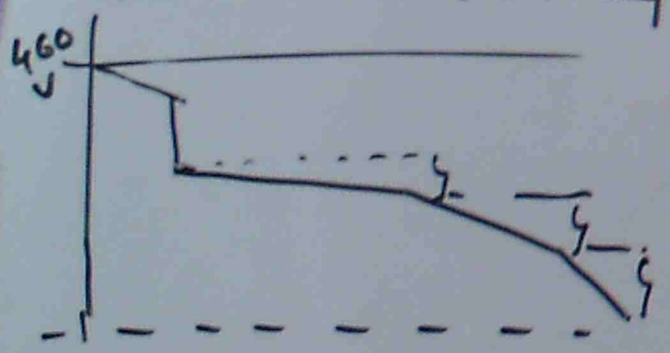
$V_2 = V \pm V_1$

V = IN PUT VOLTAGE

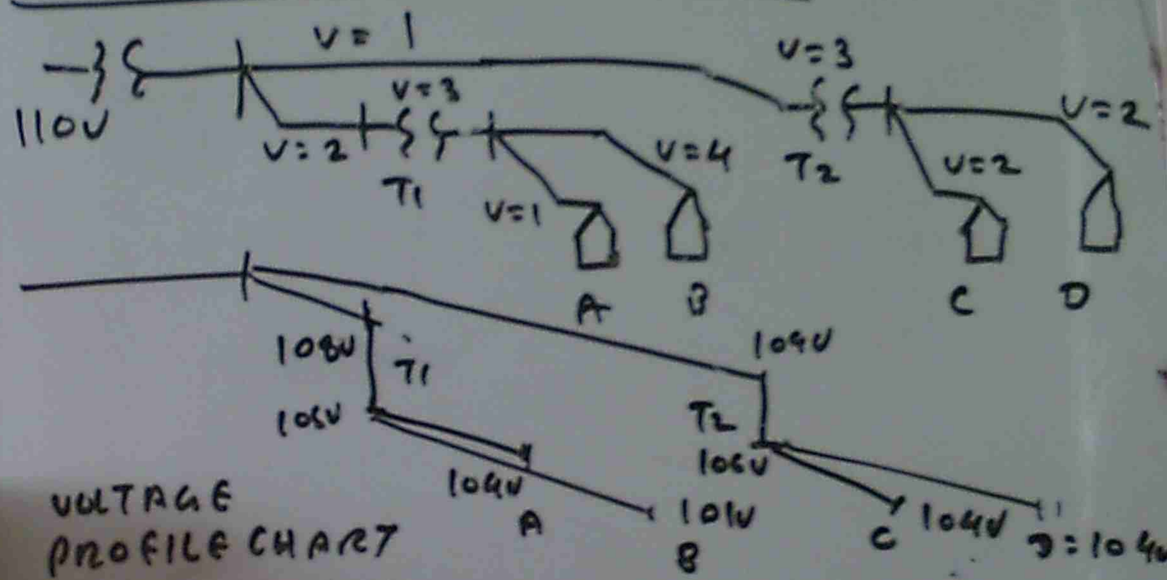
V_1 = INJECTED SERIES VOLTAGE

VOLTAGE PROFILE CHART





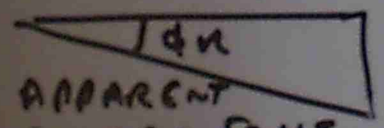
VOLTAGE PROFILE EXAMPLE



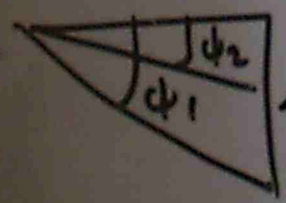
VOLTAGE PROFILE CHART

P.F IMPROVEMENT

REAL POWER = $\sqrt{3} V I \cos\phi_R$



REACTIVE POWER = $\sqrt{3} V I \sin\phi_R$



$\text{KVAR}_{\text{IMPROVED}} = \text{KW}(\tan\phi_1 - \tan\phi_2)$

$\text{KVAR}_{\text{IMPROVED}} = \frac{V_{ph}^2}{X_C} \times 3$

Ex: 200 KVA, 50Hz, PF IMPROVED FROM 0.75 → 0.9
ELINE = 415V CALCULATE CAPACITOR SIZE

$\phi_1 = \cos^{-1} 0.75 = 41$

$\phi_2 = \cos^{-1} 0.9 = 26$

KVAR CORRECT = $\frac{200}{0.75}(\tan 41 - \tan 26) = 65.2$

$X_C = \frac{415^2}{65.2 \times 10^3 / 3 \times 100}$, $C = \frac{1}{2\pi f X_C} = 100\,\mu F$

(4) STAY - GUY WIRE DESIGN

SLIDE 1 → 5, @ 5

(12) UG STRUCTURE

SLIDE 1 → 7
@ 45 → 51

(5) CROSS ARM DESIGN & PIN & BOLT DESIGN

SLIDE 1 → 8, @ 6 → @ 7

(6) POLE & LINE INSTALLATION TECHNIQUE

SLIDE 1 → 2, @ 8 → @ 11

(7) LINE DEVIATION & GALVANIZING & U G CABLE

SLIDE 1 → 10, @ 12 → @ 23

(8) STRESS IN U.G CABLE

SLIDE 1 → 10, @ 24 → @ 29

(9) UG CABLE CAPACITANCE

SLIDE 1 → 5, @ 28 → @ 30

(10) UG CABLE FAULT

SLIDE 1 → 4, @ 31/32

(10) VOLTAGE REGULATION

SLIDE (1) @ 33/34

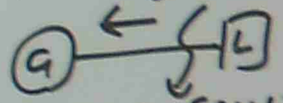
(11) BOOSTER TR

SLIDE 1 → 7 | @ 36 → 44

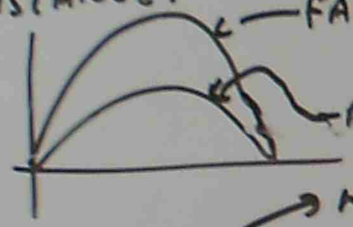
POWER SYSTEM PROTECTION

$I = \frac{V}{R}$

OVER CURRENT DUE TO ABNORMAL DECREASE IN LOAD RESISTANCE.



REVERSE POWER FLOW — FAULT



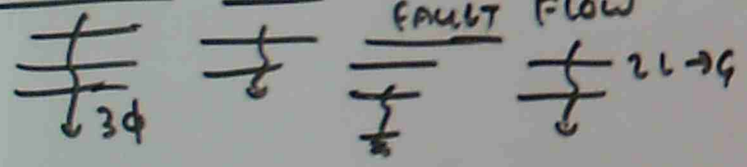
RELAY SPEED OF OPERATION → NOT TOO FAST
→ NOT TOO SLOW

MONITORING THE SYSTEM CONDITION

POWER SYSTEM

CURRENT —— FAULT / OVER CURRENT
VOLTAGE —— NEUTRAL WIRE BROKEN
FREQUENCY — $N = \frac{120f}{P}$
POWER FLOW DIRECTION → CAN NOT SYNCHRONIZE
→ SHAFT CAN BE DAMAGED DUE TO REVERSE POWER FLOW

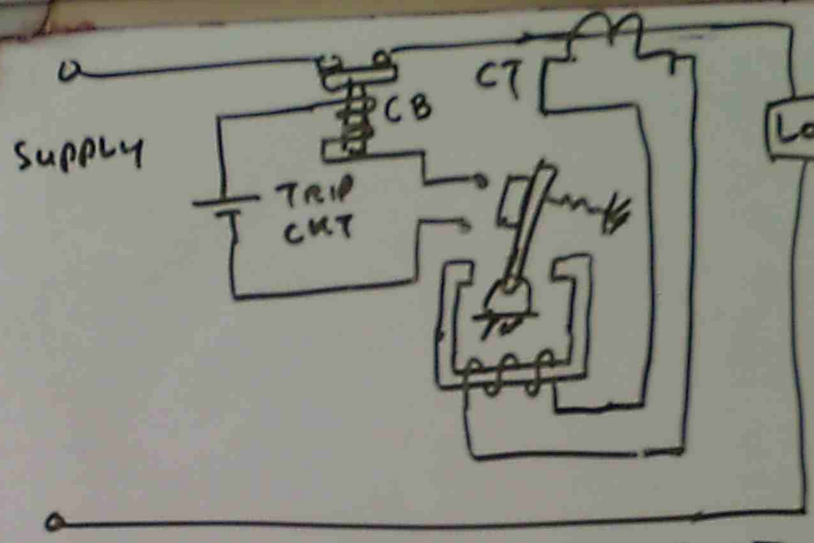
FAULT — L-L — L-G FAULT — 2L→G



CONSTRUCTION OF PROTECTION RELAY

RELAY — { MONITOR V, I, f, POWER FLOW } SUPERVISE C.B TO TO OPERATE

- ELECTRO MECHANICAL TYPE
- SOLID STATE ELECTRONIC TYPE



OPERATING — ELECTRO MAGNETISM
RESTRAINTING — SPRING

BASIC QUALITIES OF POWER SYSTEM

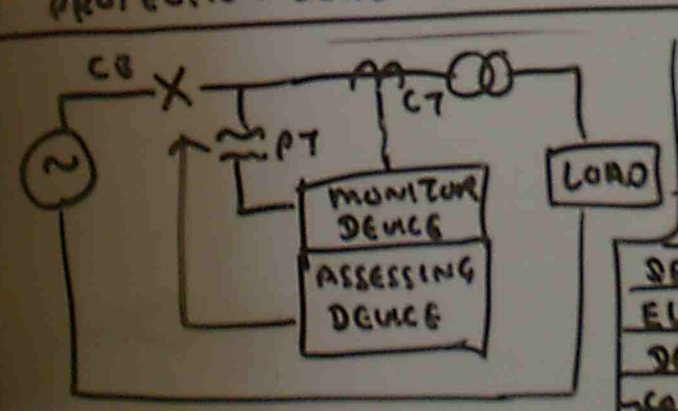
SPEED, DISCRIMINATION, RELIABILITY

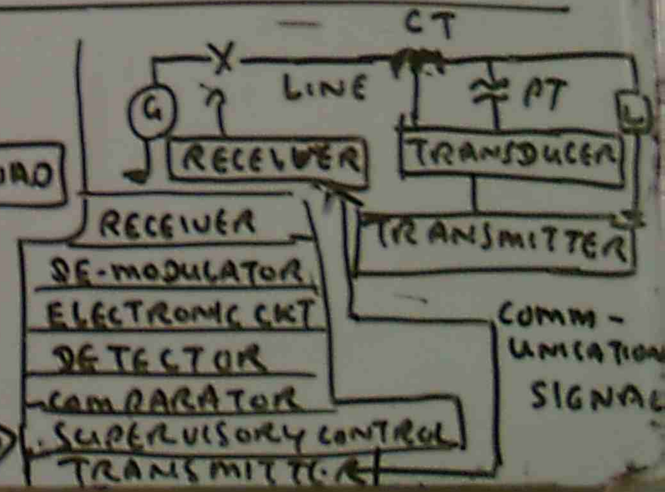
TIME DELAY TO DISCRIMINATE TEMPORARY FAULT AND PERMANENT FAULT TO MAINTAIN THE SYSTEM STABILITY

RELIABILITY

THE RELAY MUST ALWAYS OPERATE AT PRE-DETERMINED CURRENT / VOLTAGE AND TIME SETTING

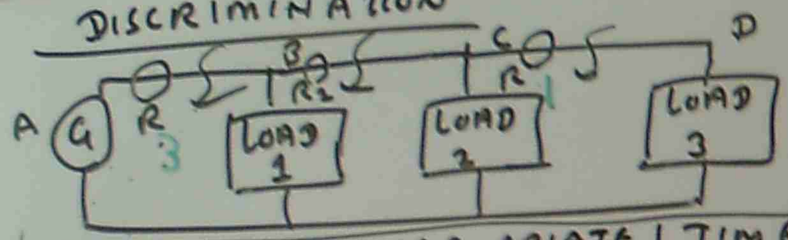
COMPONENTS & LAY OUT OF POWER SYSTEM PROTECTION SCHEME





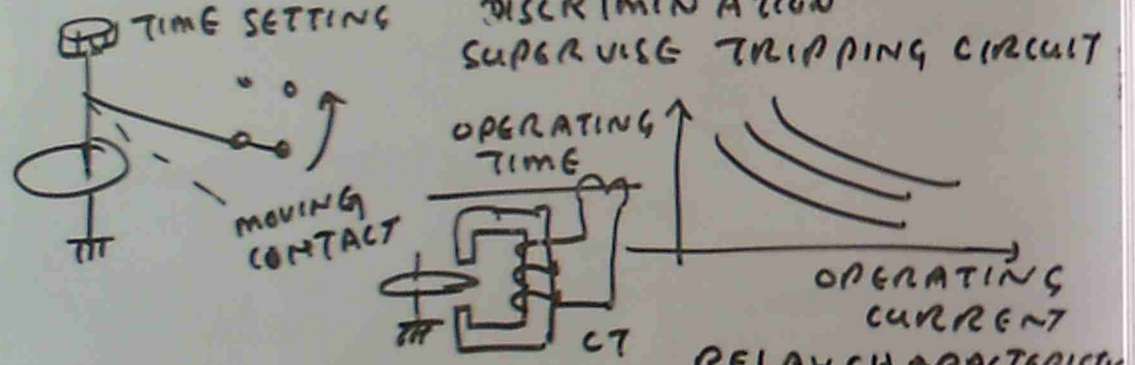
REMOTE CONTROL ⇒

DISCRIMINATION



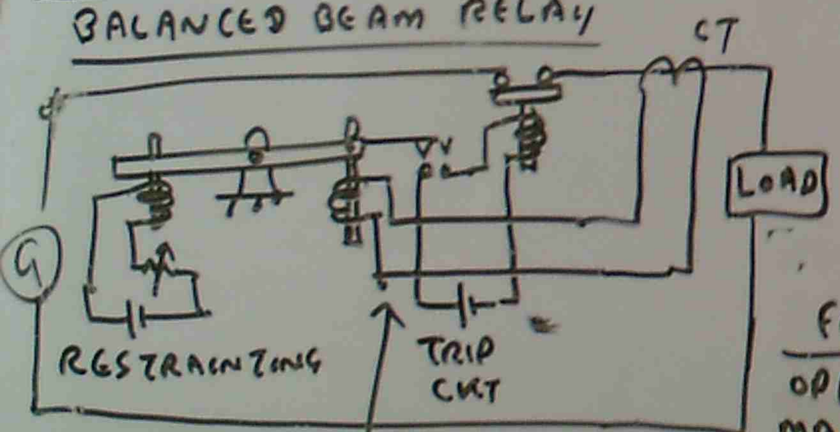
FAULT POINT	APPROPRIATE RELAY	TIME GRADING	CURRENT GRADING
C - D	R1	0.1 Sec	I_{sh_1}
B - C	R2	0.4 Sec	I_{sh_2}
A - B	R3	0.7 Sec	I_{sh_3}

RELAY OPERATION – MEASURE QUANTITY DISCRIMINATION SUPERVISE TRIPPING CIRCUIT



RELAY CHARACTERISTIC

BALANCED BEAM RELAY

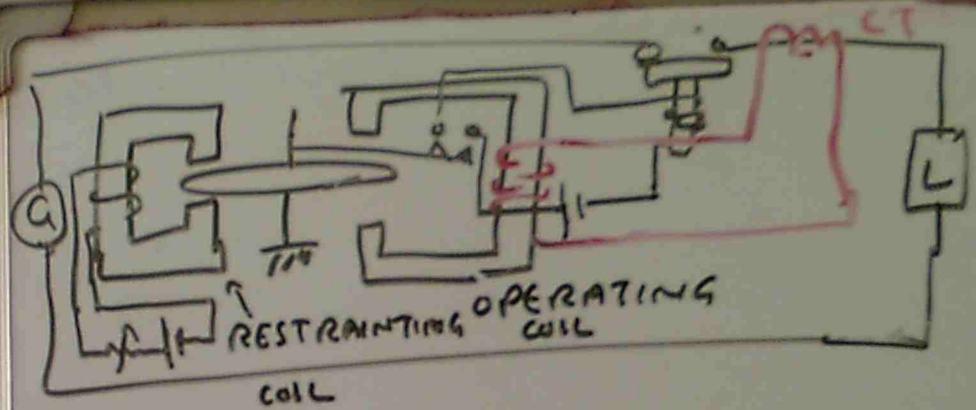


NORMAL

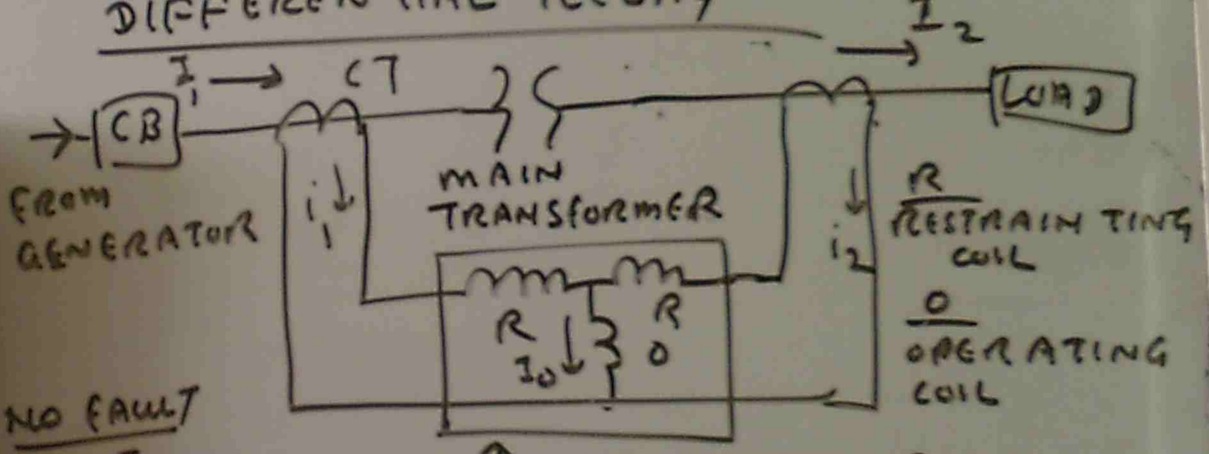
RESTRAINTING MAGNETISM > OPERATING MAGNETISM

FAULT

OPERATING MAGNETISM > RESTRAINTING MAGNETISM



DIFFERENTIAL RELAY



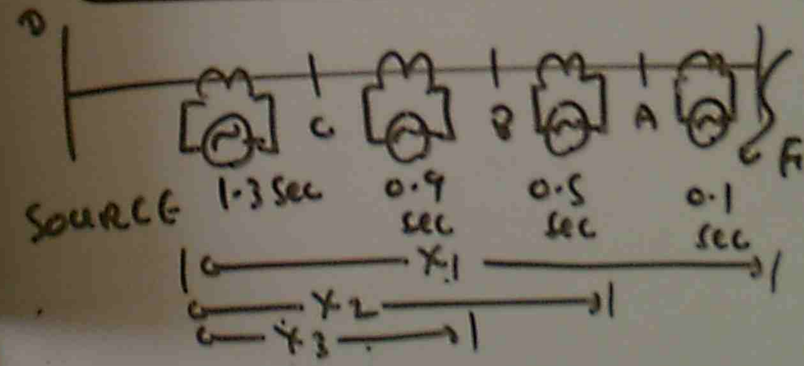
NO FAULT

$I_1 = I_2$

$i_1 = i_2 \rightarrow I_0 = 0$ – NO OPERATE

FAULT $I_1 > I_2 \rightarrow i_1 > i_2 \quad \therefore I_0 = i_1 - i_2$ OPERATE

TIME GRADING & CURRENT GRADING

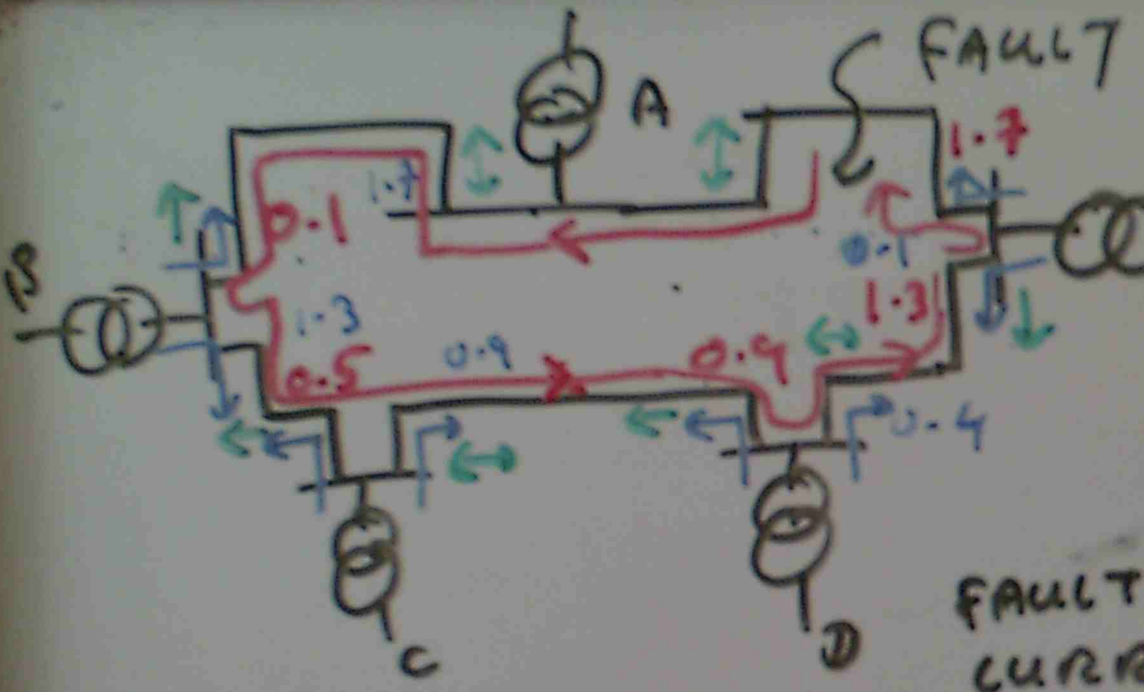


CURRENT GRADING

$X_1 > X_2 > X_3 > X_4$

$I_{sh_1} < I_{sh_2} < I_{sh_3} < I_{sh_4}$

10A < 20A < 30A < 40A

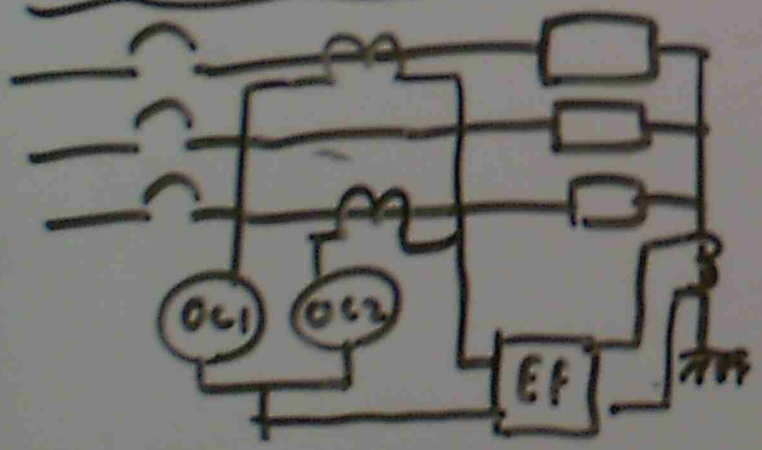


CLOSET TO MAIN POWER POINT
- NON DIRECTIONAL

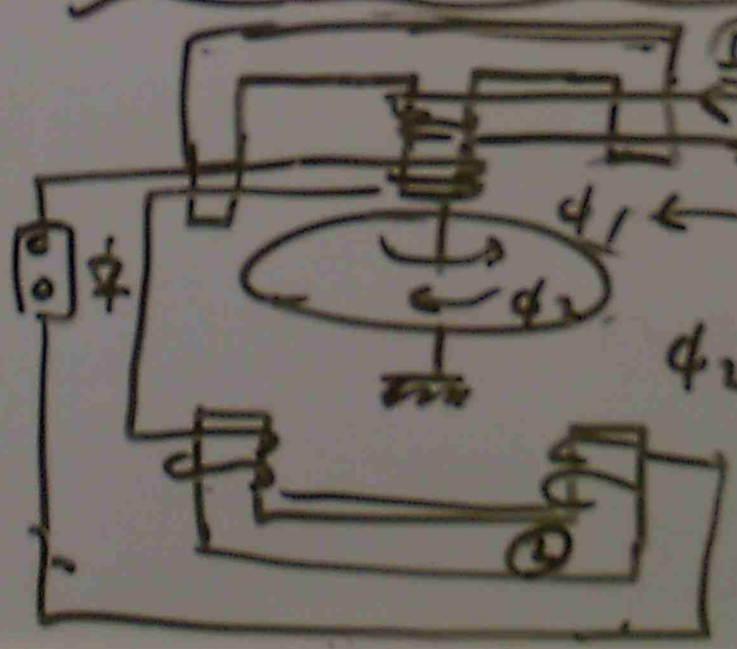
FAULT CURRENT OPPOSES NORMAL CURRENT
- DIRECTIONAL

FAULT CURRENT & NORMAL CURRENT IN SAME DIRECTION
- NON DIRECTIONAL

OVER CURRENT AND EARTH FAULT PROTECTION

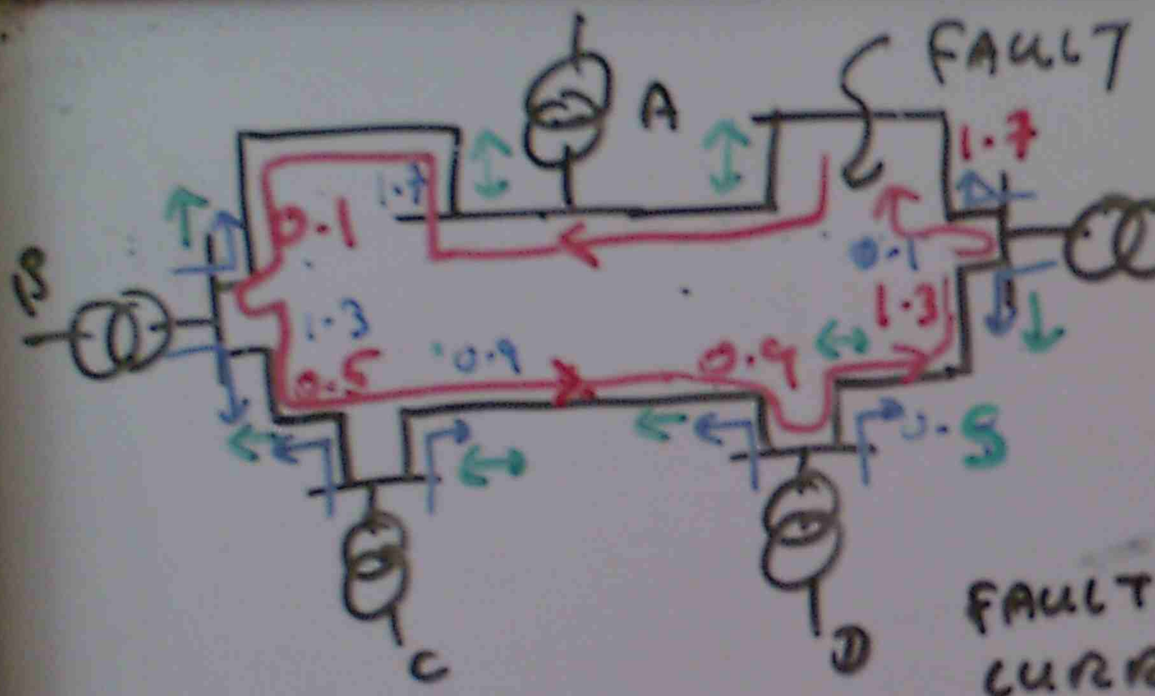


DIRECTIONAL ELEMENT



ϕ_1 ← FLUX BY MAGNET (1)

ϕ_2 - FLUX BY MAGNET (2)

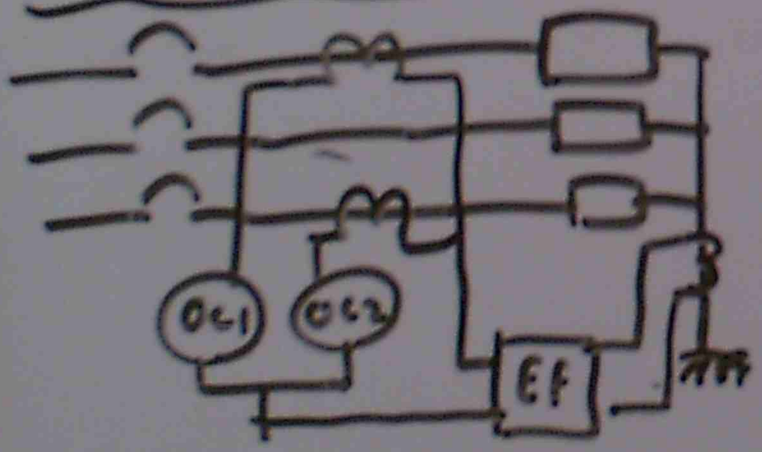


CLOSET TO MAIN POWER POINT
- NON DIRECTIONAL

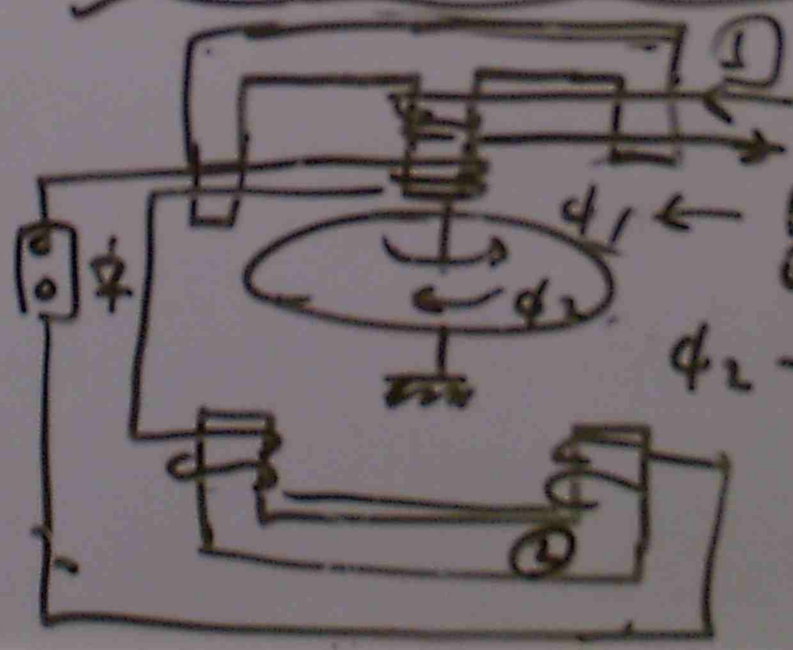
FAULT CURRENT OPPOSED NORMAL CURRENT
- DIRECTIONAL

FAULT CURRENT & NORMAL CURRENT IN SAME DIRECTION
- NON DIRECTIONAL

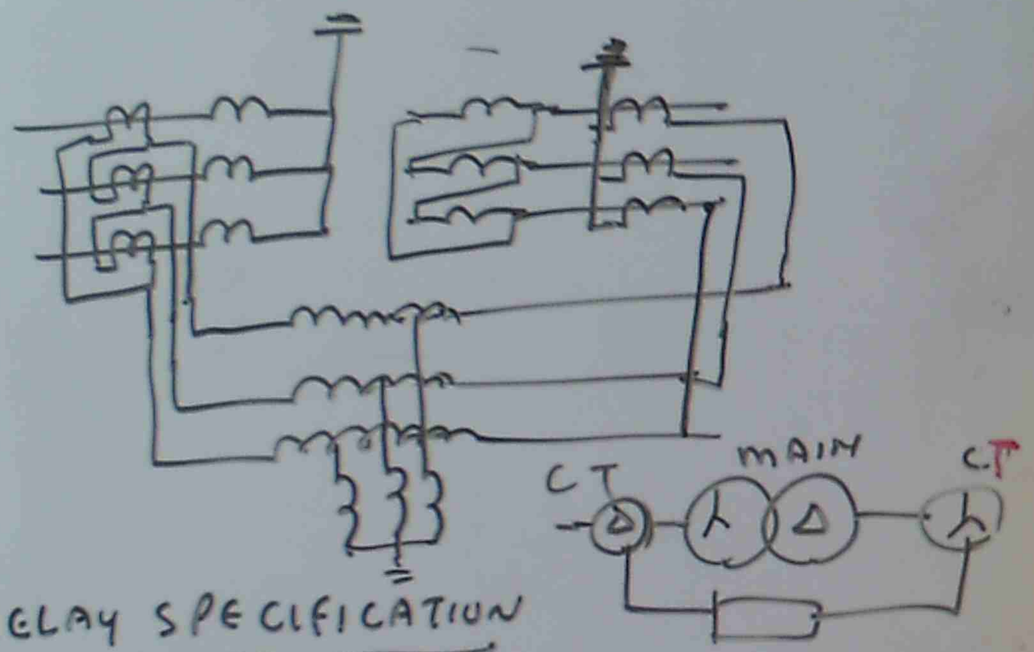
OVER CURRENT AND EARTH FAULT PROTECTION



DIRECTIONAL ELEMENT



THREE PHASE DIFFERENTIAL RELAY



RELAY SPECIFICATION

10 AMP 150/40/200 AT

- 10 AMP → RELAY NORMAL CURRENT
- 150/40 → 150% PICK UP SETTING
- 200 AT → RELAY CONTACTS CLOSE WITHIN 40 CYCLE
- 20 TIMES → RELAY NORMAL CURRENT OF 10A

TIME

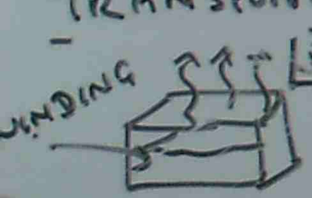


PLUG SETTING

CURRENT

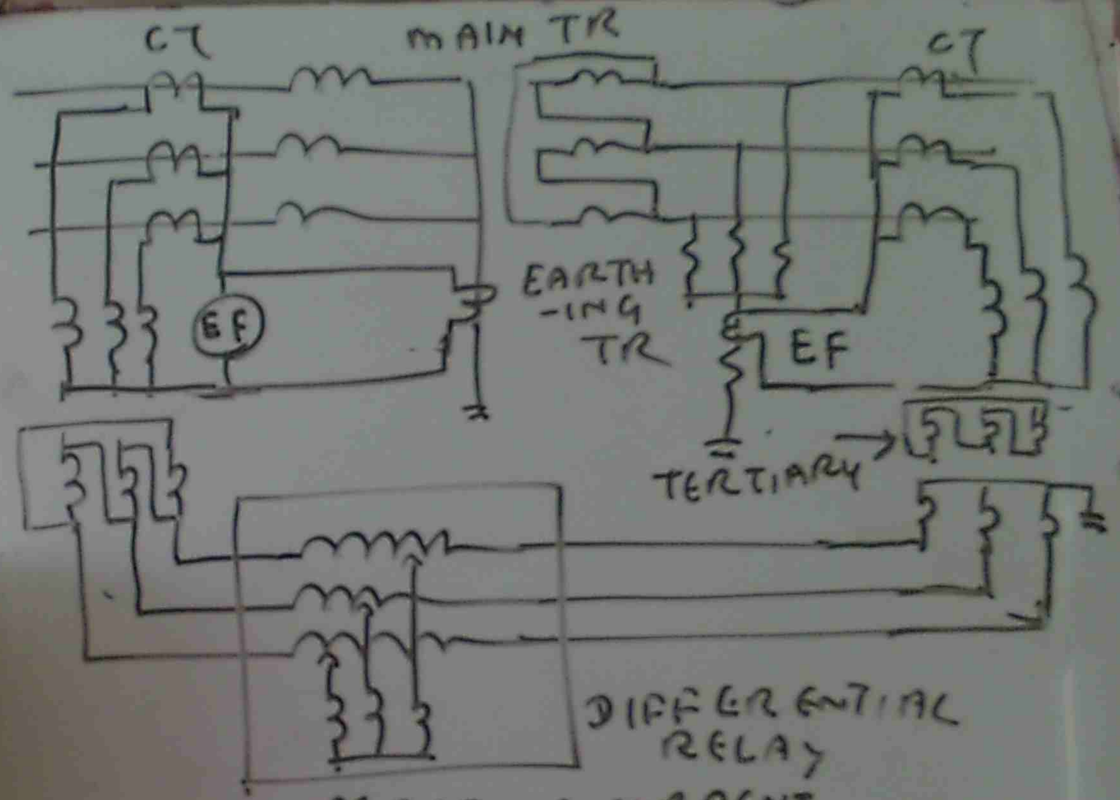
TRANSFORMER FAULTS

- INTERNAL
  - WINDING
  - TERMINAL
  - EARTH
  - SHORT CKT
  - PH – E FAULT
- EXTERNAL
  - OVER LOAD
  - EXT SC



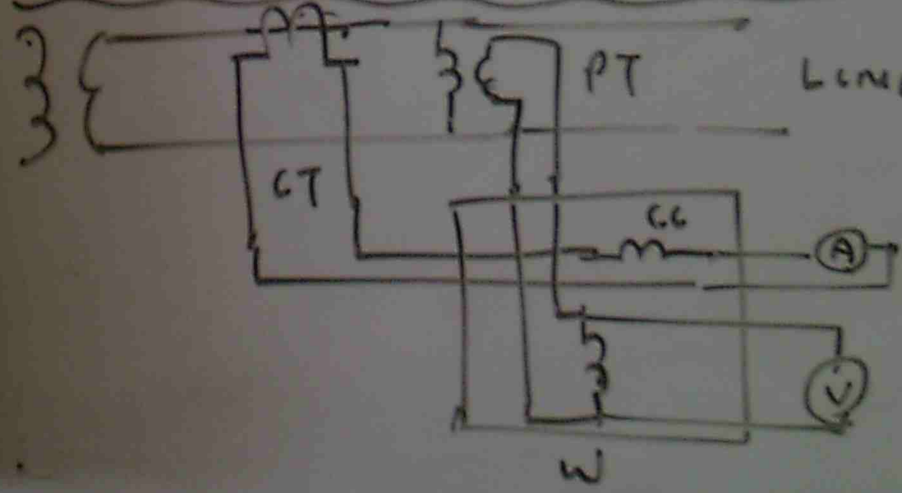
BUCHHOLZ RELAY

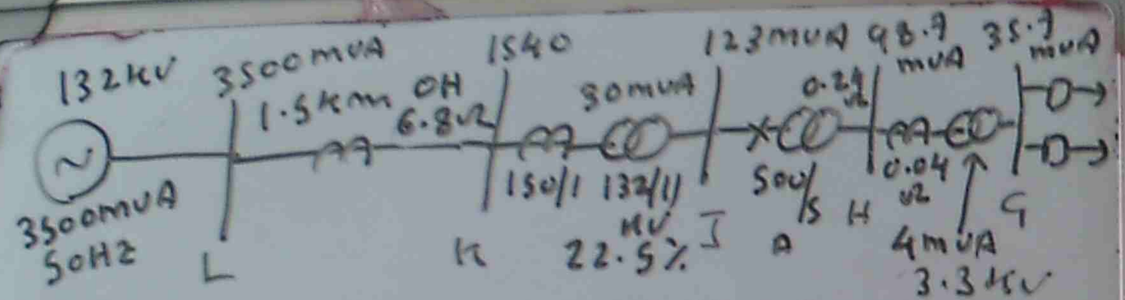
GAS OPERATED



% BIAS = $\frac{\text{OPERATING CURRENT}}{\text{RESTRAINTING CURRENT}} \times 100$

CT / PT CONNECTION IN POWER SYSTEM





ARRANGE CURRENT AND TIME GRADING FOR GIVEN POWER SYSTEM

BASE MVA = 35.7 MVA, BASE VOLTAGE = 3.3 KV

$132KV \rightarrow \frac{132}{3.3} = 40$ Pu

1540 MVA $\rightarrow \frac{1540}{35.7} = 43$ Pu

3500 MVA $- \frac{3500}{35.7} = 98$ Pu

123 MVA $\rightarrow \frac{123}{35.7} = 3.46$ Pu

98.7 MVA $- \frac{98.7}{35.7} = 2.76$ Pu

35.7 MVA $- 1$ Pu

SHORT CIRCUIT CURRENT = $\frac{\text{FULL LOAD CURRENT}}{\%\text{ IMPEDANCE}} \times 100$

$I_{FL} = \frac{\text{BASE MVA}}{\sqrt{3} \times \text{BASE VOLTAGE}} = \frac{35.7 \times 10^6}{1.7321 \times 3.3 \times 10^3} = 62.45$ Amp

$Pu = \frac{I_{FL}^2 \times (\Omega)}{\text{BASE MVA}}$

L — K

$Pu = \frac{(62.45)^2 \times 6.8}{35.7 \times 10^6} = 6.75$ Pu

K — J

$\%\ X_2 = \frac{\text{BASE MVA}}{\text{MVA 1}} \times \%X$

$= \frac{35.7}{30} \times 22.5$

$= 26.4$ Pu

J → H

$Pu = \frac{(62.45)^2 \times 0.24}{35.7 \times 10^6}$

$= 0.26$ Pu

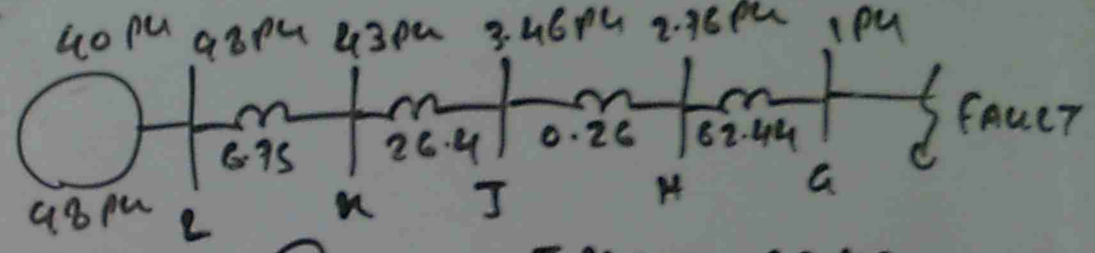
H → G

LINE → $Pu = \frac{62.45^2 \times 0.04}{35.7 \times 10^6}$

$= 0.04$ Pu

TR $\%X_2 = \frac{35.7}{4} \times 7 = 62.4$

$\%X_T = 0.04 + 62.4 = 62.44$



FAULT AT (G)

$I_{SH} = \frac{I_{FL} \times 100}{X_{L \rightarrow G}} = \frac{62.45}{6.75 + 26.4 + 0.26 + 62.44} \times 100$

$= 6499$ A

FAULT AT (H)

$I_{SH} = \frac{I_{FL}}{X_{L \rightarrow H}} \times 100 = \frac{62.45 \times 100}{6.75 + 26.4 + 0.26} = 18536$ A

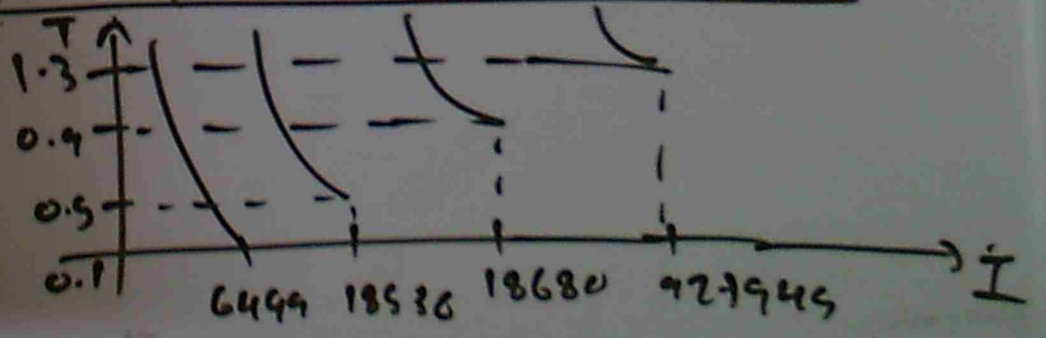
FAULT AT (J)

$I_{SH} = \frac{I_{FL} \times 100}{X_{L \rightarrow J}} = \frac{62.45 \times 100}{6.75 + 26.4} = 18680$ A

FAULT AT (K)

$I_{SH} = \frac{I_{FL} \times 100}{X_{L-K}} = \frac{62.45 \times 100}{6.75} = 927949$ A

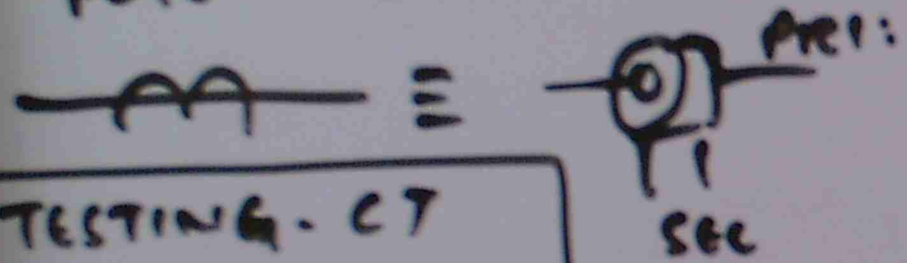
POINT	FAULT CURRENT	TIME
G	6499	0.1
H	18536	0.5
J	18680	0.4
K	927949	1.3



INSTRUMENTATION TRANSFORMER

CURRENT TRANSFORMER - TO REDUCE CURRENT

POTENTIAL TRANSFORMER - TO REDUCE VOLTAGE



10 P 150 F 15 ← RATED ACCURACY

↑ PROTECTION

SEC: VOLTAGE

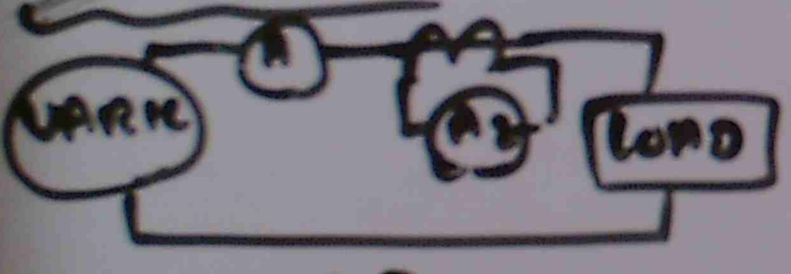
% COMPOSITE ERROR $= \frac{I_L \times 100}{I_S \times K}$

I_L = RATED SEC: CURRENT

I_S - SECONDARY EXCITING CURRENT

TESTING - CT

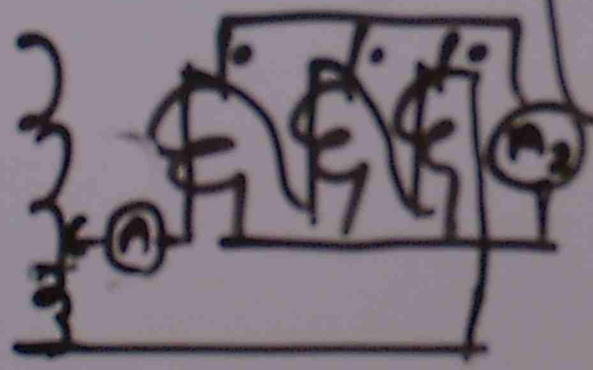
RATIO CHECK



DC POLARITY



a:+, b-, a-b+



IF POLARITY CORRECT A_2 INDICATES READING

$R_b = \frac{\text{SEC: VOLTAGE}}{20\, I_{SR}}$

$V_S = 20\, I_{SR} (R_b + R_S)$

↑ GIVEN VOLTAGE

↑ RATED SEC CURRENT

↑ BURDEN RESISTANCE

SEC: WDG DC RESISTANCE

% COMPOSITE ERROR $= \frac{I_e \times 100}{I_{SR} \times K}$

CLASS VOLTAGE V_C = SEC: REF:

DIFFERENCE BETWEEN POWER TRANSFORMER AND CURRENT TRANSFORMER

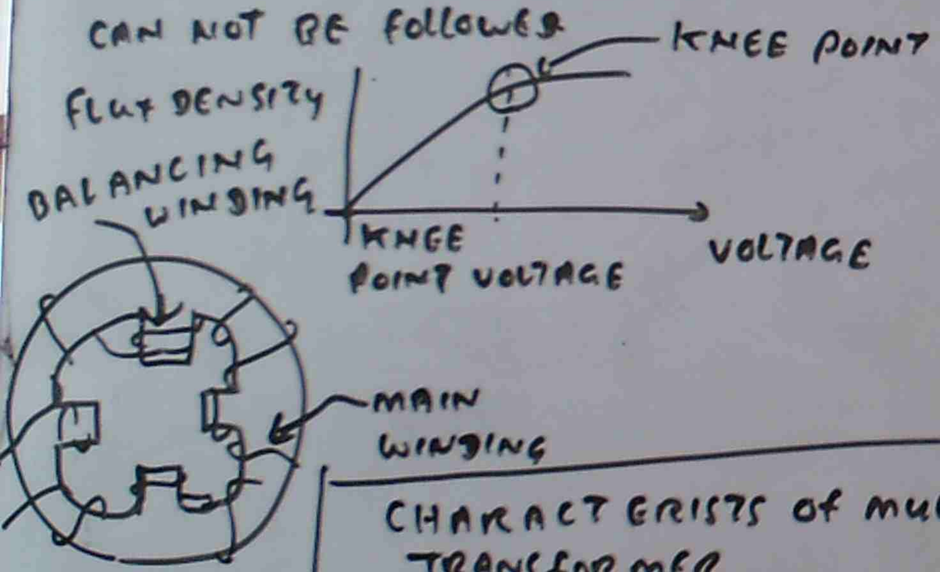
POWER TRANSFORMER

PRIMARY AND SECONDARY WINDINGS ARE TIGHTLY LINKED. $E = 4.44 f\phi T_P$

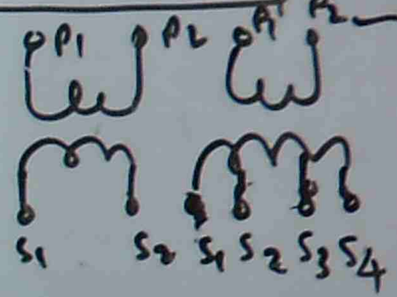
CURRENT TRANSFORMER

$$\frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2}$$

PRIMARY AND SECONDARY WINDINGS ARE LOOSELY LINKED. THE ABOVE EQUATIONS CAN NOT BE FOLLOWED



CHARACTERISTS OF MULTI TAP TRANSFORMER



$$n = \frac{\text{REQUIRED WINDING VOLTAGE}}{\text{RATED WINDING VOLTAGE}}$$

$n \times$ ORIGINAL VALUE P_S $\frac{\text{ORIGINAL VALUE}}{n}$

PY FOR 2000/1000/500/1 CURRENT TRANSFORMER 10 Ps 250 IS CLASSIFIED FOR 2000/1 WINDING WHAT ARE THE CLASSIFICATION FOR 1000/1 AND 500/1 WINDING.

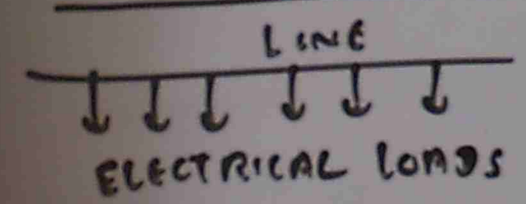
1000/1 $n = \frac{1000}{2000} = \frac{1}{2}$

$\frac{1}{2} \times 10 P_S \frac{250}{1/2} = 5 P_S 500$

500/1 $n = \frac{500}{2000} = \frac{1}{4}$

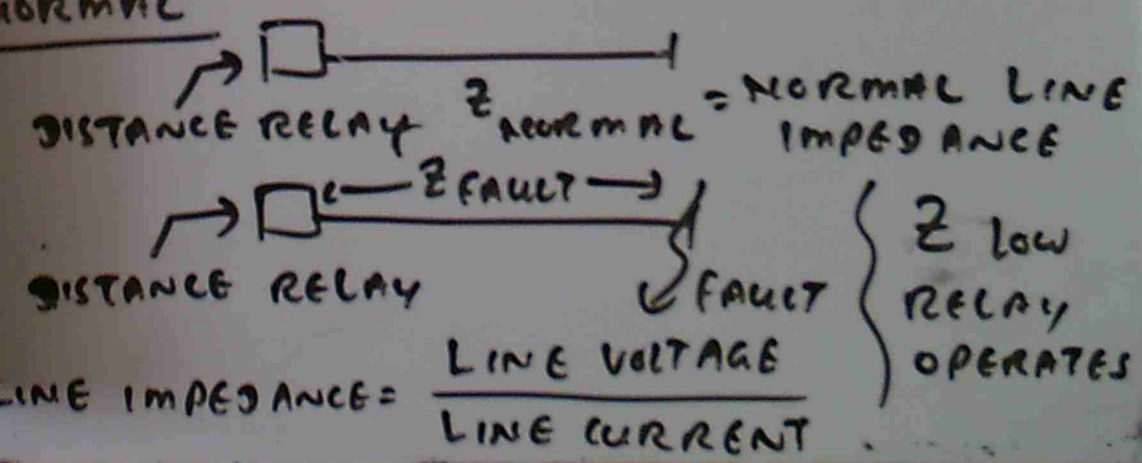
$\frac{1}{4} \times 10 P_S \frac{250}{1/4} = 2.5 P_S 1000$

DISTANCE PROTECTION SYSTEM



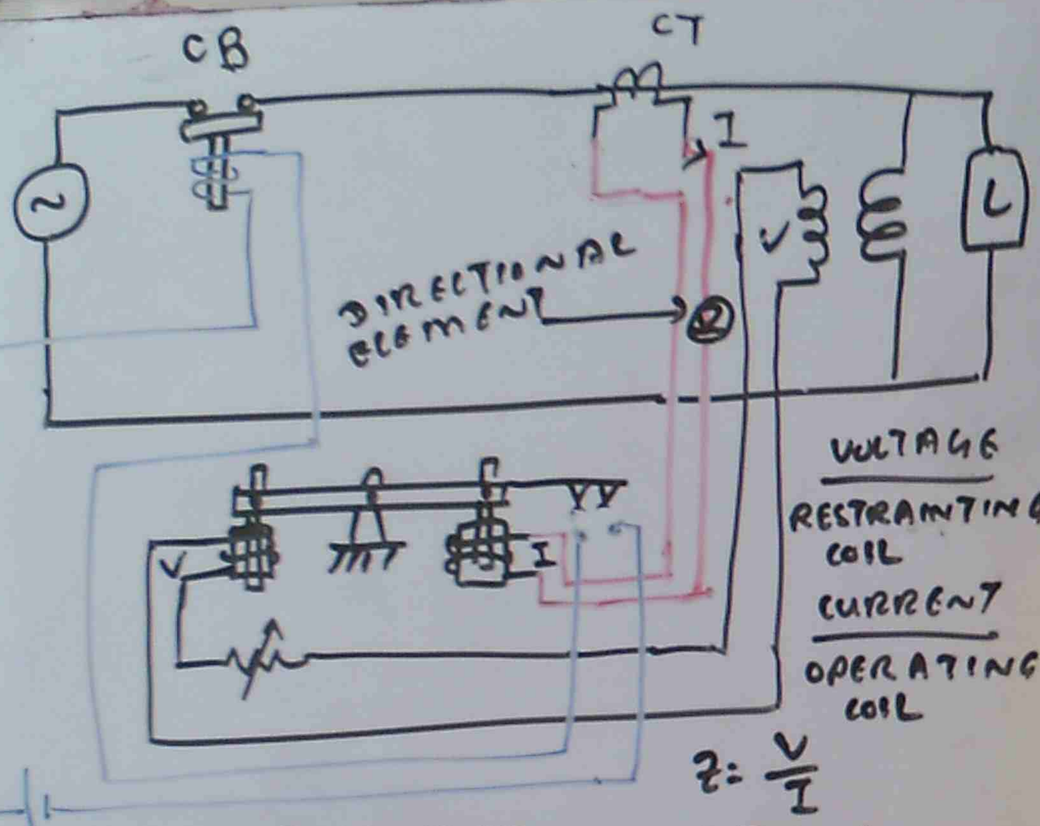
TO PROVIDE THE PROTECTION FOR THE GIVEN SYSTEM, DISTANCE RELAY SHOULD BE USED.

NORMAL



Z LOW RELAY OPERATES

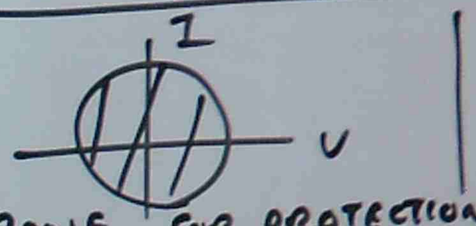
$$\text{LINE IMPEDANCE} = \frac{\text{LINE VOLTAGE}}{\text{LINE CURRENT}}$$



NORMAL - VOLTAGE HIGH, CURRENT LOW
$Z = \frac{V}{I}$ HIGH

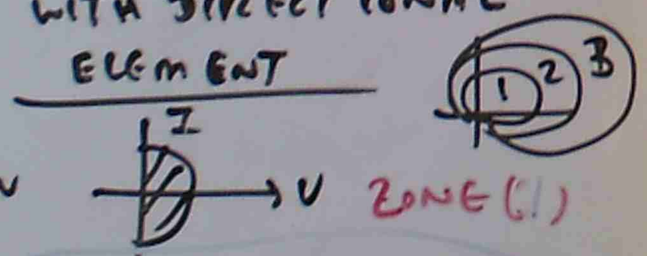
FAULT - VOLTAGE LOW, CURRENT HIGH
$Z = \frac{V}{I}$ LOW
RELAY OPERATE

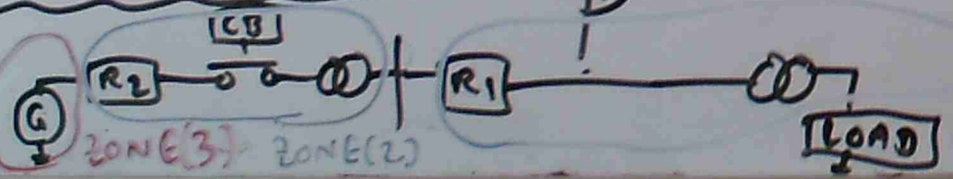
WITH OUT DIRECTIONAL ELEMENT

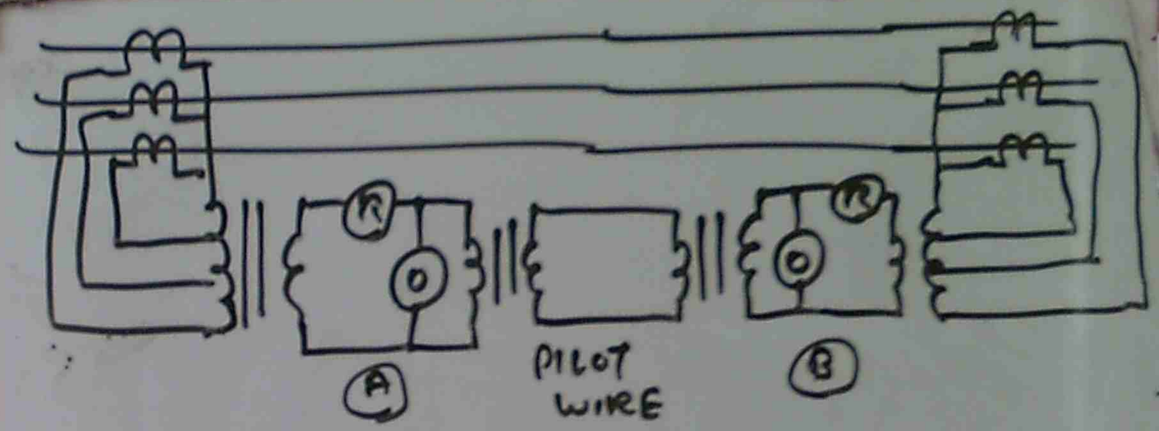


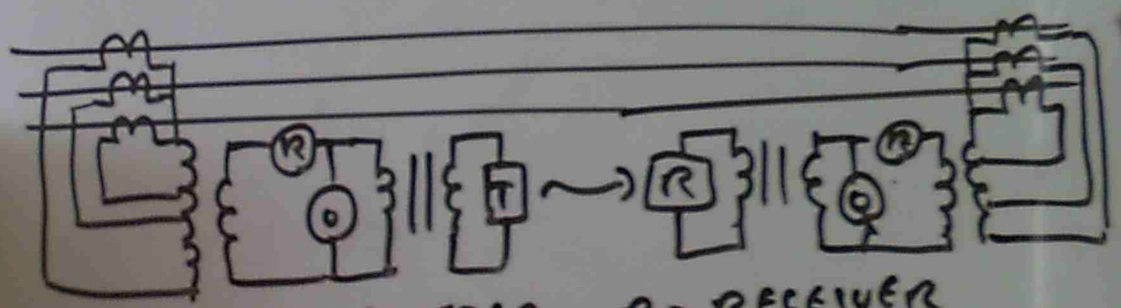
ZONE FOR PROTECTION

WITH DIRECTIONAL ELEMENT









T - TRANSMITTER, R - RECEIVER

LINE TO LINE FAULT

A → B FAULT → $I_A - I_B$ = OPERATING CURRENT — V_{AB} RESTRAINTING VOLTAGE

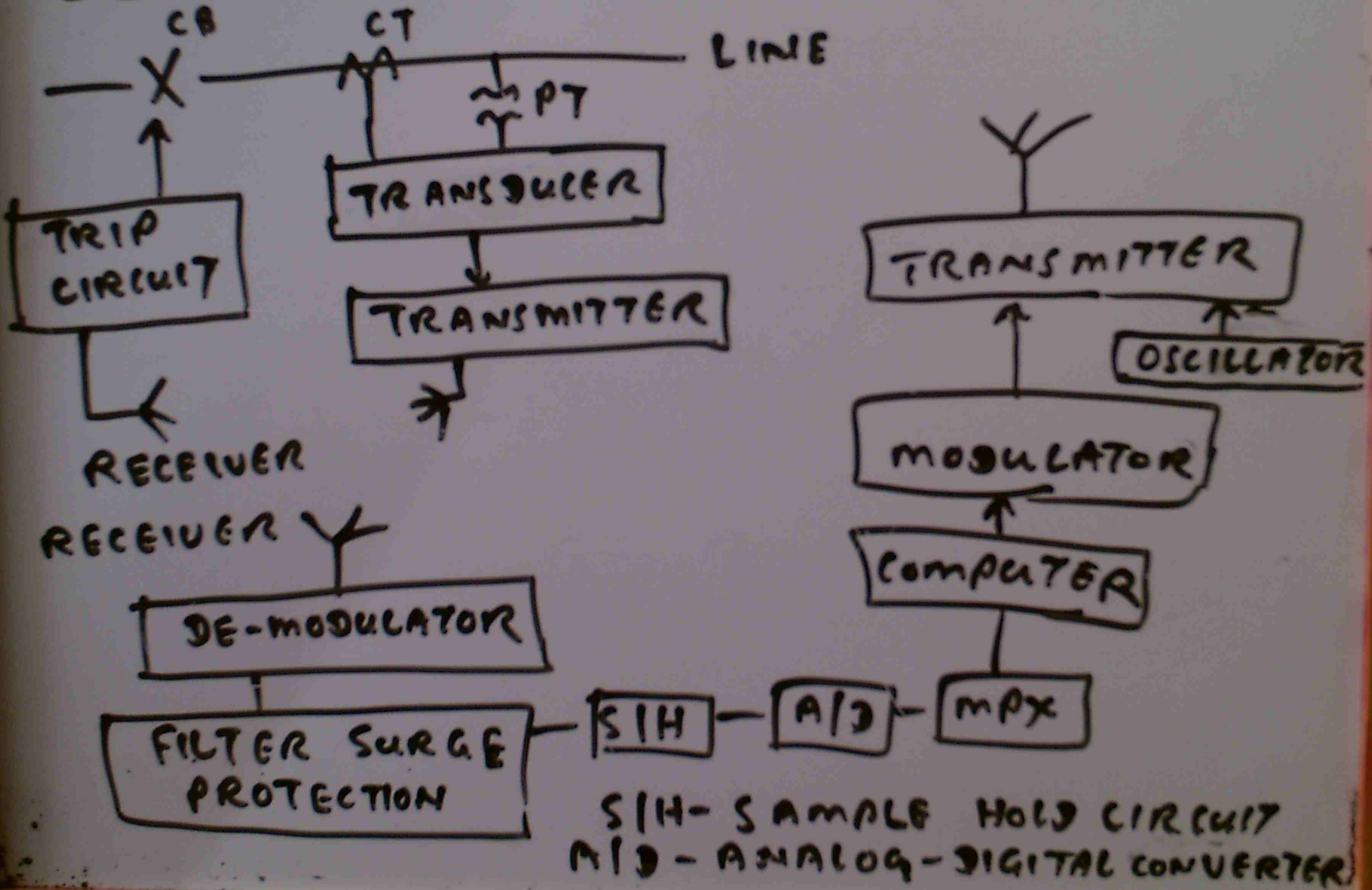
B → C FAULT → $I_B - I_C$ = OPERATING CURRENT — V_{BC} RESTRAINTING VOLTAGE

C → A FAULT → $I_C - I_A$ = OPERATING CURRENT — V_{CA} RESTRAINTING VOLTAGE

GROUND FAULT

FAULT	OPERATG	RESTRAINT
A → G	$I_{A \to G}$	V_{A-G}
B → G	$I_{B \to G}$	V_{B-G}
C → G	$I_{C \to G}$	V_{C-G}

APPLICATION OF TELECOMMUNICATION NETWORK IN POWER SYSTEM PROTECTION

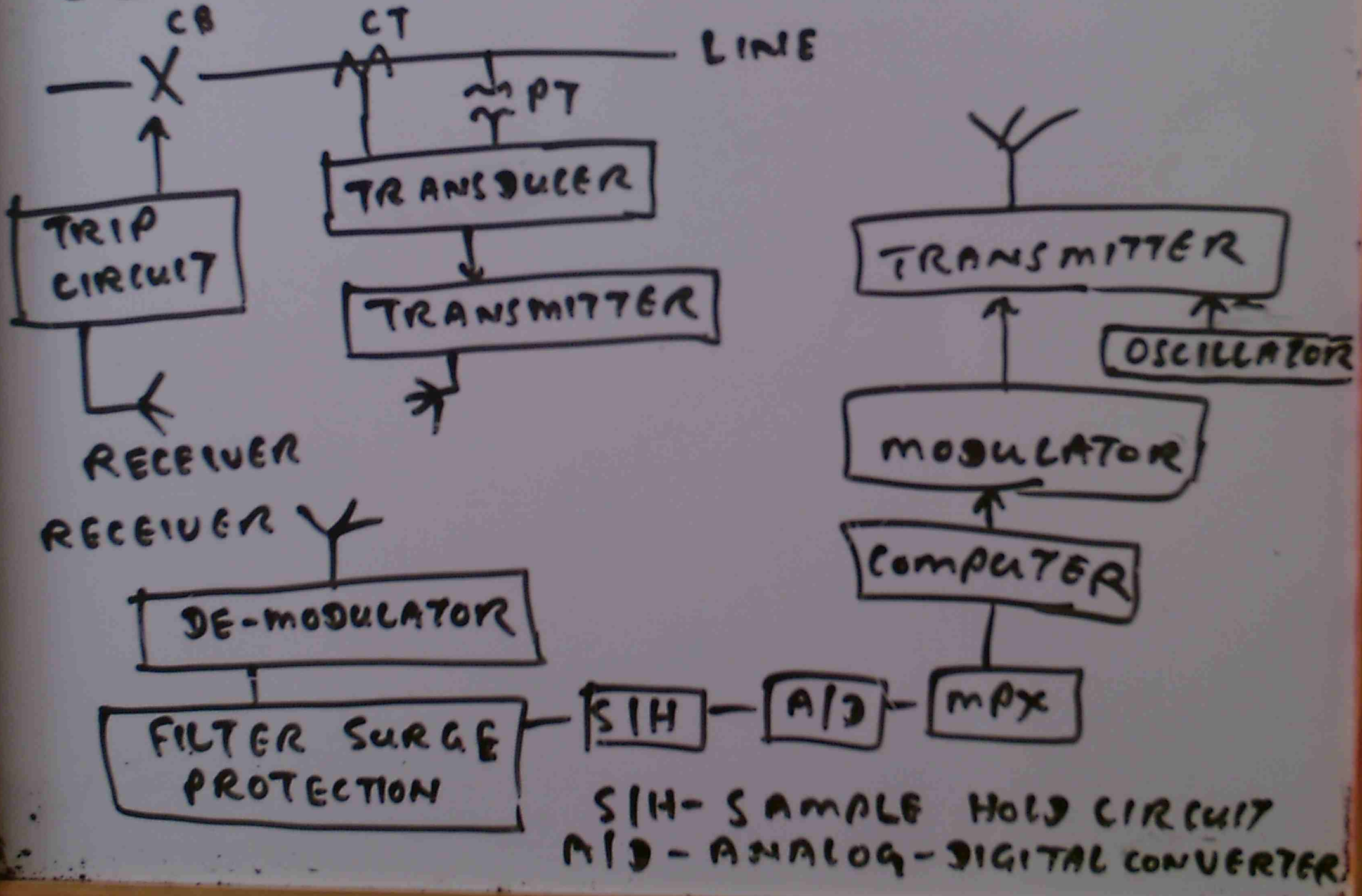


S/H - SAMPLE HOLD CIRCUIT
A/D - ANALOG - DIGITAL CONVERTER

1 - VOLTAGE HIGH, CURRENT LOW

LINE TO LINE FAULT

APPLICATION OF TELECOMMUNICATION NETWORK IN POWER SYSTEM PROTECTION



S/H - SAMPLE HOLD CIRCUIT
A/D - ANALOG-DIGITAL CONVERTER

(15) OVER CURRENT AND EARTH FAULT PROTECTION

SLIDE 1 ⟶ 12
Q1 ⟶ Q8

(16) TIME & CURRENT GRADING

SLIDE 1
Q 9

(17) POWER TRANSFORMER PROTECTION

SLIDE 1 ⟶ 8
Q10 ⟶ Q15

(18) CONNECTION OF DIFFERENTIAL RELAY

SLIDE 1 +2
Q 16

(19) THREE PHASE DIFFERENTIAL RELAY

SLIDE 1 ⟶ 2
Q17, Q18

(20) CONNECTION OF MAIN TRANSFORMER CT, DIRECTIONAL RELAY

SLIDE 1 ⟶ 3
Q19

(21) DEFINITE MINIMUM TIME POINT INTERPRETING RELAY SPECIFICATION

SLIDE 1 +2 , Q 20 ⟶ Q21

(22) CAPACITOR BANK PROTECTION

SLIDE 1 Q 22

(23) TRANSMISSION LINE PROTECTION

SLIDE 1 ⟶ 3
Q23 + Q24

(24) DISTANCE RELAY + PILOT WIRE + DIFFERENTIAL THREE PHASE LINE PROTECTION

SLIDE 1 ⟶ 8, Q25 ⟶ Q29

(25) DISTANCE PROTECTION SCHEME

SLIDE 1 ⟶ 9
Q 30 ⟶ Q 37

(26) PROTECTIVE TRANSFORMER

SLIDE 1 ⟶ 8
Q 38 ⟶ Q 45

(27) CT CHARACTERISTICS

SLIDE 1 ⟶ 3
Q 46 ⟶ Q 49

(28) MULTI TAPPED CT, CT CALCULATION TESTING CT

SLIDE 1 ⟶ 6
Q 50 ⟶ Q 53

(29) DIGITAL RELAY + TELE COM:

SLIDE 1 ⟶ 10
Q 54 ⟶ Q 61

(30) TYPICAL CONTROL POWER INSTALLATION DIAGRAM

SLIDE 1 ⟶ 3
Q 62

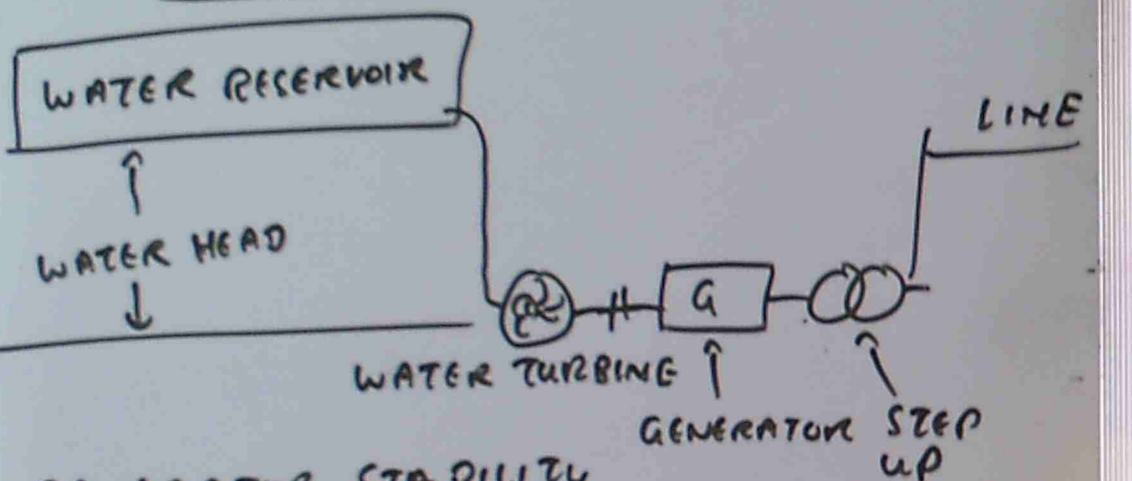
(31) 3φ VOLTAGE CONTROL DIAGRAM + COMPARATOR

SLIDE 1 ⟶ 2
Q 63

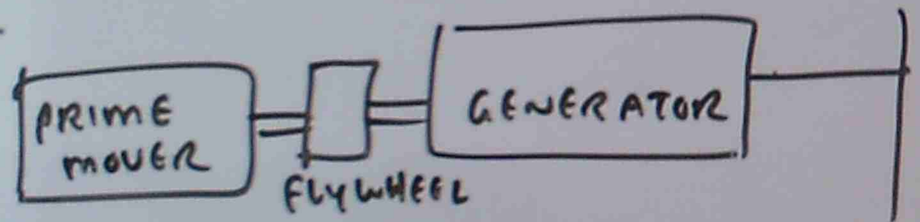
(32) OVER CURRENT & EARTH FAULT PROTECTION + DIRECTIONAL PROTECTION

SLIDE 1 ⟶ 17
Q 64 ⟶ Q 71

POWER SYSTEM OPERATION

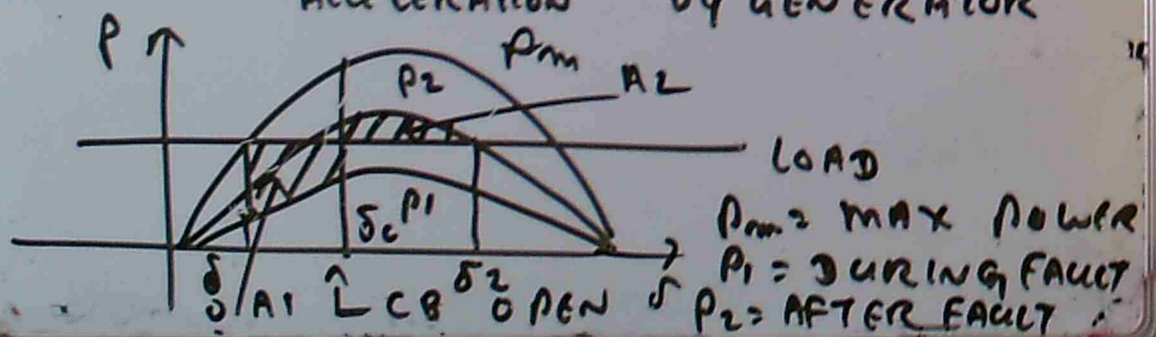


GENERATOR STABILITY



$$m_c \frac{d^2\delta}{dt^2} = P_0 - P_m \sin\delta$$

- m_c: MOMENT OF INERTIA
- $\frac{d^2\delta}{dt^2}$: ANGULAR ACCELERATION
- $P_m \sin\delta$: ELECTRICAL ENERGY OUTPUT BY GENERATOR



P_m = MAX POWER
P_1 = DURING FAULT
P_2 = AFTER FAULT

δ_0 = OPERATING δ
δ_c = CRITICAL FAULT CLEARING δ

$$\delta_c = \frac{\cos^{-1} P_1\cos\delta_0 - P_2\cos\delta_2 + P_0(\delta_0 - \delta_2)}{P_1 - P_2}$$

$$\delta_0 = \sin^{-1}\frac{P_0}{P_m}, \quad \delta_2 = 180 - \sin^{-1}\left(\frac{P_0}{P_2}\right)$$

Ph A GENERATOR OPERATING AT 50HZ DELIVERS 1 PU POWER TO INFINITE BUS THROUGH A NETWORK. MAXIMUM POWER IS 1.8 PU. DURING FAULT 0.4 P.U AFTER FAULT 1.3 PU. BY USE OF EQUAL AREA CRITERION, DETERMINE CRITICAL FAULT CLEARING ANGLE (1500RPM)

$$\delta_0 = \sin^{-1}\frac{P_0}{P_m} = \sin^{-1}\frac{1}{1.8} = 33.8^\circ$$

$$\delta_2 = 180 - \sin^{-1}\frac{P_0}{P_2} = 180 - \sin^{-1}\frac{1}{1.3} = 129.72^\circ$$

$180^\circ \longrightarrow \pi$ RADIAN

$33.8 \longrightarrow ? = \frac{\pi \times 33.8}{180} = 0.58$

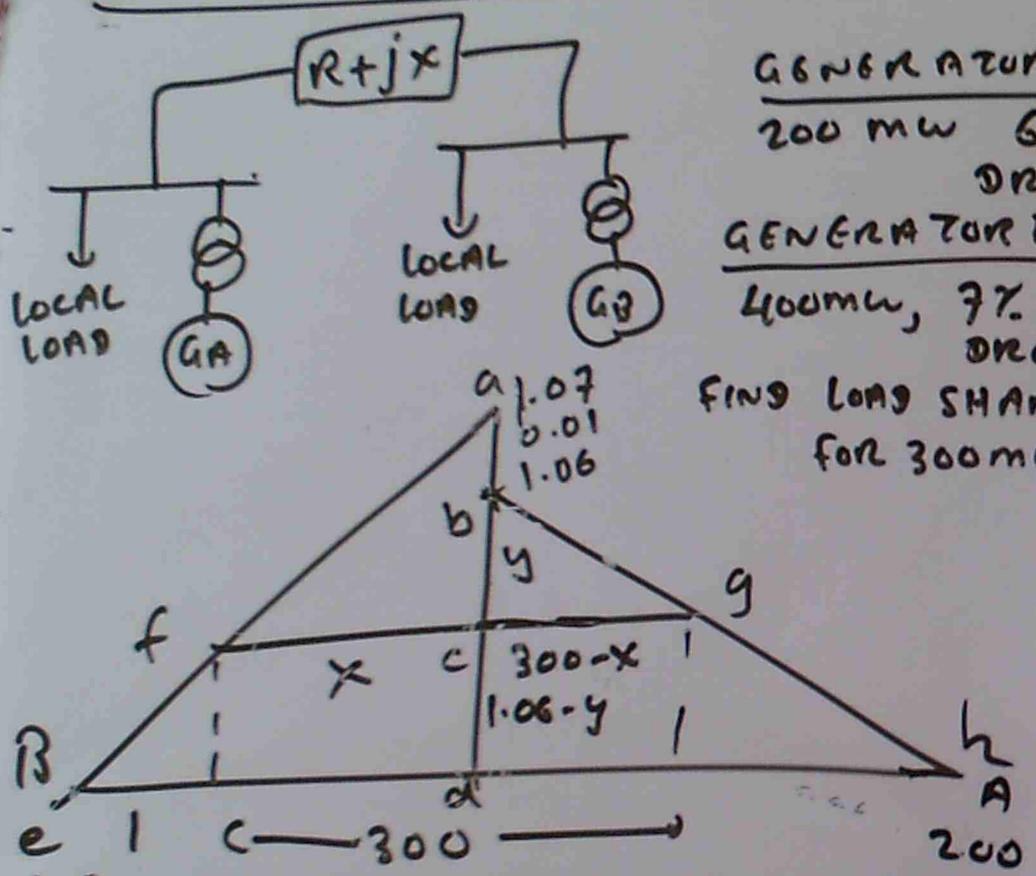
$129.72 \longrightarrow ? = \frac{\pi \times 129.72}{180} = 2.26$

$$\delta_c = \cos^{-1}\frac{0.4\cos 33.8 - 1.3\cos 129.72 + 1(2.26 - 0.58)}{0.4 - 1.3}$$

$= 58.9^\circ$

$1500 \times 360 \rightarrow 60$ sec
$58.9 \longrightarrow ?$
$= \frac{60 \times 58.9}{1500 \times 360} = 6$ ms

GENERATOR LOAD SHARING



GENERATOR (A)
200 MW 6% DROP

GENERATOR (B)
400MW, 7% DROP

FIND LOAD SHARE FOR 300MW

A LOAD SHARE X
B LOAD SHARE 300-X

$\triangle aed \;///\; \triangle afc$

$\frac{ad}{ac} = \frac{ed}{fc} \rightarrow \frac{0.07}{0.01+y} = \frac{400}{x}$ — (1)

$\triangle bdh \;///\; \triangle bcg$

$\frac{bd}{bc} = \frac{dh}{cg} \rightarrow \frac{0.06}{y} = \frac{200}{300-x}$ — (2)

$\frac{0.07}{0.01+y} = \frac{400}{x}$ — (1)

$0.07x = 400(0.01+y)$

$0.07x = 4 + 400y \rightarrow y = \frac{0.07x-4}{400}$

$\frac{0.06}{y} = \frac{200}{300-x}$ — (2)

$0.06(300-x) = 200y$

$0.06(300-x) = 200\,\frac{(0.07x-4)}{400}$

$1.8 - 0.06x = 0.035x - 2$

$0.095x = 3.8 \rightarrow x = 210$ MW (B)

(A) $= 300 - x = 300 - 210 = 90$ MW

(33) ALTERNATOR SUPPLY LOAD

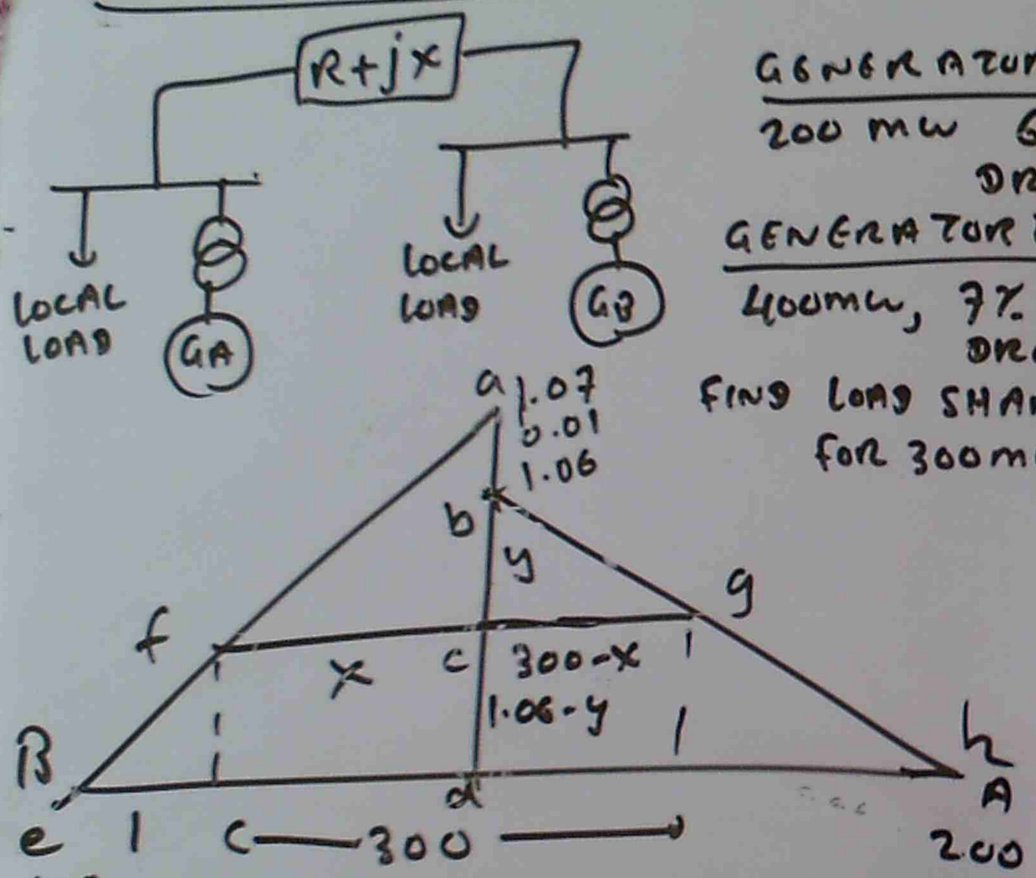
SLIDE $1 \rightarrow 4$, $\Theta 1 \rightarrow \Theta 2$

(34) STABILITY

SLIDE $1 \longrightarrow 11$

$\Theta 3 \rightarrow \Theta 4$

GENERATOR LOAD SHARING



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FIND LOAD SHARE FOR 300MW

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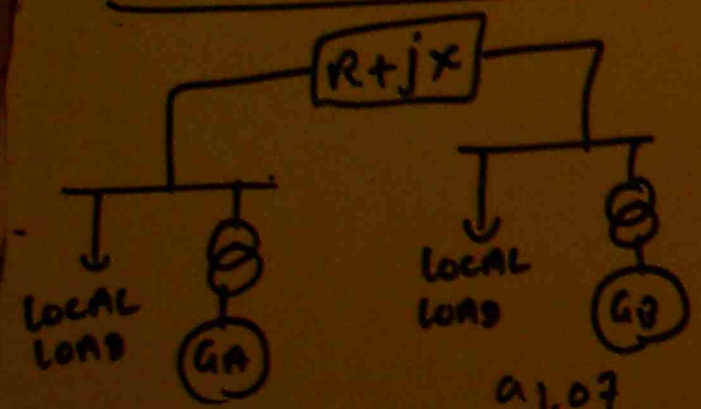
SLIDE $1 \rightarrow 4$, $\theta 1 \rightarrow \theta 2$

(34) STABILITY

SLIDE $1 \longrightarrow 11$

$\theta 3 \rightarrow \theta 4$

GENERATOR LOAD SHARING



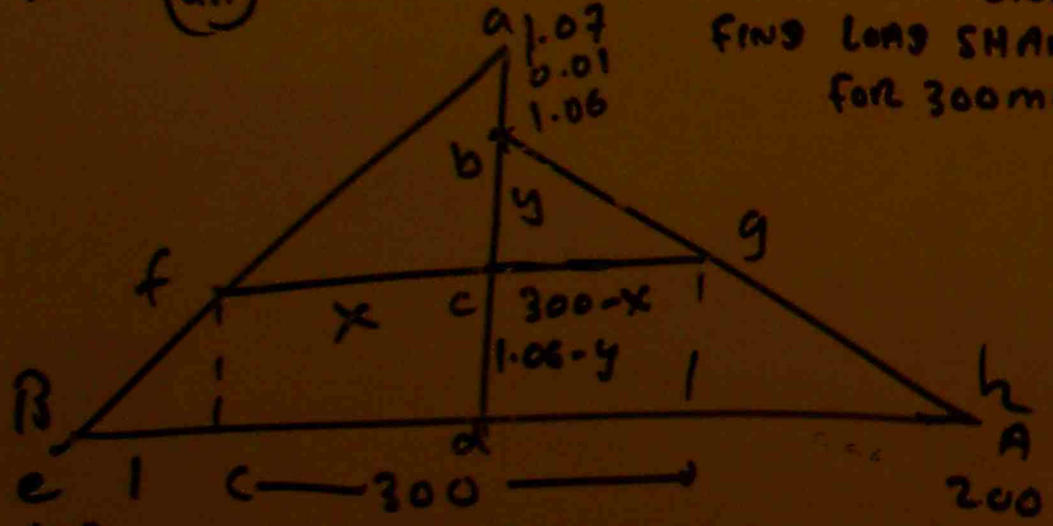
GENERATOR (A)

200 mw 6% DROP

GENERATOR (B)

400mw, 7% DROP

FIND LOAD SHARE FOR 300mw



A LOAD SHARE x

B LOAD SHARE $300-x$

$\Delta aed \;|||\; \Delta afc$

$$\frac{ad}{ac} = \frac{ed}{fc} \rightarrow \frac{0.07}{0.01+y} = \frac{400}{x} \quad \text{— (1)}$$

$\Delta bdh \;|||\; \Delta bcg$

$$\frac{bd}{bc} = \frac{dh}{cg} \rightarrow \frac{0.06}{y} = \frac{200}{300-x} \quad \text{— (2)}$$

$$\frac{0.07}{0.01+y} = \frac{400}{x} \quad \text{— (1)}$$

$$0.07x = 400(0.01+y)$$

$$0.07x = 4 + 400y \rightarrow y = \frac{0.07x-4}{400}$$

$$\frac{0.06}{y} = \frac{200}{300-x} \quad \text{— (2)}$$

$$0.06(300-x) = 200y$$

$$0.06(300-x) = 200\,\frac{(0.07x-4)}{400}$$

$$1.8 - 0.06x = 0.035x - 2$$

$$0.095x = 3.8 \rightarrow x = 40 \text{ mw (B)}$$

$$(A) = 300 - x = 300 - 40 = 260 \text{ mw}$$

(33) ALTERNATOR SUPPLY LOAD

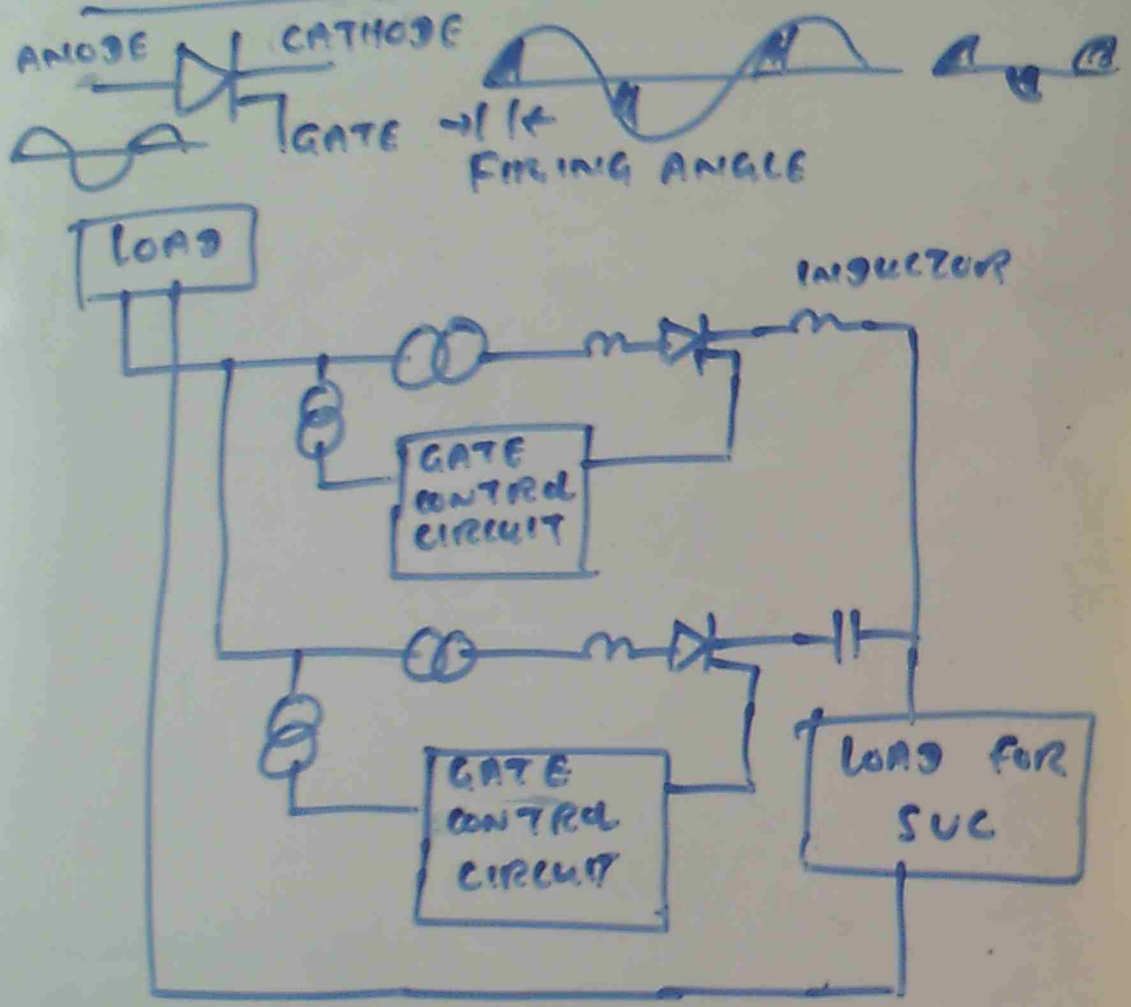
SLIDE 1 → 4, Q1 → Q2

(34) STABILITY

SLIDE 1 → 11

Q3 → Q4

STATIC VAR COMPENSATION SYSTEM



THE CONDITION OF POWER FACTOR IN THE SYSTEM IS DETECTED BY GATE CONTROL CIRCUIT. DEPENDING ON P.F NATURE, THE SWITCHING TO INDUCTOR & CAPACITOR ARE MADE BY SVC (STATIC VAR CONTROL SYSTEM)

THE EQUATION TO DETERMINE THE CONSUMER'S BEHAVIOUR

$$T_{gi} \times P_{gi} = -B_{gi} - C_{gi} \times P_{gi} + \lambda \qquad i = 1, 2 \cdots m$$

$$T_{dj} \times P_{dj} = B_{dj} + C_{dj} P_{dj} - \lambda \qquad j = 1, 2, \cdots m$$

P_{gi} = POWER SUPPLY OF PERIOD "i"

P_{dj} = POWER DEMAND OF CONSUMER "j"

$B_{gi} + C_{gi} \times P_{gi}$ = INDIVIDUAL COST OF CONSUMER "i"

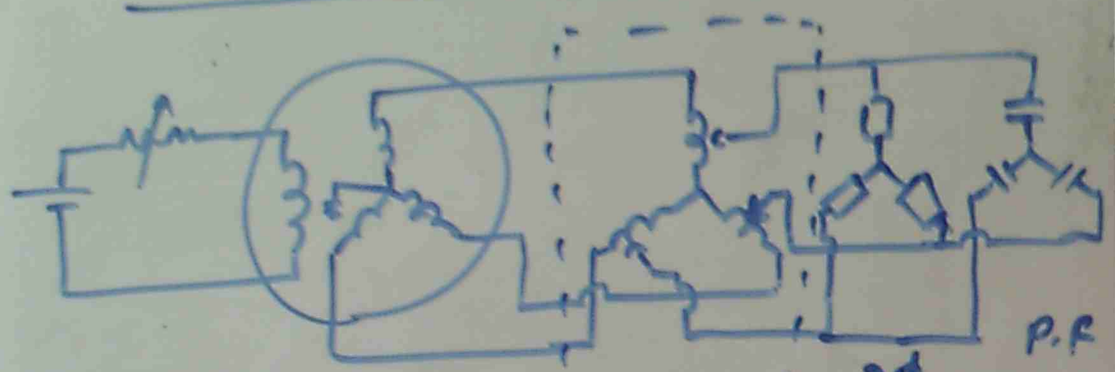
$B_{dj} + C_{dj} \times P_{dj}$ = MANAGERIAL BENEFIT OF CONSUMER "j"

λ = PRICE OF POWER

T_{gi} = SUPPLY SYSTEM CONSTANT

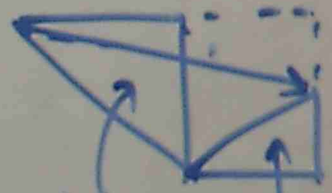
T_{dj} = CONSUMER DEMAND CONSTANT

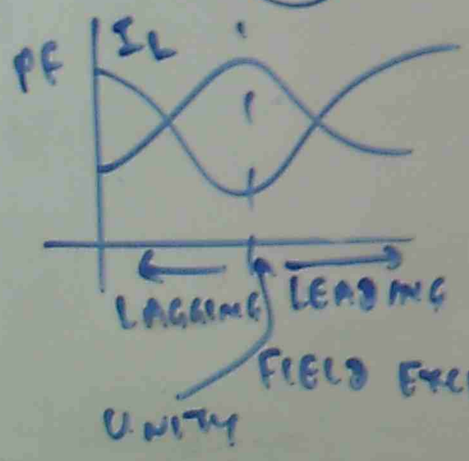
VOLTAGE AND POWER FACTOR CONTROL

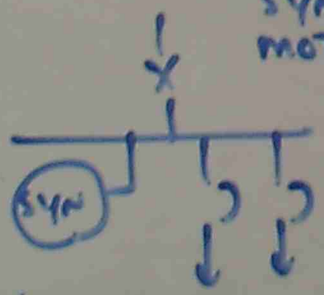


REACTIVE POWER CONTROL BY SYNCHRONOUS MOTOR

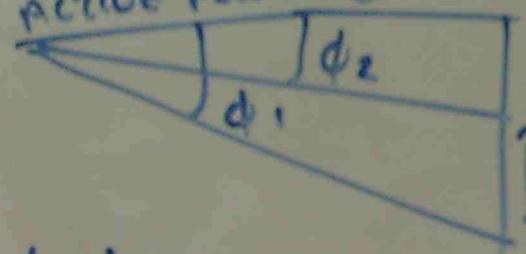




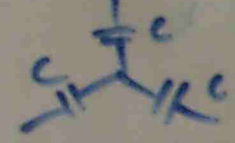




ACTIVE POWER (W) = I^2R

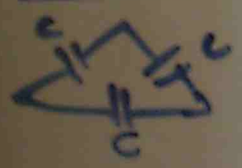


3ϕ Y



$$C = \frac{\frac{W}{3}(\tan\phi_1 - \tan\phi_2)}{2\pi f \left(\frac{V_{LINE}}{\sqrt{3}}\right)^2}$$

3ϕ Δ

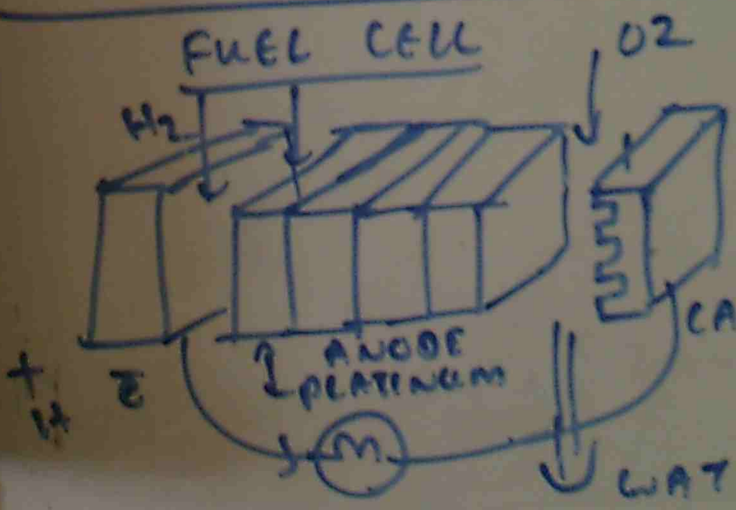


$$C = \frac{\frac{W}{3}(\tan\phi_1 - \tan\phi_2)}{2\pi f V_{LINE}^2}$$

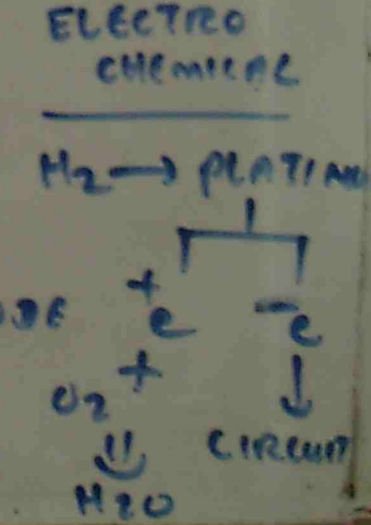
1ϕ

$$C = \frac{W(\tan\phi_1 - \tan\phi_2)}{2\pi f V^2}$$

$\phi_1 = \cos^{-1} PF_1$, $\phi_2 = \cos^{-1} PF_2$



ELECTRO CHEMICAL



(34) STABILITY

SLIDE (1) → (11)

Q_3 + Q4

---

(35) CORONA + SHORT CIRCUIT + TRANSIENT FAULT + VOLTAGE SURGE REFLECTION

SLIDE (1) → (19)

Q5 → Q18

---

(36) REACTIVE POWER CONTROL STATIC VAR COMPENSATION

SLIDE (1) → (3)

Q19 → Q21

---

(37) LINE POWER FLOW

SLIDE (1) + (2)

Q22

---

(38) COMPUTERISED CONTROL + IP BASED

SLIDE (1) → (23)

Q23 → Q37

---

(39) METERING + POWER SURGE

SLIDE (1) → (15)

Q38 → Q43

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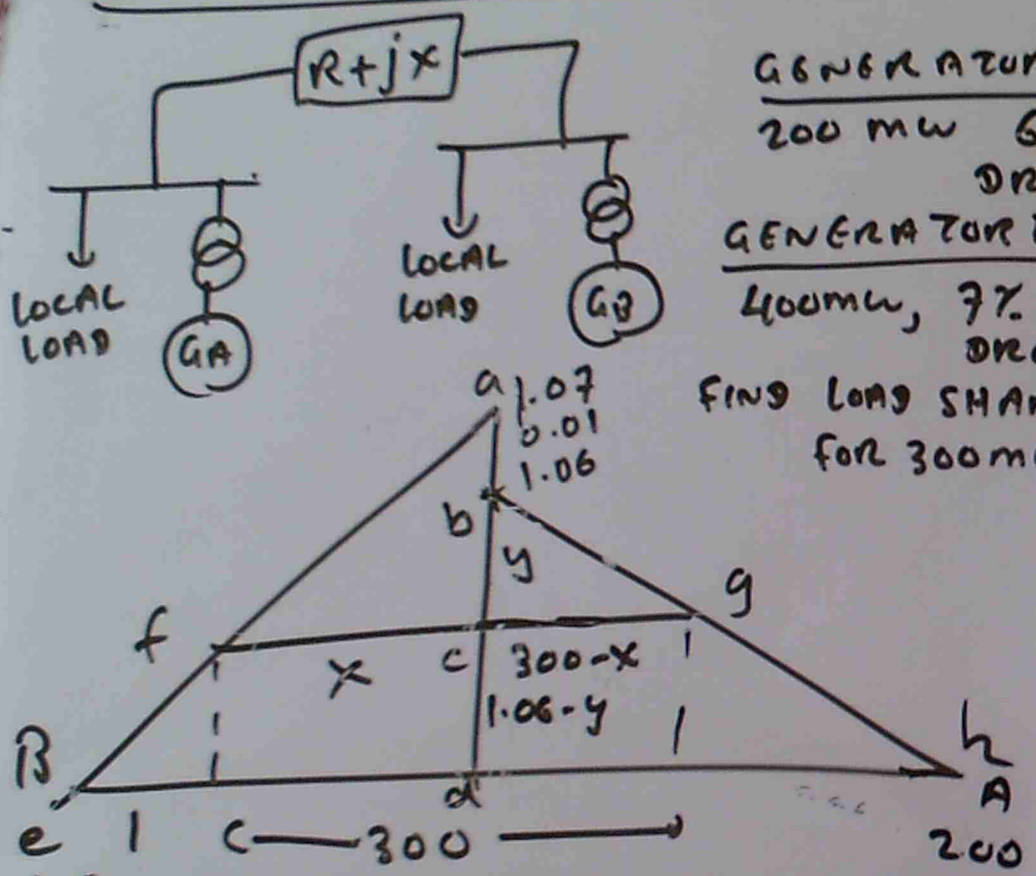
(40) POWER SYSTEM ECONOMIC + FUEL CELL

SLIDE (1) → (5) Q44 → Q46

GENERATOR LOAD SHARING



GENERATOR (A)
200 MW 6% DROP

GENERATOR (B)
400MW, 7% DROP

FIND LOAD SHARE FOR 300MW

A LOAD SHARE X
B LOAD SHARE 300-X

$\triangle aed \;///\; \triangle afc$

$\frac{ad}{ac} = \frac{ed}{fc} \rightarrow \frac{0.07}{0.01+y} = \frac{400}{x}$ — (1)

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$0.06(300-x) = 200\,\frac{(0.07x-4)}{400}$

$1.8 - 0.06x = 0.035x - 2$

$0.095x = 3.8 \rightarrow x = 210$ MW (B)

(A) $= 300 - x = 300 - 210 = 90$ MW

(33) ALTERNATOR SUPPLY LOAD

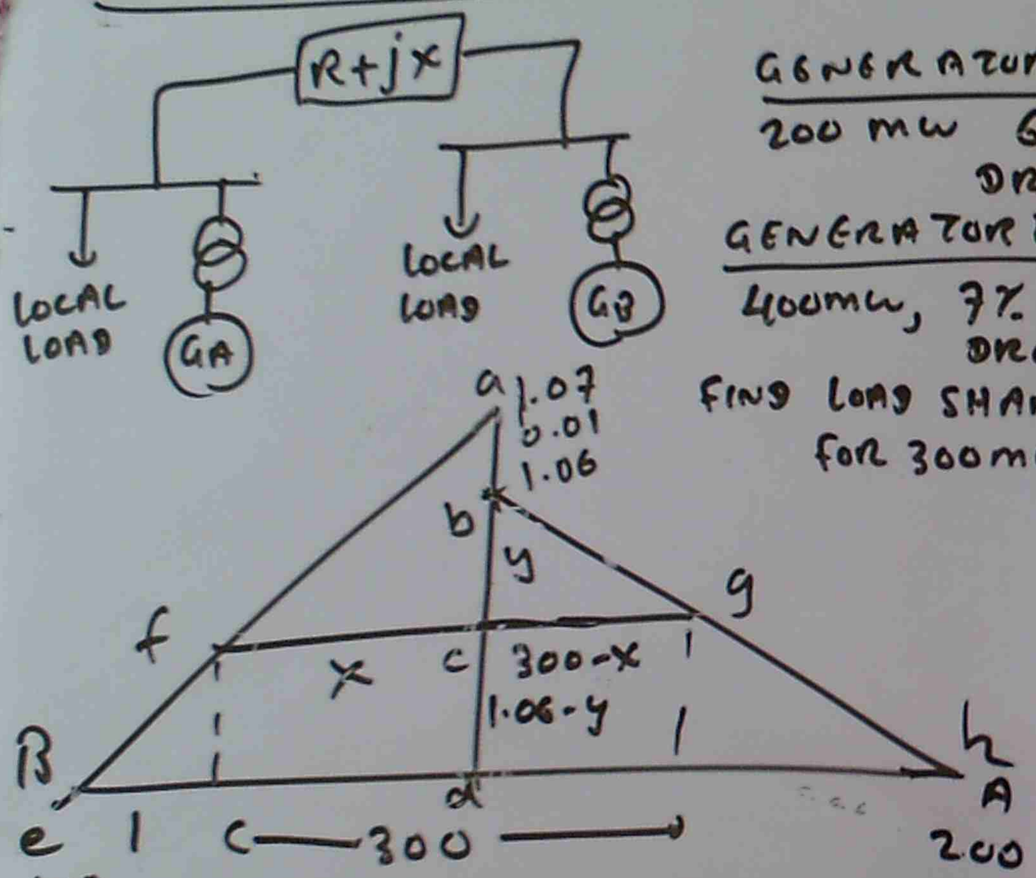
SLIDE $1 \rightarrow 4$, $\Theta 1 \rightarrow \Theta 2$

(34) STABILITY

SLIDE $1 \longrightarrow 11$

$\Theta 3 \rightarrow \Theta 4$

GENERATOR LOAD SHARING



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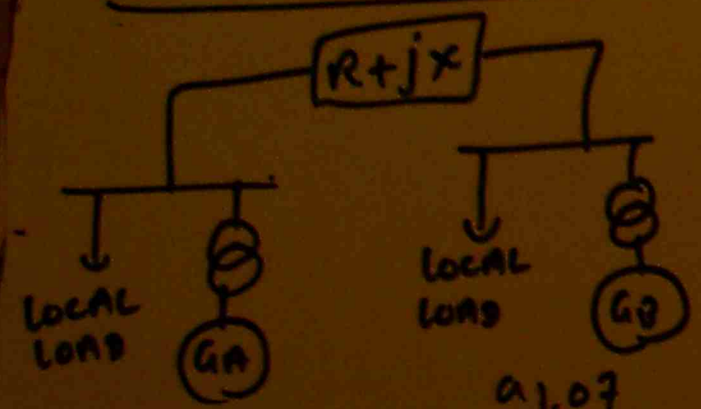

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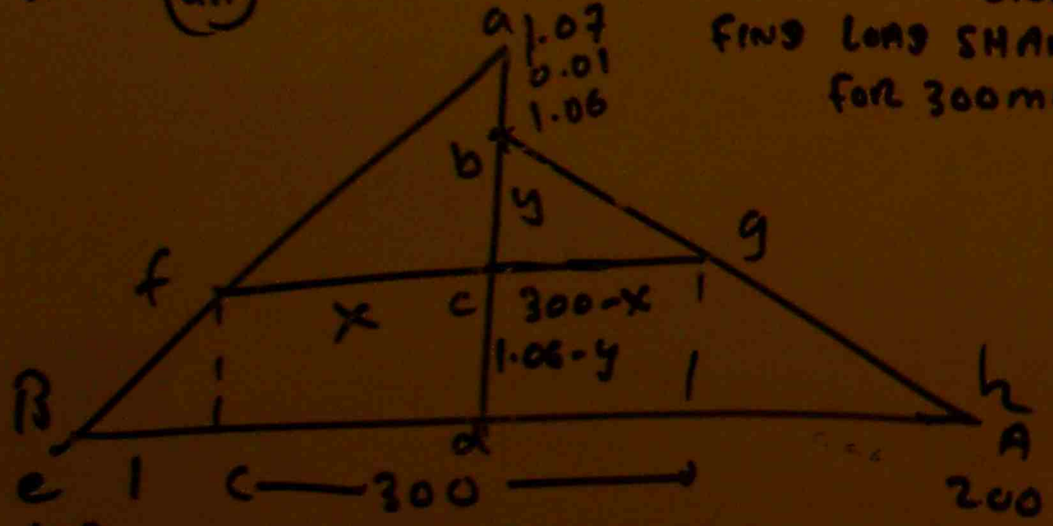


A LOAD SHARE x

B LOAD SHARE $300-x$

$\Delta aed \;|||\; \Delta afc$

$$\frac{ad}{ac} = \frac{ed}{fc} \rightarrow \frac{0.07}{0.01+y} = \frac{400}{x} \quad \text{— (1)}$$

$\Delta bdh \;|||\; \Delta bcg$

$$\frac{bd}{bc} = \frac{dh}{cg} \rightarrow \frac{0.06}{y} = \frac{200}{300-x} \quad \text{— (2)}$$

$$\frac{0.07}{0.01+y} = \frac{400}{x} \quad \text{— (1)}$$

$$0.07x = 400(0.01+y)$$

$$0.07x = 4 + 400y \rightarrow y = \frac{0.07x-4}{400}$$

$$\frac{0.06}{y} = \frac{200}{300-x} \quad \text{— (2)}$$

$$0.06(300-x) = 200y$$

$$0.06(300-x) = 200\,\frac{(0.07x-4)}{400}$$

$$1.8 - 0.06x = 0.035x - 2$$

$$0.095x = 3.8 \rightarrow x = 40 \text{ mw (B)}$$

$$(A) = 300 - x = 300 - 40 = 260 \text{ mw}$$

(33) ALTERNATOR SUPPLY LOAD

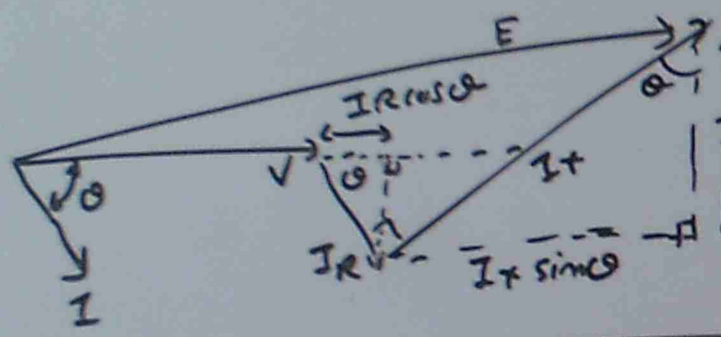
SLIDE 1 → 4, Q1 → Q2

(34) STABILITY

SLIDE 1 → 11

Q3 → Q4

POWER FLOW EQUATION

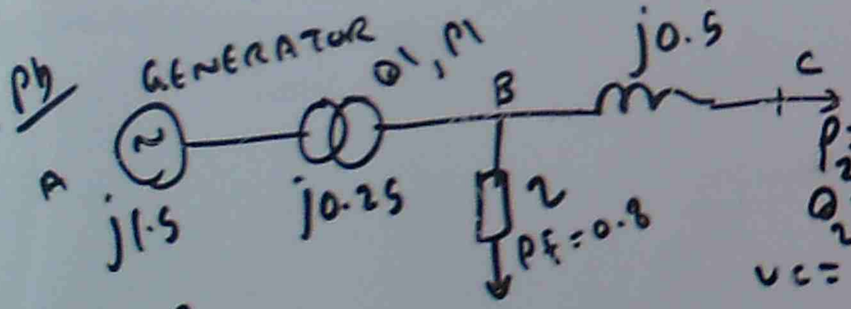


$$E = \sqrt{(V + IR\cos\Theta + I\times\sin\Theta)^2 + (I\times\cos\Theta - IR\sin\Theta)^2}$$

$I\cos\Theta = \frac{P}{V}$, $I\sin\Theta = \frac{Q}{V}$

$$E = \sqrt{\left(V + \frac{Q\times}{V}\right)^2 + \left(\frac{P\times}{V}\right)^2}$$

Pb



$V_B = ?$

$$V_B = \sqrt{\left(V_C + \frac{Q_2 X_{BC}}{V_C}\right)^2 + \left(\frac{P_2 X_{BC}}{V_C}\right)^2}$$

$$= \sqrt{\left(1 + \frac{0.2\times 0.5}{1}\right)^2 + \left(\frac{0.5\times 0.5}{1}\right)^2}$$

$$= 1.12 \text{ pu}$$

$$V_A = \sqrt{\left(V_B + \frac{Q_1 X_{AB}}{V_B}\right)^2 + \left(\frac{P_1 X_{AB}}{V_B}\right)^2}$$

(P_1, Q_1) = power flow to Z + power loss + power flow to C

$$P_Z = \frac{V_B^2}{Z}\cos\Theta_Z = \frac{1.12^2}{2}\cos 36.8 = 0.5 \text{ pu}$$

$$Q_Z = \frac{V_B^2}{Z}\sin\Theta_Z = \frac{1.12^2}{2}\sin 36.8 = 0.37 \text{ pu}$$

$$I_{BC} = \frac{P + jQ}{V_C} = \frac{0.5 + j0.2}{1} = \sqrt{0.5^2 + 0.2^2} = 0.55$$

$$Q_{BC} = I_{BC}^2 X_{BC} = (0.55)^2 \times 0.5 = 0.145$$

$P_1 = P_Z + P_2 = 0.5 + 0.5 = 1 \text{ pu}$

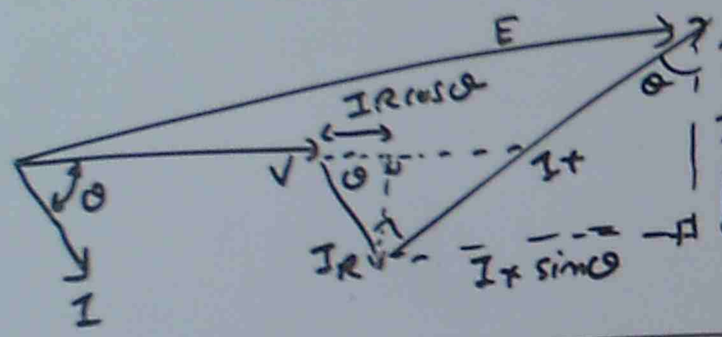
$Q_1 = Q_Z + Q_{BC} + Q_2 = 0.37 + 0.145 + 0.2 = 0.72$

$$V_A = \sqrt{\left(V_B + \frac{Q_1 X_{AB}}{V_B}\right)^2 + \left(\frac{P_1 X_{AB}}{V_B}\right)^2}$$

$$= \sqrt{\left(1.12 + \frac{0.72\times 0.25}{1.12}\right)^2 + \left(\frac{1\times 0.25}{1.12}\right)^2}$$

$$= \sqrt{1.28^2 + 0.223^2} = \sqrt{1.63 + 0.049} = 1.29 \text{ pu}$$

POWER FLOW EQUATION

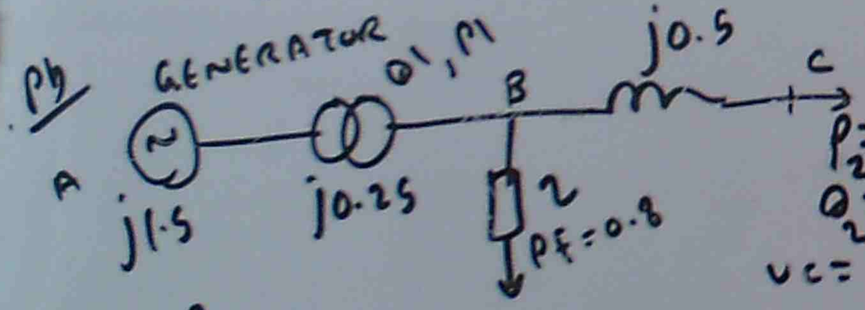


$$E = \sqrt{(V + IR\cos\Theta + I\times\sin\Theta)^2 + (I\times\cos\Theta - IR\sin\Theta)^2}$$

$I\cos\Theta = \frac{P}{V}$, $I\sin\Theta = \frac{Q}{V}$

$$E = \sqrt{\left(V + \frac{Q\times}{V}\right)^2 + \left(\frac{P\times}{V}\right)^2}$$

Ex



$V_B = ?$

$$V_B = \sqrt{\left(V_C + \frac{Q_2 X_{BC}}{V_C}\right)^2 + \left(\frac{P_2 X_{BC}}{V_C}\right)^2}$$

$$= \sqrt{\left(1 + \frac{0.2\times 0.5}{1}\right)^2 + \left(\frac{0.5\times 0.5}{1}\right)^2}$$

$$= 1.12 \text{ pu}$$

$$V_A = \sqrt{\left(V_B + \frac{Q_1 X_{AB}}{V_B}\right)^2 + \left(\frac{P_1 X_{AB}}{V_B}\right)^2}$$

(P_1, Q_1) = power flow to 2 + power loss + power flow to C

$$P_2 = \frac{V_B^2}{Z}\cos\Theta_Z = \frac{1.12^2}{2}\cos 36.8 = 0.5 \text{ pu}$$

$$Q_2 = \frac{V_B^2}{Z}\sin\Theta_Z = \frac{1.12^2}{2}\sin 36.8 = 0.37 \text{ pu}$$

$$I_{BC} = \frac{P + jQ}{V_C} = \frac{0.5 + j0.2}{1} = \sqrt{0.5^2 + 0.2^2} = 0.55$$

$$Q_{BC} = I_{BC}^2 X_{BC} = (0.55)^2 \times 0.5 = 0.145$$

$P_1 = P_2 + P_2 = 0.5 + 0.5 = 1 \text{ pu}$

$Q_1 = Q_2 + Q_{BC} + Q_2 = 0.37 + 0.145 + 0.2 = 0.72$

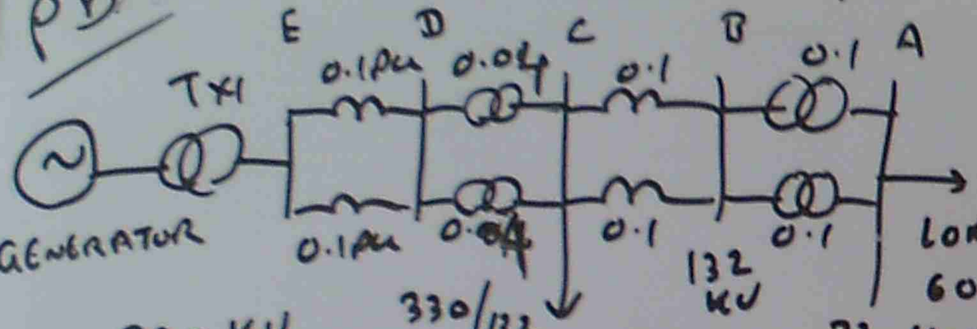
$$V_A = \sqrt{\left(V_B + \frac{Q_1 X_{AB}}{V_B}\right)^2 + \left(\frac{P_1 X_{AB}}{V_B}\right)^2}$$

$$= \sqrt{\left(1.12 + \frac{0.72\times 0.25}{1.12}\right)^2 + \left(\frac{1\times 0.25}{1.12}\right)^2}$$

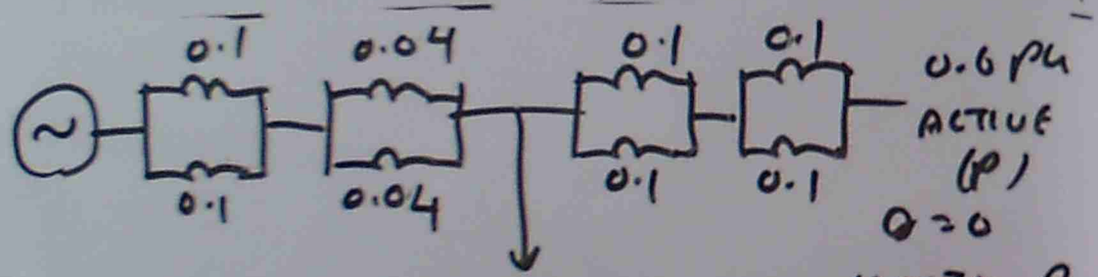
$$= \sqrt{1.28^2 + 0.223^2} = \sqrt{1.63 + 0.049} = 1.29 \text{ pu}$$

BASE = 100 MW

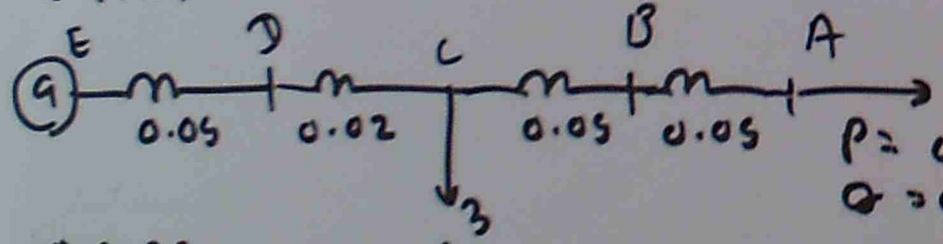
PD



FIND TOTAL MW & MVAR SUPPLIED BY GENERATOR

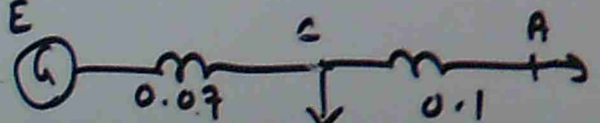


$\frac{0.1 \times 0.1}{0.1+0.1} = 0.05$ ACTIVE = 3, 0.9 PF



0.9 PF → $\theta = \cos^{-1} 0.4 = 26°$

ACTIVE = 3, REACTIVE = $3 \tan 26 = 1.46$ PU



$$V_C = \sqrt{\left(V_A + \frac{Q X_{CA}}{V_A}\right)^2 + \left(\frac{P X_{CA}}{V_A}\right)^2}$$

$$V_C = \sqrt{\left(1 + \frac{0 \times 0.1}{1}\right)^2 + \left(\frac{0.6 \times 0.1}{1}\right)^2} = 1.001$$

$$I_{C \to A} = \frac{P + jQ}{V_A} = \frac{0.6 + j0}{1} = 0.6$$

$\overrightarrow{EC}$ POWER = A POINT ACTIVE POWER + C-A ACTIVE POWER LOSS + C PT POWER

$$P_{EC} = 0.6 + I^2 \times 0 + 3 = 3.6 \text{ PU}$$

EC POWER = A POINT REACTIVE POWER + C-A POWER LOSS + C PT POWER

REACTIVE $= 0 + I^2 \times X_{CA} + 1.46$

$= 0.6^2 \times 0.1 + 1.46 = 1.496$ PU

$$I_{EC} = \frac{P_{EC} + jQ_{EC}}{V_C} = \frac{3.6 + j1.496}{1.001}$$

$$= \frac{\sqrt{3.6^2 + 1.496^2}}{1.001} = 3.84 \text{ PU}$$

TOTAL POWER SUPPLIED BY GENERATOR

ACTIVE POWER = E→C ACTIVE POWER = 3.6 PU

REACTIVE POWER = E→C REACTIVE POWER + E-C REACTIVE POWER LOSS

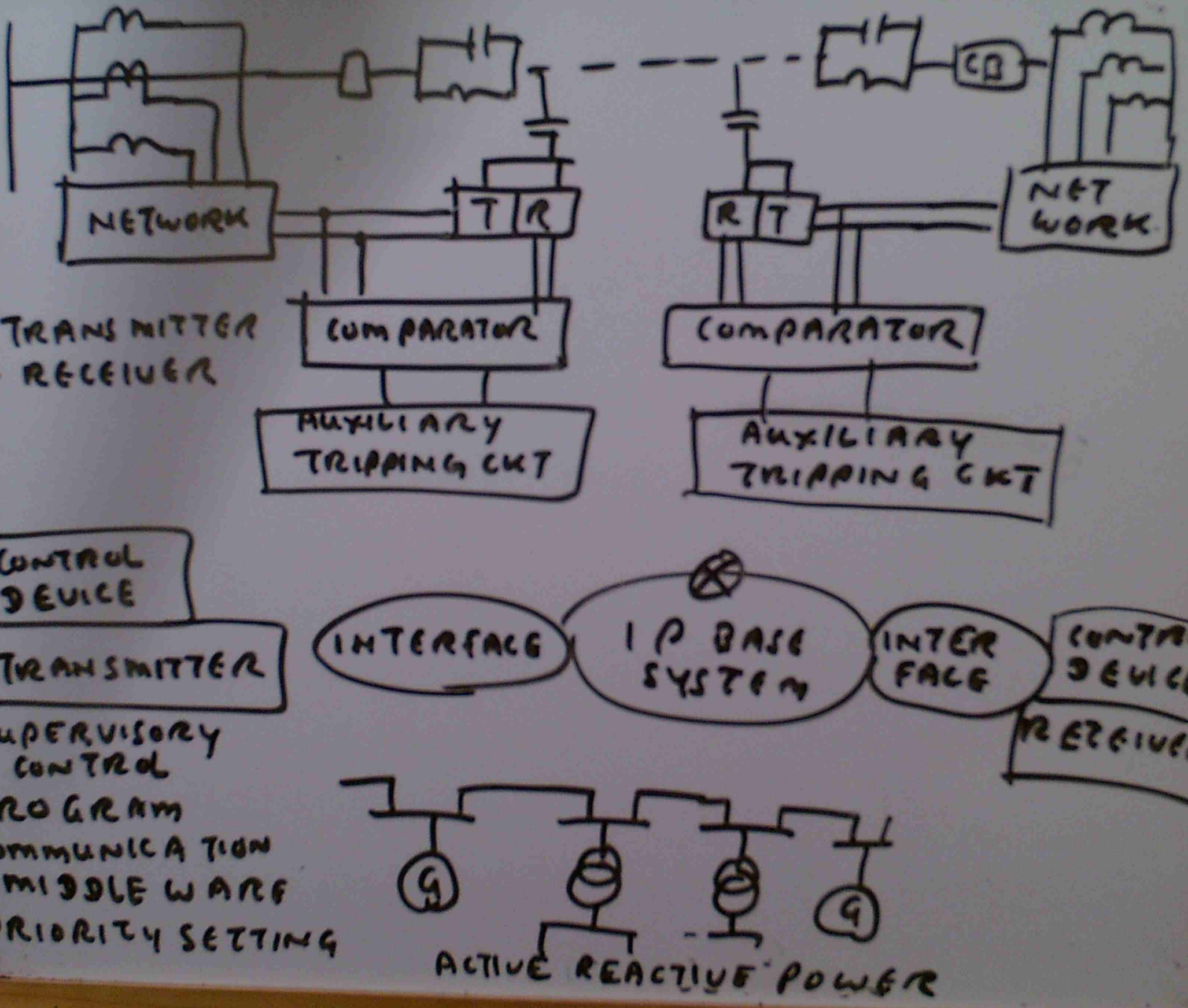
$= Q_{EC} + I_{EC}^2 \times X_{EC}$

$= 1.496 + 3.84^2 \times 0.07$

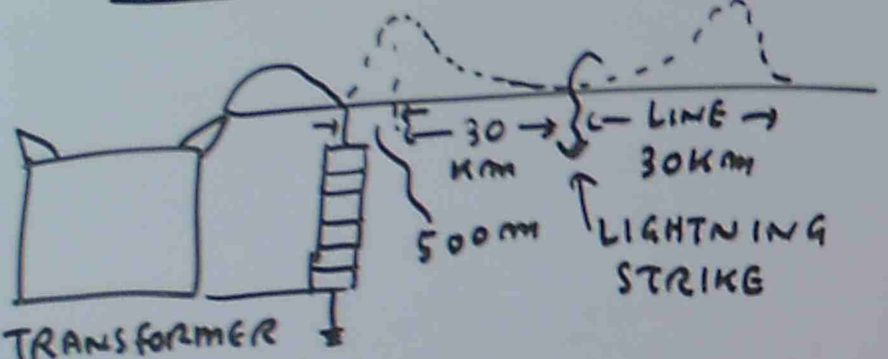
$= 2.555$ PU

$100 \times 3.6 = 360$ MW

$2.55 \times 100 = 255.5$ MVAR


NETWORK
T R
CB
R T
NET WORK
T - TRANSMITTER
R - RECEIVER
COMPARATOR
COMPARATOR
AUXILIARY TRIPPING CKT
AUXILIARY TRIPPING CKT
CONTROL DEVICE
TRANSMITTER
INTERFACE
IP BASE SYSTEM
INTER FACE
CONTROL DEVICE
RECEIVER
SUPERVISORY CONTROL
PROGRAM
COMMUNICATION
MIDDLE WARE
PRIORITY SETTING
G
G
ACTIVE
REACTIVE
POWER

SURGE IN POWER SYSTEM

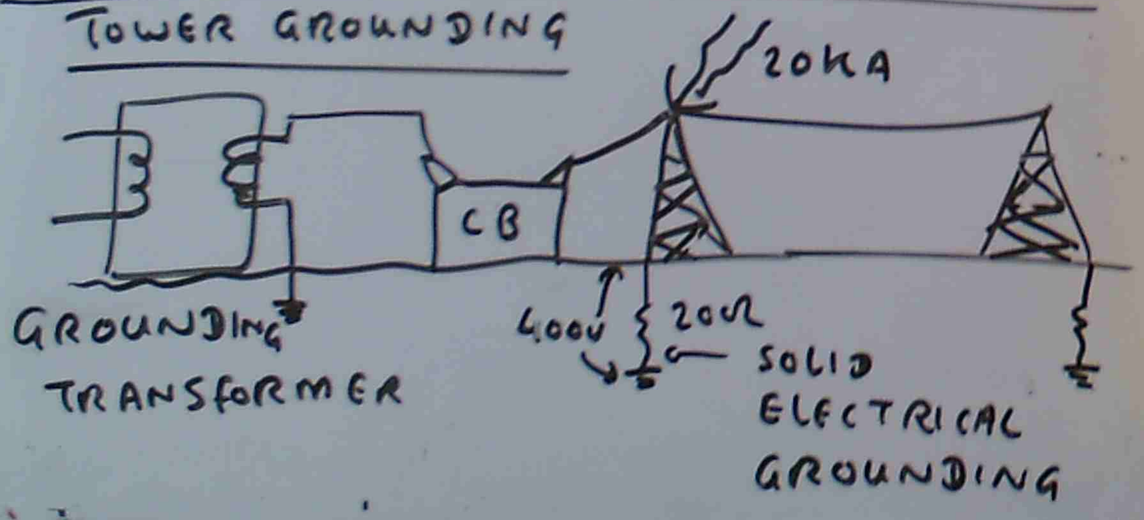


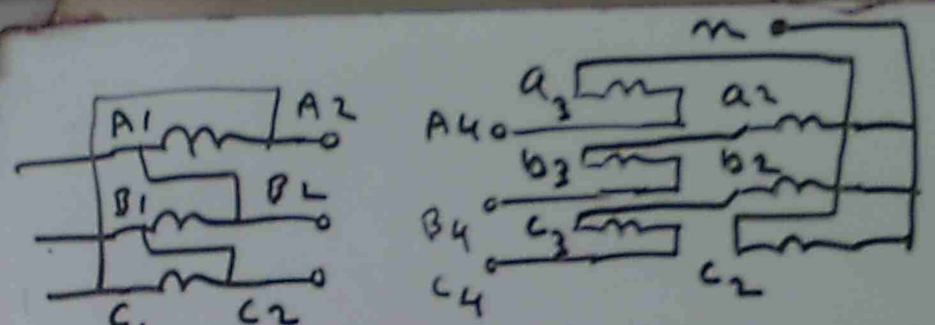
BASE IMPULSE INSULATION LEVEL FOR ELECTRICAL COMPONENTS (BIL)

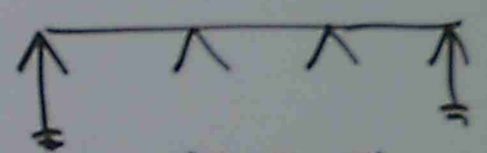
TEMPERATURE OF INSULATION SHOULD WITHSTAND THE HIGH VOLTAGE FOR A SMALL PERIOD DURING WHICH THE LIGHTNING ARRESTER DIVERTS THE SURGE VOLTAGE INTO THE GROUND

BIL = 4CKV (RMS)
(OR) 65KV (PEAK)

TOWER GROUNDING

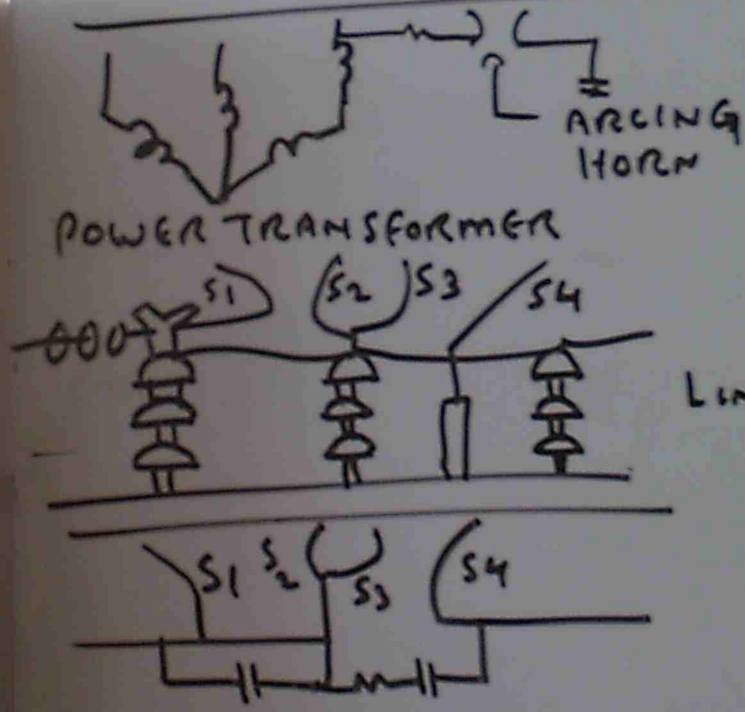




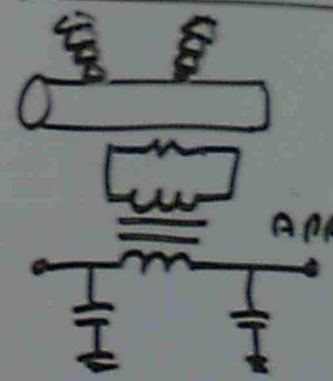


Δ/Z TRANSFORMER

POWER SURGE PROTECTION FOR TRANSMISSION LINE

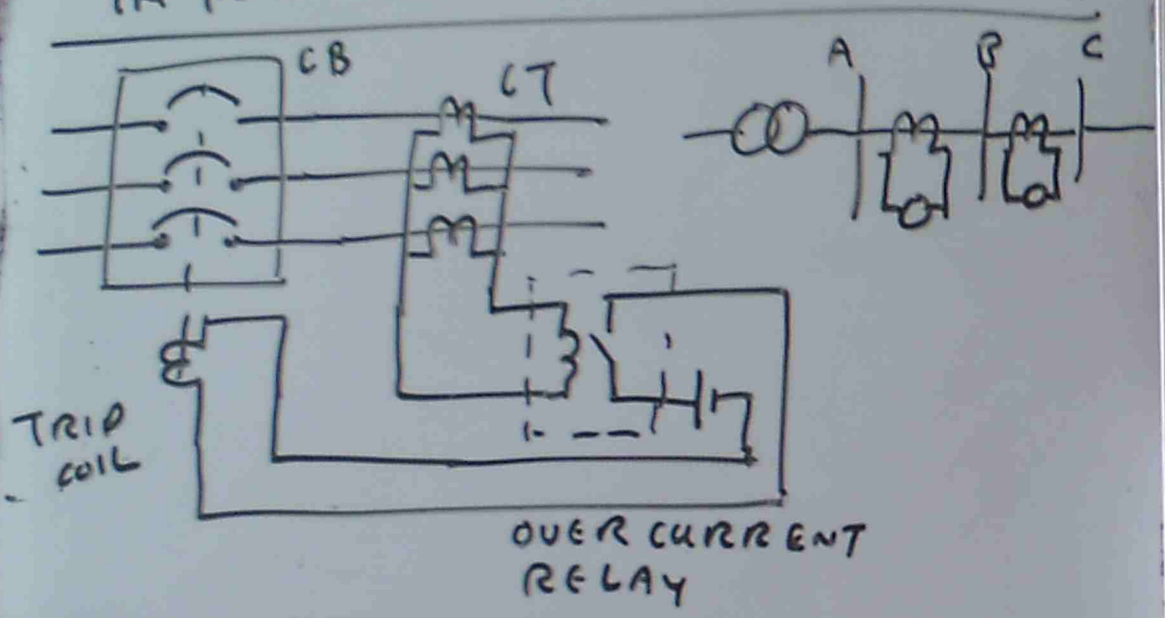


SURGE ARRESTER



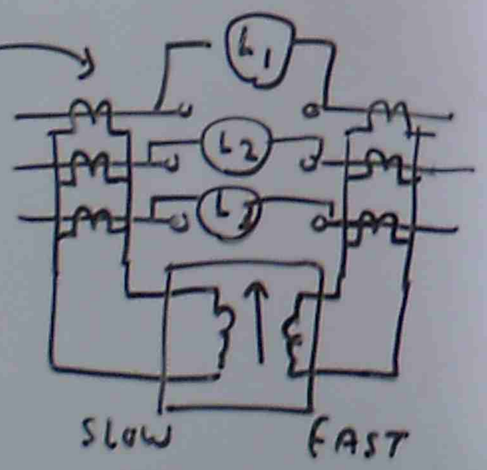
LIGHTNING STRIKE NEAR THE POWER TRANSFORMER IS PROTECTED BY ARCING HORN. LIGHTNING ARRESTER PROVIDES THE LIGHTNING PROTECTION FOR POWER LINE. WHEN POWER SURGE OCCURS DUE TO SWITCHING (OR) UNBALANCE VOLTAGE, SURGE ABSORBS IT.

LOCATION OF CURRENT TRANSFORMERS IN POWER SYSTEM

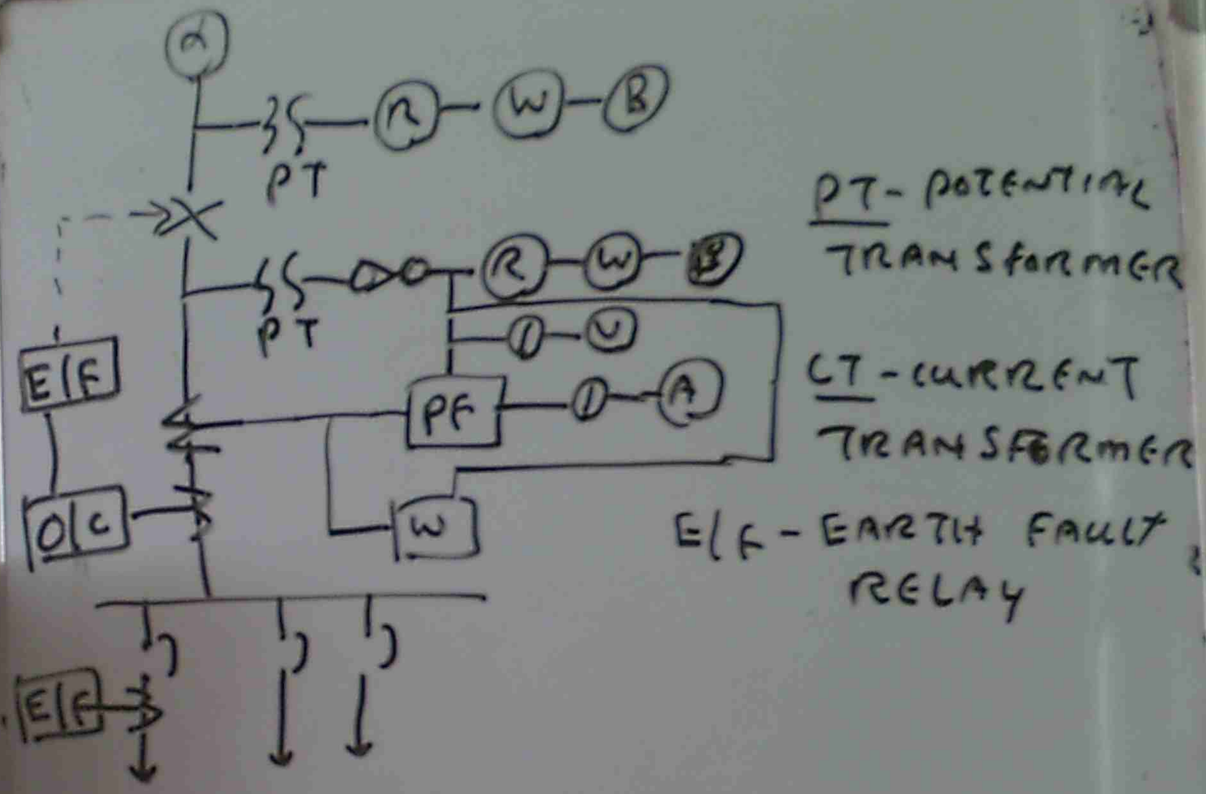


THE OVER CURRENT RELAYS ARE ALLOCATED AT THE LINE SECTIONS. THEY PROVIDE THE PROTECTION FOR THE SECTIONS OF LINE.

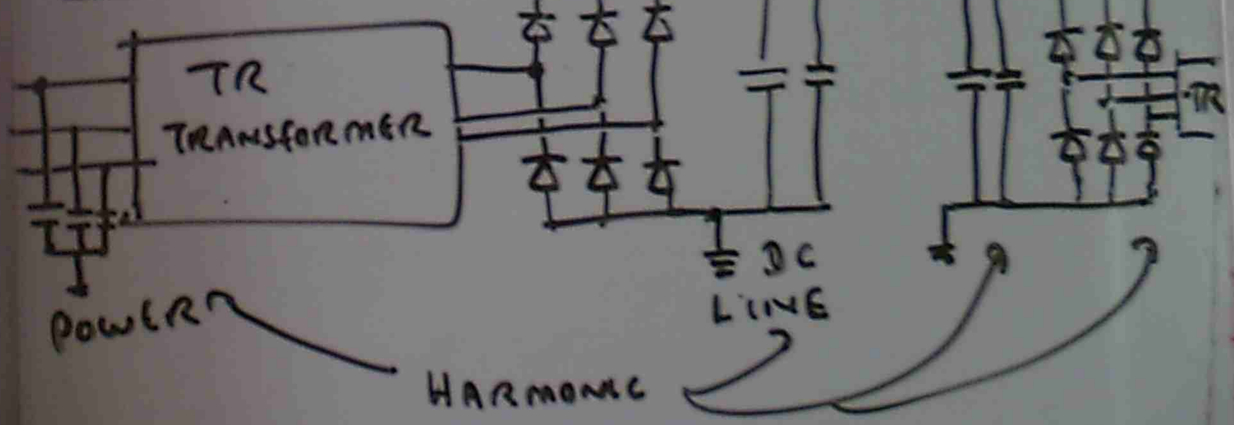




SYNCHROSCOPE CONNECTION.



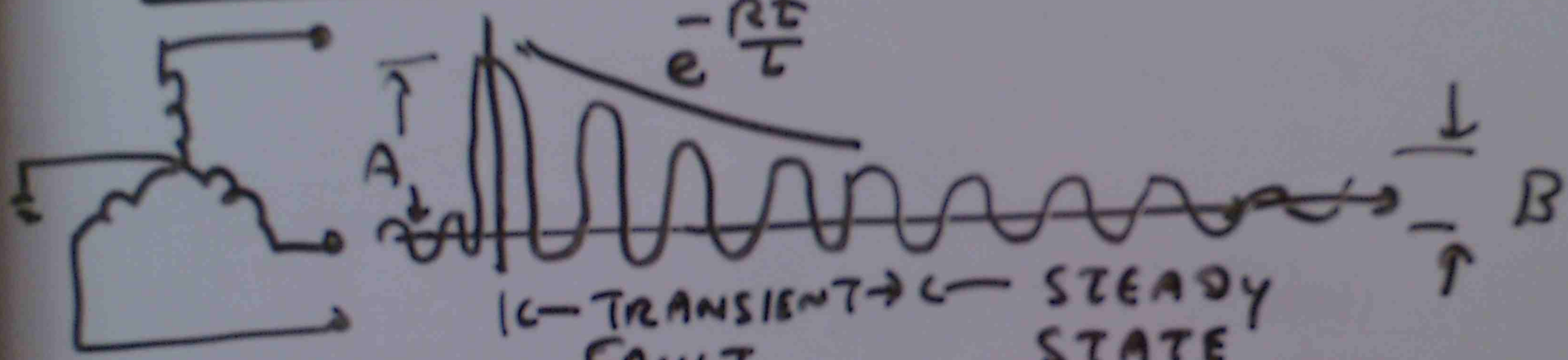
HARMONIC FILTER



ED AT THE LINE SECTIONS.

HARMONIC FILTER

SHORT CIRCUIT CURRENT OF ALTERNATOR



FAULT CURRENT IS FULL LOAD CURRENT

STEADY STATE SHORT CIRCUIT CURRENT 4→6 TIME FULL LOAD CURRENT

$$i_{sc} = A e^{-\frac{Rt}{L}} + B$$

$$A = \frac{E}{\sqrt{R^2 + \omega^2 L^2}} \sin\left(\alpha - \tan^{-1}\frac{\omega L}{R}\right)$$

$$B = \frac{E}{\sqrt{R^2 + \omega^2 L^2}} \sin\left(\omega t + \alpha - \tan^{-1}\frac{\omega L}{R}\right)$$

POWER FACTOR

ϕ = angle between E and Z

$$\omega = 2\pi f$$

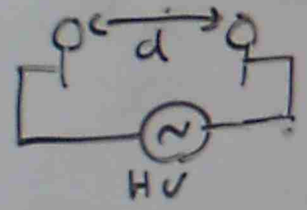
CORONA

CORONA FORMS WHEN THE VOLTAGE OF A CONDUCTOR PASSES THE DISRUPTIVE CRITICAL VOLTAGE. THIS OCCURS ON EACH CONDUCTOR AT EVERY HALF CYCLE AND CONTRIBUTES A TRIPLE HARMONIC TO THE CHARGING CURRENT.

DISRUPTIVE CRITICAL VOLTAGE

BREAK DOWN STRENGTH of AIR AT 76cm PRESSURE 25°C IS 30KV/cm (OR) 21.1KV RMS/cm







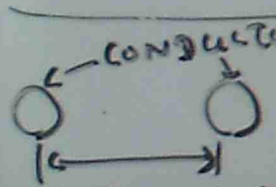
$\delta = \frac{3.92b}{293+T}$ b = HEIGHT of MERCURY

E_g = BREAK DOWN VOLTAGE TO NEUTRAL

$E_g = m\,\delta\,g_b\,r\,Ln\frac{D}{r}$

$g_b = 21.1$ r = RADIUS of CONDUCTOR

m = 1 FOR SMOOTH WIRE
= 0.93 FOR ROUGHED (OR) WEATHERED WIRE
= 0.87 STRANDED WIRE



VISUAL CRITICAL VOLTAGE $E_v = 21.1\,m\,\delta\,r\left(1+\frac{0.3}{\sqrt{\delta r}}\right)Ln\frac{D}{r}$ KV RMS TO NEUTRAL

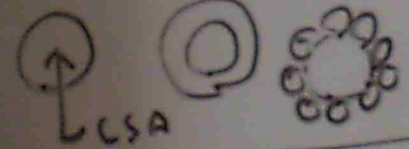
DISTURBANCE

- POWER LOSS
- INTERFERENCE TO TELECOM: SYSTEM

TO AVOID THE CORONA, THE DISTANCE BETWEEN CONDUCTORS NEEDS TO BE INCREASED TO INCREASE THE DISRUPTIVE CRITICAL VOLTAGE. BUT SUCH DISTANCE LIMITED BY COST

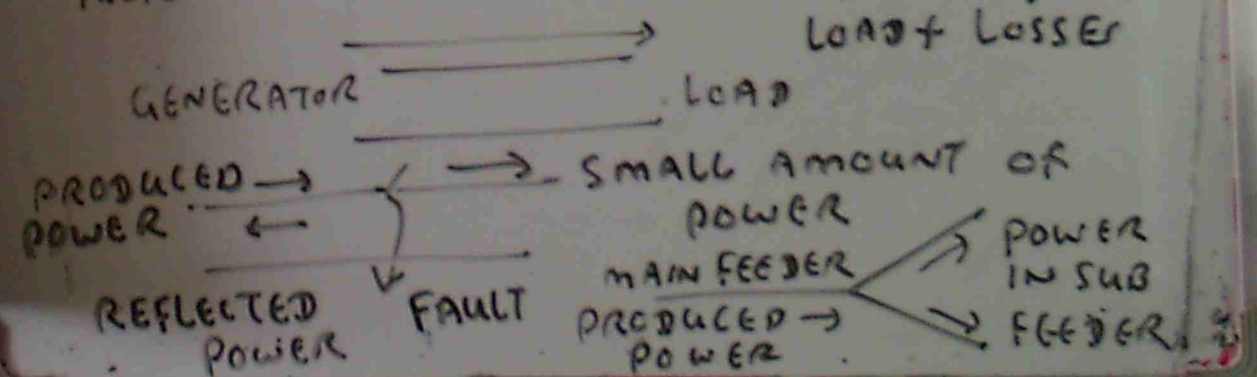
IN PRACTICAL, HOLLOW CONDUCTORS ARE UTILIZED STEEL CORE, ALUMINIUM STRANDED

CONDUCTORS → INCREASE STRENGTH
→ REDUCE THE POSSIBILITY FOR CORONA.



VOLTAGE SURGE & DIRECTION

NORMAL PRODUCED ENERGY = ABSORBED ENERGY AT LOAD + LOSSES



CAUSES of SURGE

RESONANT, SWITCHING, INSULATION FAILURE
ARCING TO EARTH, LIGHTNING STRIKE

SWITCHING VOLTAGE

SWITCHING EMF VELOCITY $v = \frac{1}{\sqrt{LC}}$

L = INDUCTANCE, C = CAPACITANCE OF LINE

$i = \frac{E}{\sqrt{C/L}} - \frac{E}{Z}$, $Z = \sqrt{\frac{L}{C}}$

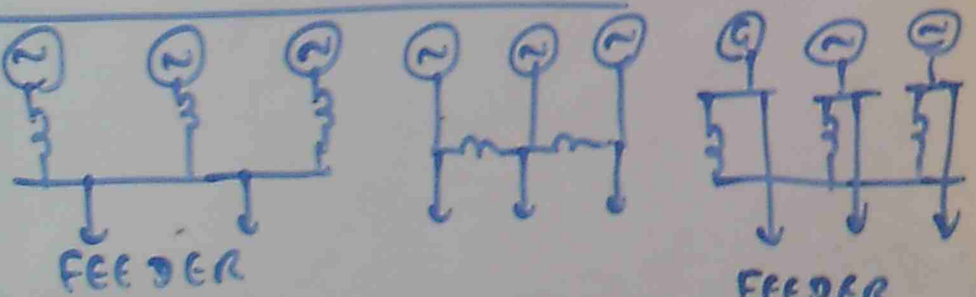
$L = 4 \ln \frac{2}{r} \times 10^{-6}$ H/cm

$C = \frac{1}{4 \ln \frac{2}{r}}$ μF/cm

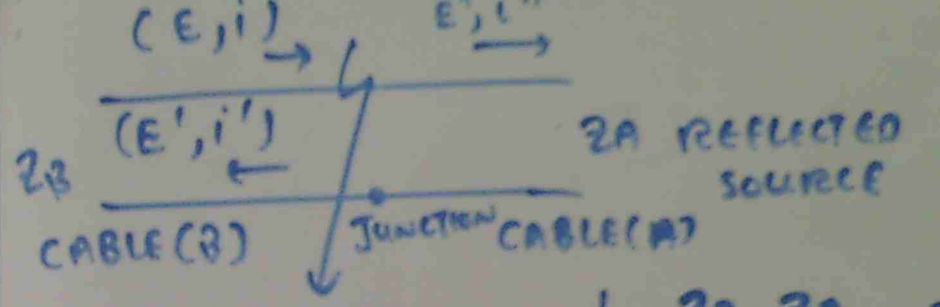
Z = SWITCHING IMPEDANCE (SURGE IMPEDANCE)

400 → 600Ω OVER HEAD LINE
40 → 60Ω CABLE

CURRENT LIMITING REACTORS



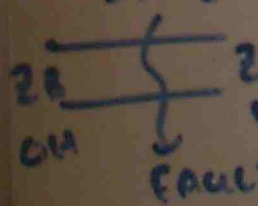
CALCULATION OF VOLTAGE SURGE



$i'' = \frac{Z_B - Z_A}{Z_B + Z_A} i$, $E' = \frac{Z_B - Z_A}{Z_B + Z_A} E$

Z = NATURAL IMPEDANCE = $\sqrt{\frac{L}{C}}$, $E'' = E + E'$

Pb/ A TRANSMISSION LINE HAS 0.0125 μf CAPACITANCE AND 1.5 mH INDUCTANCE IT IS JOINED WITH A CABLE 0.3 μf CAPACITANCE AND 0.25 mH INDUCTANCE CALCULATE (a) NATURAL IMPEDANCE OF OH LINE
(b) NATURAL IMPEDANCE OF UG CABLE
(c) REFLECTED CREST VOLTAGE
(d) MAXIMUM VOLTAGE AT JUNCTION
LINE VOLTAGE = 50 KV



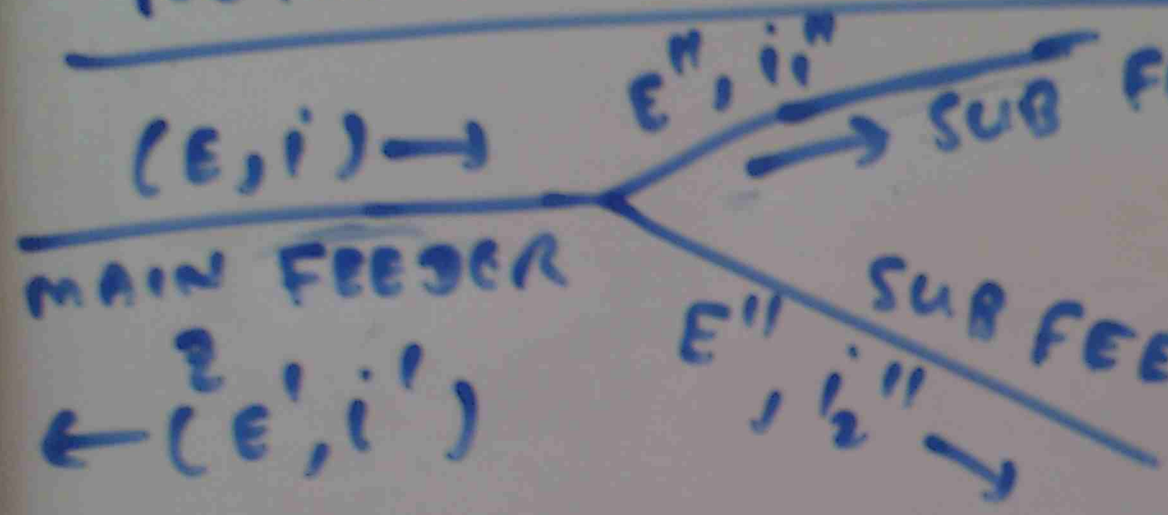
UG CABLE $Z_A = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.25 \times 10^{-3}}{0.3 \times 10^{-6}}} = 28.4\Omega$

OH LINE $Z_B = \sqrt{\frac{L}{C}} = \sqrt{1.5 \times 10^{-3} / 0.125 \times 10^{-6}} = 346.4\Omega$

$E' = \frac{Z_B - Z_A}{Z_B + Z_A} E = \frac{346.4 - 28.4}{346.4 + 28.4} \times 50 = 42.3$ KV

$E'' = E + E' = 50 + 42.3 = 92.3$ KV

REFLECTION AT JUNCTION

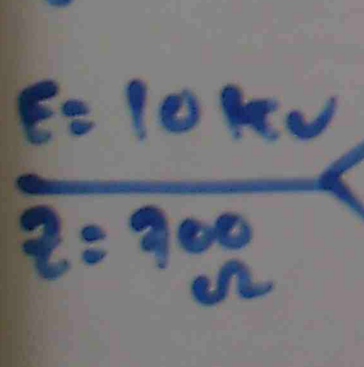


$$E' = \frac{E\left(\frac{1}{Z} - \frac{1}{Z_1} - \frac{1}{Z_2}\right)}{\frac{1}{Z} + \frac{1}{Z_1} + \frac{1}{Z_2}}$$

$$E'' = E + E'$$

$$i_1'' = \frac{E''}{Z_1}, \quad i_2'' = \frac{E''}{Z_2}$$

Pb 10KV LINE WITH WITH 900Ω IS CONNECTED TO 100Ω AND 200Ω LINE.
CALCULATE (i) REFLECTED VOLTAGE (ii) MAXIMUM JUNCTION (iii) MAXIMUM CURRENTS IN JUNCTION.



$$E' = \frac{E\left(\frac{1}{Z} - \frac{1}{Z_1} - \frac{1}{Z_2}\right)}{\frac{1}{Z} + \frac{1}{Z_1} + \frac{1}{Z_2}}$$

$$= \frac{10{,}000\left(\frac{1}{900} - \frac{1}{100} - \frac{1}{200}\right)}{\frac{1}{900} + \frac{1}{100} + \frac{1}{200}}$$

$$= -8260V$$

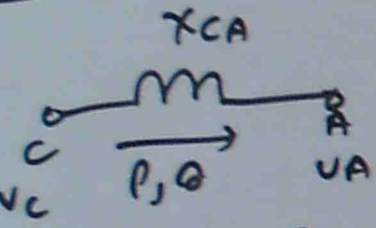
$$E'' = E + E' = 10000 + (-8260)$$

$$= 1740V$$

$$i_1'' = \frac{E''}{Z_1} = \frac{1740}{100} = 17.4A$$

$$i_2'' = \frac{E''}{Z_2} = \frac{1740}{200} = 8.7A$$

VOLTAGE & POWER FLOW RELATIONSHIP



VA - VOLTAGE AT POINT(A) SENDING END VOLTAGE

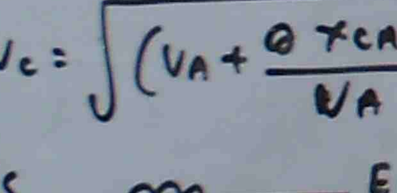
VC - VOLTAGE AT POINT(C) RECEIVING END VOLTAGE

P = ACTIVE POWER FLOW C → A (WATT)

Q = REACTIVE POWER FLOW C → A (VAR)

$$V_C = \sqrt{\left(V_A + \frac{Q X_{CA}}{V_A}\right)^2 + \left(\frac{P X_{CA}}{V_A}\right)^2}$$

Ph



P = 1000WATT

Q = 500 VAR

FIND - ES

$$E_S = \sqrt{\left(E_R + \frac{Q X}{E_R}\right)^2 + \left(\frac{P X}{E_R}\right)^2}$$

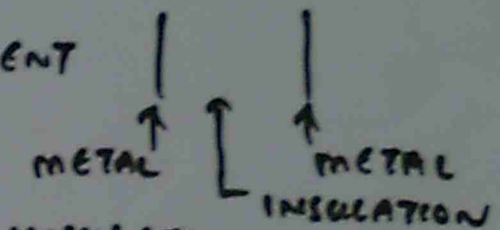
$$= \sqrt{\left(200 + \frac{500 \times 5}{200}\right)^2 + \left(\frac{1000 \times 5}{200}\right)^2}$$

$$= \sqrt{212.5^2 + 25^2} = 213.9V$$

INSULATION

INSULATION IS REQUIRED TO KEEP THE ELECTRICAL CONDUCTORS SEPARATED FROM OTHERS.

- CAPACITANCE
- SURFACE LEAKAGE CURRENT
- ELECTRICAL HYSTERESIS



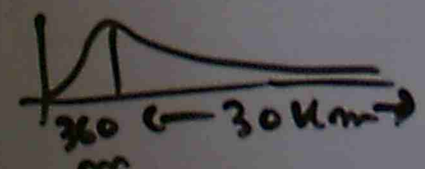
FACTORS THAT DETERIORATE INSULATION

- CHEMICAL IMPACT, DENSITY, LIGHTNING TRAVELLING VOLTAGE SURGE, HARMONIC

TO PROTECT INSULATION FROM EXTERNAL IMPACT

- INVESTIGATE THE SOURCE, PROTECT FROM HARMONIC (SWITCHING POWER SUPPLY
  - BAND PASS
  - BAND STOP
  - LOW PASS
- STUDY THE BREAK DOWN VOLTAGE
- CHEMICAL + LEAKAGE PROTECTION

LIGHTNING PROTECTION AS 1768.1991



THE SWITCHING POWER SUPPLY CAN PRODUCE THE SWITCHING SURGES APPROPRIATE FILTER MUST BE UTILIZED TO REMOVE THE SWITCHING SURGES.

SITE EARTHING

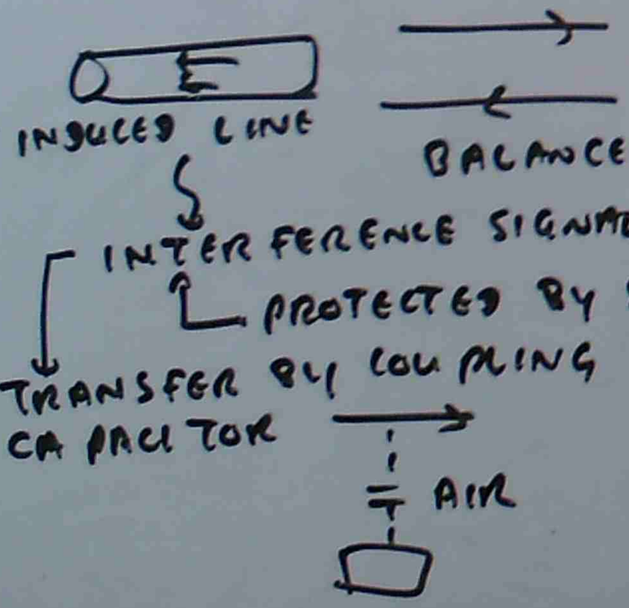
① TO AVOID PHYSICAL DAMAGE TO BUILDING & EQUIPMENT DUE TO DIRECT & INDIRECT LIGHTNING STRIKES

② TO PROVIDE SAFE WORKING ENVIRONMENT DURING LIGHTNING STRIKE

③ TO PROVIDE SHIELDING & ALTERNATIVE PATH FOR INDUCED CURRENT TO REDUCE THE EFFECT OF COUPLED NOISE ON ELECTRONIC EQUIPMENT

④ TO PROVIDE AN EQUIPOTENTIAL PLATFORM ON WHICH ELECTRONIC EQUIPMENTS CAN OPERATE WITHOUT LARGE DIFFERENTIAL VOLTAGE

TOUCH VOLTAGE, STEP VOLTAGE, MESH VOLTAGE



COUPLING, ELECTRICAL SHIELDING SURGE PROTECTION

APPLIANCES, TRANSIENT VOLTAGE SUPPRESSOR, ISOLATION TRANSFORMER, UPS

POOR POWER FACTOR

DOWNGRADED EFFICIENCY, LINE CAPACITY
POOR VOLTAGE REGULATION, INCREASED SYSTEM LOSSES
IMPROVED BY CAPACITOR BANK, SYNCHRONOUS MOTOR, STATIC VAR CONTROL SYSTEM

HARMONIC — HARMONIC DISTORTION DEPENDS ON

- LEVEL OF HARMONIC GENERATION
- SYSTEM FREQUENCY RESPONSE CHARACTERISTICS

HARMONIC → TEMPERATURE RISE, VIBRATION, LIFE TIME, HEATING

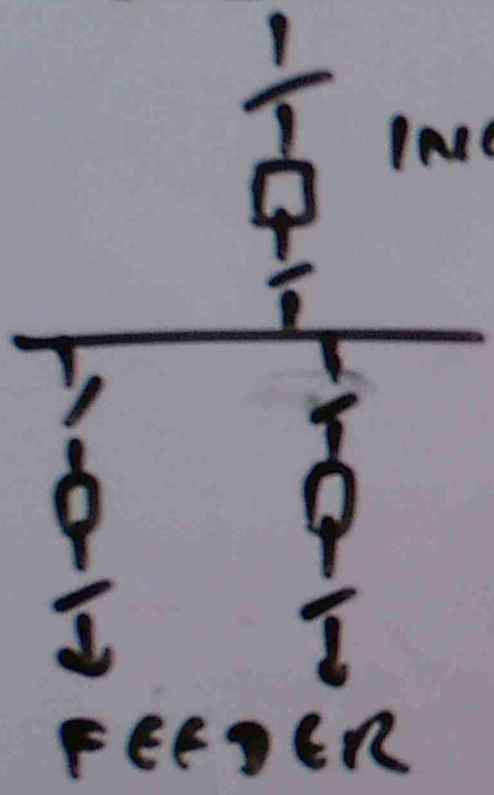
TOTAL HARMONIC DISTORTION TO BE CALCULATED
FILTER TO BE USED.

(1) VOLTAGE AND POWER RELATIONSHIP

SLIDE (1) ⟶ (17)

Q1 ⟶ Q12

POWER SYSTEM CONTROL EQUIPMENTS



INCOMING LINE

MAIN FEEDER
SECTIONALISING
RECLOSER
BOOSTER, BIL

FEEDER

SUBSTATION EQUIPMENTS

POWER
VOLTAGE
CONTROL

- TR
- BOOSTER
- VOLTAGE
- REGULATOR
- P.F CORRECTION

CONTROL CIRCUIT

- AUXILIARY CIRCUIT
- PROTECTION EQUIPMENTS
- C.B
- RECLOSER
- RELAY SYSTEM

BUSBAR

- POWER DISTRIBUTION
- SECTIONALIZE SWITCH

METERING

GROUNDING

- SUBSTATION GROUND

SUBSTATION OPERATION

- CONTROL PROTECTION
- H.V SWITCH GEAR
- PROTECTION SETTING
- RELAY TRANSFORMER
- REGULAR MAINTENANCE WORK

IMPORTANT AUXILIARY SYSTEMS

TRANSFORMER COOLING, AIR CIRCUIT BREAKING
POLARITY TESTING FOR PARALLEL OPERATION
OF TRANSFORMERS, SURGE / LIGHTNING
ARRESTER, INTERRUPT CONTROL CIRCUIT.

ELECTRIC ARC EXTINGUISHING

ARC — RADIATING, IONIZING
ARC — HIGH TEMPERATURE
ARC — ELECTRON COLLISION
} ARC INTERRUPTION

HIGH RESISTANCE METHOD, COOLING ARC,
REDUCING C.S.A OF ARC
SPLITTING ARC, DEIONIZING

LENGTHENING ARC
HIGH PRESSURE

SUBSTATION GROUNDING

GROUND RESISTANCE, SOIL RESISTIVITY
↳ CORROSION

TYPES OF PROTECTIONS IN SUB STATION

ELECTRICAL RACE WAYS, SUBSTATION GROUNDING
VOLTAGE REGULATOR, CIRCUIT BREAKER
INSTRUMENT TRANSFORMER
RELAYING DIFFERENTIAL, PILOT, VOLTAGE SURGE
DIVERTER, MICRO WAVE RELAY, STABILITY CONTROL

CIRCUIT BREAKER

OIL CIRCUIT BREAKER, AIR CIRCUIT BREAKER
VACUUM INTERRUPTER, FUSE SF6 - CB

WIDE AREA MONITORING & CONTROL SYSTEM

- EMERGENCY OPERATION FUNCTION
LOCATE FAULT, VERIFY CORRECT PROTECTION,
SHED THE UNIMPORTANT LOADS, MANUAL RE-
ROUTING, DISPATCH THE MAINTENANCE CREWS
ANALYZE THE CAUSE OF FAULT

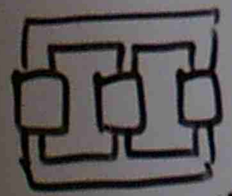
(2) POWER SYSTEM CONTROL EQUIPMENT

SLIDE (1) → (9) Q13 → Q19

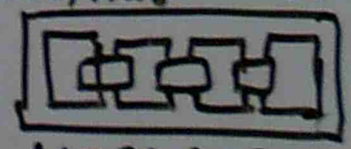
HARMONIC

HARMONIC — HIGHER FREQUENCY — REDUCE DIELECTRIC STRENGTH OF INSULATION

HARMONIC VOLTAGE — OVER VOLTAGE



3-LIMBS - HIGHER HARMONIC



5-LIMBS → FOR HARMONIC RETURN PATH

$$E_t = \sqrt{E_f^2 + E_H^2}$$

$$THD = \frac{f_H}{f_F}$$

E_f = FUNDAMENTAL VOLTAGE
E_H - HARMONIC VOLTAGE
E_t - TOTAL VOLTAGE EFFECTED BY HARMONIC
THD - TOTAL HARMONIC DISTORTION
f_H - HARMONIC FREQ; f_F - FUNDAMENTAL FREQ

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HIGH RESISTANCE METHOD, COOLING ARC,
REDUCING C.S.A OF ARC
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SUBSTATION GROUNDING

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SLIDE (1) → (9) Q13 → Q19

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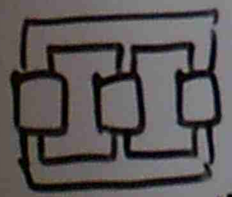
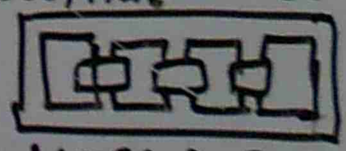
HARMONIC — HIGHER FREQUENCY — REDUCE DIELECTRIC STRENGTH OF INSULATION
HARMONIC VOLTAGE — OVER VOLTAGE



3-LIMBS - HIGHER HARMONIC



5-LIMBS → FOR HARMONIC RETURN PATH

$$E_t = \sqrt{E_f^2 + E_H^2}$$

$$THD = \frac{f_H}{f_F}$$

E_f = FUNDAMENTAL VOLTAGE
E_H - HARMONIC VOLTAGE
E_t - TOTAL VOLTAGE EFFECTED BY HARMONIC
THD - TOTAL HARMONIC DISTORTION
f_H - HARMONIC FREQ: f_F - FUNDAMENTAL FREQ

Pa THE CURRENT IN A SYSTEM IS 62.5A IN WHICH 59 Amp IS FUNDAMENTAL. CALCULATE TOTAL HARMONIC DISTORTION IF THE HARMONIC IS COMBINATION OF 3rd, 5th & 7th, 3rd HARMONIC IS 15.6A, 5th HARMONIC IS 10.3A, FIND 7th HARMONIC

$E_t = \sqrt{E_f^2 + E_H^2} \rightarrow E_t^2 = E_f^2 + E_H^2 \rightarrow E_H^2 = E_t^2 - E_f^2$

$\therefore E_H = \sqrt{E_t^2 - E_f^2} = \sqrt{62.5^2 - 59^2} = 20.6$ Amp

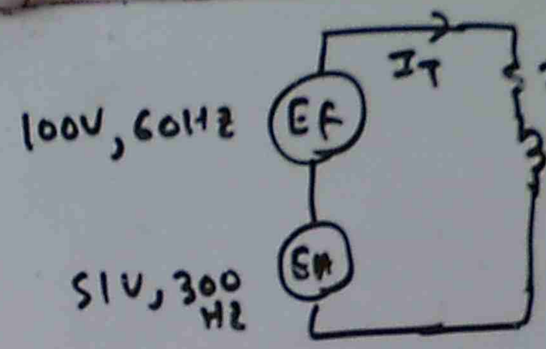
$THD = \frac{E_H}{E_F} = \frac{20.6}{59} = 0.344 \rightarrow 34.4\%$

$E_H^2 = E_{H(3rd)}^2 + E_{H(5th)}^2 + E_{H(7th)}^2$

$E_{H(7th)} = \sqrt{E_H^2 - E_{H(3rd)}^2 - E_{H(5th)}^2}$

$= \sqrt{20.6^2 - 15.6^2 - 10.3^2} = 9.66$ Amp

Pb THE GIVEN FIGURE SHOWS A DISTORTED VOLTAGE SOURCE COMPOSED OF A FUNDAMENTAL 100V, 60Hz AND A 5th HARMONIC 51V. THE SOURCE IS CONNECTED TO A RESISTOR 24Ω IN SERIES WITH AN INDUCTANCE 18.6mH CALCULATE (a) TOTAL IMPEDANCE AT FUNDAMENTAL (b) FUNDAMENTAL CURRENT (c) ACTIVE & REACTIVE POWER AT FUNDAMENTAL (d) TOTAL IMPEDANCE AT 5th HARMONIC (e) 5th HARMONIC CURRENT (f) ACTIVE & REACTIVE POWER AT 5th HARMONIC



$X = 2\pi f L$

(a) $X_f = 2 \times 3.1416 \times 60 \times 18.6 \times 10^{-3}$

$= 7\Omega$

$Z_f = \sqrt{R^2 + X_f^2} = \sqrt{24^2 + 7^2} = 25\Omega$

(b) $I_f = \frac{E_f}{Z_f} = \frac{100}{25} = 4A$

(c) $P_f = I_f^2 \times R = 4^2 \times 24 = 384$ W

$Q_f = I_f^2 \times X = 4^2 \times 7 = 112$ VAR

$S_f = \sqrt{P_f^2 + Q_f^2} = \sqrt{384^2 + 112^2} = 400$ VA

(d) $X_{SH} = 2\pi f_{SH} L = 2 \times 3.1416 \times 300 \times 18.6 \times 10^{-3}$

$= 35\Omega$

$Z_{SH} = \sqrt{R^2 + X_{SH}^2} = \sqrt{24^2 + 35^2} = 42.4\Omega$

(e) $I_{SH} = \frac{E_{SH}}{Z_{SH}} = \frac{51}{42.4} = 1.2A$

$P_{SH} = I_{SH}^2 \times R = 1.2^2 \times 24 = 34.6$ W

$Q_{SH} = I_{SH}^2 \times X_{SH} = 1.2^2 \times 35 = 50.4$ VAR

(f) $S_{SH} = \sqrt{P_{SH}^2 + Q_{SH}^2} = \sqrt{34.6^2 + 50.4^2} = 61.13$ VAR

HARMONIC ANALYSIS

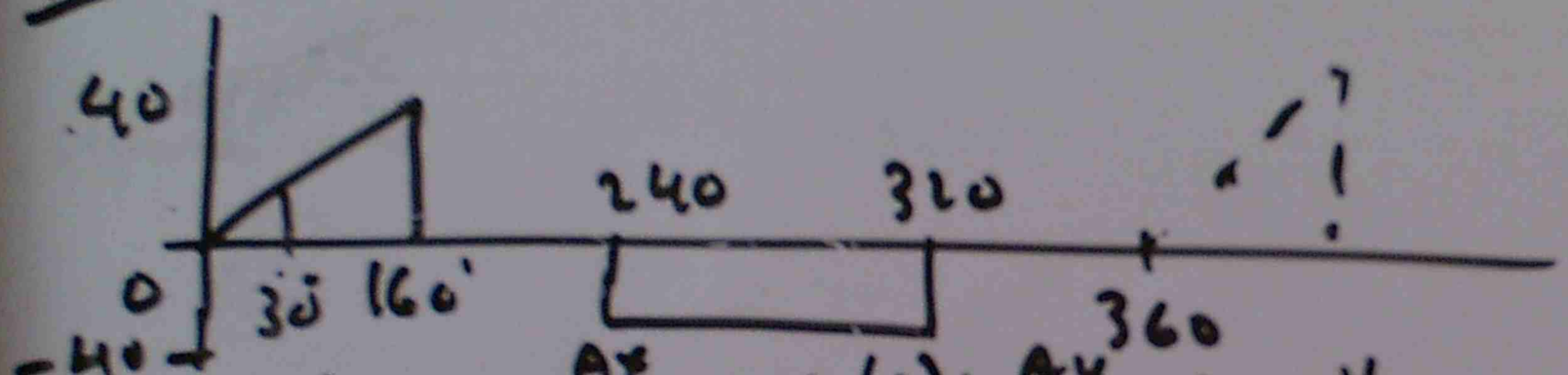
$X = \frac{S_1 D}{180}$, $Y = \frac{S_2 D}{180}$

$A_H = \sqrt{X^2 + Y^2}$

$S_1 = \sum$ COSINE COMPONENTS

$S_2 = \sum$ SINE COMPONENTS

Q3 ANALYZE THE FOLLOWING HARMONIC



θ	A	A_x $A\cos\theta$ (x)	A_y $A\sin\theta$ (y)	S_1 $\Sigma = -47.5$	S_2 $\Sigma = 175.4$
0	0				
30	$\frac{40\times30}{160} = 7.5$	$7.5\cos30 = 6.5$	$7.5\sin30 = 3.75$		
60	$\frac{40\times60}{160} = 15$	$15\cos60 = 7.5$	$15\sin60 = 11$		
90					
120					
150	$\frac{40\times150}{60} = 37.5$	$37.5\cos150 = -37.5$	$37.5\sin150 = 18.75$		
180	0	0	0		
210					
240	$\frac{-40+0}{2} = -20$	$-20\cos240 = 10$	$-20\sin240 = 17.3$		
270					
300	-40	$-40\cos300 = -20$	$-40\sin300 = 34.6$		
330	0	0	0		
360	0	0	0		

$$X = \frac{S_1 D}{180} = \frac{-47.5\times30}{180}$$
$$= -7.9$$

$$Y = \frac{S_2 D}{180} = \frac{175.4\times30}{180}$$
$$= 29.3$$

$$A_m = \sqrt{X^2 + Y^2}$$
$$= \sqrt{(-7.9)^2 + 29.3^2}$$
$$= 30.36 \checkmark$$

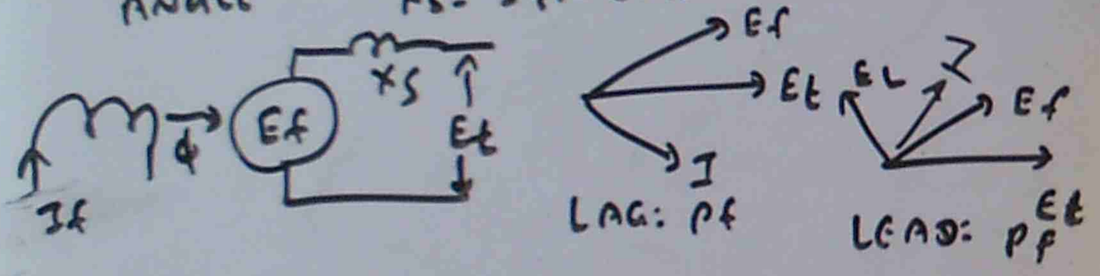
SYNCHRONOUS GENERATOR LOADING EFFECT

$$P = \frac{E_f \times E_t}{X_s} \sin\delta$$

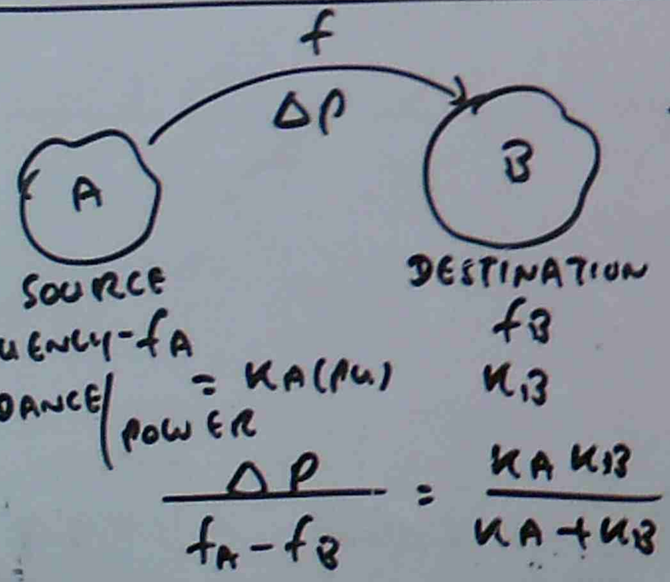
P - POWER, E_f = NO LOAD GENERATED VOLTAGE

δ = COUPLING ANGLE | E_t = LOAD TERMINAL VOLTAGE

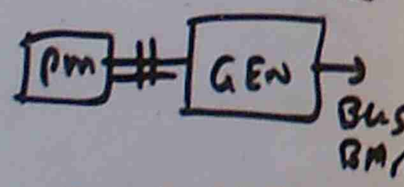
X_s = SYNCHRONOUS REACTANCE



EFFECT OF GOVERNOR CHARACTERISTICS & POWER TRANSFER



$$\frac{\Delta P}{f_A - f_B} = \frac{K_A K_B}{K_A + K_B}$$



m = SHAFT INERTIA

δ = ANGULAR DISPLACEMENT

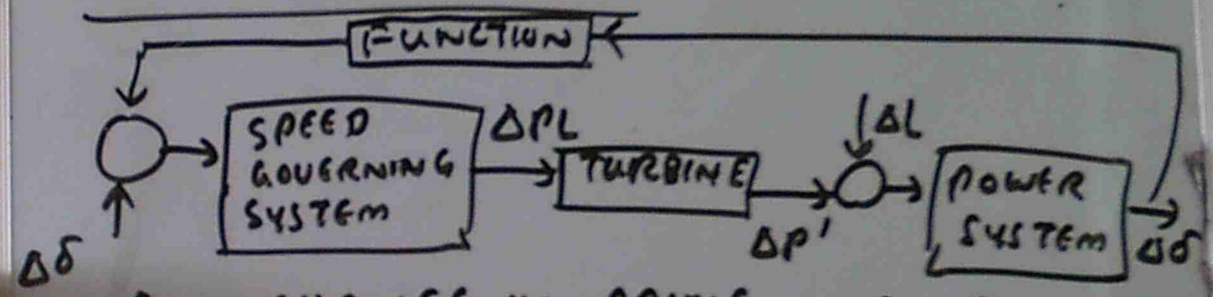
K = MACHINE COEFFICIENT

ΔP = POWER TRANSFER

ΔP_L = LOAD POWER CHANGE

$$m\frac{d^2\delta}{dt^2} + K\Delta\delta = \Delta P - \Delta P_L$$

GOVERNOR CONTROL

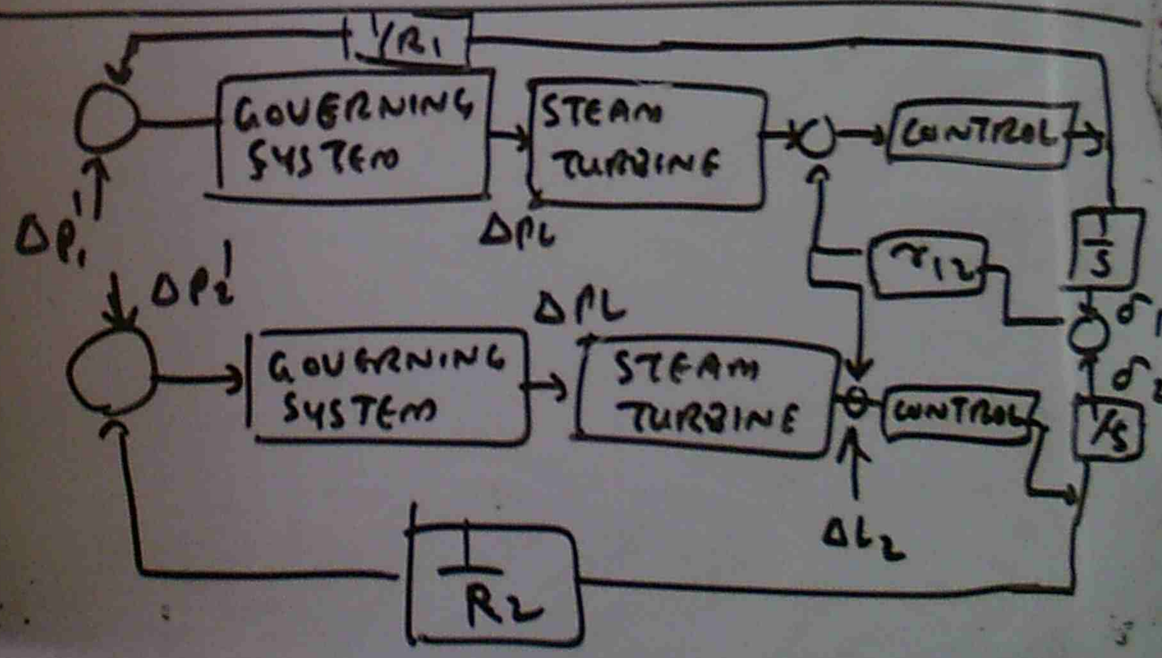


ΔP_L = CHANGE IN PRIME MOVER & LOAD POWER

$\Delta P'$ = CHANGE IN SPEED CHANGER SETTING

$\Delta\delta$ = CHANGE IN ANGULAR POSITION

R = SPEED REGULATION



PD/ TWO POWER SYSTEMS A & B, EACH HAS A REGULATION R_1 OF 0.1 PU (ON RESPECTIVE CAPACITY BASE) AND STIFFNESS K OF 1 PU. THE CAPACITY OF SYSTEM (A) IS 1500 MW & B 1000 MW. THE TWO SYSTEMS ARE INTERCONNECTED THROUGH A LINE AND ARE INITIALLY AT 60 HZ. IF THERE IS A 100 MW LOAD CHANGE IN SYSTEM (A), CALCULATE THE CHANGE IN THE STEADY STATE VALUE OF FREQUENCY AND POWER TRANSFER

K_A = STIFFNESS (K) × P_A = 1 × 1500 = 1500

K_B = STIFFNESS (K) × P_B = 1 × 1000 = 1000

$R_A = \frac{\Delta f}{\text{FULL LOAD CAPACITY}} = \frac{R \times f}{\text{FULL LOAD CAPACITY OF (A)}} = \frac{0.1 \times 60}{1500} = \frac{6}{1500}$ HZ/MW

$R_B = \frac{\Delta f}{\text{FULL LOAD CAPACITY}} = \frac{R \times f}{\text{FULL LOAD CAPACITY OF (B)}} = \frac{0.1 \times 60}{1000} = \frac{6}{1000}$ HZ/MW

$\Delta f = \frac{-\Delta P_L}{(P_A + R_A) + (P_B + R_B)}$

$= \frac{-100}{(1500 + \frac{6}{1500})(1000 + \frac{6}{1000})} = -0.034$ HZ

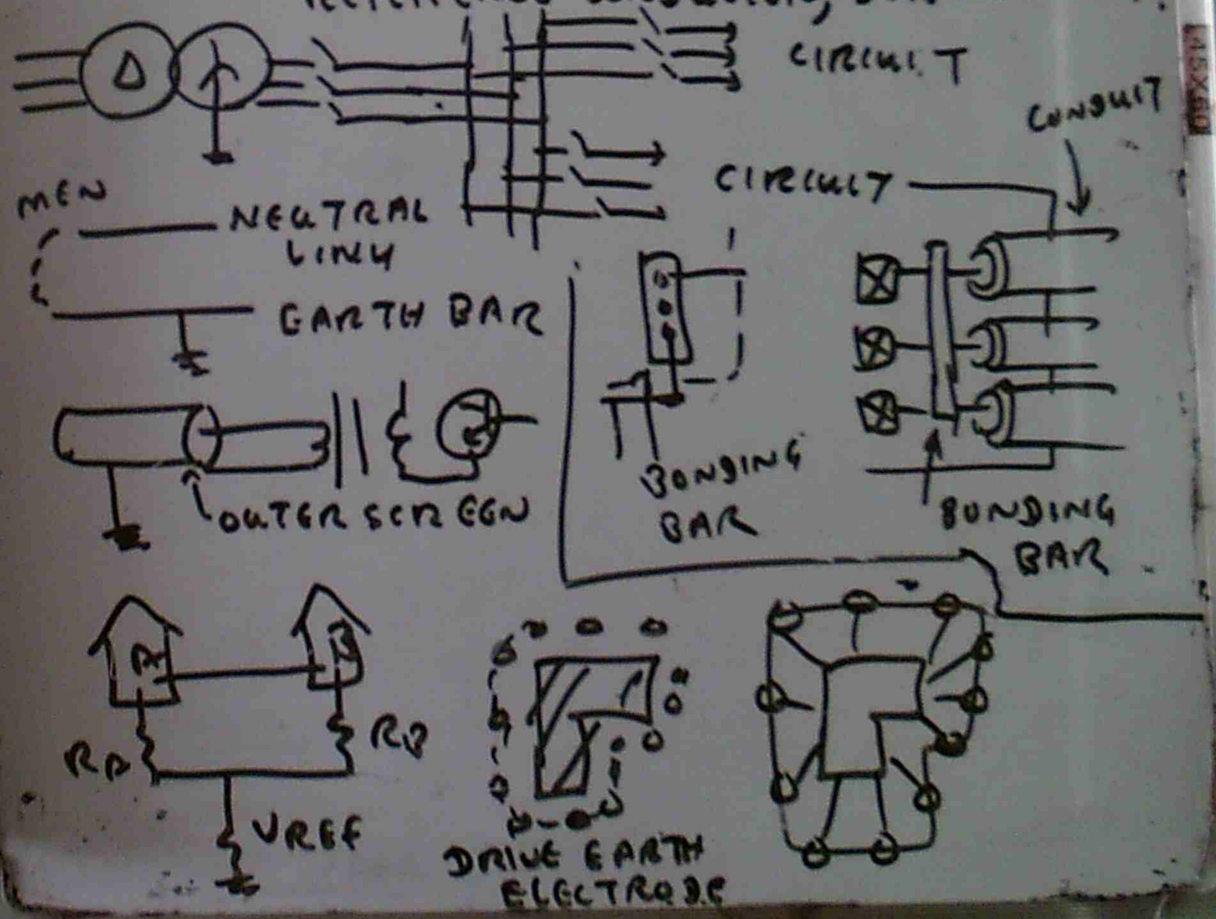
POWER TRANSFER $P_{12} = T_{12}(\delta_1 - \delta_2) = \frac{-\Delta P (K_B + 1)/R_B}{(K_A + \frac{1}{R_A}) + (K_B + \frac{1}{R_B})}$

$= \frac{-100(1000+1)/\frac{6}{1000}}{(1500 + \frac{6}{1500}) + (1000 + \frac{6}{1000})} = -6$ MW

POWER LINE EARTHING

TO AVOID PHYSICAL DAMAGE TO BUILDING & EQUIPMENTS DUE TO LIGHTNING STRIKE SAFE WORKING ENVIRONMENT, SHIELDING, EQUIPOTENTIAL PLATFORM.

EARTHING - NEUTRAL, SAFETY, SIGNAL REFERENCE CONDUCTOR, SCREEN REF.



TYPE OF INSULATOR

OIL IMPREGNATED PAPER, VARNISH, POLYETHYLENE.

INSULATOR DIELECTRIC BEHAVIOUR

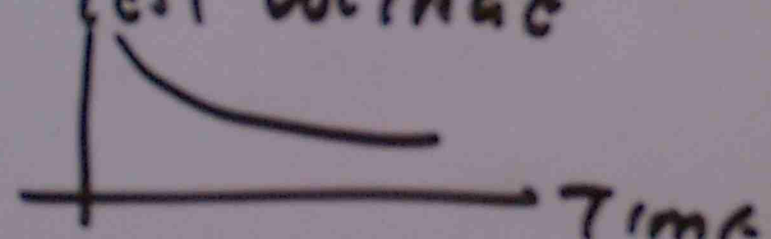
CAPACITANCE EFFECT, LEAKAGE CURRENT, ELECTRIC FIELD

SURFACE LEAKAGE CURRENT

THE INSULATOR MUST HAVE THE CAPACITY TO WITHSTAND

THE PUNTURE STRESS

TESTING INSULATOR

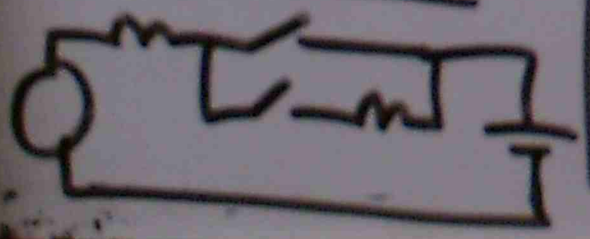


TIME REQUIRED FOR BREAK DOWN

(I) LIGHTNING

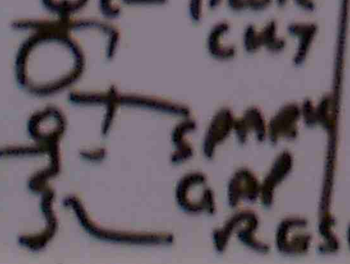


(II) SWITCHING TRANSIENT



BIL

CONTACT WITH HIGHER VOLTAGE CIRCUITS



V_i = ORIGINAL VOLTAGE

V = REFLECTED VOLTAGE

R = LINE RESISTANCE

Z_c = CHARACTERISTANCE IMPEDANCE = $\sqrt{\frac{L}{C}}$

$$V = V_i \frac{R - Z_c}{R + Z_c}$$

BREAK DOWN 30KV/cm

(3) HARMONIC

SLIDE (1) → (21)

Q20 → Q28

---

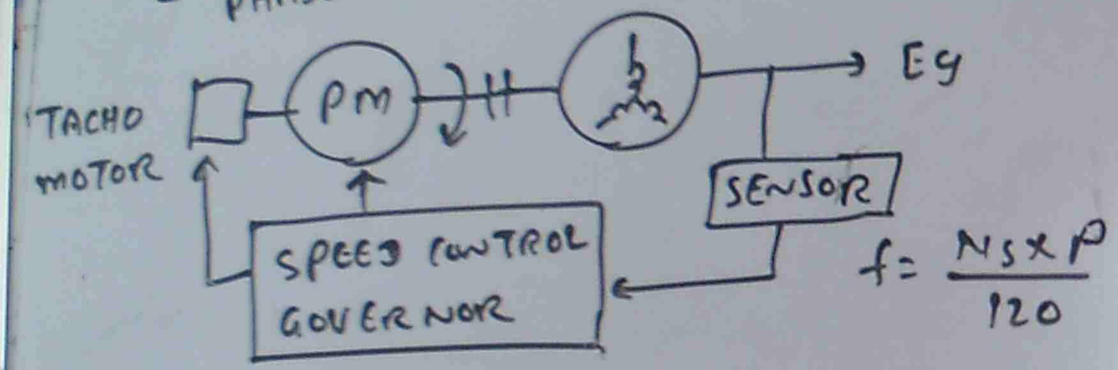
(4) POWER LINE EARTHING

SLIDE (1) → (10)

Q29 → Q38

RELIABILITY OF POWER SYSTEM

- VOLTAGE MUST BE CONSTANT
- FREQUENCY MUST BE CONSTANT
- PHASE SEQUENCE MUST BE CORRECT



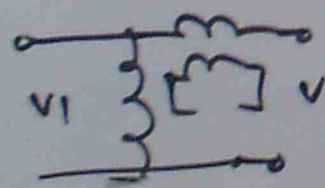
$$f = \frac{N_s \times P}{120}$$

VOLTAGE VARIATION

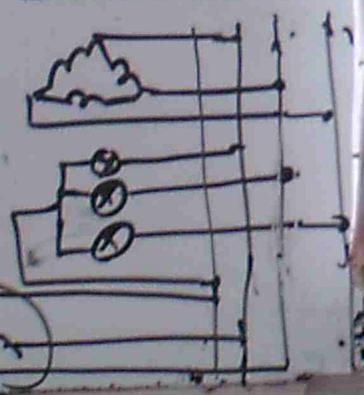
- VOLTAGE AT THE SOURCE CAN NOT BE CONTROLLED
- VOLTAGE AT SECONDARY TRANSFORMER VARIES
- VOLTAGE DROP IN TRANSMISSION & DISTRIBUTION LINES.

VOLTAGE CONTROL



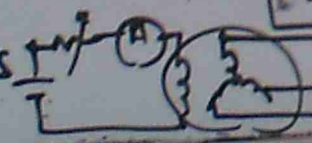


LOAD PF CONTROL



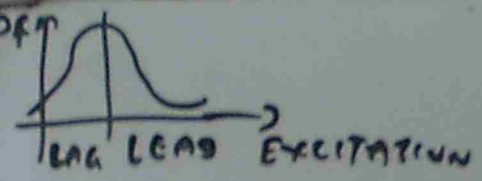


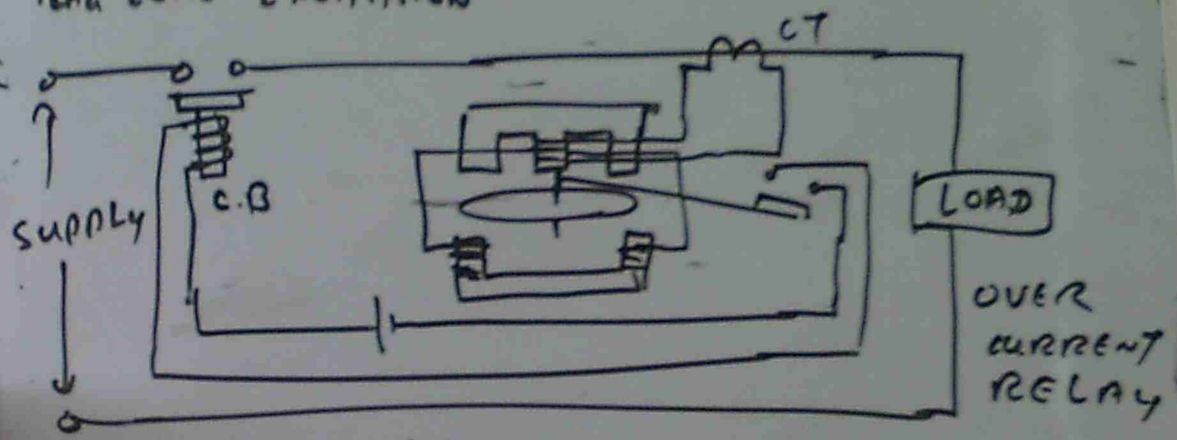
SYNCHRONOUS MOTOR



POWER LINE PROTECTION

- PROTECTIVE RELAY
- CIRCUIT BREAKER

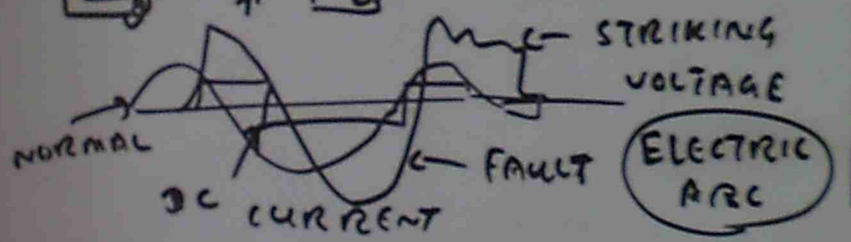


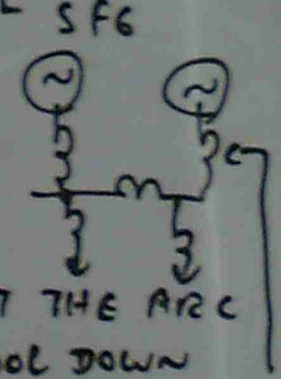


CIRCUIT BREAKER

- ARC LENGTHENING
- ARC SPLITTING
- ARC COOLING — NATURAL, AIR BLAST, OIL, SF6







CONTROLLING ARC

- SHORTEN THE ARCING PERIOD, LIMIT THE ARC MAGNITUDE, SPLIT THE ARC & COOL DOWN

MAINTAING SYSTEM STABILITY

- AUTOMATIC RECLOSING SYSTEM. WHEN TEMPORARY FAULT HAPPENS, THE C.B MUST RECLOSE AS SOON AS FAULT IS CLEAR.

SOURCE of ELECTRICAL INTERFERENCE

CAUSED BY LIGHTNING STRIKE, HARMONIC INTERFERENCE.

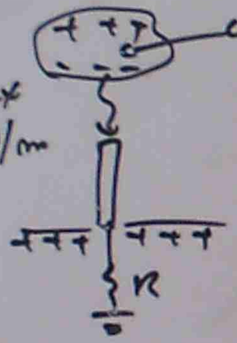
HARMONIC REDUCTION CONCEPT

- USE OF FIVE LIMBS TRANSFORMER
- USE OF HARMONIC FILTER
- USE OF BIGGER SIZE NEUTRAL WIRE

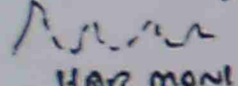
INTERFERENCE

SOURCE OF INTERFERENCE, VICTIM WHICH IS UPSET BY INTERFERENCE, INTERFERENCE COUPLING PATH

LIGHTNING STRIKE — DIRECT, SIDE FLUX 500KV/m



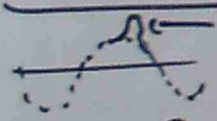


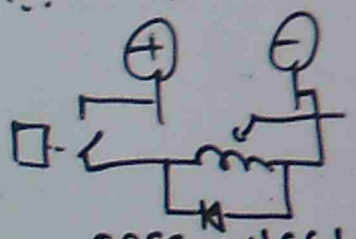


PEAK LIGHTNING VOLTAGE = SURGE IMPEDANCE / 2 × LIGHTNING CURRENT

TO WITHSTAND LIGTNING
- APPROPRIATE GROUNDING
- BIL (BASIC INSULATION LEVEL)

SWITCHING TRANSIENT





IMPACT

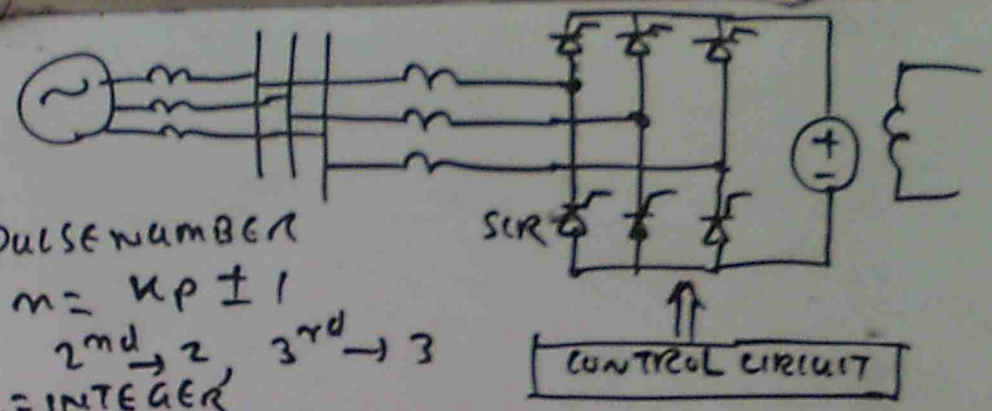
- DISRUPTION OF NORMAL OPERATION
- DEGRADING OF COMPONENT
- DAMAGE TO EQUIPMENTS

POWER SYSTEM FAULTS

CAUSED BY PHASE TO PHASE INSULATOR FAILURE
PHASE TO EARTH INSULATOR FAILURE.

SOURCE OF HARMONIC

POWER ELECTRONIC CONVERTER, TRANSIENT CAUSED BY TRANSFORMER, CAPACITOR ENERGIZATION

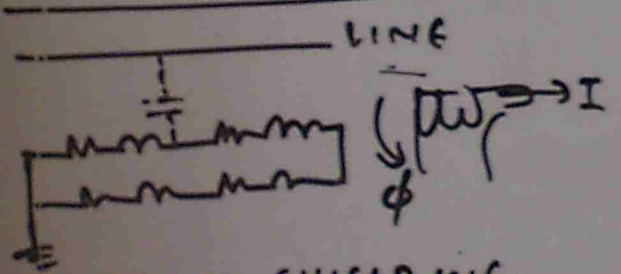


PULSE NUMBER
$n = kp \pm 1$
$2^{nd} \rightarrow 2$, $3^{rd} \rightarrow 3$
k = INTEGER
p = PULSE NUMBER OF INTEGER

$f_n = (kp \pm 1) f_1$, f_n = n^{th} HARMONIC FREQUENCY, f_1 = FUNDAMENTAL FREQUENCY

$I_{rms} = \sqrt{I_2^2 + I_3^2 + I_5^2 + \cdots}$

COUPLING ELECTRICAL INTERFERENCE



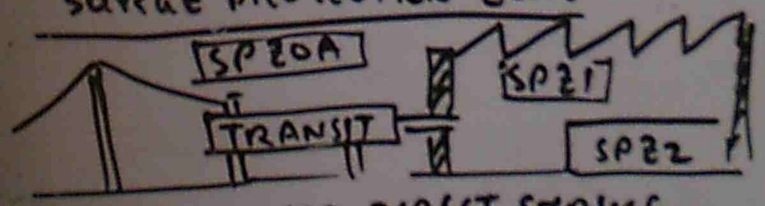
ELECTRICAL SHIELDING

ELECTROMAGNETIC SHIELD FOR
- METALLIC EQUIPMENTS, ENCLOSURE, CABINET, STRUCTURAL STEEL IN BUILDING
- REINFORCING STEEL IN REINFORCED CONCRETE MUST BE PROVIDED

REDUCTION OF INTERFERENCE

- USE OF TWISTED PAIR WIRE
- SHIELDING
- GROUNDING FOR CONTROL CIRCUITS IN DISTRIBUTION SYSTEM

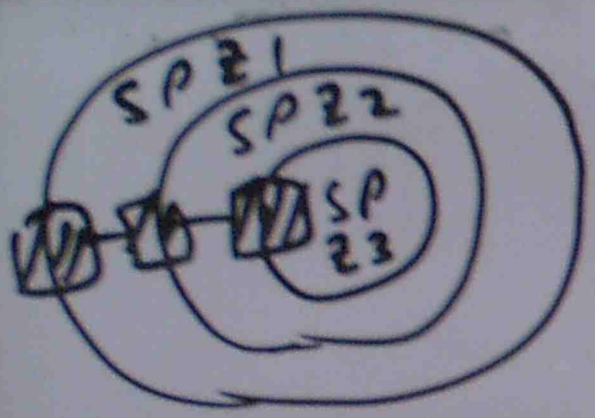
SURGE PROTECTION ZONE

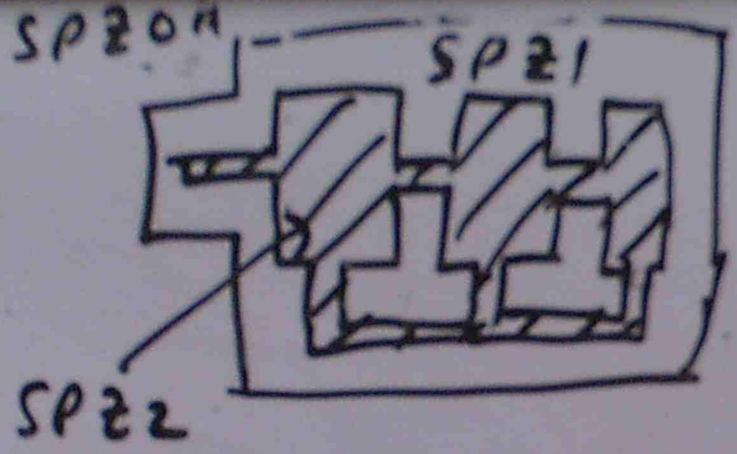


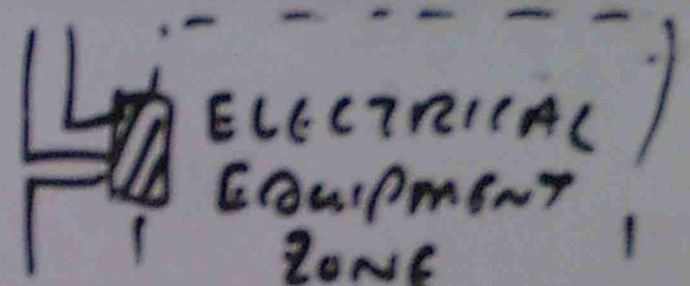
SPZ-0A - DIRECT STRIKE
SPZ1 - NO DIRECT STRIKE
SPZ-2 - NO DIRECT STRIKE, CONDUCTIVE PATH
SPZ-3

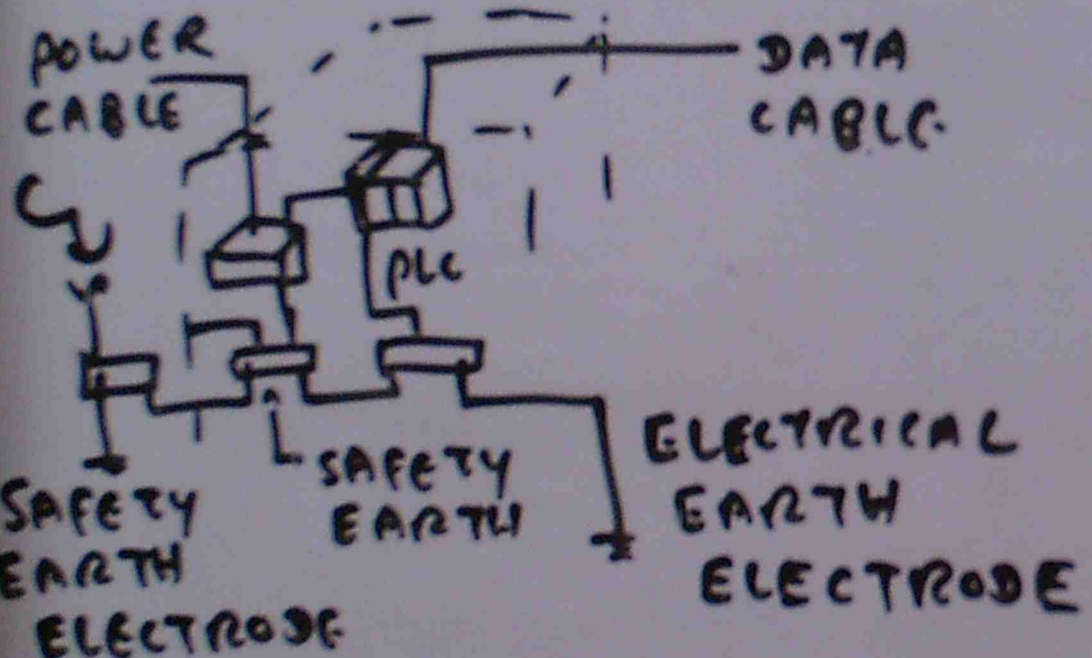
CONDUCTION PATH FOR MAGNETIC FIELD WITH ATTENUATION.

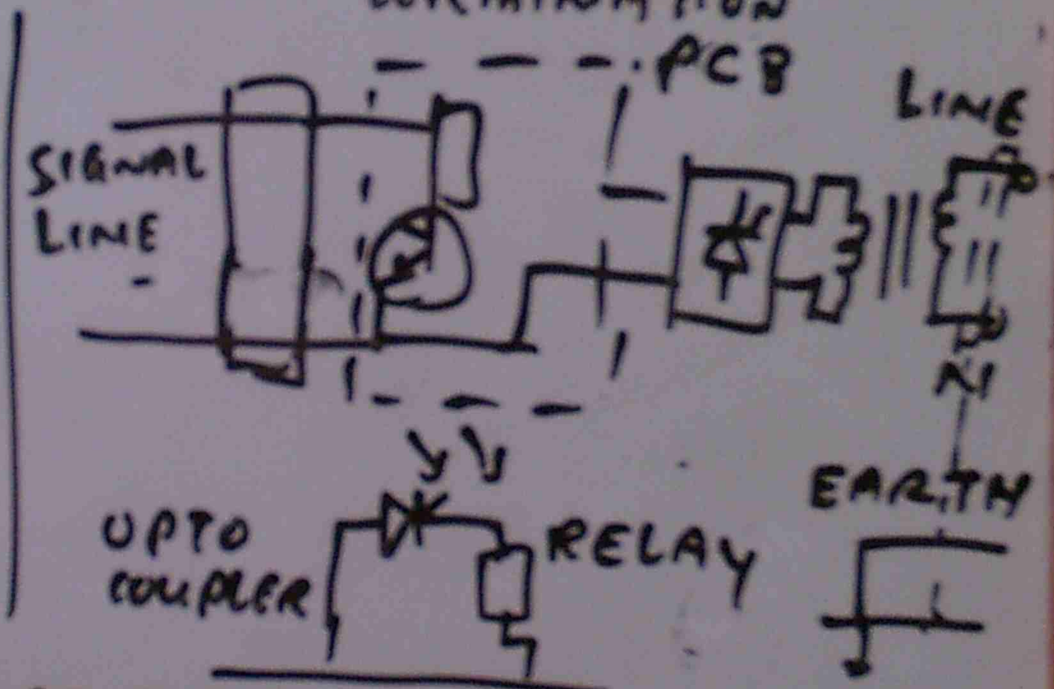
APPROPRIATE GROUNDING



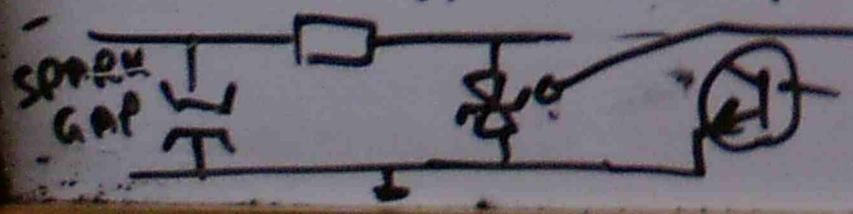


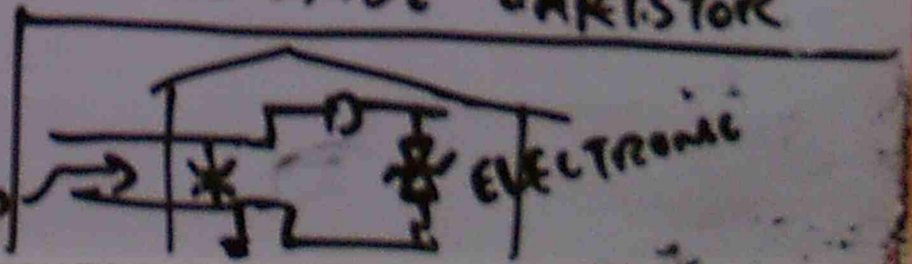




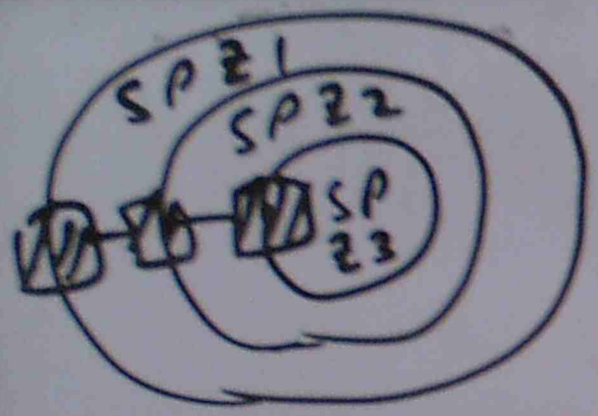


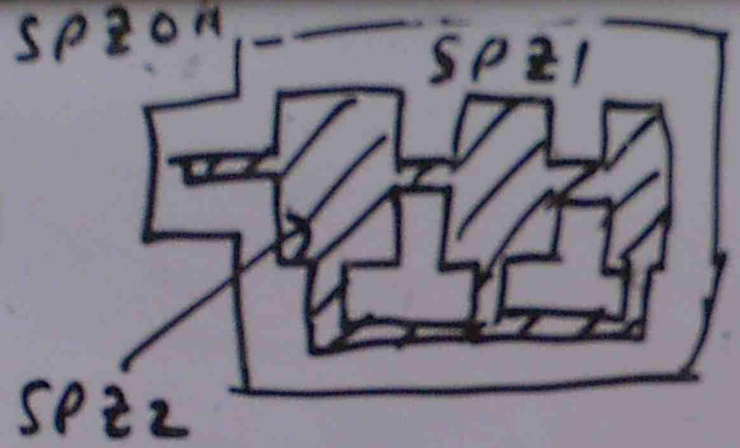
THE MAIN PURPOSE of SURGE PROTECTION UNIT SPU IS TO CLAMP THE VOLTAGE BETWEEN THE SIGNAL LINES & SIGNAL REFERENCE CONDUCTOR.
1st PROTECTION - SILICON SUPPRESSOR, 2nd - METAL OXIDE VARISTOR
COARSE - SPARK GAP ARRESTER.

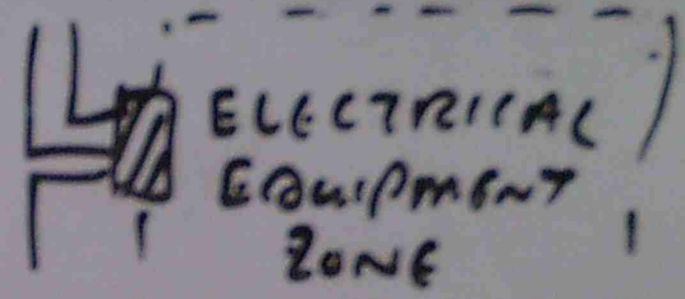


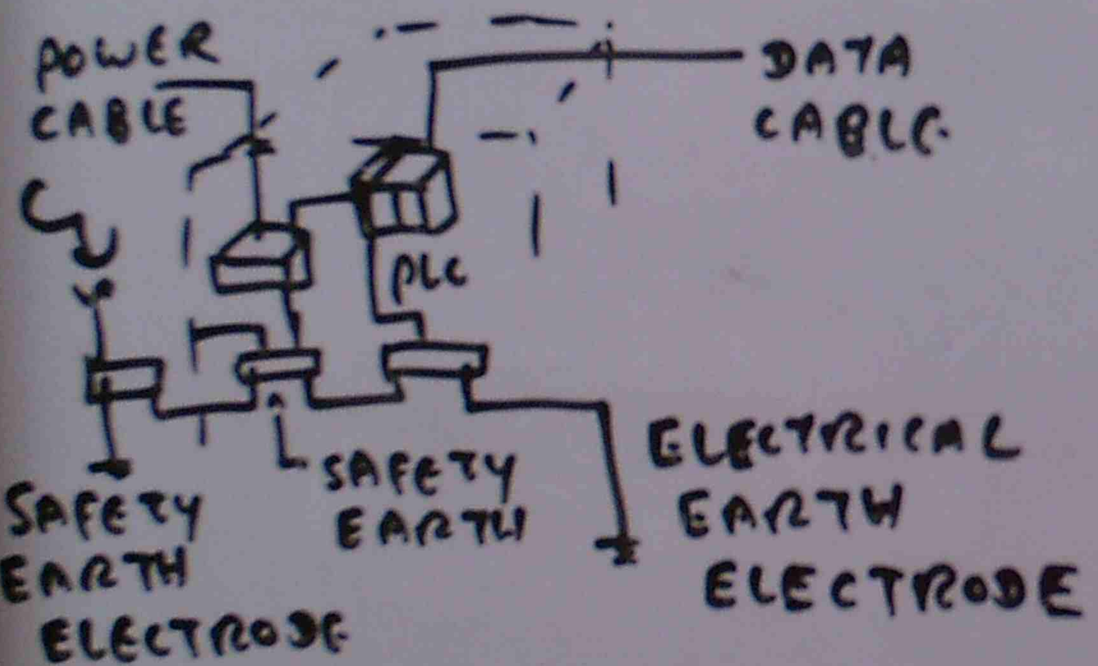


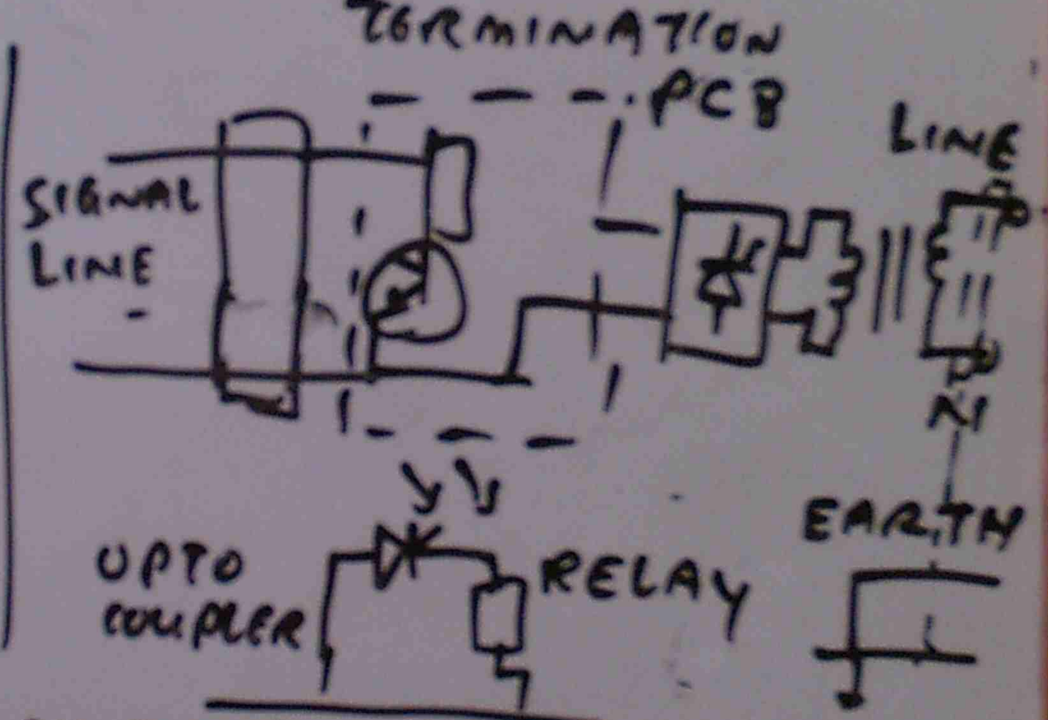
APPROPRIATE GROUNDING











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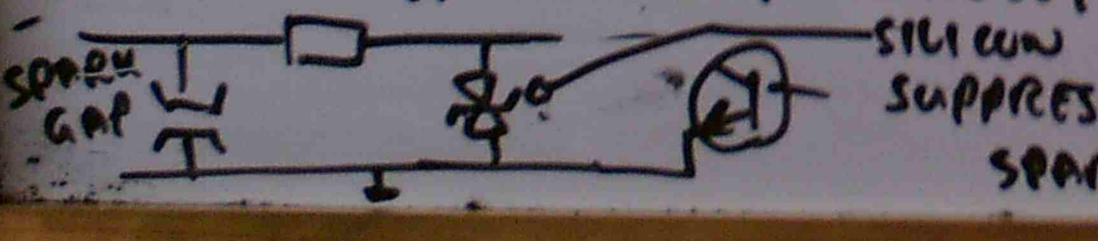
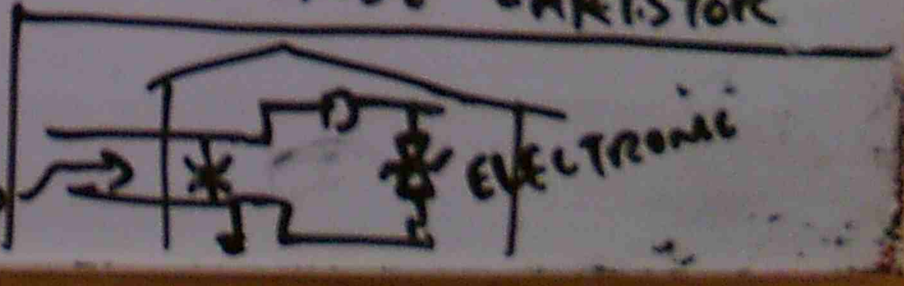
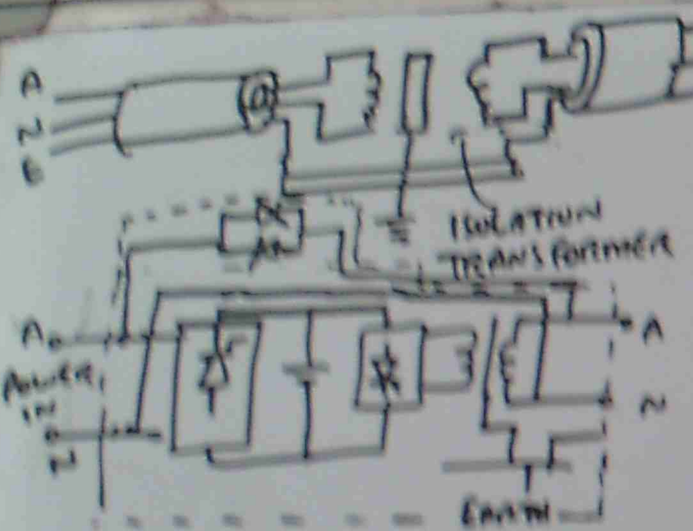




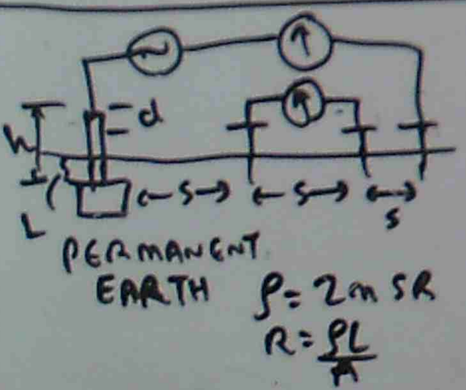


POWER LINE CONDITIONER

- ISOLATE TRANSFORMER REGULATED OUTPUT VOLTAGE
- FILTER EXTERNAL NOISE
- SHORT CIRCUIT PROTECTION

SOIL RESISTIVITY & EARTH ELECTRODE

THE MAIN OBJECTIVE OF EARTHING ELECTRICAL SYSTEM IS TO ESTABLISH A COMMON REFERENCE POTENTIAL FOR THE POWER SUPPLY SYSTEM, BUILDING STRUCTURE, PLANT STEEL WORK, ELECTRICAL CONDUIT CABLE LADDER TRAYS & INSTRUMENTATION SYSTEM. A SUITABLE LOW RESISTANCE CONNECTION TO EARTH IS DESIRABLE HOWEVER IT DEPENDS ON (a) SOIL RESISTIVITY (b) SIZE & TYPE OF ELECTRODE USED (c) DEPTH TO WHICH ELECTRODE IS BURIED, (d) MOISTURE AND CHEMICAL CONTENTS OF SOIL



$\rho = 2\pi SR$

$R = \frac{\rho L}{A}$

E - POTENTIAL DIFFERENCE ACROSS THE CONDUCTOR

I - CURRENT FLOWING THROUGH THE CONDUCTOR

R - RESISTANCE OF CONDUCTOR

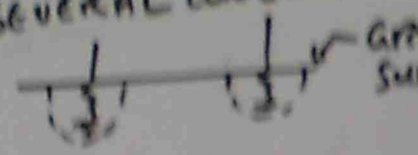
ρ - RESISTIVITY

L - LENGTH OF EARTHING ELECTRODE

A - C.S.A OF EARTH ELECTRODE

EARTH RESISTANCE DEPENDS ON

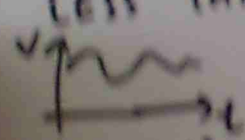
SINGLE DRIVEN ROD, MULTIPLE DRIVEN ROD, SEVERAL CONDUCTORS BURIED IN GROUND

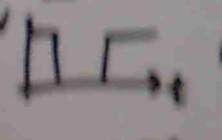




POWER QUALITY

INTERRUPTION - INTERRUPTION OCCURS WHEN THE SUPPLY VOLTAGE (OR) LOAD CURRENT DECREASES TO LESS THAN 1 MINUTE





POOR POWER QUALITY

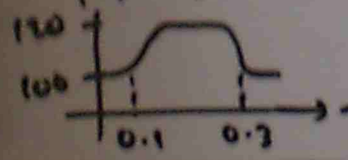
SAG (DIP) SAGS ARE SHORT DURATION REDUCTIONS IN THE RMS VOLTAGE BETWEEN 0.1 AND 0.9 PU. VOLTAGE SAGS ARE CAUSED BY

- ENERGIZING THE HEAVY LOADS
- SINGLE LINE TO GROUND FAULT

LOAD TRANSFER FROM ONE SOURCE TO REMOTE SOURCE

SWELL

THE INCREASE OF VOLTAGE MAGNITUDE BETWEEN 1.1 TO 1.8 PU IS CALLED SWELL.



THE SWELL IS CAUSED BY

- SWITCHING OFF LARGE LOAD
- ENERGIZING CAPACITOR BANK
- VOLTAGE INCREASE OF UNFAULTED PHASE DURING SINGLE L-L FAULT

DEFINITION OF POWER QUALITY

THE QUALITY OF VOLTAGE AND/OR THE QUALITY OF CURRENT CAN BE DEFINED AS THE MEASURE ANALYSIS AND IMPROVEMENT OF THE BUS VOLTAGE TO MAINTAIN A SINUSOIDAL WAVE FORM AT RATED VOLTAGE AND FREQUENCY.

POWER QUALITY

THE SYSTEM MUST BE DESIGNED AND OPERATED MINIMIZING POWER QUALITY SYSTEM.
END USER - PROPER WIRING, GROUNDING,
MANUFACTURER - ELECTRONICS DEVICES THAT KEEP ELECTRICAL DISTURBANCE TO MINIMUM

MAIN CAUSES OF DISTURBANCES TO POWER QUALITY

LOW FREQUENCY - HARMONICS, SIGNALLING VOLTAGE FLUCTUATING VOLTAGE, VOLTAGE DIP, VOLTAGE IMBALANCE POWER FREQUENCY VARIATION, DC COMPONENT IN AC

RADIATION MAGNETIC FIELD, ELECTRIC FIELD

HIGH FREQUENCY - INDUCED CONTINUOUS VOLTAGE CURRENT, UNI DIRECTIONAL

TRANSIENT, OSCILLATORY TRANSIENT

MAGNITUDE OF EVENT 90% → 110%

1→3 CYCLE ~ SHORT, 1→3 MINUTE LONG
1→3 HR VERY LONG

TRANSIENT

IMPULSIVE TRANSIENT - SUDDEN FREQUENCY CHANGE IN STEADY CONDITION OF VOLTAGE, CURRENT (OR) BOTH

OSCILLATORY TRANSIENT - SUDDEN FREQUENCY CHANGE IN THE STEADY STATE CONDITION OF VOLTAGE, CURRENT (OR) BOTH THAT INCLUDE + (OR) - POLARITY VOLTAGES

VOLTAGE IMBALANCE IN 3φ SYSTEM

NON TRANSPOSED, BLOWN OUT FUSE, FUSE BLOWN OUTS IN 1φ, 3φ CAPACITOR BANK.

WAVE FORM DISTORTION

PRESENCE OF DC CURRENT AND/OR VOLTAGE COMPONENT IN AC SYSTEM

EFFECT 1/2 CYCLE SATURATION OF TRANSFORMER
GENERATION OF EVEN HARMONIC, HEATING

HARMONIC IS CAUSED BY INDUSTRIAL NON LINEAR LOADS SUCH AS TRANSFORMER, INVERTER,

NOTCHING MOMENTARY SHORT CIRCUIT BETWEEN TWO COMMUTATING PHASES REDUCING LINE VOLTAGE
- REPRESENTED BY ELECTRIC NOISE, FLICKERING.

POWER FREQUENCY VARIATION

CAUSED BY CHANGE IN ROTATIONAL SPEED OF ELECTROMAGNETIC GENERATOR.



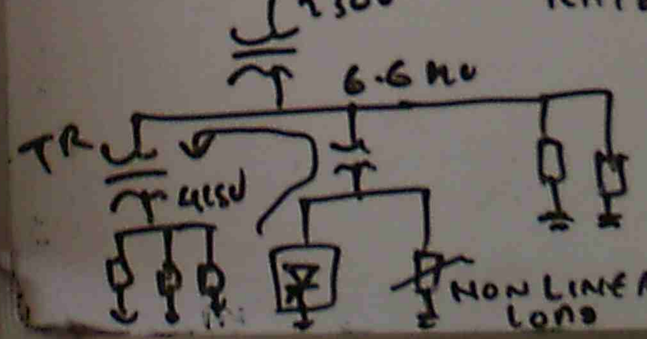
$$\text{FORM FACTOR} = \frac{I_{RMS}}{I_{AVERAGE}}$$

$$I_{RMS} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 \cdots I_n^2}{(n-1)}}$$

$$I_{AVG} = \frac{I_2 + I_3 + I_4 \cdots I_n}{(n-1)}$$

$$\text{RIPPLE FACTOR} = \sqrt{\left(\text{FORM FACTOR}\right)^2 - 1}$$

$$\text{TOTAL HARMONIC DISTORTION} = \frac{\sqrt{\sum_2^n (I^h)^2}}{\text{RATED CURRENT}}$$



POWER QUALITY IMPROVEMENT

- HARMONIC CANCELLATION
- FILTERING
- USE OF ISOLATION TR
- DERATING

POWER QUALITY IN SYNCHRONOUS MACHINES

UNBALANCED LOAD, VOLTAGE, SATURATION, HEATING, MECHANICAL VIBRATION

$V = Ri + \frac{di}{dt}$ $\quad T = K \frac{2}{3\sqrt{3}} [\phi_a (i_b - i_c) + \phi_b (i_c - i_a) + \phi_c (i_a - i_b)]$

$I_d = \frac{-R_d V_d + V_q (E_f - V_q)}{X_d X_q + R_a^2}$, $I_q = \frac{X_d V_d + R_d (E_f - V_q)}{X_d X_q + R_a^2}$

d - DIRECT , q - QUADRATURE

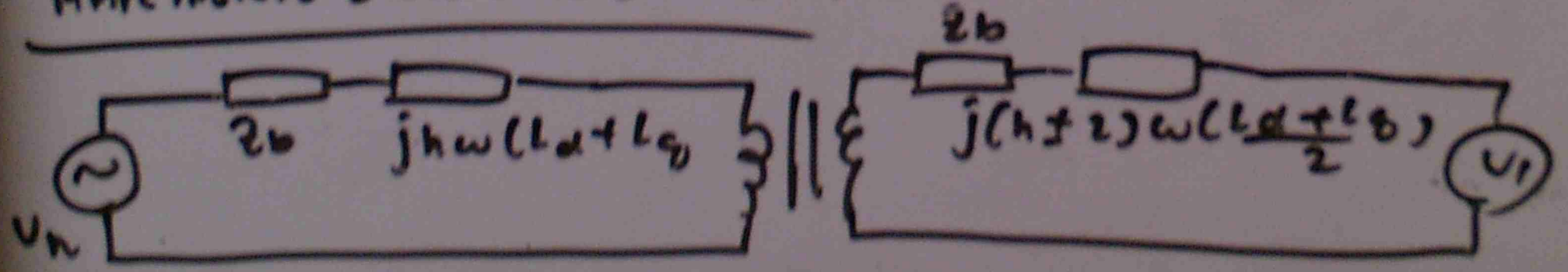
$F = \frac{1}{2} \mu_0 (H_m^2 - H_t^2)$, F = MECHANICAL FORCE -7 — μ_0 = PERMEABILITY $4\pi \times 10$

H_m = NORMAL MAGNETIZING FORCE, H_t = TANGENTIAL MAGNETIZING

$T = F \times r$

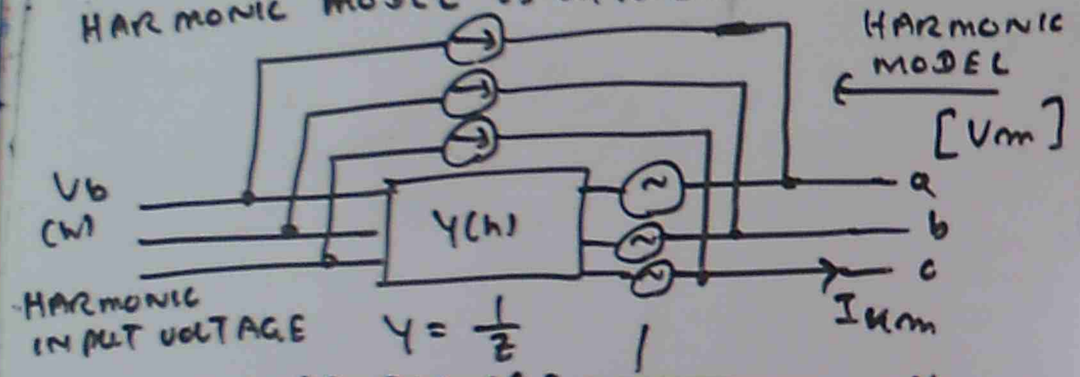
HARMONIC MODELLING - { FREQUENCY CONVERSION
SATURATION
MACHINE LOAD FLOW

HARMONIC EQUIVALENT CKT



HARMONIC CAN FLOW IN TO EXCITATION CIRCUIT & GENERATES THE VOLTAGE INFECTED BY HARMONIC

IN SELF EXCITATION SYSTEM OF GENERATOR, THE HARMONIC COMPONENT IN OUTPUT VOLTAGE CAN FLOW IN TO THE EXCITER SYSTEM AND GENERATES THE VOLTAGE INFECTED WITH HARMONIC. THE HARMONIC MUST BE PROPERLY FILTERED. IN THIS CASE THE HARMONIC MODEL IS UTILIZED



$Y = \frac{1}{Z}$

ADMITTANCE = $\frac{1}{\text{IMPEDANCE}}$

ALLOWING THE FLOW OF CURRENT

$\frac{V_m}{\text{TERMINAL VOLTAGE}}$

$$I_{abc}(h) = Y(h) \times \left[V_{abc}(h) \right] + I_f(h)$$

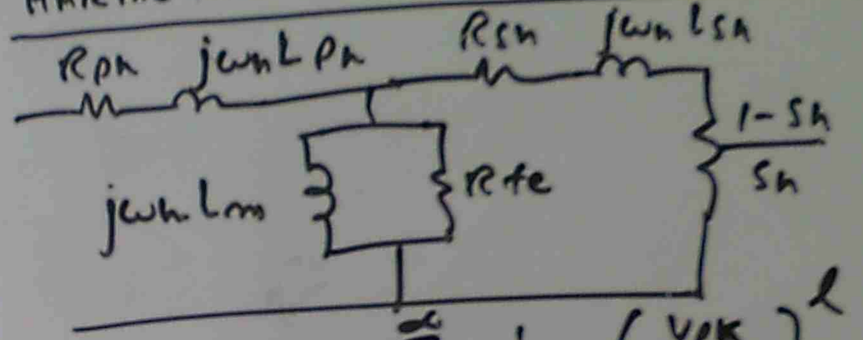
- $I_{abc}(h)$: A,B,C LINE CURRENT WITH HARMONIC
- $Y(h)$: HARMONIC ADMITTANCE (ABILITY TO ALLOW HARMONIC)
- $V_{abc}(h)$: A,B,C LINE VOLTAGES INFLUENCED BY HARMONIC
- $I_f(h)$: FIELD EXCITATION INFLUENCED BY HARMONIC

THE HARMONIC COMPONENT MUST BE FILTERED TO ACHIEVE THE GOOD POWER QUALITY.

LIFE TIME REDUCTION OF TRANSFORMERS AND INDUCTION MACHINES BY HARMONIC

- TEMPERATURE RISE, INTERMITTENT OPERATION
- VIBRATION, FAULT & SHORT CIRCUITS

HARMONIC EQUIVALENT OF INDUCTION MOTOR



$$\Delta T_h = K \sum_{h=2}^{\infty} \frac{1}{h^2} \left(\frac{V_{pk}}{V_{pL}} \right)^{\ell}$$

$$S_L = \text{SLIP} = \frac{\text{NO LOAD SPEED} - \text{FULL LOAD SPEED}}{\text{NO LOAD SPEED}}$$

h = HARMONIC, h = 2 → 2nd HARMONIC

V_{pk} - PEAK VOLTAGE, V_{pL} - NORMAL VOLTAGE

R_{PL} - STATOR RESISTANCE, R_{SL} - ROTOR RESISTANCE

$j\omega L_{PL}$ - STATOR INDUCTANCE $j\omega L_{SL}$ - ROTOR INDUCTANCE

$$K = \frac{\frac{\Delta T_{h2}}{\Delta T_{h1}} \left(\frac{V_{ph1}/V_{pL}}{V_{ph2}/V_{pL}} \right)}{\log\left(\frac{h_1}{h_2}\right)}$$

$$\ell = \frac{\log\left[\frac{\Delta T_{h2}}{\Delta T_{h1}} \left(\frac{V_{ph1}/V_{pL}}{V_{ph2}/V_{pL}} \right) \right]}{\log\left(\frac{h_1}{h_2}\right)}$$

V_{ph_1} - 100 HZ VOLTAGE

V_{ph_2} - 150 HZ VOLTAGE

ΔT_{h_1} - TEMPERATURE RISE (1)

ΔT_{h_2} - TEMPERATURE RISE (2)

V_{pL} - NORMAL VOLTAGE

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(5) POWER LINE

SLIDE (3) → (27)

@ 39 → 53

(6) SIGNAL COUPLING EARTHING

SLIDE (1) → (29) | @ 54 - 63

(7) POWER QUALITY

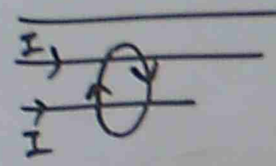
SLIDE (1) → (27)

@ 64 → 78

HARMONIC LOSSES IN TRANSFORMER

SKIN EFFECT | HYSTERESIS & EDDY CURRENT LOSSES | PROXIMITY EFFECT





DERATING of 1ϕ TRANSFORMER → COST of RUNNING THE MACHINE AT DERATED CAPACITY
↳ USE of HARMONIC FILTER

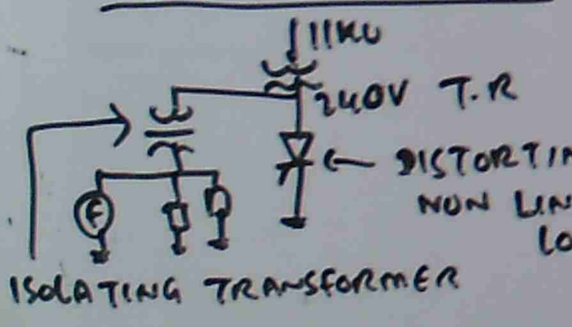
VARIOUS OPERATING MODELS of ROTATING MACHINES → STEADY STATE, SHORT TERM
STEADY STATE WITH SHORT TERM
STEADY STATE WITH INTERMITTENT OPERATION

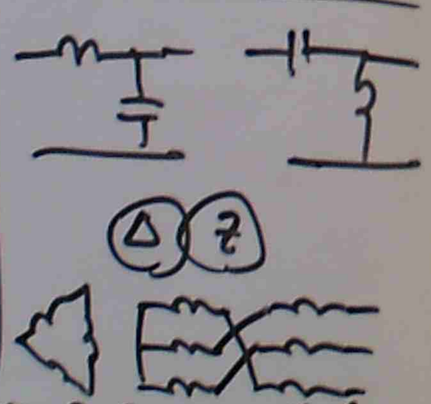
VIBRATION & TORQUE FLUCTUATIONS

POSSIBLE IMPACTS of POWER QUALITY IN TRANSFORMER

CORE SATURATION, CORE LOSSES, COPPER LOSSES, MALFUNCTIONING OF RELAYS, REDUCTION OF EFFICIENCY DERATING, P.F DECREASE, PARALLEL RESONANCE

HARMONIC FILTERING





INTERACTION WITH POWER SYSTEM, FORMING 11 & RESONANT CIRCUIT, HARMONIC COMPENSATION

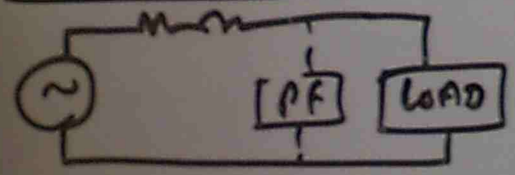
INTERACTION of HARMONIC WITH CAPACITORS

MIS APPLICATION, HARMONIC PROPAGATION, UNBALANCE, VOLTAGE INCREASE, SERIES RESONANCE

SOLUTION TO VOLTAGE INCREASE

DETUNE THE CKT BY CHANGING CAPACITOR BANK SIZE
SWITCH LARGE BANKS IN MORE THAN ONE SECTION of POWER SYSTEM. USE SURGE ARRESTERS,
L.V P.F CORRECTION BANK.
USE PROPERLY TUNED FILTER. INSTALL ISOLATION TR
USE TRANSIENT SURGE SUPPRESSORS

REACTIVE POWER COMPENSATION

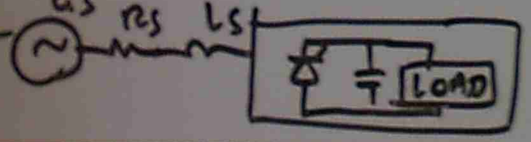


P+jQ

P.F CORRECTION CAPACITOR
- IMPROVE VOLTAGE PROFILE
- REDUCE POWER SYSTEM LOSSES
- RELEASE SYSTEM CAPACITY

- INCREASE PLANT RATING

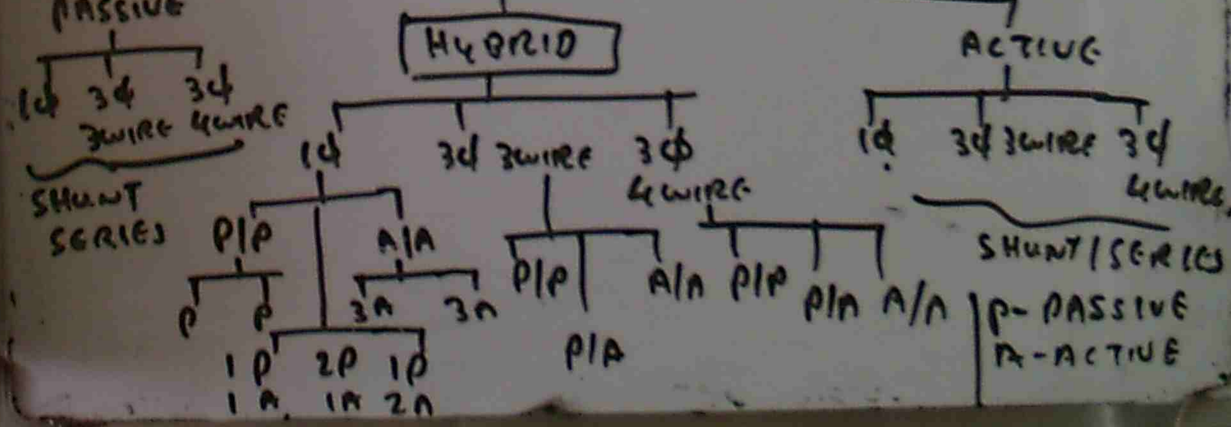
FILTER



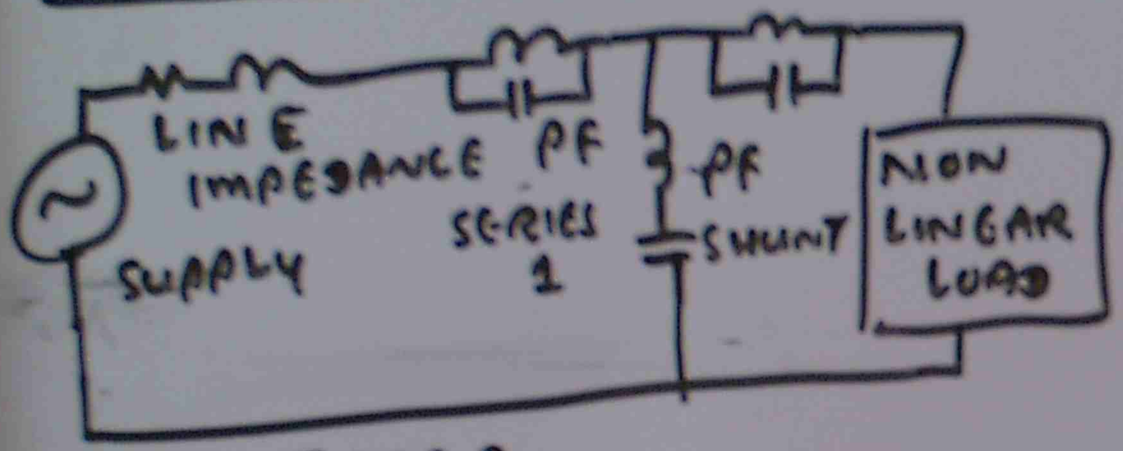
FILTER CLASSIFICATION

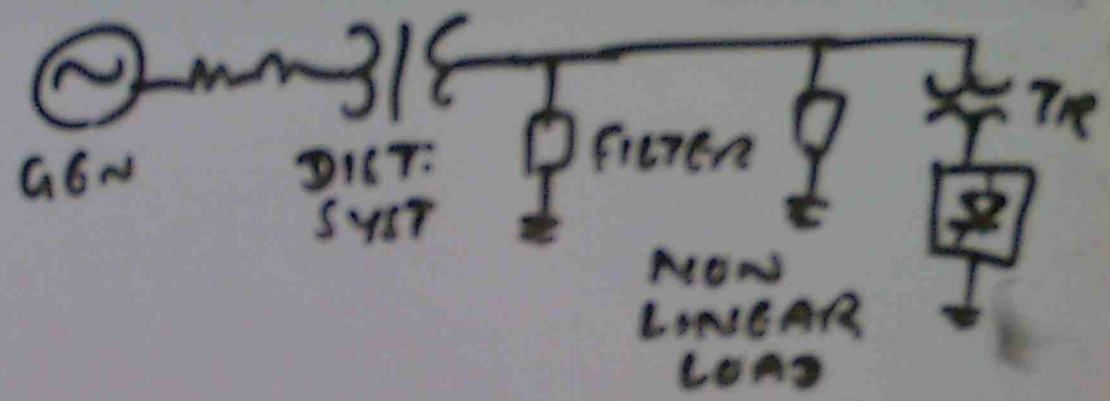
TOPOLOGY, NO. & TYPE SUPPLY SYSTEM, POWER COMPENSATION RATING

POWER FILTER

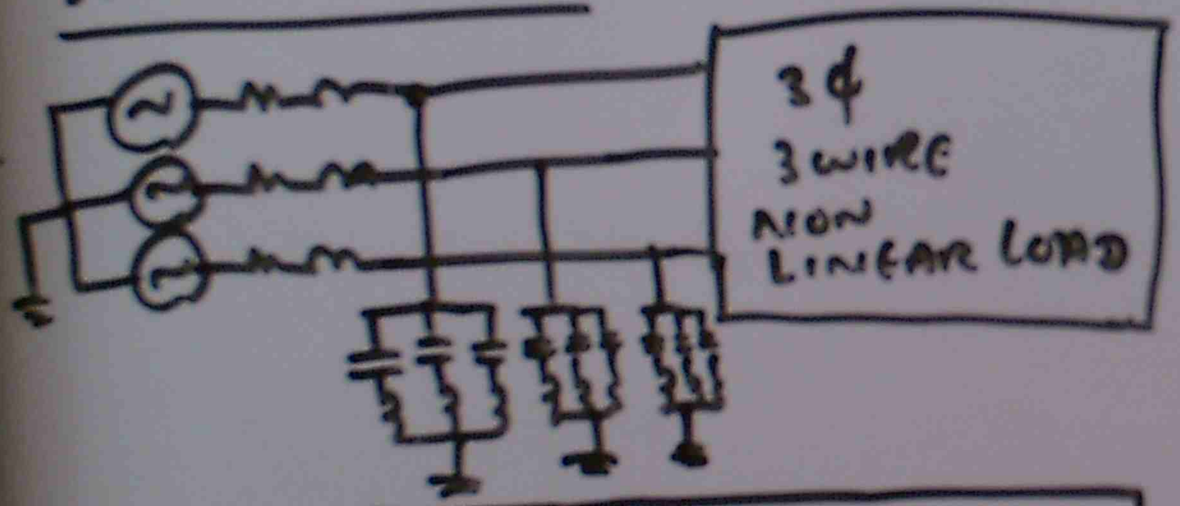


HYBRID FILTER

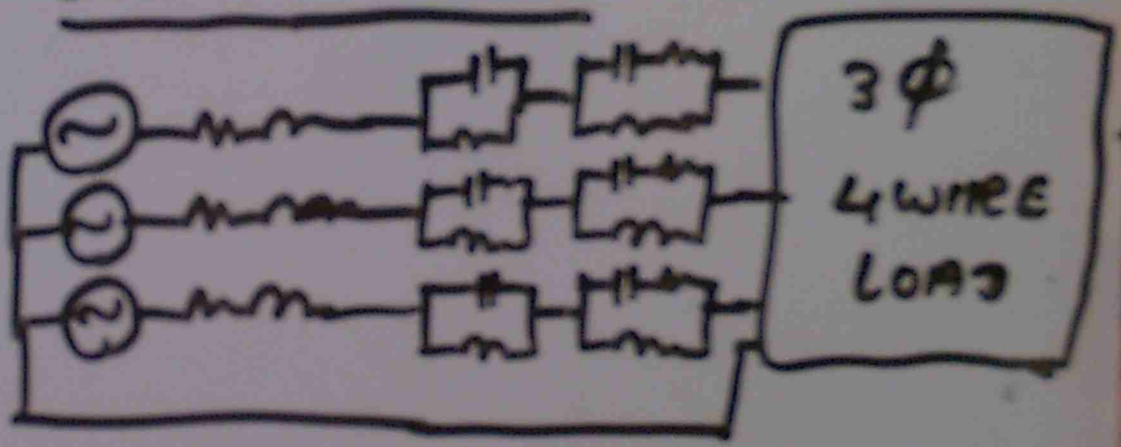


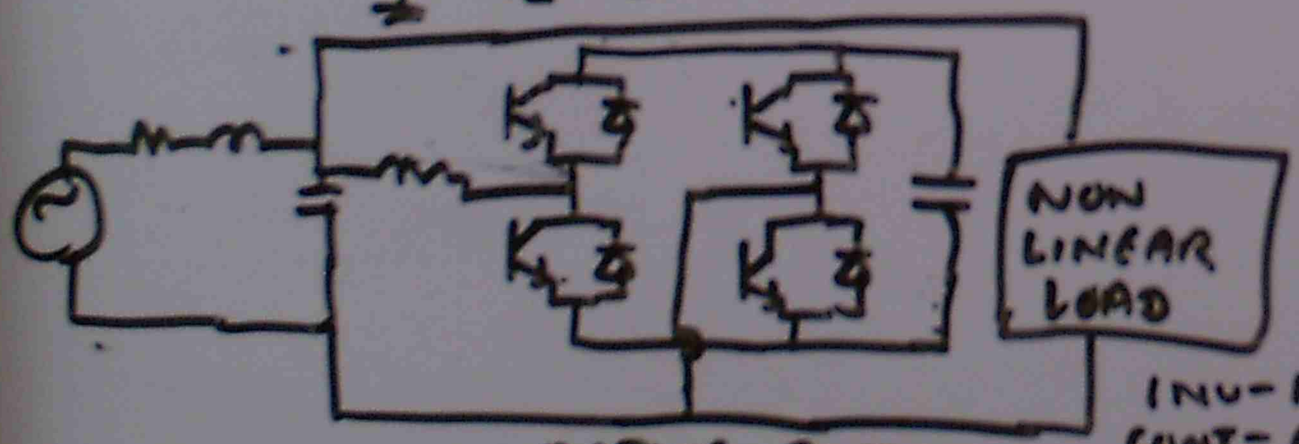


SHUNT FILTER



SERIES FILTER

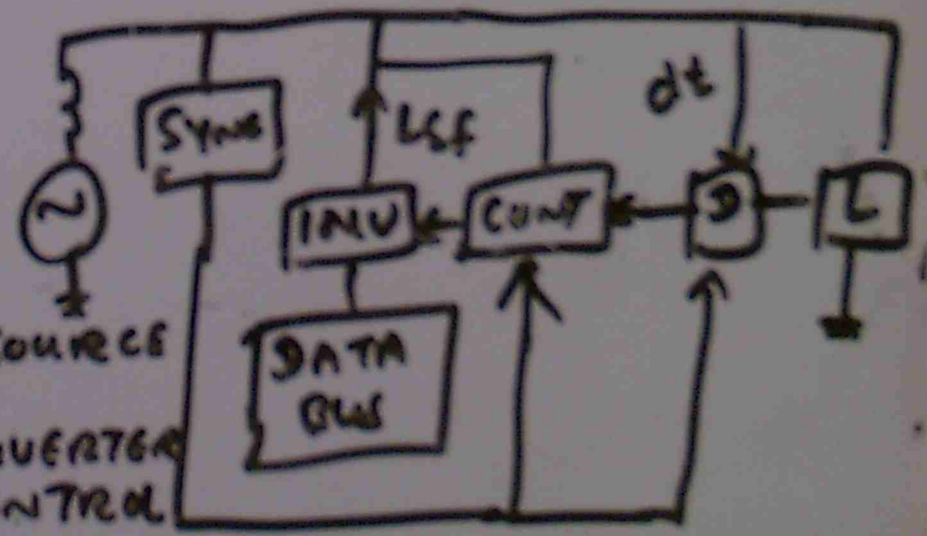




ACTIVE FILTER

SENSOR TRANSFORMER- MEASURE WAVE FORM

DISTORTION IDENTIFIER- SIGNAL PROCESSING



INV- INVERTER
CONT- CONTROL
D- DISTORTION IDENTIFIER
L- NON LINEAR LOAD

INVERTER - ACTIVE FILTERING
CONTROL - CURRENT CONTROL LOOP

RELIABILITY IMPROVEMENT

FAST INTERRUPTING SWITCH & FAULT CURRENT LIMITER

↳ IMPROVE RELIABILITY → APPLIED NETWORK SECURITY

- RISK ANALYSIS
- CURRENT & FUTURE TECHNICAL CONCEPT
- DATA COMMUNICATION

→ REDUCTION OF VOLTAGE SAG DURING SHORT CIRCUIT

→ IMPROVEMENT OF POWER SYSTEM STABILITY

→ REDUCTION of MAXIMUM OCCURING MECHANICAL AND ELECTRICAL TORQUE OF GENERATOR

→ ELEMENT OF THE INTERRUPTING BURDEN ON CIRCUIT BREAKER BY LIMITING FAULT CURRENT TO A DESIRABLE LEVEL.

TYPES of EMERGENCY

- FAILURE of A MAJOR POWER SYSTEM COMPONENT
- SIMULTANEOUS FAILURE OF MORE THAN ONE COMPONENT AT DIFFERENT LOCATIONS.
- OUTAGE of POWER SYSTEM WITHIN AN ENTIRE REGION.
- DISRUPTION of SENSING (OR) COMMUNICATION NETWORK.

SOLUTION APPROACH

- TECHNIQUE TO CONTROL COMMUNICATION NETWORK
- CONTROL INFORMATION PROCESSING
- NETWORK CONFIGURATION
- INDEPENDENCE IN NETWORK
- MULTIPLE SUPPLIES

) HARMONIC LOSSES IN TRANSFORMER

IDE(1) → (19)
Q 79 → Q 85

PREPARATION FOR EMERGENCY

PREPARATION BEFORE EMERGENCY

- OPERATING REGIONS SHOULD OPERATE INDEPENDENTLY
- PERMITTING INTENTIONAL ISLANDING
- OPTIMAL LOAD SHEDDING OCCURED TO MAINTAIN ESSENTIAL LOADS
- LIMIT THE SHORT CIRCUIT CURRENT

DURING FAILURE

- EMERGENCY CURRENT LIMITER LIMIT THE CURRENT
- CUT OFF THE CIRCUIT BREAKER BY RELAY
- RECLOSING

FAULT CURRENT LIMITER → RECLOSING SWITCH → CIRCUIT BREAKER

AFTER FAILURE

- OPTIMAL LOAD SHEDDING, EFFICIENCY IMPROVEMENT

DEMAND MANAGEMENT

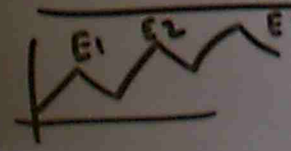
- DISTRIBUTED GENERATION, GREATER ACCESS TO UTILITIES
- PLAN FOR FUTURE LOAD GROWTH, COMPETITION of RETAIL CUSTOMERS

DISTRIBUTED CONTROL

DIRECT CONTROL TECHNIQUE, LOAD CONTROL TECHNIQUE

- METERS FOR LIGHTING, VENTILATION CONTROL
  CONTROL OF TARGETED EQUIPMENTS

HARMONIC CALCULATIONS



$$E_{T_{rms}} = \sqrt{E_1^2 + E_2^2 + E_3^2}$$

RELIABILITY IMPROVEMENT

FAST INTERRUPTING SWITCH & FAULT CURRENT LIMITER

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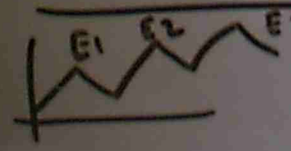
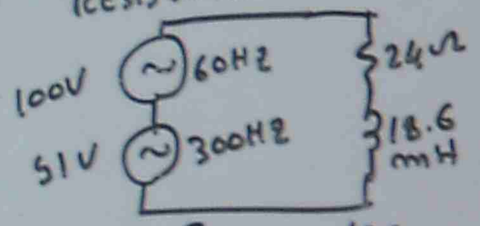
HARMONIC CALCULATIONS



$$E_{T_{rms}} = \sqrt{E_1^2 + E_2^2 + E_3^2}$$

P9 THE GIVEN FIGURE SHOWS A DISTORTED VOLTAGE SOURCE COMPOSED OF A FUNDAMENTAL OF 100V, 60HZ AND 5TH HARMONIC OF 51V, 300 HZ. THE SOURCE IS CONNECTED TO A RESISTOR OF 24Ω IN SERIES WITH AN INDUCTANCE OF 18.6mH AT 60 HZ. CALCULATE (a) Z AT 60HZ & 300 HZ (b) ACTIVE AND REACTIVE POWER ABSORBED BY RESISTOR AND INDUCTOR (c) TOTAL POWER DISSIPATED



$X_L = 2\pi fL = 2 \times 3.1416 \times 60 \times 18.6 \times 10^{-3}$

$X_{60\Omega} = 7\ \Omega$

$Z_{60} = \sqrt{R^2 + X_{60}^2} = \sqrt{24^2 + 7^2} = 25\Omega$

$I_{60} = \frac{E_{60}}{Z_{60}} = \frac{100}{25} = 4A$

$P_{60} = I_{60}^2 R = 4^2 \times 24 = 384W$

$Q_{60} = I_{60}^2 X_{60} = 4^2 \times 7 = 112\ VAR$

300HZ $X_{300} = 2\pi fL = 2 \times 3.1416 \times 300 \times 18.6 \times 10^{-3} = 35\Omega$

$Z_{300} = \sqrt{R^2 + X_{300}^2} = \sqrt{24^2 + 35^2} = 42.4\Omega$

$I_{300} = \frac{E_{300}}{Z_{300}} = \frac{51}{42.4} = 1.2A$, $P_{300} = I_{300}^2 \times R = 1.2^2 \times 24 = 34.6W$

$Q_{300} = I_{300}^2 \times X_{300} = 1.2^2 \times 35 = 520\ VAR$

$I_T = \sqrt{I_{60}^2 + I_{300}^2} = \sqrt{4^2 + 1.2^2} = 4.18A$

$P_T = \sqrt{P_{60}^2 + P_{300}^2} = \sqrt{384^2 + 34.6^2} = 418.6W$

P8 NO.4 AWG CABLE HAVING A LENGTH OF 75m HAS A RESISTANCE OF 25.7mΩ WHEN IT CARRIES A 60HZ CURRENT OF 100A. IT'S TEMPERATURE IS THEN 70C IN AN AMBIENT TEMPERATURE OF 25C. AFTER INSTALLATION OF AN ELECTRONIC DRIVE, THE CABLE WAS FOUND TO CARRY AN ADDITIONAL 7TH HARMONIC CURRENT OF 50A, 420 HZ, CALCULATE THE NEW LOSSES IN THE CABLE AND APPROXIMATE TEMPERATURE RISE. IF ADDITIONAL LOSS IS 25% TEMPERATURE RISE IS ALSO 25%.

ORIGINAL CURRENT 100A AT 60HZ

ORIGINAL COPPER LOSS = $I^2R = 100^2 \times 25.7 \times 10^{-3} = 257W$

7TH HARMONIC → 50A AT 420 HZ

LOSSES DUE TO HARMONIC CONTENT = $I_H^2 R = 50^2 \times 25.7 \times 10^{-3} = 64W$

TOTAL POWER LOSSES = ORIGINAL COPPER LOSS + HARMONIC LOSS

$= 257 + 64 = 321$ WATT

% ADDITIONAL LOSS = $\frac{\text{HARMONIC LOSS}}{\text{ORIGINAL LOSS}} \times 100 = \frac{64}{321} \times 100 = 25\%$

TEMPERATURE RISE = $\frac{\%\ \text{ADDITIONAL LOSS} + 100}{100} \times$ ORIGINAL TEMP:

$= \frac{25 + 100}{100} \times 70 = 81C$

$E_{60} = 4.44 f_{60} \phi_{60} N$

$E_{180} = 4.44 f_{180} \phi_{180} N$

P9 THE PRIMARY WINDING OF A TRANSFORMER CARRIES A DISTORTED CURRENT HAVING FUNDAMENTAL CURRENT = 520A, 3RD HARMONIC = 270A 23RD HARMONIC = 47A. DC RESISTANCE OF WDG = 3mΩ STRAY LOSSES = 4% OF TOTAL JOULE EFFECT CALCULATE (a) I_T (b) R (c) JOULE EFFECT LOSSES (d) THE STRAY LOSSES (e) I_T PRODUCING HIGHEST JOULE LOSS (f) I_T PRODUCING LARGEST STRAY LOSS.

(a) $I_T = \sqrt{I_f^2 + I_{3rd}^2 + I_{23}^2} = \sqrt{520^2 + 270^2 + 47^2} = 587.8\,A$

(b) $K_T = \dfrac{(1 \text{ for } I_f)^2 I_f^2 + (3 \text{ for } 3rd)^2 I_{3rd}^2 + (23 \text{ for } 23rd)^2 I_{23}^2}{I_T^2}$

$= \dfrac{1^2 \times 520^2 + 3^2 \times 270^2 + 23^2 \times 47^2}{587.8^2} = 6.06$

(c) JOULE EFFECT LOSSES $= I_T^2 R_0 = 587.8^2 \times 3\times10^{-3} = 1037\,W$

(d) STRAY LOSS $= \%$ STRAY LOSS $\times$ JOULE EFFECT LOSS $\times K$

$= \frac{4}{100} \times 1037 \times 6.06 = 251$ WATT

(e) TOTAL LOSS = JOULE EFFECT LOSS + STRAY LOSS

$= 1037 + 251 = 1288\,W$

(f) LARGEST STRAY LOSS $= \dfrac{(23 \text{ FOR } I_{23rd})^2 I_{23}^2}{I_T^2} = \dfrac{23^2 \times 47^2}{587.8^2} = 3.38$

LARGEST STRAY LOSS $=$ TOTAL STRAY LOSS $\times \dfrac{K_{23}}{K_T} = \dfrac{251 \times 3.38}{6.06} = 140\,W$

PD A 3ϕ SYNC: GENERATOR PRODUCES AN OC LINE VOLTAGE 6928 V. DC EXCITING CURRENT 50A, AC TERMINALS ARE SHORT CIRCUITED CURRENT 800A. FIND X_S & EY IF 12Ω IS CONNECTED TO TERMINAL.

$X_S = Z_S = \dfrac{E_f/\text{ph}}{I_{sc}} = \dfrac{6928/\sqrt{3}}{800} = 5\,\Omega$

$I = \dfrac{E_f}{\sqrt{R^2 + X_S^2}} = \dfrac{4000}{\sqrt{12^2 + 5^2}} = 308A$

$V_{T\,\text{LINE}} = \sqrt{3}\,IR = \sqrt{3} \times 308 \times 12 = 6408\,V$

P7 A 30 MUA, 15 KV, 60 HZ AC GENERATOR HAS A SYNCHRONOUS REACTANCE 1.2 PU AND AC RESISTANCE 0.02 PU.

CALCULATE

(a) BASE VOLTAGE, BASE POWER, BASE IMPEDANCE

(b) ACTUAL VALUE OF SYNCHRONOUS REACTANCE

(c) ACTUAL WINDING RESISTANCE / PHASE

(d) TOTAL FULL LOAD COPPER LOSS.

$$\text{BASE IMPEDANCE} = \frac{(\text{BASE VOLTAGE / PHASE})^2}{\text{BASE POWER / PHASE}}$$

(a) $V_{BASE/ph} = \frac{15000}{\sqrt{3}} = 8660\,V$

$P_{BASE/ph} = \frac{30\,MUA}{3} = 10\,MVA$

$BASE\ Z = \frac{(8660)^2}{10 \times 10^6} = 7.5\ \Omega$

(b) SYNCHRONOUS REACTANCE ACTUAL VALUE = $Pu(X) \times BASE(Z)$

$= 1.2 \times 7.5 = 9\ \Omega$

(c) $R_{ACTUAL} = Pu(R) \times BASE\ R$

$= 0.02 \times 7.5 = 0.15\ \Omega$

(d) FULL LOAD COPPER LOSS $= (I_{pu})^2 \times R_{pu} \times P_{BASE/ph}$

$= 1^2 \times 0.02 \times 10\,MVA$

$= 0.2\,MW = 200\,KW$

FULL LOAD 3ϕ COPPER LOSS

$= 3 \times 200 = 600\,KW$

(q) PREPARATION FOR EMERGENCY

SLIDE (1) ⟶ (24)

@ 86 ⟶ 93

POWER GENERATION

$$\text{BASE IMPEDANCE} = \frac{(\text{BASE VOLTAGE})^2}{\text{BASE V.A}}$$

$$\text{RATED CURRENT} = \frac{\text{BASE V.A}}{\sqrt{3} \times \text{BASE VOLTAGE}}$$

Pb A 250 MVA, 25 kV, 3φ STEAM TURBINE GENERATOR HAS A SYNCHRONOUS REACTANCE OF 1.6 PU AND A TRANSIENT REACTANCE X_d' OF 0.23 PU. IT DELIVERS IT'S RATED OUTPUT AT A POWER FACTOR OF 100%. A SHORT CIRCUIT SUDDENLY OCCURS ON THE LINE CLOSE TO THE GENERATING STATION.
CALCULATE (a) BASE IMPEDANCE (b) RATED VOLTAGE DROP (c) TRANSIENT REACTANCE (d) INITIAL SHORT CIRCUIT CURRENT (e) STEADY STATE VALUE OF CURRENT AT SHORT CIRCUIT.

(a) BASE IMPEDANCE $= \frac{E_{BASE}^2}{S_{BASE}} = \frac{(25000)^2}{250 \times 10^6} = 2.5\ \Omega$

(b) RATED CURRENT $= \frac{S\text{-BASE}}{\sqrt{3}\, E_{BASE}} = \frac{250 \times 10^6}{1.7321 \times 25 \times 10^3}$
$= 5771$ Amp

$X_S = 1.6$ PU $= 1.6 \times 2.5 = 4\ \Omega$

RATED VOLTAGE DROP $= I_{RATED} \times X_S$
$= 5771 \times 4 = 23100$ V

(c) TRANSIENT REACTANCE $= X_d' = Z$ PU $= 0.23 \times 2.5\ \Omega$
$= 0.575\ \Omega$

(d) E_{BASE} / PH: $\frac{E\text{-BASE}}{\sqrt{3}} = \frac{25}{\sqrt{3}} = 14.4$ kV

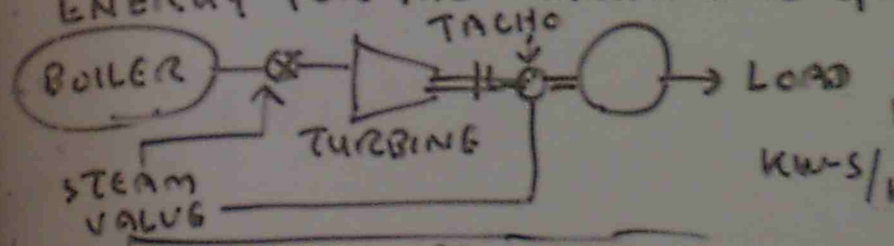
$E_f = \sqrt{(E\text{-BASE})^2 + (IX_S)^2} = \sqrt{14.4^2 + 23.1^2} = 27.2$ kV

INITIAL SHORT CIRCUIT CURRENT $= \frac{E_f}{X_d'} = \frac{27.2 \times 10^3}{0.575} = 47300$ A

(e) STEADY STATE SHORT CIRCUIT CURRENT $= \frac{E_f}{X_S} = \frac{27.2 \times 10^3}{4} = 6800$ A

GENERATOR CONTROL LOAD FLOW

Pb AN ISOLATED 75 MVA SYNCHRONOUS GENERATOR FEEDS IT'S OWN LOAD AND OPERATES INITIALLY AT 3000 RPM, 50 HZ. A 20 MW LOAD IS SUDDENLY APPLIED AND THE STEAM VALVE TO THE TURBINE COMMENCES TO OPEN AFTER 0.5 SEC TO THE TIME LAG IN THE GOVERNOR SYSTEM. CALCULATE THE FREQUENCY TO WHICH THE GENERATOR VOLTAGE DROPS BEFORE THE STEAM FLOW MEETS THE NEW LOAD. THE STORED ENERGY FOR THE MACHINE IS 4 KW-S/KVA



NO LOAD STORED ENERGY $= \text{KW-S/KVA} \times \text{MACHINE CAPACITY}$
$= 4 \times 75 \times 10^3 = 300 \times 10^3$

$$f = \sqrt{\frac{\text{NO LOAD STORED ENERGY} - \text{APPLIED LOAD ENERGY}}{\text{NO LOAD STORED ENERGY}}} \times \text{RATED FREQ}$$

APPLIED LOAD ENERGY $=$ POWER $\times$ TIME $= 20 \times 10^3 \times 0.5$
$= 10 \times 10^3$ KJ

$$f = \sqrt{\frac{300 \times 10^3 - 10 \times 10^3}{300 \times 10^3}} \times 50 = 49.2\ \text{HZ}$$

POWER GENERATION

$$\text{BASE IMPEDANCE} = \frac{(\text{BASE VOLTAGE})^2}{\text{BASE V.A}}$$

$$\text{RATED CURRENT} = \frac{\text{BASE V.A}}{\sqrt{3} \times \text{BASE VOLTAGE}}$$

Ph A 250 MVA, 25 kV, 3φ STEAM TURBINE GENERATOR HAS A SYNCHRONOUS REACTANCE OF 1.6 PU AND A TRANSIENT REACTANCE X_d' OF 0.23 PU. IT DELIVERS IT'S RATED OUTPUT AT A POWER FACTOR OF 100%. A SHORT CIRCUIT SUDDENLY OCCURS ON THE LINE CLOSE TO THE GENERATING STATION.
CALCULATE (a) BASE IMPEDANCE (b) RATED VOLTAGE DROP (c) TRANSIENT REACTANCE (d) INITIAL SHORT CIRCUIT CURRENT (e) STEADY STATE VALUE OF CURRENT AT SHORT CIRCUIT.

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$= 5771$ Amp

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RATED VOLTAGE DROP $= I_{RATED} \times X_S$
$= 5771 \times 4 = 23100$ V

(c) TRANSIENT REACTANCE $= X_d' \times Z_{PU} = 0.23 \times 2.5\ \Omega$
$= 0.575\ \Omega$

(d) $E_{BASE/PH} = \frac{E_{BASE}}{\sqrt{3}} = \frac{25}{\sqrt{3}} = 14.4$ kV

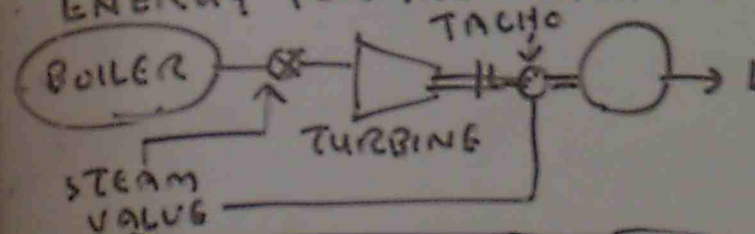
$E_f = \sqrt{(E_{BASE})^2 + (IX_S)^2} = \sqrt{14.4^2 + 23.1^2} = 27.2$ kV

INITIAL SHORT CIRCUIT CURRENT $= \frac{E_f}{X_d'} = \frac{27.2 \times 10^3}{0.575} = 47300$ A

(e) STEADY STATE SHORT CIRCUIT CURRENT $= \frac{E_f}{X_S} = \frac{27.2 \times 10^3}{4} = 6200$ A

GENERATOR CONTROL LOAD FLOW

Ph AN ISOLATED 75MVA SYNCHRONOUS GENERATOR FEEDS IT'S OWN LOAD AND OPERATES INITIALLY AT 3000 RPM, 50 HZ. A 20MW LOAD IS SUDDENLY APPLIED AND THE STEAM VALVE TO THE TURBINE COMMENCES TO OPEN AFTER 0.5 SEC TO THE TIME LAG IN THE GOVERNOR SYSTEM. CALCULATE THE FREQUENCY TO WHICH THE GENERATOR VOLTAGE DROPS BEFORE THE STEAM FLOW MEETS THE NEW LOAD. THE STORED ENERGY FOR THE MACHINE IS 4 KW-S/KVA



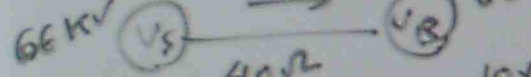
NO LOAD STORED ENERGY $= \text{KW-S/KVA} \times \text{MACHINE CAPACITY} = 4 \times 75 \times 10^3 = 300 \times 10^3$

$$f = \sqrt{\frac{\text{NO LOAD STORED ENERGY} - \text{APPLIED LOAD ENERGY}}{\text{NO LOAD STORED ENERGY}}} \times \text{RATED FREQ}$$

APPLIED LOAD ENERGY $= \text{POWER} \times \text{TIME} = 20 \times 10^3 \times 0.5$
$= 10 \times 10^3$ KJ

$$f = \sqrt{\frac{300 \times 10^3 - 10 \times 10^3}{300 \times 10^3}} \times 50 = 49.2\ \text{HZ}$$

pb/ TWO UNITS OF GENERATION MAINTAIN 66KV AND 60 KV LINE AT THE ENDS OF AN INTERCONNECTOR OF INDUCTIVE REACTANCE PER PHASE OF 40Ω AND WITH NEGLIGIBLE RESISTANCE AND SHORT CAPACITANCE. A LOAD OF 10 MW IS TO BE TRANSFERRED FROM THE 66KV UNIT TO THE OTHER END. CALCULATE THE NECESSARY CONDITION BETWEEN TWO ENDS INCLUDING PF OF CURRENT TRANSMITTED.



POWER TRANSFER/ph $= \frac{10\times10^6}{3} = 3.33\times10^6$ W

VOLTAGE DIFFERENCE DUE TO POWER TRANSFER $V_d = \frac{X\ \Delta P}{V_{R(ph)}} = \frac{40\times3.33\times10^6}{\frac{60\times10^3}{\sqrt{3}}} = 3840$

$\sin\delta = \frac{\Delta V_d}{V_S} = \frac{3840}{\frac{66000}{\sqrt{3}}} = 0.101$

$\delta = \sin^{-1}0.101 = 3.44^\circ$

REACTIVE POWER TRANSFER $= \frac{E_{S(ph)}\times E_{R(ph)}}{X}\delta$

$= \frac{\frac{66000}{\sqrt{3}}\times\frac{60,000}{\sqrt{3}}}{40}\cdot = 33\times10^6$ VAR

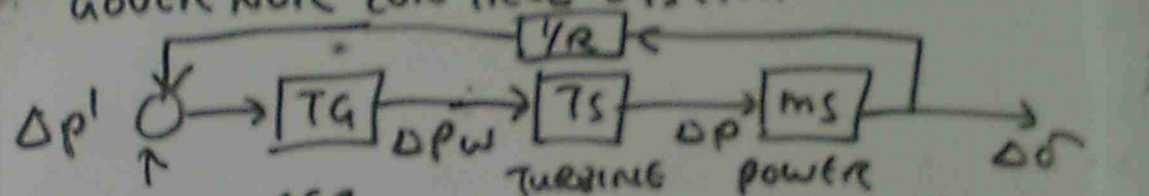
$\tan\phi = \frac{\Delta Q}{\Delta P} = \frac{33\times10^6}{3.33\times10^6} = 10.34$

$\phi = \tan^{-1}10.34 = 84.2^\circ$, PF $= \cos 84.2 = 0.1$

SYNCHRONIZING

(1) INCOMING MACHINE FREQUENCY = BUSBAR FREQ
(2) INCOMING MACHINE VOLTAGE = BUS BAR VOLTAGE
(3) INCOMING MACHINE PHASE SEQUENCE = BUSBAR PHASE SEQUENCE

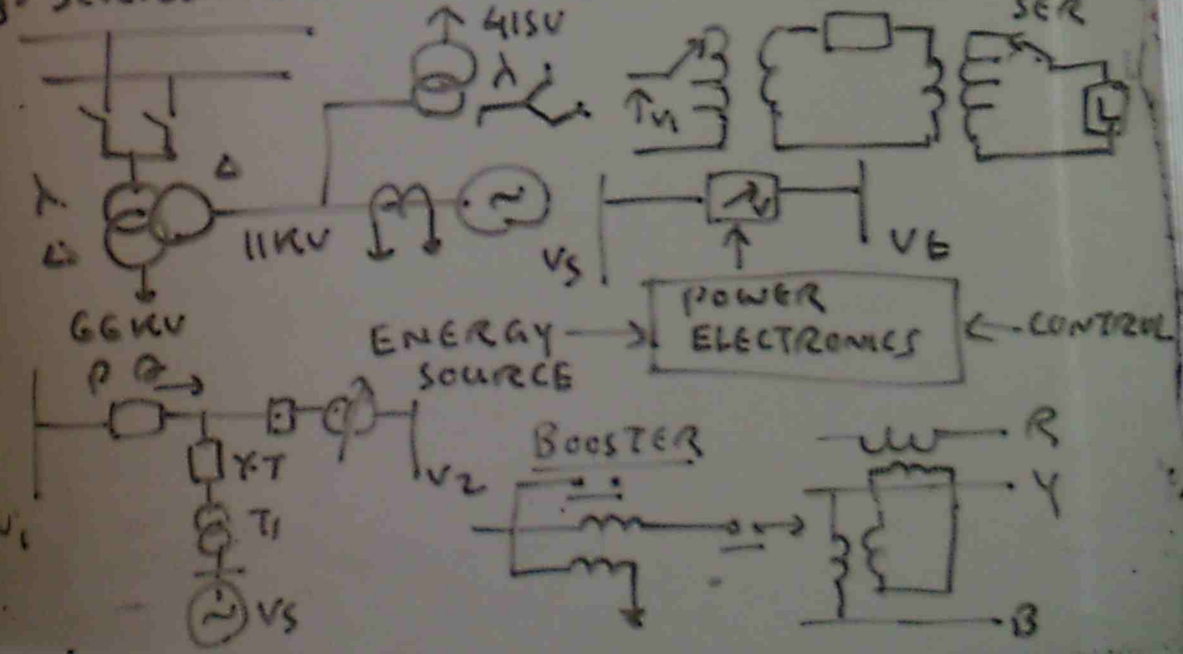
GOVERNOR CONTROL SYSTEM



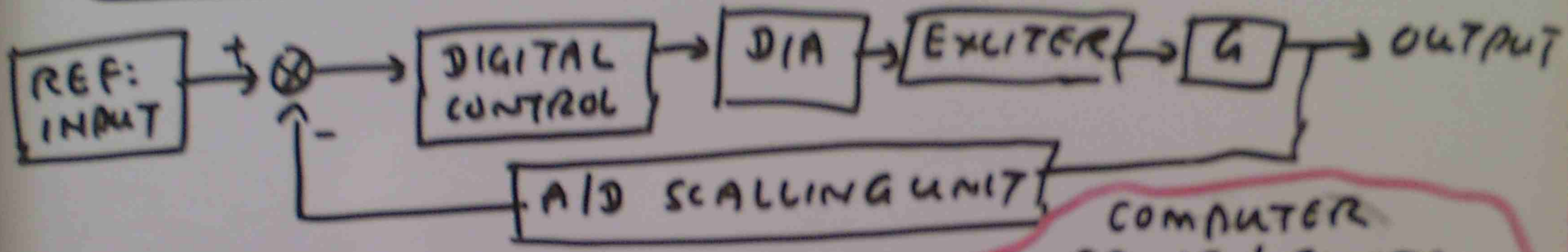
ΔP^1 - CHANGE IN SPEED CHANGER SETTING
TG - SPEED GOVERNING SYSTEM
ΔPW - STEAM POWER CHANGE
MS - GENERATOR INERTIA
$\Delta\delta$: CHANGE IN POWER ANGLE
R - GOVERNOR FUNCTION
TS - TURBINE
ΔP - CHANGE IN TURBINE MECH: POWER OUTPUT

METHOD OF VOLTAGE CONTROL

(1) INJECTION OF REACTIVE POWER
(2) SHUNT CAPACITOR / REACTOR
(3) SERIES CAPACITOR (4) SYNCHRONOUS CONDENSER

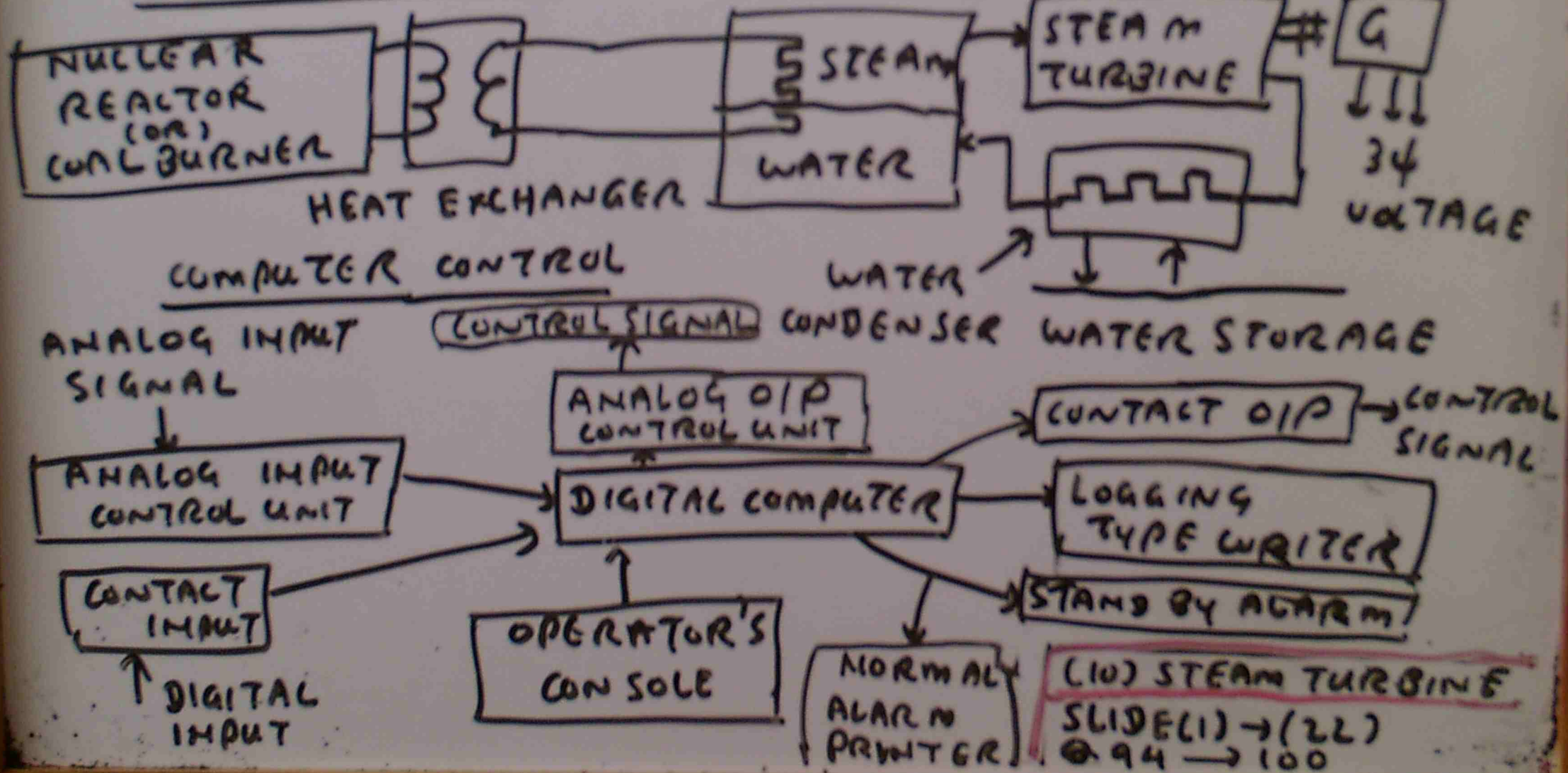


DIGITAL EXCITATION SYSTEM



STEAM TURBINE SYSTEM

COMPUTER TURBINE / SYSTEM COMPONENTS



POWER SYSTEM PROTECTION

THE PROTECTION OF ELECTRICAL POWER SYSTEM FROM THE FAULT THROUGH THE ISOLATION OF FAULTY PARTS FROM THE REST OF THE ELECTRICAL NETWORK. THE OBJECTIVE OF PROTECTION SCHEME IS TO KEEP THE POWER SYSTEM STABILITY BY ISOLATING ONLY THE COMPONENTS THAT ARE UNDER THE FAULT, WHILST LEAVING AS MUCH OF THE NETWORK AS POSSIBLE STILL IN OPERATION

COMPONENTS OF POWER SYSTEM PROTECTION SCHEME

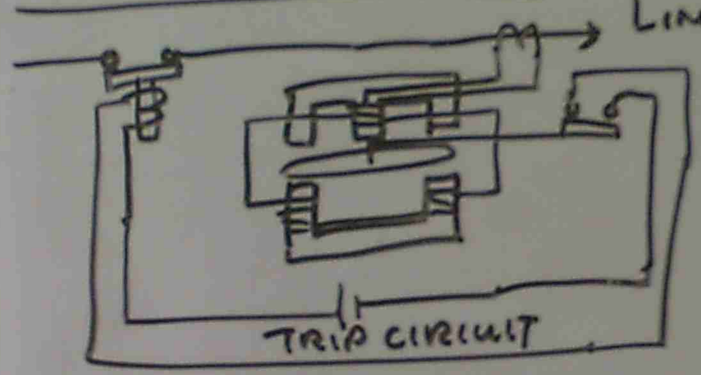
SMALL SYSTEM - FUSE, MEDIUM/LARGE SYSTEM - PROTECTIVE RELAY / CB

AUTOMATIC LINE SECTIONALIZER — SELF CONTAINED CIRCUIT, OPENING DEVICE, THAT AUTOMATICALLY OPENS THE MAIN CIRCUIT AFTER SENSING AND RESPONDING TO A PRE-DETERMINED NUMBER OF SUCCESSIVE MAIN CURRENT IMPULSES

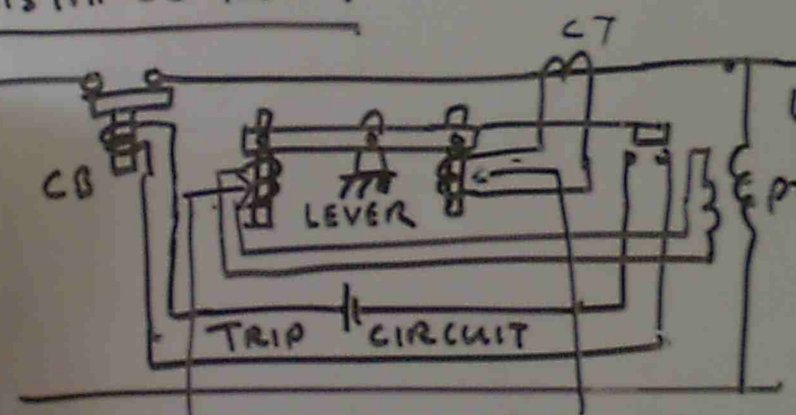
RECLOSER - OPEN AND RECLOSE FOR TEMPORARY FAULT

BIL - BASIC INSULATION LEVEL
A REFERENCE INSULATION LEVEL THAT MEASURES THE ABILITY OF THE INSULATION TO WITHSTAND THE VERY HIGH VOLTAGE SURGES

OVER CURRENT RELAY



DISTANCE RELAY

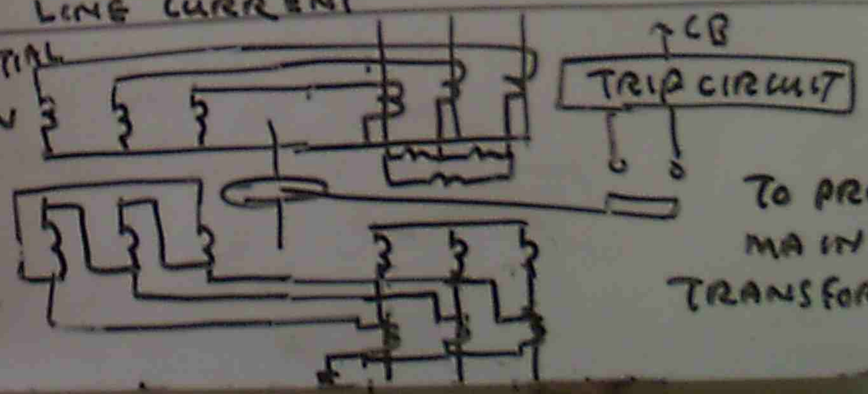


OPERATING FLUX ∝ LINE CURRENT
RESTRAINTING FLUX ∝ LINE VOLTAGE

FAULT LINE VOLTAGE IS LOW, LINE CURRENT IS HIGH

$$Z = \frac{\text{LINE VOLTAGE}}{\text{LINE CURRENT}}$$

DIFFERENTIAL PROTECTION



TO PROTECT MAIN TRANSFORMER

OVER CURRENT RELAY

GENERAL PROTECTION

DISTANCE RELAY

TO PROTECT THE LINE WITH THROUGH POWER FLOW - OUT

CT — CURRENT TRANSFORMER

PT — POTENTIAL TRANSFORMER

NORMAL
LINE VOLTAGE IS HIGH
LINE CURRENT IS LOW

TRANSMISSION LINE - 132KV, 230KV, 330KV
500KV

DISTRIBUTION LINE - 66KV, 33KV, 11KV, 415V

INSULATOR PIN INSULATOR - 415V
DISC INSULATOR (11KV, 33KV)

INSULATOR STRING - 132KV ⟶ 500KV
TRANSMISSION LEVEL VOLTAGES

POLE STRENGTH WIND FORCE, CONDUCTOR WEIGHT, TENSION IN CONDUCTOR

LINE DEVIATION

DISTRIBUTION TRANSFORMER

RATING BETWEEN 3 TO 500KVA
PRIMARY VOLTAGE 0.6KV OR GREATER

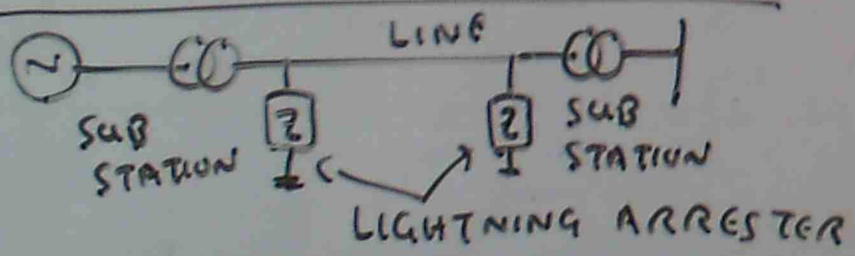
UNDERGROUND TRANSFORMER

INSTALLED IN CONCRETE MONO BLOCKS.

RATING

HT - 66KV, 132KV, 230KV, 330KV, 500KV
LT - 415V, 11KV, 33KV, 66KV

SURGE (OR) LIGHTNING ARRESTER



SUB STATION EQUIPMENTS

- REVENUE METER, P.F CONTROL, ELECTRONIC METERING

PROTECTIVE SWITCH GEAR

- AIR CIRCUIT BREAKER (ACB)
- AIR BLAST CIRCUIT BREAKER (ABCB)
- OIL CIRCUIT BREAKER (OCB)
- VACUUM CIRCUIT BREAKER
- SF6 CIRCUIT BREAKER

ARC INTERRUPTION

HIGH RESISTANCE METHOD

ARC RESISTANCE IS MADE TO INCREASE WITH TIME SO THAT THE CURRENT BECOMES INSUFFICIENT TO MAINTAIN ARC.

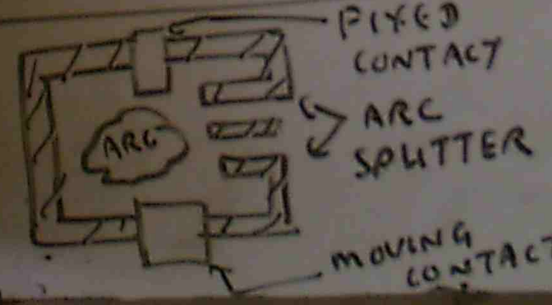
ARC RESISTANCE CAN BE INCREASED BY
(1) LENGTHENING ARC (2) COOLING THE ARC
(3) REDUCING THE C.S.A of ARC
(4) SPLITTING THE ARC

LOW RESISTANCE - USED FOR AC ONLY

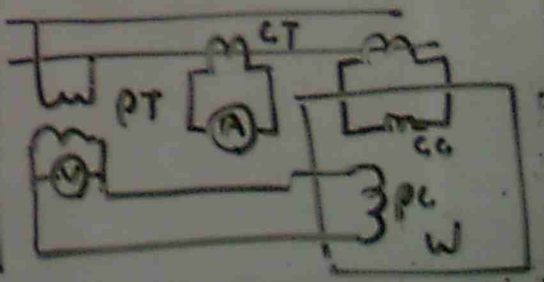
DE IONISATION

LENGTHENING THE GAP, HIGH PRESSURE, COOLING BLAST EFFECT.

OIL CIRCUIT BREAKER



INSTRUMENT TRANSFORMER



PROTECTION SYSTEM

- PILOT WIRE PROTECTION SYSTEM
- MICRO WAVE RELAYING
- WIDE AREA MONITORING & CONTROL SYSTEM

(11) POWER SYSTEM PROTECTION

SLIDE (1) → (17)

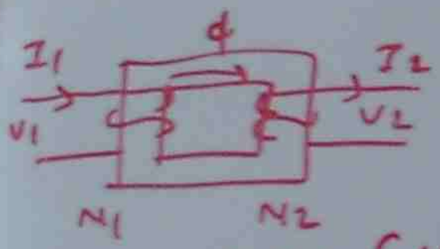
101 → 113

(1) POWER TRANSFORMER RATING

TRANSFORMER RATING

VOLTAGE RATING | CURRENT RATING | V.A RATING

$$\text{RATED CURRENT} = \frac{\text{V.A RATING}}{\text{VOLTAGE RATING}}$$



$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = a$$

TURN RATIO

N = NO. OF TURNS
ϕ = FLUX (Wb)
f = FREQUENCY

$E_{RMS} = 4.44\, f N \phi_{MAX}$ (VOLT)

$\phi = B \times A$

B = FLUX DENSITY (T)
A = C.S.A (m^2)

$$\%\ \text{VOLTAGE REGULATION} = \frac{V_{\text{NO LOAD}} - V_{\text{FULL LOAD}}}{V_{\text{FULL LOAD}}} \times 100$$



$N \times I = H \times l$

$N \times I = \sum H l$

l = LENGTH OF MAGNETIC CIRCUIT

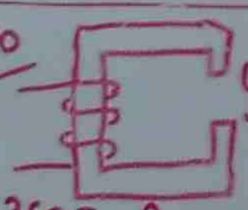
H = MAGNETIZING FORCE

$B = \mu \times H$ (μ = PERMEABILITY)

$\mu = \mu_0 \times \mu_r$

$\mu_0 = 4\pi \times 10^{-7}$

P10



N = 350 T $\hat{L}$ CORE LENGTH

B = 1.105 T 1250mm

CALCULATE CURRENT

μ_r STEEL = 1800

$NI = HL = H_{IRON} L_{IRON} + H_{AIR\ GAP} L_{AIR\ GAP}$

$$350 \times I = \frac{B}{\mu_0 \mu_r} L_{IRON} + \frac{B}{\mu_0} L_{AIR\ GAP}$$

$$350 \times I = \frac{1.105}{4\pi \times 10^{-7} \times 1800} \times \frac{1250}{1000} + \frac{1.105}{4\pi \times 10^{-7}} \times \frac{0.15}{1000}$$

$I = 2.1\ A$

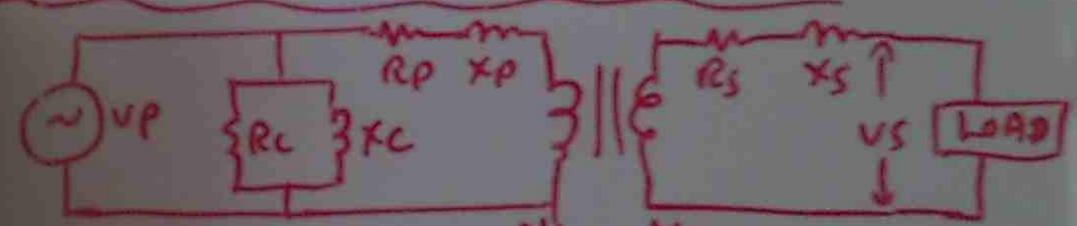
(2) LOSSES IN TRANSFORMER

TOTAL LOSSES

IRON LOSS | COPPER LOSS (PRIMARY, SECONDARY)

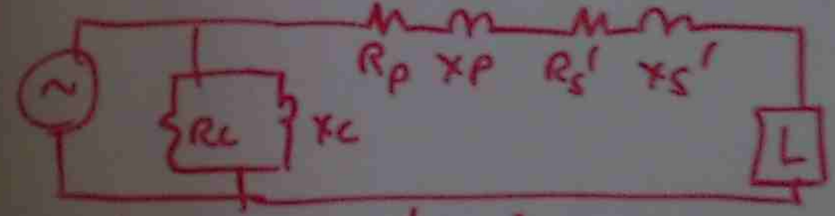
IRON LOSS: EDDY CURRENT LOSS | HYSTERESIS LOSS

TRANSFORMER EQUIVALENT CIRCUIT



$$\frac{R_P}{R_S} = \frac{X_P}{X_S} = a^2$$

$$a = \frac{N_1}{N_2}$$

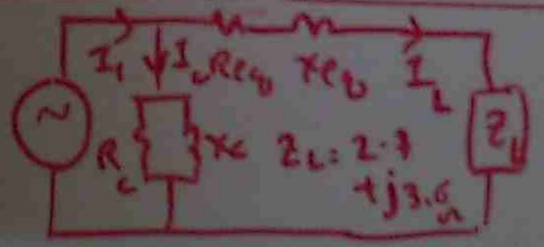


$R_S' = a^2 R_S$, $X_S' = a^2 X_S$

$R_e = R_P + R_S' = R_P + a^2 R_S$

$X_e = X_P + X_S' = X_P + a^2 X_S$

P9



$R_{eB} = 0.3\ \Omega$

$X_{eB} = 0.4\ \Omega$

$R_C = 200\ \Omega$

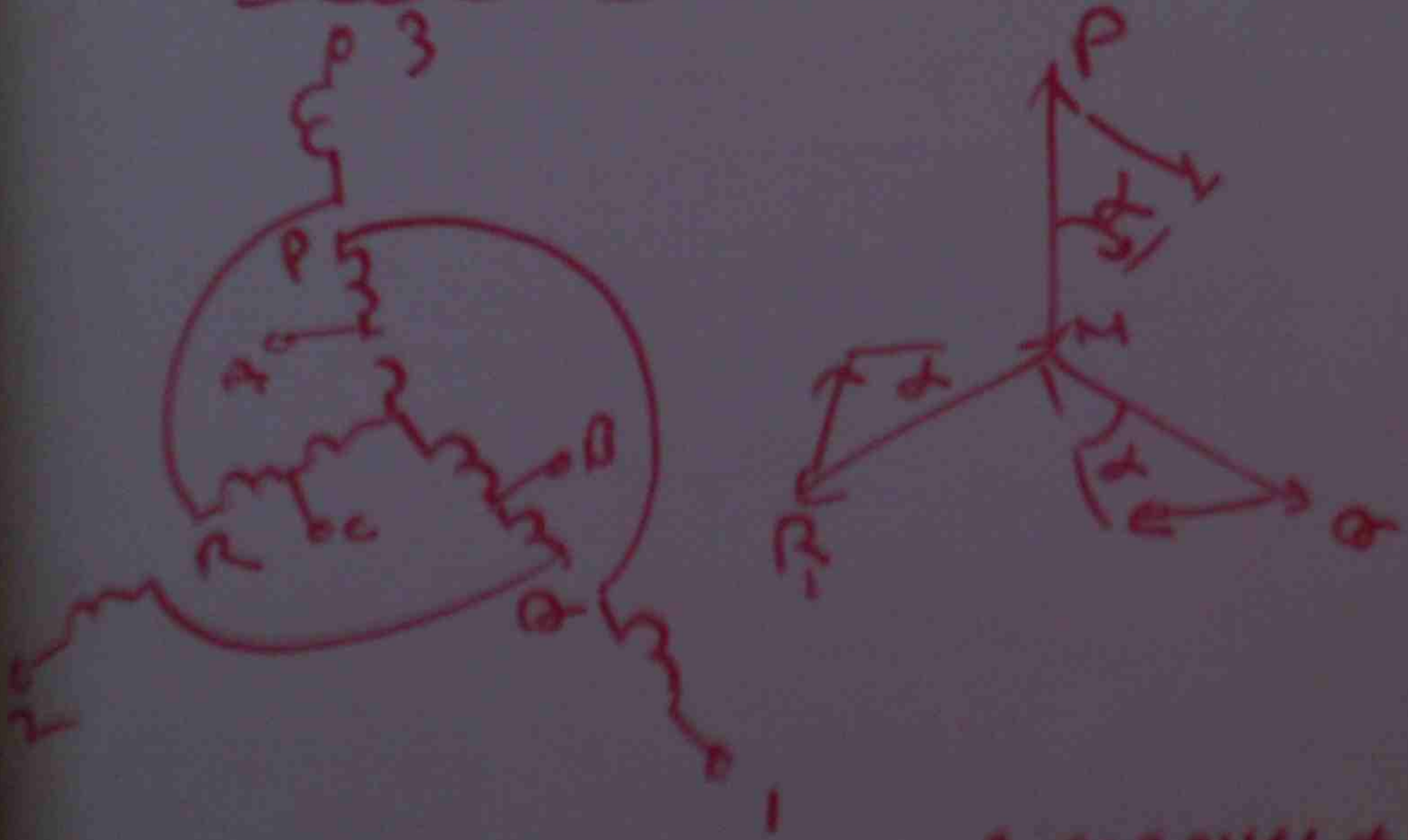
$X_C = 200\ \Omega$

$V = 200\ V$

FIND
I_L
I_C,
I
COPPER LOSS

IRON LOSS

PHASE TRANSFORMER



(12) WINDING SERIES & PARALLEL + PHASE SHIFT

SLIDE (1) ⟶ (15)

Q.86 ⟶ Q.91

pb $Z_T = R_{eq} + jX_{eq} + R_L + jX_L$

$= 0.3 + j0.4 + 2.7 + j3.6 = 3 + j4$

$= \sqrt{3^2+4^2} \angle \tan^{-1} 4/3 = 5 \angle 53.2\Omega$

$I_L = \frac{V}{Z_T} = \frac{200}{5\angle 53.2} = 40 \angle -53.2$ A

$I_C = \frac{V}{R_C} - j\frac{V}{X_C} = \frac{200}{200} - j\frac{200}{200} = 1 - j1$

$= \sqrt{1^2+1^2} \angle -\tan^{-1} 1/1 = 1.414 \angle -45$

$I_1 = I_L + I_C = 40(\cos 53.2 - j\sin 53.2) + 1 - j1$

$= 24 - j32 + 1 - j1 = 25 - j33$ A

$I_1 = \sqrt{25^2+33^2} \angle -\tan^{-1}\frac{33}{25} = 41.4 \angle -52.85$ A

COPPER LOSS $= I_1^2 R_{eq} = 40^2 \times 0.3 = 1600 \times 0.3 = 480$ W

IRON LOSS $= \frac{V^2}{R_C} = \frac{200^2}{200} = 200$ W

- INPUT POWER: $VI\cos\phi = 200 \times 41.4 \cos 52.85$

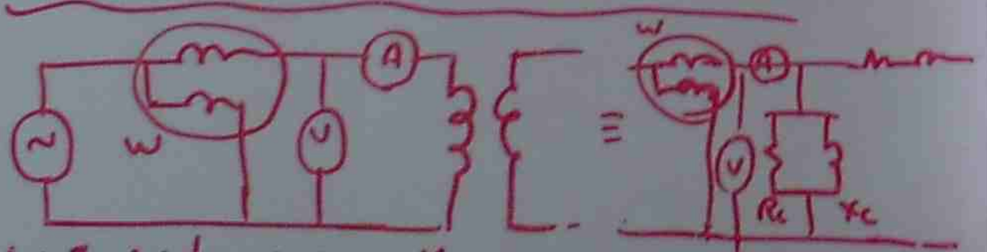
$= 5000$ W

OUTPUT = INPUT − LOSSES $= 5000 - (200+480) = 4320$ W

EFFICIENCY $= \frac{\text{OUTPUT}}{\text{INPUT}} \times 100 = \frac{4320}{5000} \times 100 = 86.4\%$

OPEN CIRCUIT + SHORT CIRCUIT TEST

OPEN CKT



$W = V \times I \cos\phi$, $\phi = \cos^{-1}\frac{W}{VI}$

$R_C = \frac{V}{I\cos\phi}$, $X_C = \frac{V}{I\sin\phi}$

SHORT CKT



$R_e = \frac{W}{I^2}$, $Z_e = \frac{V}{I}$, $X_e = \sqrt{Z_e^2 - X_e^2}$

pb 200/400V TRANSFORMER, $I_0 = 0.7$A, $P_0 = 60$W OPEN CKT TEST

SHORT CKT TEST − $V_{SC} = 9$V, $I_{SC} = 6$A, $P_{SC} = 26$W DETERMINE EQUIVALENT CKT

CCT − PROVIDE L.V, HV SIDE OPEN

$P_0 = \frac{V_0^2}{R_C} \rightarrow R_C' = \frac{V_0^2}{P_0} = \frac{200^2}{60} = 666.7\Omega$

$\cos\phi = \frac{P_0}{V_{OC} \times I_0} = \frac{60}{200 \times 0.7} = 0.478 \rightarrow \phi = \cos^{-1} 0.478 = 64.8$

$X_C' = \frac{V}{I\sin\phi} = \frac{200}{0.7\sin 64.8} = 317.8\Omega$

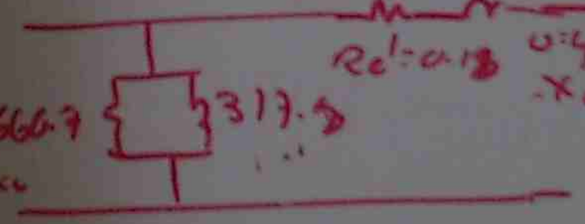
- SCT L.V SIDE SHORT: $(I_{SC}')^2 \times R_{eq}'' = 26 \rightarrow 6^2 \times R_{eq}'' = 26 \rightarrow R_{eq}'' = 0.72\Omega$

$Z_{eq}'' = \frac{V}{I_{SC}'} = \frac{9}{6} = 1.5\Omega \rightarrow X_{eq}'' = \sqrt{(Z_{eq}'')^2 - (R_{eq}'')^2}$

$X_{eq}'' = \sqrt{1.5^2 - 0.72^2} = 1.31\Omega$

$R_e' = a^2 R_e'' = (\frac{200}{400})^2 \times 0.72 = 0.18$

$X_e' = a^2 X_e'' = (\frac{200}{400})^2 \times 1.31 = 0.4$



EQUIVALENT CKT

TRANSFORMER REGULATION

$$\%\,\text{REGULATION} = \frac{I_p(R_{eq}\cos\theta \pm X_{eq}\sin\theta)}{V_p} \times 100$$

$$= \%R_{eq}\cos\theta \pm \%X_{eq}\sin\theta$$

{ + LAGGING, − LEADING

COPPER LOSS AT ANY LOAD = $(\text{LOAD RATIO})^2 \times$ FULL LOAD COPPER LOSS

$$\text{LOAD RATIO} = \frac{\text{ANY LOAD V.A}}{\text{FULL LOAD V.A}}$$

IRON LOSS - EVER CONSTANT

ANY OUT PUT LOAD = LOAD RATIO × RATED V.A × P.F

P1 KVA = 500, COPPER LOSS = 4 KW, IRON LOSS = 2.4 KW

FIND ½ LOAD EFFICIENCY AT 0.8 PF LAGGING

½ LOAD OUT PUT = L × V.A × PF = $\frac{1}{2} \times 500 \times 0.8 = 200$ KW

½ LOAD COPPER LOSS = $L^2 \times$ F/L Cu loss = $(\frac{1}{2})^2 \times 4 = 1$ KW

$$\text{EFFCY} = \frac{\text{O/P}}{\text{I/P}} \times 100 = \frac{200}{200 + 1 + 2.4} \times 100 = 98.1\%$$

(1) TRANSFORMER CONSTRUCTION	(2) POWER TRANSFORMER MAGNETISATION	(3) T.R EQUIVALENT CKT
SLIDE (1) → (12) | Q1 → Q14	SLIDE (1) → (24) | Q15 → Q24	SLIDE (1) → (16) Q25 → Q29

TRANSFORMER REGULATION

$$\%\,\text{REGULATION} = \frac{I_p(R_{eq}\cos\theta \pm X_{eq}\sin\theta)}{V_p} \times 100 \quad \begin{cases} + \text{ LAGGING} \\ - \text{ LEADING} \end{cases}$$

$$= \%R_{eq}\cos\theta \pm \%X_{eq}\sin\theta$$

COPPER LOSS AT ANY LOAD = $(\text{LOAD RATIO})^2 \times$ FULL LOAD COPPER LOSS

$$\text{LOAD RATIO} = \frac{\text{ANY LOAD V.A}}{\text{FULL LOAD V.A}}$$

IRON LOSS - EVER CONSTANT

ANY OUT PUT LOAD = LOAD RATIO $\times$ RATED V.A $\times$ P.F

Pr KVA = 500, COPPER LOSS = 4 KW, IRON LOSS = 2.4 KW
FIND 1/2 LOAD EFFICIENCY AT 0.8 PF LAGGING

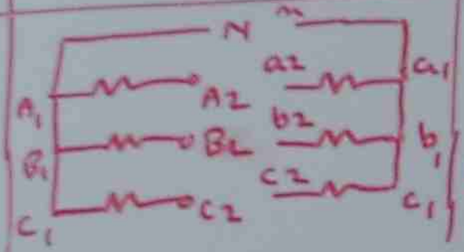
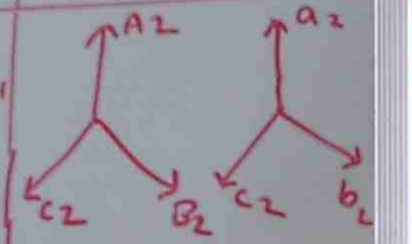
1/2 LOAD OUT PUT = L $\times$ V.A $\times$ PF = $\frac{1}{2} \times 500 \times 0.8 = 200$ KW

1/2 LOAD COPPER LOSS = $L^2 \times$ F/L Cu loss = $(\frac{1}{2})^2 \times 4 = 1$ KW

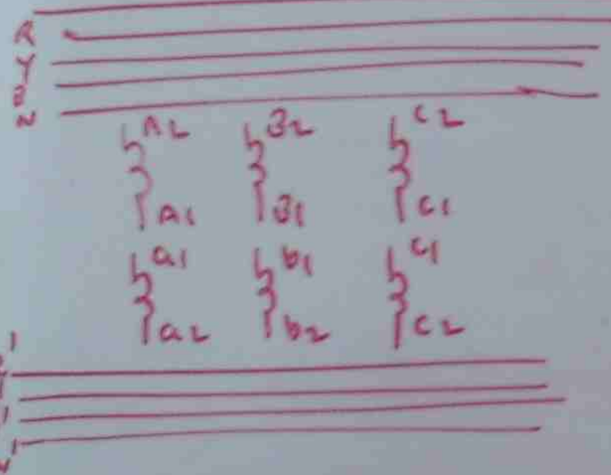
$$\text{EFFCY} = \frac{\text{O/P}}{\text{I/P}} \times 100 = \frac{200}{200+1+2.4} \times 100 = 98.1\%$$

(1) TRANSFORMER CONSTRUCTION	(2) POWER TRANSFORMER MAGNETISATION	(3) T.R EQUIVALENT CKT
SLIDE (1) → (12) | Q1 → Q14	SLIDE (1) → (24) | Q15 → Q24	SLIDE (1) → (16) Q25 → Q29

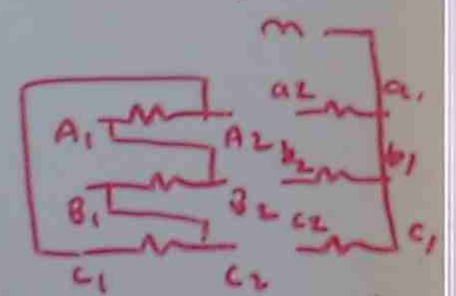
POWER TRANSFORMER CONNECTION

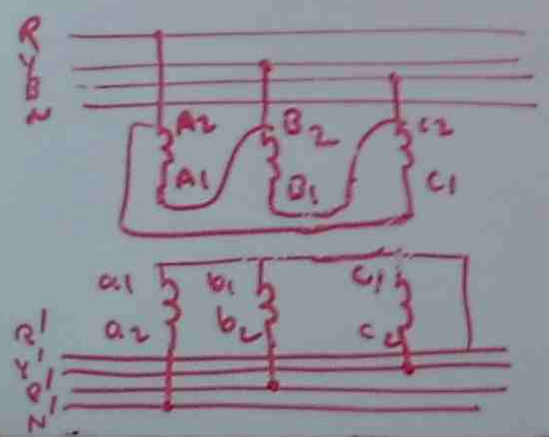
GROUP NO. SYMBOL	CONNECTION	E.M.F VECTOR
PHASE ∡ 1 1 Yy0 0		

CONNECT DY11 CONNECTION



DY11





GROUP		CONNECTION	∡
G1	1	Yy_0 Dd_0 Dz_0	0°
G2	2	Yy_6 Dd_6 Dz_6	180
G3	3	Dy_1 Yd_1 Yz_1	−30°
G4	4	Dy_{11} Yd_{11} Yz_{11}	+30°

STUDY TRANSFORMER CONNECTION CHART

Yy_0 – Yy_6	SMALL H.V TRANSFORMER / 3φ CORE TYPE
Dd_0, Dd_6 –	LARGE L.V TRANSFORMER
Dy, Yd –	POWER SUPPLY TRANSFORMER
Yz, Zy	EARTHING TRANSFORMER 3rd HARMONIC REDUCTION

3φ TRANSFORMER EQUIVALENT CIRCUIT

Pb 10MVA, YY 33KV/11KV

NO LOAD TEST

LINE VOLTAGE = 11KV
LINE CURRENT = 15A
POWER = 75 KW

SHORT CIRCUIT TEST

LINE VOLTAGE = 1650V L-L
LINE CURRENT = I_{RATED}
POWER = 90KW

NO LOAD TEST

$E_0 = \frac{11000}{\sqrt{3}} = 6350V$ $\quad P_0 = \frac{75000}{3} = 25000$

$R_0 = \frac{V_0^2}{P_0} = \frac{(6350)^2}{25000} = 1613\Omega$, $\quad I_{R0} = \frac{V_0}{R_0} = \frac{6350}{1613} = 3.94$ Amp

$I_{X0} = \sqrt{I_0^2 - I_{R0}^2} = \sqrt{15^2 - 3.94^2} = 14.47$ Amp

$X_0 = \frac{V_0}{I_{X0}} = \frac{6350}{14.47} = 438.8\Omega$ | $R_0' = 1613\left(\frac{33}{11}\right)^2 = 14.5K\Omega$, $X_0' = 438.8\left(\frac{33}{11}\right)^2 = 3.95K\Omega$

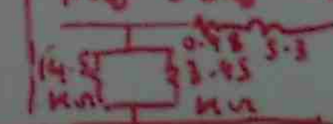
SHORT CIRCUIT TEST

$E_{sc} = \frac{1650}{\sqrt{3}} = 953V$, $\quad P_{sc} = \frac{90\times10^3}{3} = 30{,}000W$

$I_{RATED} = \frac{10\times10^6}{\sqrt{3}\times33\times10^3} = 175$ A

$R_{eq_0} = \frac{P_{sc}}{I_{eq_0}^2} = \frac{30{,}000}{(175)^2} = 0.98\Omega$

$Z_{eq_0} = \frac{E_{sc}}{I_{sc}} = \frac{953}{175} = 5.4\Omega$ | $X_{eq_0} = \sqrt{Z_{eq_0}^2 - R_{eq_0}^2} = \sqrt{5.4^2 - 0.98^2} = 5.3\Omega$



MAXIMUM EFFICIENCY OF POWER TRANSFORMER

AT MAXIMUM EFFICIENCY →
IRON LOSS = COPPER LOSS

IRON LOSS = L^2 × FULL LOAD COPPER LOSS | L = LOAD RATIO

$\therefore L = \sqrt{\frac{\text{IRON LOSS}}{\text{FULL LOAD COPPER LOSS}}}$

Ph 500 KVA, 6600/440 IRON LOSS = 2.4KW
COPPER LOSS = 4KW

FIND THE LOAD AT MAXIMUM EFFICIENCY
0.8 P.F LAGGING

$L = \sqrt{\frac{\text{IRON LOSS}}{\text{COPPER LOSS}}} = \sqrt{\frac{2.4}{4}} = 0.851$

O/P AT MAX. EFFICIENCY = L × KVA × PF
= 0.851 × 500 × 0.8 = 425.5 KW

COPPER LOSS AT MAXIMUM EFFICIENCY = L^2 × FULL LOAD COPPER LOSS
= $(0.851)^2$ × 4 = 2.4 KW

$\%\eta = \frac{\text{O/P}}{\text{O/P} + \text{COPPER LOSS} + \text{IRON LOSS}} \times 100 = \frac{425.5}{425.5 + 2.4 + 2.4} \times 100$
= 98.38%

ALL DAY EFFICIENCY

ALL DAY EFFICIENCY = $\frac{\text{ENERGY OUTPUT FOR 24HR}}{\text{ENERGY INPUT FOR 24HR}} \times 100$

ENERGY OUTPUT IN KWH = POWER OUTPUT (KW) × TIME (HR)

ENERGY INPUT IN KWH = POWER INPUT (KW) × TIME (HR)

Ph 100 KVA, IRON LOSS = 500W, FULL LOAD COPPER LOSS = 750W
8 HR – 80KW – 0.8 PF LAG
6 HR – 50KVA – 0.9 PF LAG
4 HR – 25KVA – 20 KW
3 HR – ENERGIZED NO LOAD
3 HR – DE-ENERGIZED

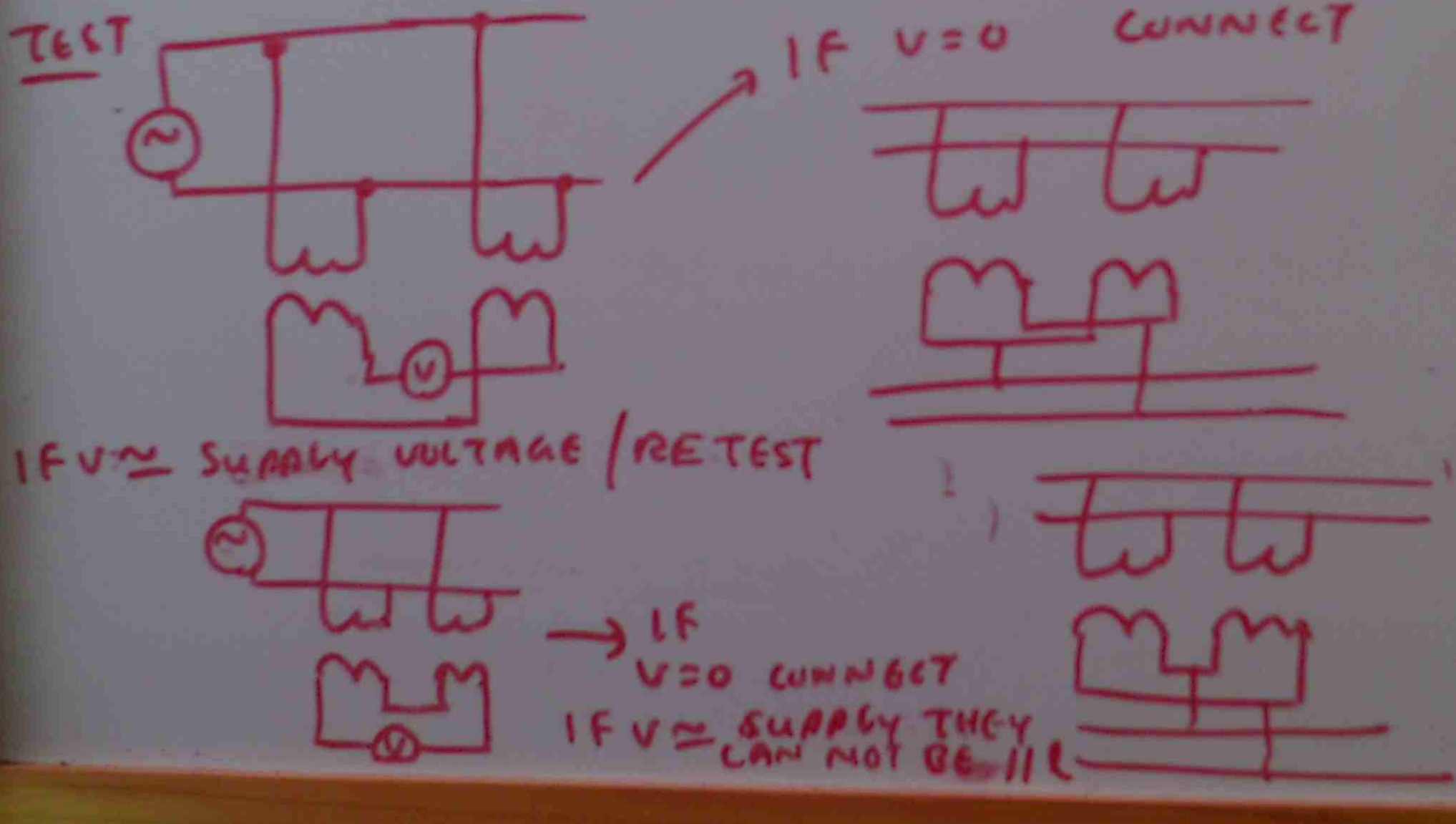
FIND ALL DAY EFFICIENCY

TIME	CONDITION	OUTPUT KWH	IRON LOSS	COPPER LOSS	INPUT
8 HR	80KW, 0.8PF LOAD VA = $\frac{80}{0.8}$ = 100 $L = \frac{VA}{VA\ FL} = \frac{100}{100}$ = 1	80×8 = 640 KWH	$\frac{500}{1000}$ ×8 4KWH	F/L $\frac{750}{1000}$ × 8 = 6	640+4 +6 =650
6 HR	50KVA, 0.9 $L = \frac{VA}{VA\ FL} = \frac{50}{100} = \frac{1}{2}$	50×0.9×6 270 KWH	$\frac{500}{1000}$ ×6 3KWH	1/2 LOAD $(\frac{1}{2})^2 \times \frac{750}{1000}$ ×6 = 1.125	270+3 +1.125 = 274.125
4 HR	25KVA, 20KW $L = \frac{25}{100} = \frac{1}{4}$	20×4 = 80 KWH	$\frac{500}{1000}$ ×4 2KWH	1/4 LOAD $(\frac{1}{4})^2 \times \frac{750}{1000}$ ×4 = 0.1875	80+2+ 0.1875 = 82.1875
3 HR	NO LOAD	0	$\frac{500}{1000}$ ×3 = 1.5	0	1.5
3 HR	DE-ENERGIZE	0	0	0	0
$\eta = \frac{940}{1007} \times 100 = 93.3\%$		OUTPUT 940		INPUT	1007

//l – PARALLEL OPERATION OF 1ϕ TRANSFORMER

CONDITION FOR PARALLEL OPERATION

(i) SAME VOLTAGE RATIO
(ii) SAME % IMPEDANCE
(iii) TERMINALS OF LIKE POLARITY MUST BE CONNECTED TOGETHER



(3) TRANSFORMER EQUIVALENT CIRCUIT

SLIDE 1 → 16

Q 25 → Q 29

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(4) POLARITY TESTING

SLIDE 3 → 23

Q 30 → Q 36

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(5) TRANSFORMER LOSSES + VOLTAGE REGULATION

SLIDE 1 → 11

Q 37 → Q 44

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(7) THREE PHASE TRANSFORMER CONNECTION

SLIDE 7 → 17

Q 51 → Q 53

TRANSFORMER PARALLEL OPERATION + LOAD SHARING

$KVA_1 = KVA_T \times \frac{Z_1}{Z_1+Z_2}$, $KVA_2 = KVA_T \times \frac{Z_2}{Z_1+Z_2}$

$Z_{NEW} = Z_{OLD} \times \frac{KVA-BASE}{KVA-OLD}$

Q1) A 2700 KVA PF 0.9 LAGGING IS SUPPLIED BY TWO TRANSFORMERS IN PARALLEL.

$TR(A) = 2000\ KVA$, $Z_A = 3+j2\ \Omega$

$TR(B) = 1000\ KVA$ $Z_B = 3+j5\ \Omega$

FIND LOAD ON EACH TRANSFORMER

2000 KVA ⇒ BASE

$Z_A = 3+j2\ \Omega$

$Z_{B(NEW)} = Z_{B(OLD)} \times \frac{KVA\ BASE}{KVA\ OLD}$

$= 3+j5 \times \frac{2000}{1000} = 6+j10$

$KVA_T = \frac{KW}{PF} = \frac{2700}{0.9} = 3000$

$KVA_{(A)} = KVA_{(T)} \times \frac{Z_1}{Z_1+Z_2} = 3000 \times \frac{3+j2}{3+j2+6+j10}$

$= \frac{3000 \times \sqrt{3^2+2^2}}{\sqrt{9^2+12^2}} = \frac{3000\sqrt{13}}{\sqrt{225}} = 721$ KVA

$KVA_{B} = KVA_{(T)} \times \frac{Z_2}{Z_1+Z_2} = \frac{3000 \times (6+j10)}{3+j2+6+j10}$

$= \frac{3000\ (\sqrt{6^2+10^2}}{\sqrt{9^2+12^2}} = \frac{3000 \times 11.66}{15} = 2332$ KVA

TRANSFORMER (A) CAN TAKE LOAD SHARE. TRANSFOR (B) WILL BE OVERLOADED TO TAKE IT'S LOAD SHARE

(6) PARALLEL OPERATION

SLIDE (1) → (9), Q 45 → Q 50

(9) HARMONIC IN TRANSFORMER ALL DAY EFFICIENCY

SLIDE 31 → 33, Q 63

(10) UNBALANCED LOAD + PARALLEL + COOLING + TAP CHANGING + EFFICIENCY

SLIDE 5 → 16

Q 67 → Q 72

(13) POLARITY

SLIDE 1 → 14

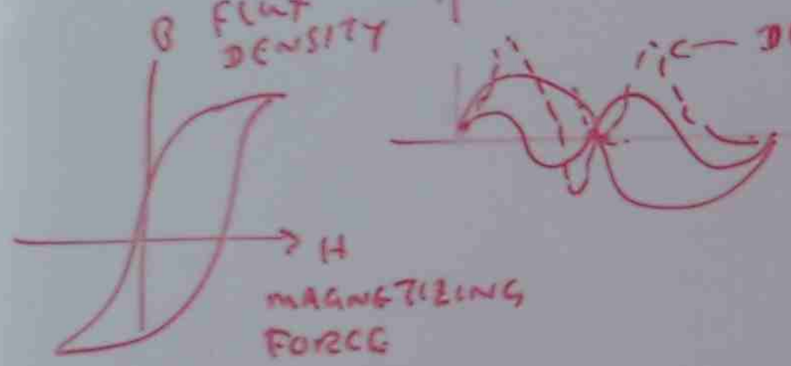
Q 92

HARMONICS IN TRANSFORMERS

FUNDAMENTAL - E_{MAX} — $E = E_{MAX} \sin \omega t$

+

2nd HARMONIC — $E = E_{MAX} \sin 2\omega t$



HARMONIC CAUSES DISTORTION OF WAVEFORMS.

DISTORTION CAUSES CORE LOSS

↑ CORE LOSS ∝ FREQUENCY ↑

PHASE RELATIONSHIP

3rd, 9th HARMONIC → IN PHASE WITH EACH OTHER

5th, 7th, 11th, 13th HARMONIC → DISPLACED BY 120°

HARMONIC EFFECT DEPENDS ON
- WHETHER PHASES ARE MAGNETICALLY SEPARATED (OR) LINKED
- WHETHER PHASES ARE ELECTRICALLY SEPARATED OR LINK

HARMONIC CAN FLOW IN Δ, NOT IN λ

Y/Δ | Δ/Y - HARMONIC FLOWS IN Δ

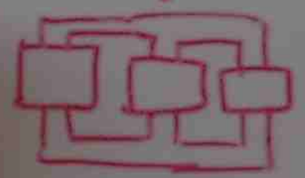
Y Y WITH NEUTRAL - NEUTRAL CARRIES HARMONIC

Y Y WITHOUT NEUTRAL - NO WAY OUT FOR HARMONIC

- DISTORTED FLUX & WAVE FORM

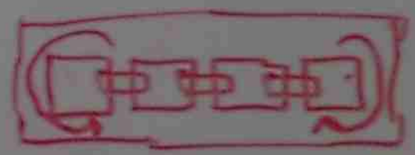
TO CARRY HARMONIC CURRENT, Y Y WITH NO NEUTRAL, TERTIARY WINDING IS PROVIDED

3 LIMB



NO HARMONIC PATH

5 LIMB



HARMONIC RETURN PATH

EFFECT OF HARMONIC ON TRANSFORMER

- I^2R LOSS, INCREASED CORE LOSS, MAGNETIC INTERFERENCE TO COMMUNICATION CIRCUITS

SOURCE OF HARMONIC

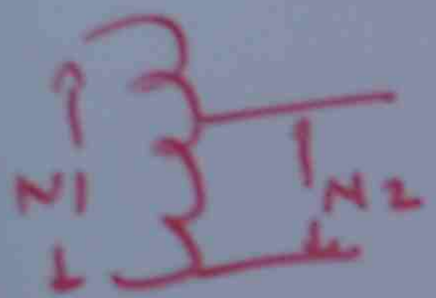
ELECTRONIC SWITCHING DEVICES, MAGNETIC WINDING GASEOUS DISCHARGE LAMPS

(a) HARMONIC IN TRANSFORMER + ALL DAY EFFICIENCY

SLIDE 13 ⟶ 25

Ø 57 → Ø 61

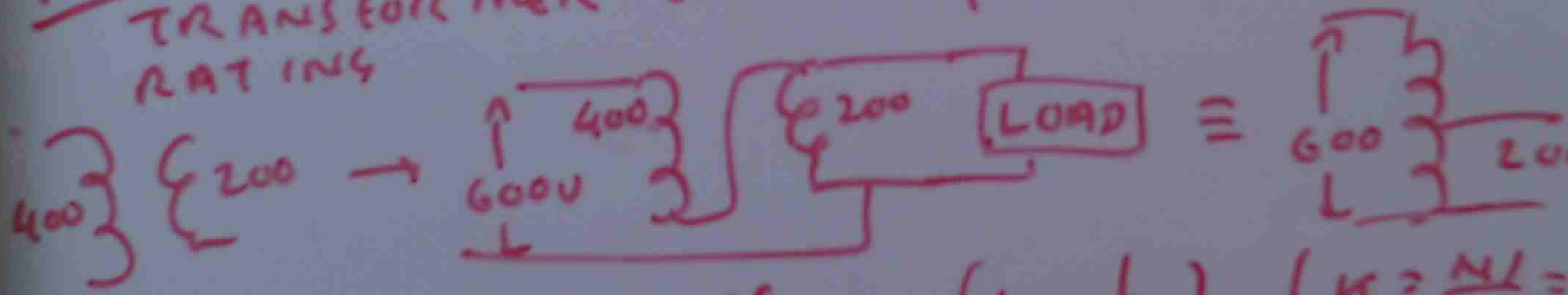
TRANSFORMER PROBLEM + AUTO TRANSFORMER



VA of AUTO TR (STEP DOWN) = VA of 2W3G TR $\times \left(1 - \frac{1}{K}\right)$, $K = \frac{N1}{N2}$

VA of AUTO TR (STEP UP) = VA of 2W3G TR $\left(1 - K\right)$, $K = \frac{N1}{N2}$

Pb SKETCH THE CONNECTION FOR 400/200V 50 VA TRANSFORMER TO SUPPLY 600/200V & FIND RATING



RATING = RATING OF 2W3G TR $\times \left(1 - \frac{1}{K}\right)$ $\left(K = \frac{N1}{N2} = \frac{V1}{V2} = \frac{600}{200} = 3\right)$

$= 50\left(1 - \frac{1}{3}\right) = 50 \times \frac{2}{3} \approx 33.3$ VA

---

(8) TRANSFORMER PROBLEMS + AUTO TRANSFORMER

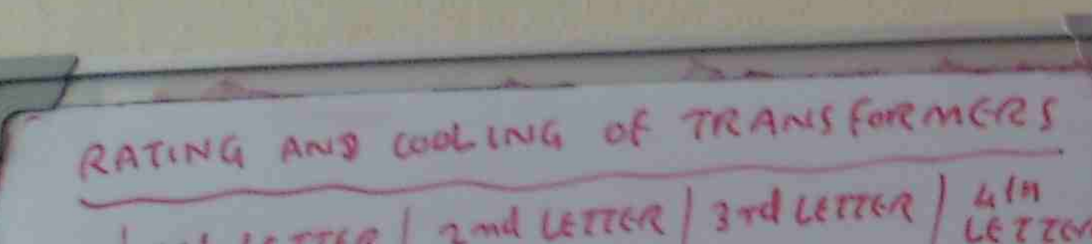
SLIDE 1 ⟶ 8 / 054

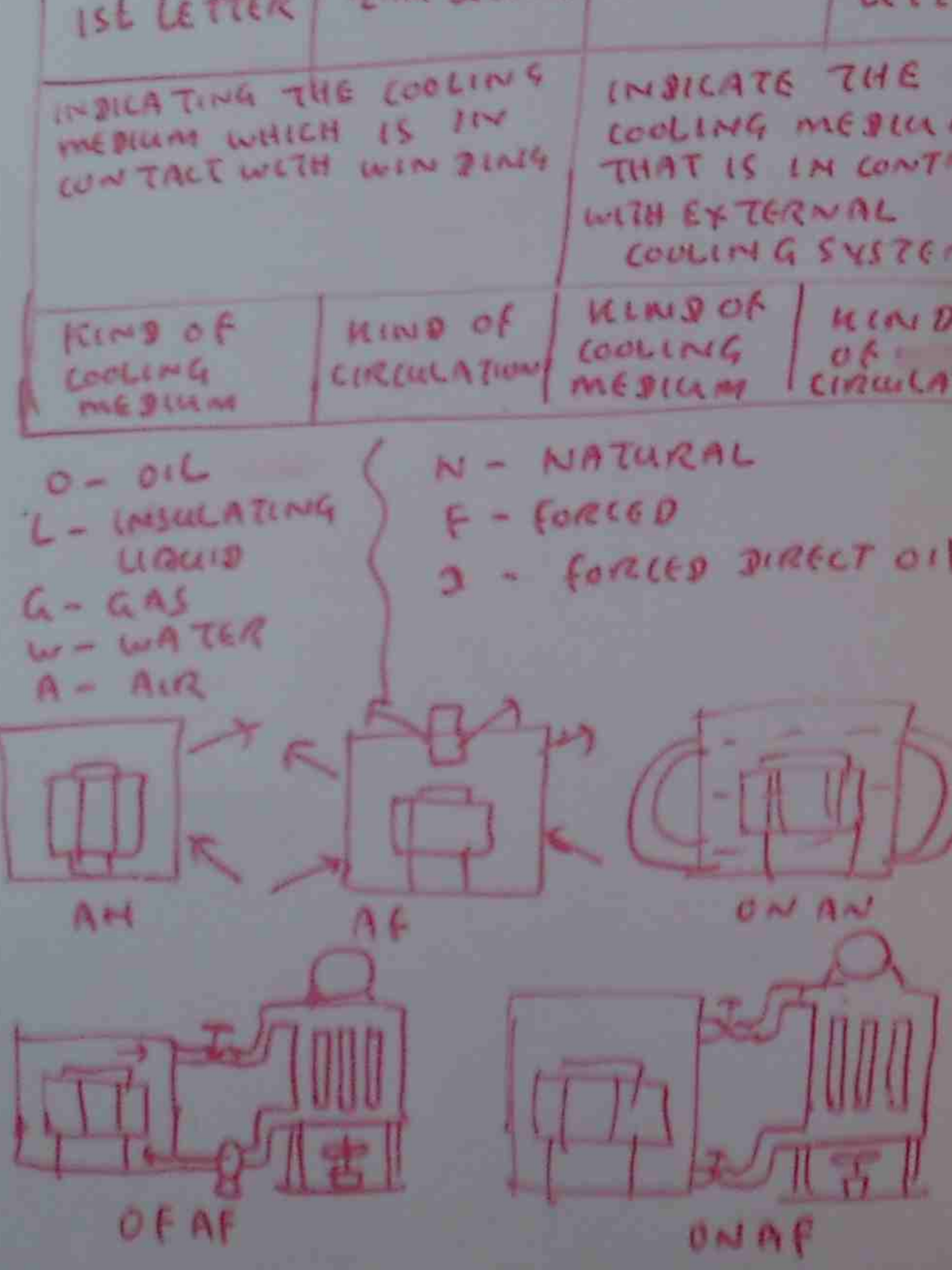
RATING AND COOLING OF TRANSFORMERS

1st LETTER	2nd LETTER	3rd LETTER	4th LETTER
INDICATING THE COOLING MEDIUM WHICH IS IN CONTACT WITH WINDING		INDICATE THE COOLING MEDIUM, THAT IS IN CONTACT WITH EXTERNAL COOLING SYSTEM	
KIND OF COOLING MEDIUM	KIND OF CIRCULATION	KIND OF COOLING MEDIUM	KIND OF CIRCULATION

O - OIL
L - INSULATING LIQUID
G - GAS
W - WATER
A - AIR

N - NATURAL
F - FORCED
D - FORCED DIRECT OIL





TRANSFORMER COOLING OIL TEST

- ELECTRIC STRENGTH
- WATER CONTENT
- LOSS TANGENT
- RESISTIVITY

- ACIDITY
- SLUDGE
- FLASH POINT

OIL CONSERVATOR / SEALED SYSTEM

TRANSFORMER PROTECTION

GAS OPERATED BUCHHOLZ RELAY

(1) RATING + CONSERVATOR SYSTEM

SLIDE (1) ⟶ (12)

@73 ⟶ @82

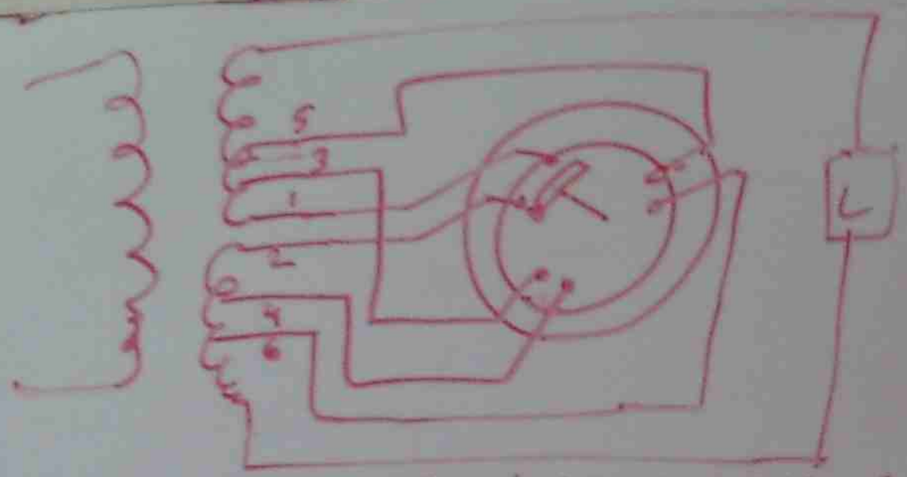
TAP CHANGING & VOLTAGE REGULATION

TAP CHANGING IS EFFECTED AT DIFFERENT STAGES OF ELECTRICITY DISTRIBUTION SYSTEM AS UNDER

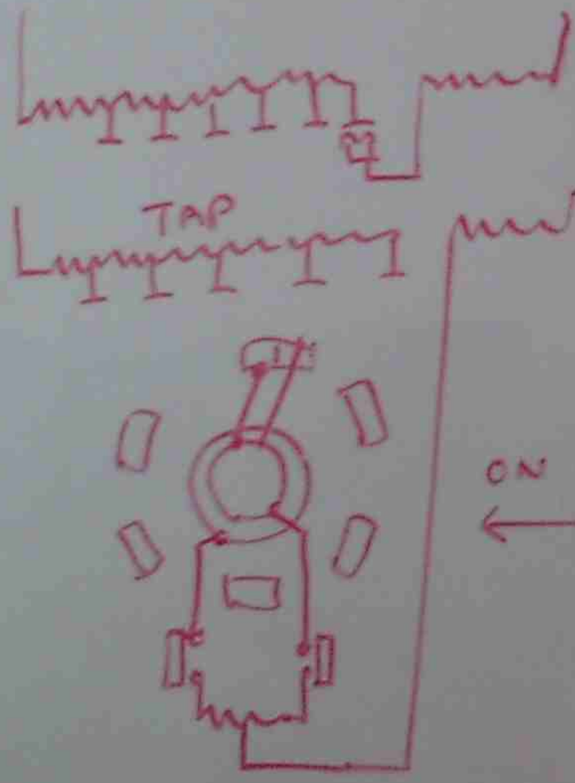
(a) AT THE POWER STATION, TO CONTROL THE VOLTAGE, TO STEP UP TRANSFORMER

(b) AT THE SUPPLY POINT, TO CONTROL THE VOLTAGE TO SMALLER SUBSTATIONS, STEP DOWN TRANSFORMERS ARE USED IN CASE



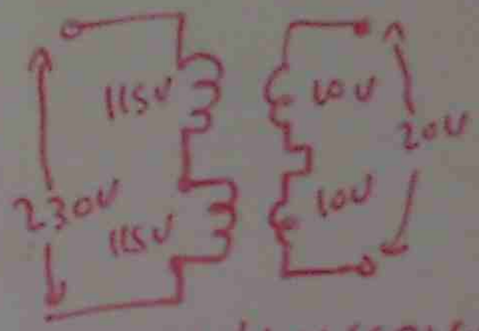


OFF LOAD TAP CHANGER

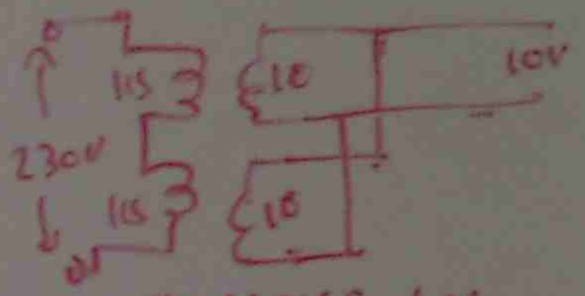


ON LOAD TAP CHANGER

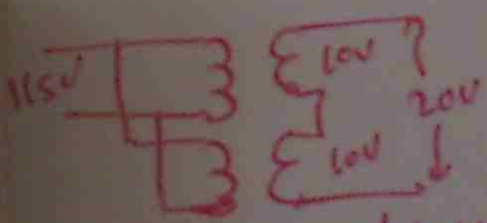
CONNECTING TRANSFORMER WINDINGS IN SERIES AND PARALLEL



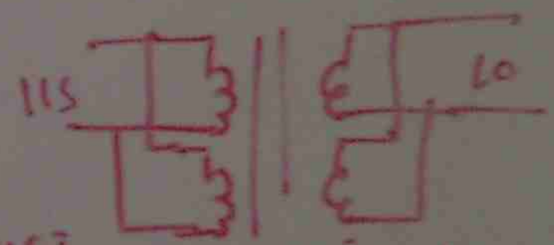
HV SERIES/ L.V SERIES



HV SERIES, LV PARALLEL



HV PARALLEL/ L.V SERIES



HV PARALLEL L.V PARALLEL

Ex AN ELECTRICAL PLANT DRAW 100 AMPAT 0.7 PF LAGGING. 2300/230V 60 KVA ΔD TRANSFORMER

CALCULATE (a) KW, KVA (b) RATED SECONDARY PHASE & LINE CURRENTS

(a) $P_T = \sqrt{3} V I \cos\theta = \frac{1.7321 \times 230 \times 100 \times 0.7}{1000} = 27.4$ KW

KVA $= \frac{KW}{PF} = \frac{27.4}{0.7} = 39.8$ KVA

(b) SECONDARY $I_L = 100A$

$I_{PH} = \frac{100}{\sqrt{3}} = 57.7A$

$\frac{I_{2PH}}{I_{1PH}} = \frac{V_{1PH}}{V_{2PH}} \frac{\frac{2300}{\sqrt{3}}}{230}$

$\frac{57.7}{I_{1PH}} = \frac{10}{\sqrt{3}} \rightarrow I_{1PH} = 10$ ON LINE A

TRANSMISSION LINE

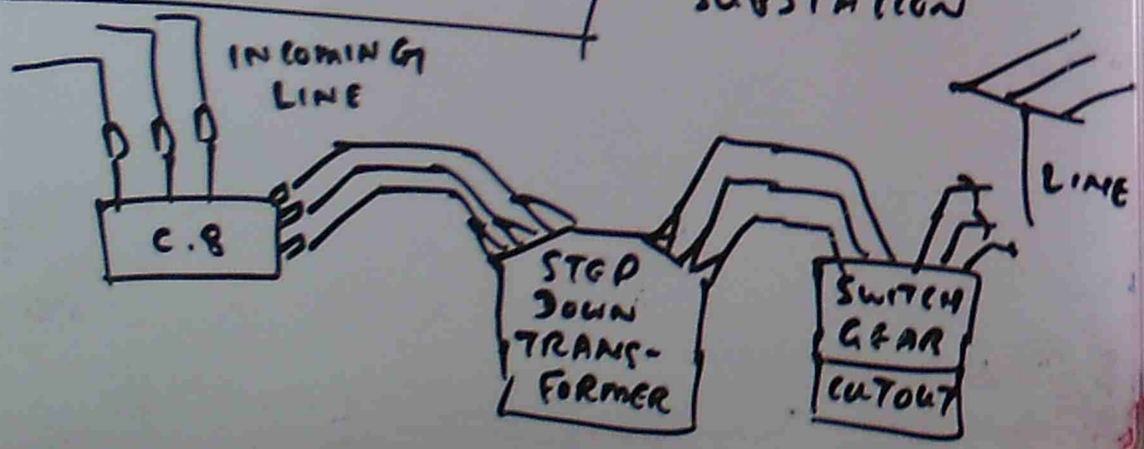
GENERATOR
11KV
HIGH VOLTAGE TRANSMISSION
132KV
SUBSTATION
33KV
33KV
SUBSTATION
11KV, 6.6KV 3.3KV
HIGH VOLTAGE MAIN
415V
240/415V

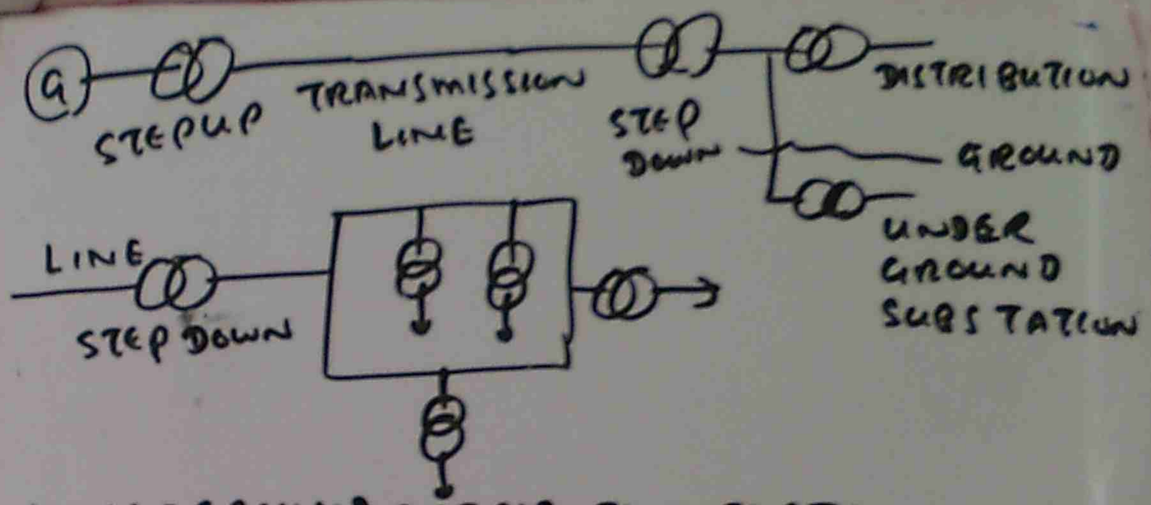
DISTRIBUTION SYSTEM

RADIAL
RING MAIN

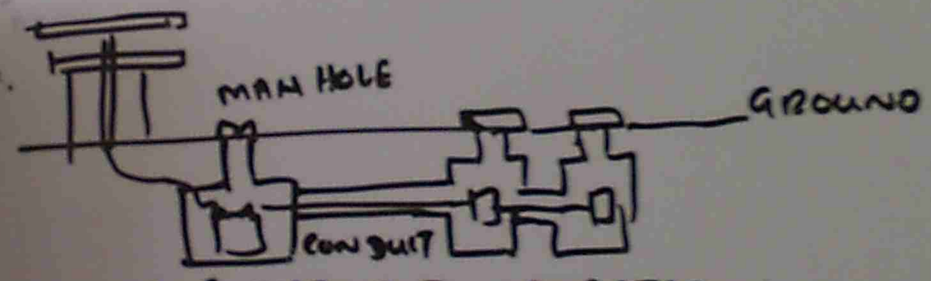
SUBSTATION

STEP UP/DOWN PROTECTION
ENERGY MEASUREMENT
- STEPUP SUBSTATION
- STEP DOWN SUBSTATION
- DISTRIBUTION
- U.G DISTRIBUTION SUBSTATION





UNDERGROUND DISTRIBUTION SYSTEM



U.G DISTRIBUTION SUBSTATION

COMPONENTS

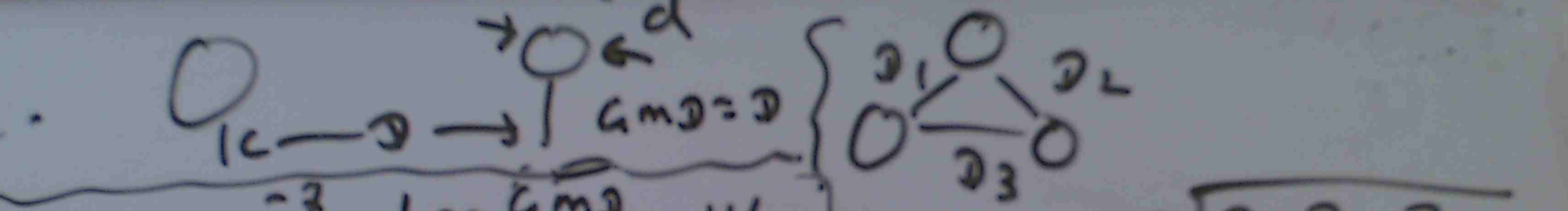
C.B(AIR, OIL, SF6) BUS SUPPORT INSULATOR, CAPACITOR BANK, CONVERTER, C.T, PT, FREQUENCY CHANGER LIGHTNING ARRESTER, REACTOR, RELAY, SCADA

CONTINUITY OF SUPPLY

BACK UP, RECTIFIER, BATTERY CHARGER FILTER, SURGE PROTECTOR

CIRCUIT BREAKER

ARC LENGTHENING, ARC COOLING, ARC SPLITTING
ARC CONSTRAINTING
CIRCUIT BREAKER, BREAKING CAPACITY



$$L = 2\times10^{-7} \times \ln\frac{GmD}{GmR} \quad H/m$$

$$C = \frac{2\pi\varepsilon}{\ln\frac{GmD}{GmR}} \quad F/m$$

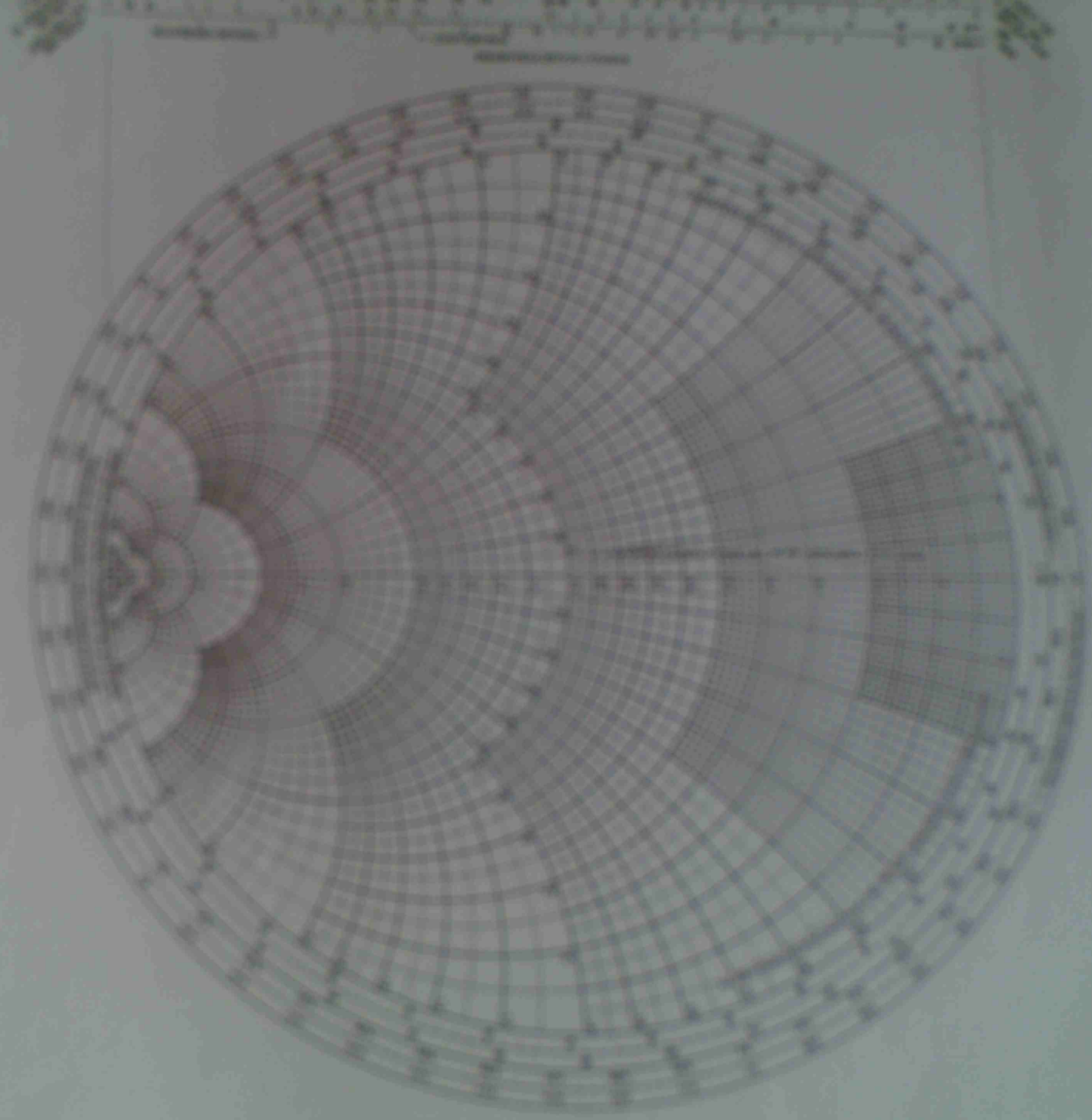
Ex 300 mm LINE, d = 1 cm, D = 1 m, 0.03Ω/km
CALCULATE L & C $\varepsilon = \frac{1}{36\pi}$

$$L = 2\times10^{-7} \times \ln\frac{GmD}{GmR} = 2\times10^{-7}\ln\frac{1}{\frac{1}{100}} = 2\times10^{-7}\times4.6 \; H/m$$

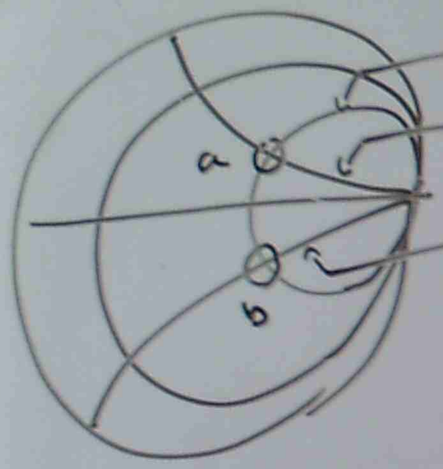
for 300 mm $= 2\times10^{-7}\times4.6\times300\times10^{3} = 0.276\,H$

$$X_L = 2\pi fL = 2\times3.1416\times50\times0.276 = 86.7\,\Omega$$

$$C = \frac{2\pi\varepsilon}{\ln\frac{D}{r}} = \frac{2\pi\times\frac{1}{36\pi}}{\ln\frac{1}{\frac{1}{100}}} = 0.012\times10^{-9}\ F/m$$



SMITH CHART



$a = 2 + j3$

$b = 2 - j3$

(If) $a = 2 - j3$

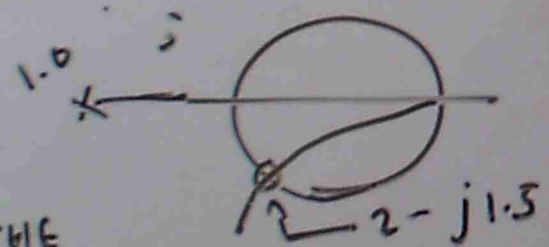
$b = a^* = 2 + j3$

Pb FIND THE INPUT IMPEDANCE & VSWR OF A TRANSMISSION LINE 4.3λ LONG WHEN $Z_0 = 100\Omega$ AND $Z_L = 200 - j150\Omega$

NORMALIZE LOAD $= \frac{Z_L}{Z_0} = \frac{200 - j150}{100} = 2 - j1.5$

STEP(1)

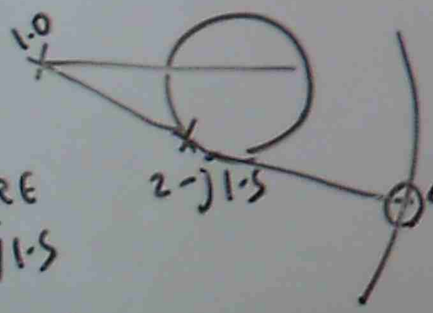
PLACE $2 - j1.5\Omega$



STEP(2) JOIN THE CENTRE TO $2 - j1.5\Omega$

STEP(3)

JOIN CENTRE & $2 - j1.5$



STEP(4) EXTEND TO OUTER CIRCLE

STEP(5)

$\frac{4.3\lambda}{0.5\lambda} = 8$ CIRCLE $+ 0.3\lambda$

$= 0.292 + 0.3$

$= 0.592\lambda$

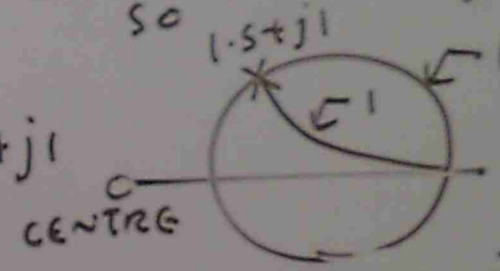
Pb A LOAD OF $75\Omega + j50\Omega$ IS TO BE MATCHED TO A 50Ω TRANSMISSION LINE USING A $\frac{\lambda}{4}$ MATCHING SECTION. DETERMINE THE PROPER LOCATION AND CHARACTERISTIC IMPEDANCE OF THE MATCHING SECTION.

LET $Z_0 = 50\Omega$

NORMALIZE IT $\rightarrow \frac{75 + j50}{50} = 1.5 + j1$

STEP(1)

PLACE $1.5 + j1$



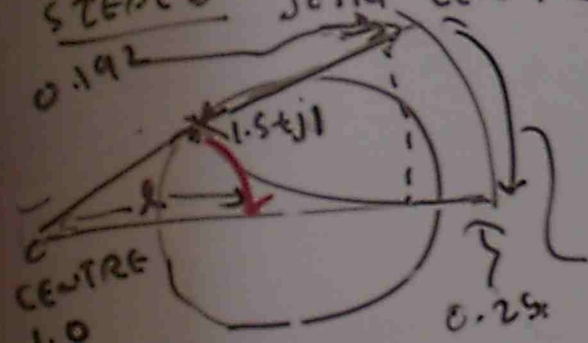
STEP(2) JOIN CENTRE AND $1.5 + j1$ POINT

STEP(3)

EXTEND THE LINE TO OUTER CIRCLE

FIND DIFFERENCE

$0.25 - 0.192 = 0.058\lambda$



AT THIS POINT THE LINE IS TO BE CUT AND $\frac{\lambda}{4}$ SECTION IS TO BE INSERTED.

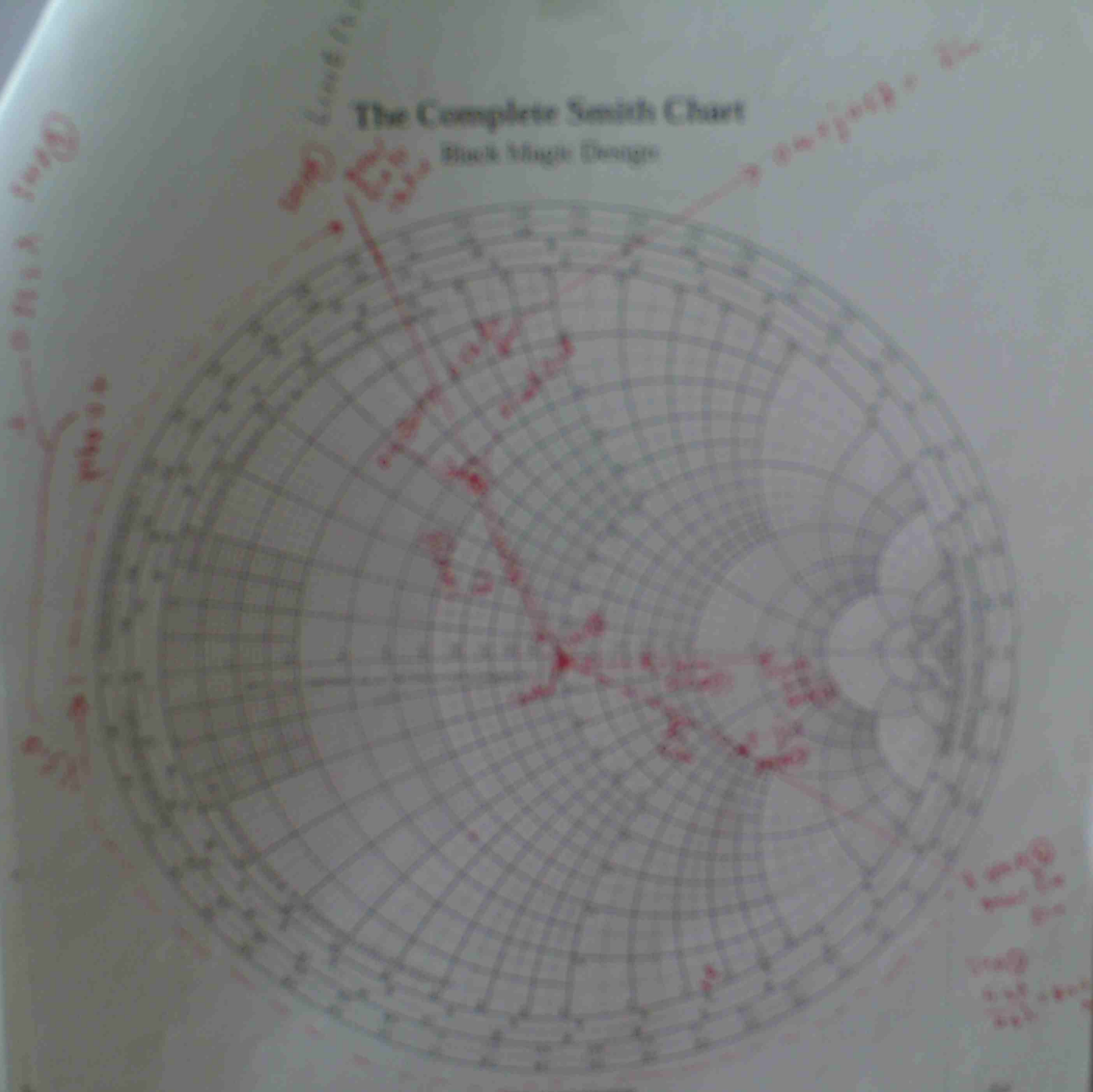
STEP(4) MEASURE THE DISTANCE BETWEEN CENTRE AND $1.5 + j1$. DRAW THE ARC FROM $1.5 + j1$ TO MEET THE HORIZONTAL LINE MEASURE "l". VSWR = 2.4

$R_L = \text{VSWR} \times Z_0 = 2.4 \times 50 = 120\Omega$

$Z_0' = \sqrt{Z_0 R_L} = \sqrt{50 \times 120} = 77.5\Omega$

The Complete Smith Chart

Black Magic Design



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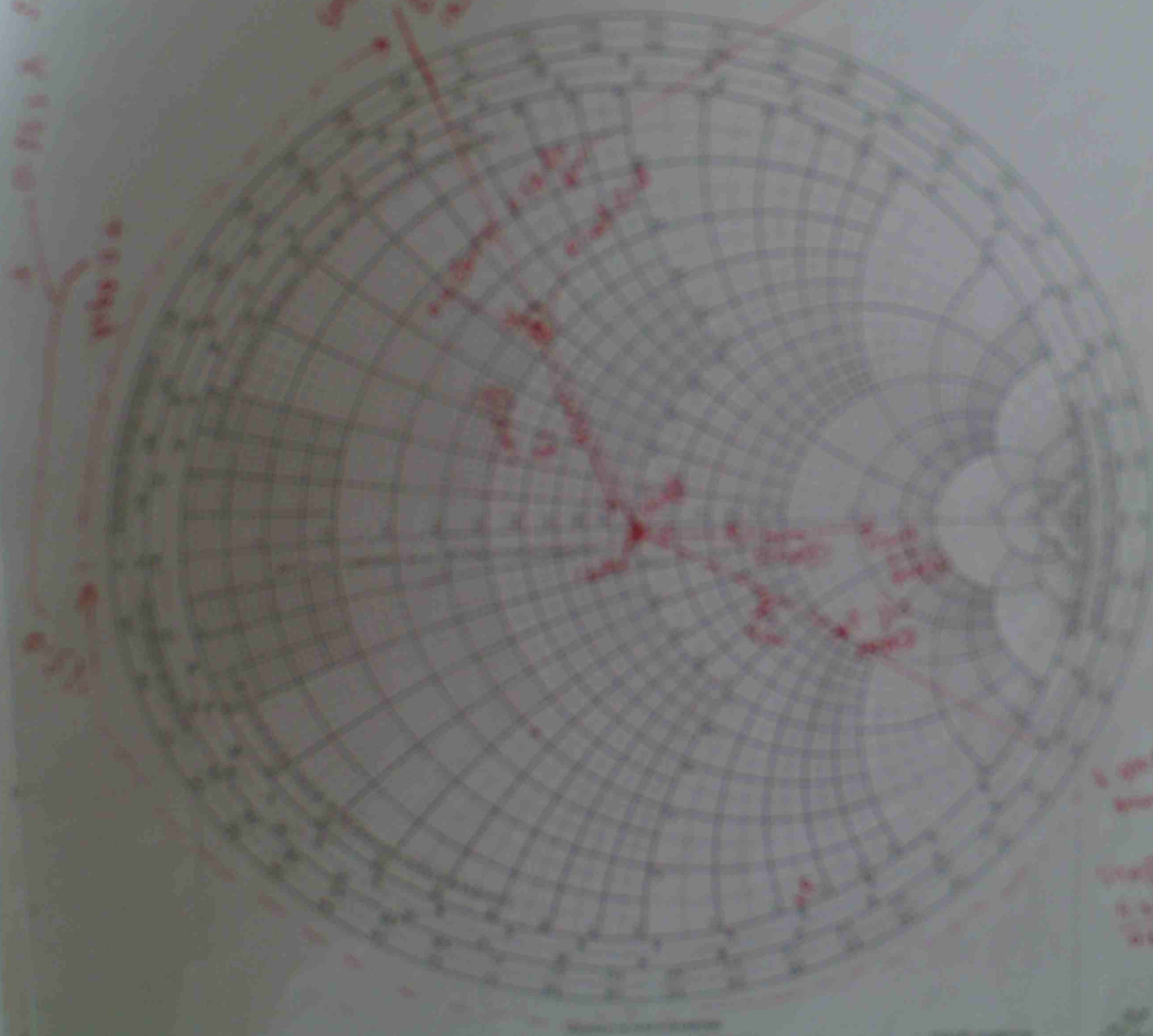

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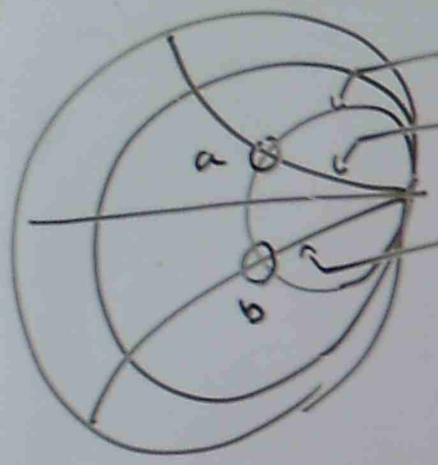

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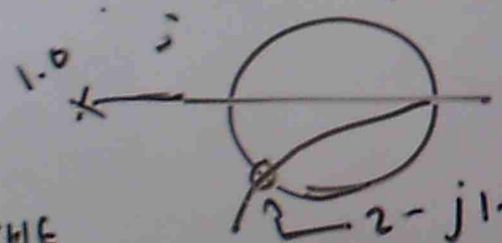
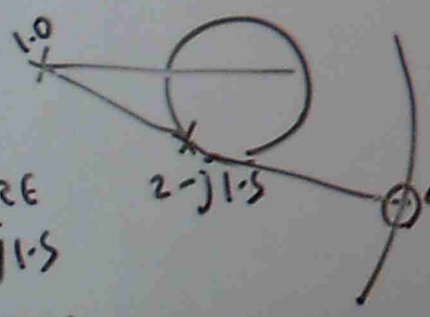


STEP(2) JOIN THE CENTRE TO $2 - j1.5\Omega$

STEP(3)

JOIN CENTRE & $2 - j1.5$



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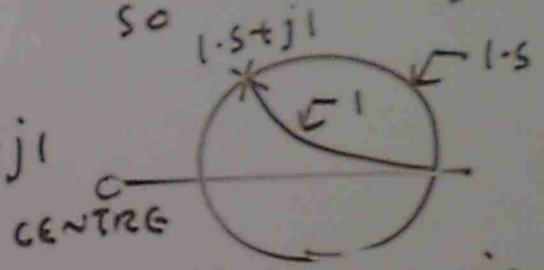
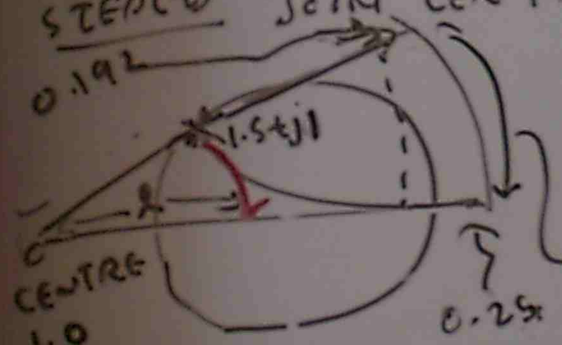


STEP(2) JOIN CENTRE AND $1.5 + j1$ POINT



STEP(3)

EXTEND THE LINE TO OUTER CIRCLE

FIND DIFFERENCE

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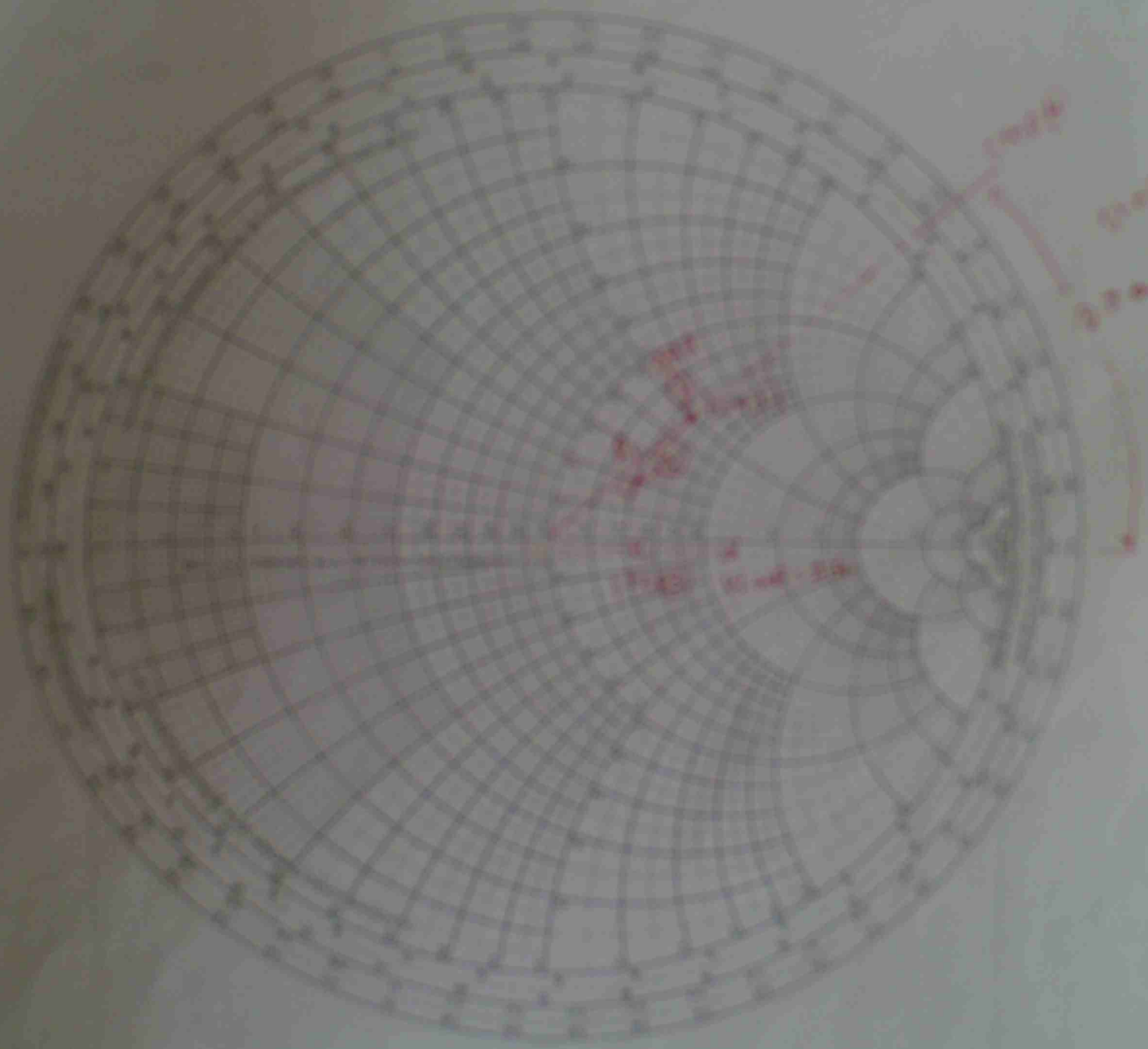
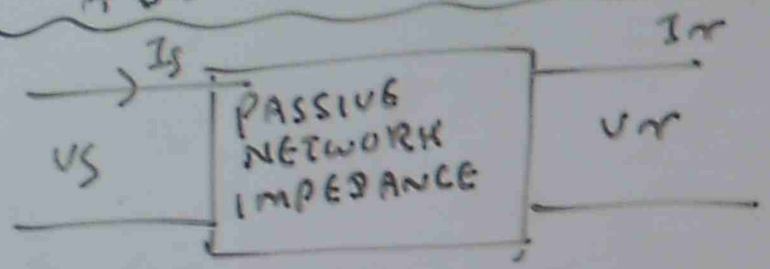
The Complete Smith Chart

Black Magic Design



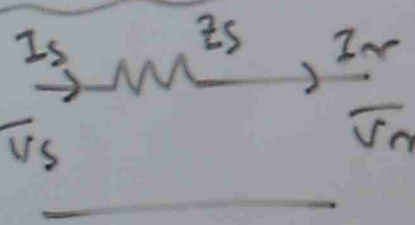
FOUR TERMINALS NETWORK
A B C D CONSTANTS



$$V_S = A V_r + B I_r$$

$$I_S = C V_r + D I_r$$

SERIES IMPEDANCE



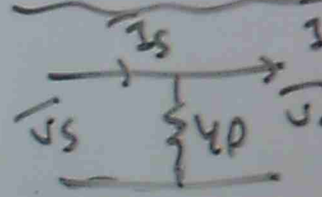
$A = 1.0$, $B = Z_S$

$C = 0$, $D = 1.0$

$\therefore \bar{V}_S = V_r + Z_S I_r$

$\bar{I}_S = 0\,\bar{V}_r + \bar{I}_r$

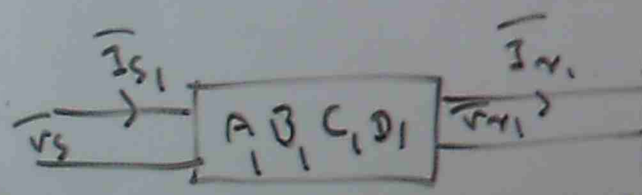
SHUNT ADMITTANCE



$V_S = \bar{V}_r + 0\,\bar{I}_r$

$\bar{I}_S = Y_p \bar{V}_r + \bar{I}_r$

$A = 1.0$, $B = 0$, $C = Y_p$, $D = 1.0$



$A_{eq} = A_1 A_2 + B_1 C_2$

$B_{eq} = A_1 B_2 + B_1 D_2$

$\bar{V}_S = A_{eq} \bar{V}_r + B_{eq} \bar{I}_r$

$I_S = C_{eq} \bar{V}_r + D_{eq} I_r$

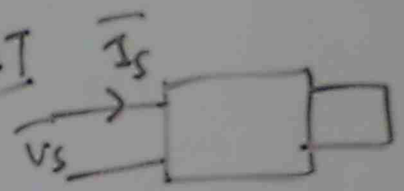
OPEN



$A = \frac{V_S}{V_r}$

$C = \frac{I_S}{V_r}$

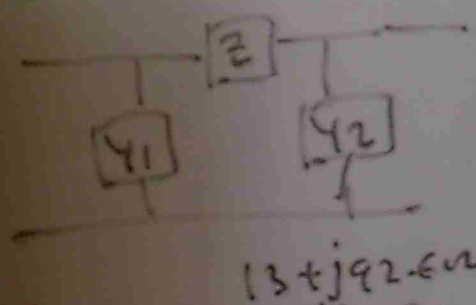
SHORT



$B = \frac{V_S}{I_r}$

$D = \frac{I_S}{I_r}$

A B C D CONSTANT π CIRCUIT



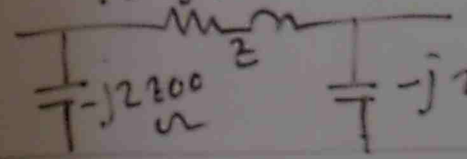
$A = 1 + Y_1 Z$

$B = Z$

$C = Y_1 + Y_2 + Y_1 Y_2 Z$

$D = 1 + Z Y_1$ $(A = D)$

Pb



$Z = 13 + j92.6 = 93.6 \angle 82\ \Omega$

$Y_1 = \frac{1}{-j2800} = 0.000357 \angle 90\ \mho$

$Y_2 = \frac{1}{-j2800} = 0.000357 \angle 90\ \mho$

$A = 1 + Y_2 Z = 1 + 0.000357 \angle 90 \times 93.6 \angle 82$

$1 - 0.033 + j0.00465 = 0.967 \angle 0.3$

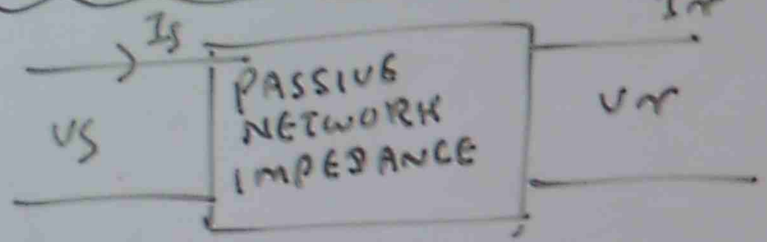
$B = 93.5 \angle 82\ \Omega$

$C = Y_1 + Y_2 + Y_1 Y_2 Z = 0.000357 \angle 90 + 0.000357 \angle 90 + 93.6 \angle 82\ 0.000357 \angle 90 \times 0.000357 \angle 90$

$C = 0.0007$

$D = A = 0.967$

FOUR TERMINALS NETWORK
A B C D CONSTANTS



$V_S = A V_r + B I_r$

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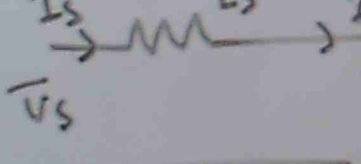
SERIES IMPEDANCE



$A = 1.0$, $B = Z_S$

$C = 0$, $D = 1.0$

$\therefore \bar{V}_S = \bar{V}_r + Z_S \bar{I}_r$

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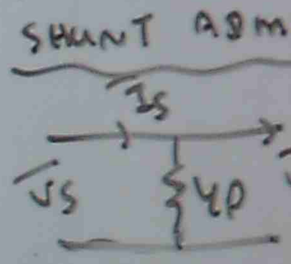
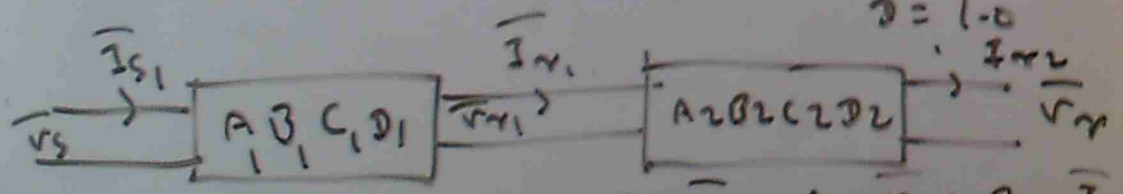
SHUNT ADMITTANCE



$\bar{V}_S = \bar{V}_r + 0\,\bar{I}_r$

$\bar{I}_S = Y_p \bar{V}_r + \bar{I}_r$

$A = 1.0$, $B = 0$, $C = Y_p$, $D = 1.0$



$A_{eq} = A_1 A_2 + B_1 C_2$

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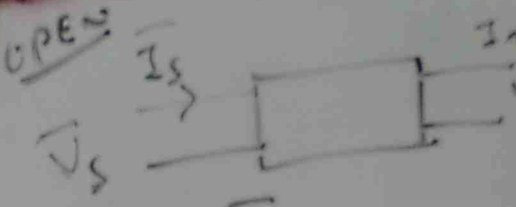
$\bar{V}_S = A_{eq} \bar{V}_r + B_{eq} \bar{I}_r$

$\bar{I}_S = C_{eq} \bar{V}_r + D_{eq} \bar{I}_r$

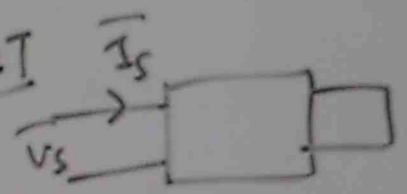
OPEN



$A = \frac{V_S}{V_r}$

$C = \frac{I_S}{V_r}$

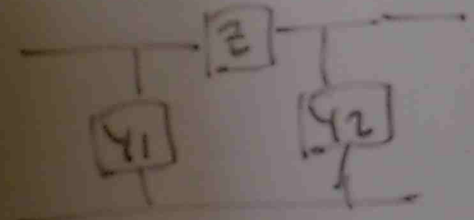
SHORT



$B = \frac{V_S}{I_r}$

$D = \frac{I_S}{I_r}$

A B C D CONSTANT π CIRCUIT



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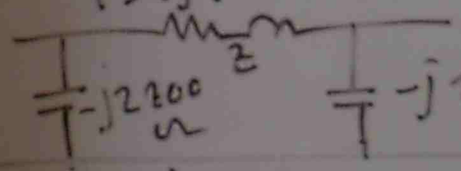
Pb



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$A = 1 + Y_2 Z = 1 + 0.000357 \angle 90 \times 93.6 \angle 82$

$= 1 - 0.033 + j0.00465 = 0.967 \angle 0.3$

$B = 93.6 \angle 82\ \Omega$

$C = Y_1 + Y_2 + Y_1 Y_2 Z = 0.000357 \angle 90 + 0.000357 \angle 90$

$+ 93.6 \angle 82\ 0.000357 \angle 90 \times 0.000357 \angle 90$

$C = 0.0007$

$D = A$

$= 0.967$

(1) COMPARING POWER SYSTEMS

SLIDE 1 → 7
@1 → @4

(2) DC TRANSMISSION SYSTEMS

SLIDE 1 → 11
@5 → @7

(3) REFLECTION IN TRANSMISSION LINE

SLIDE 1 → 12
@8 → @12

(4) POWER FACTOR CORRECTION

SLIDE 1 → 9
@13 → @15

(5) OVER HEAD TRANSMISSION LINE

SLIDE 1 → 14
@16 → @25

(6) WAVE FORMS IN TELECOM LINE

SLIDE 1 → 12
@26 → @30

(7) LING IMPEDANCE MATCHING

SLIDE 1 → 11
@32 → @32

(8) SMITH CHART

SLIDE 1 → 9
@39 → @40

(9) TRANSMISSION LINE OVER VIEW

SLIDE 1 → 16
@41 → @47

(10) SMITH CHART + WAVE GUIDE

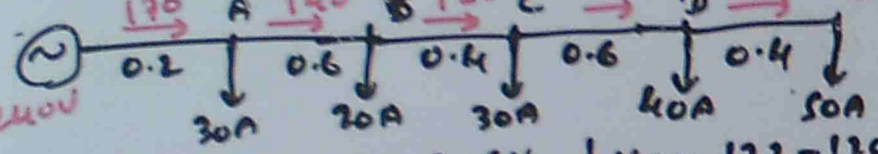
SLIDE 1 → 13
@48 → @50

(11) POWER TRANSMISSION LINE, P.U VALUE

SLIDE 1 → 22
@51 → @58

DC TRANSMISSION LINE

pb THE FOLLOWING IS THE ARRANGEMENT OF 240V DC SUPPLY SYSTEM.



$V_A = 240 - 170 \times 0.2 = 206V$

$V_B = 206 - 140 \times 0.6 = 122V$

$V_C = 122 - 120 \times 0.4 = 76V$

$V_D = 76 - 90 \times 0.6 = 22V$

$V_E = 22 - 50 \times 0.4 = 2V$

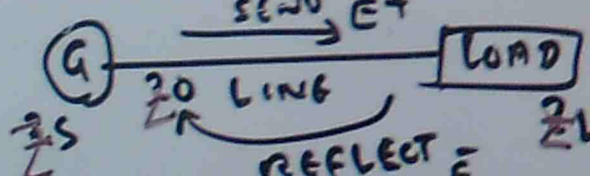
LINE OUTPUT: $206 \times 30 + 122 \times 20 + 76 \times 30 + 22 \times 40 + 2 \times 50 = 9680W$

LINE LOSS: $170^2 \times 0.2 + 140^2 \times 0.6 + 120^2 \times 0.4 + 90^2 \times 0.6 + 50^2 \times 0.4 = 29160W$

I/P: LOSS + OUTPUT: $29160 + 9680 = 38840W$

% EFFICIENCY: $\frac{O/P}{I/P} \times 100 = \frac{9680}{38840} \times 100 = 25\%$

TRANSMISSION LINE REFLECTION



$\gamma = \Gamma$ = REFLECTION COEFFICIENT

$\gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$

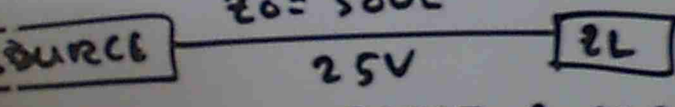
REFLECTED POWER: $\gamma^2 \times$ FORWARD WAVE POWER

RMS CURRENT: $\sqrt{\frac{\text{REFLECTED WAVE POWER}}{\text{LOAD RESISTANCE}}}$

$\bar{E} = \gamma \bar{E}^+$

VOLTAGE STANDING WAVE RATIO VSWR $= \frac{|E^+| + |\bar{E}|}{|E^+| - |\bar{E}|}$

pb A 50Ω TRANSMISSION LINE CONNECTED TO LOAD IMPEDANCE $75 + j60\Omega$ THE FORWARD WAVE RMS VALUE ON LINE IS 25V. CALCULATE (a) POWER DELIVERED TO RESISTANCE PART (b) RMS CURRENT IN REFLECTED WAVE (c) PEAK VOLTAGE IN FORWARD AND BACKWARD WAVE (d) VSWR (e) RETURN LOSS IN dB



(a) POWER IN RESISTIVE PART: $\frac{V^2}{R} = \frac{25^2}{75} = 12.5W$

(b) RMS CURRENT: $\sqrt{\frac{\text{REFLECTED WAVE POWER}}{\text{LOAD RESISTANCE}}}$

$\gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{75 + j100 - 50}{75 + j100 + 50} = \frac{25 + j100}{125 + j100} = \frac{\sqrt{25^2 + 100^2}}{\sqrt{125^2 + 100^2}} = 0.4688$

REFLECTED WAVE POWER: $\gamma^2 \times P_{FORWARD} = (0.4688)^2 \times 12.5 = 2.747W$

RMS CURRENT: $\sqrt{\frac{2.747}{75}} = 0.191$ Amp

(c) $E^+ = \sqrt{2} E_{rms} = 1.4142 \times 25 = 35.6V$

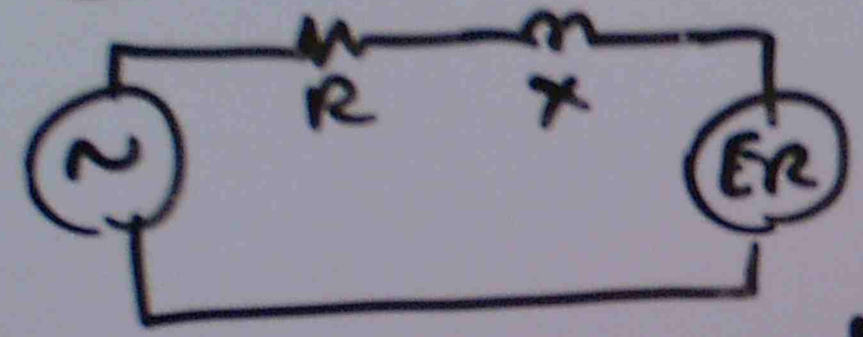
$\bar{E} = \gamma E^+ = 0.4688 \times 35.6 = 16.57V$

(d) VSWR: $\frac{E^+ + \bar{E}}{E^+ - \bar{E}} = \frac{35.36 + 16.57}{35.36 - 16.57} = 2.764$

(e) RETURN LOSS (dB) $= 10 \log_{10} \frac{\text{REFLECTED POWER}}{} = 10 \log_{10} 2.747 = 4.4dB$

POWER LINE CALCULATION

Pb



THREE PHASE EQUIVALENT
LOAD POWER = 1500 WATT
P.F = 0.8, & 460V
LINE IMPEDANCE ⇒ Z = 2 + j5 Ω

CALCULATE (a) E_S FOR PF LAGGING (b) PF LEADING

$$I = \frac{\text{POWER}}{\sqrt{3} \times E \times \cos\phi} = \frac{1500}{460 \times 0.8} = 4.08 \text{ Amp} \qquad E_{ph} = \frac{460}{\sqrt{3}} = 265$$

LAGGING PF $\theta = \cos^{-1} 0.8 = 36.8^\circ \Rightarrow 4.08 \angle -36.8$ Amp

$$E_S = E_R + I(R + jX) = 265 + 4.08\angle -36.8\,(2 + j5)$$

$$E_S = 265 + 4.08 \angle -36.8 \sqrt{2^2+5^2} \angle \tan^{-1}\tfrac{5}{2} =$$

$$= 265 + 4.08 \angle -36.8 \times 5.385 \angle 63.5 = 265 + 21.97 \angle 31.3$$

$$E_S = 265 + 21.97\,(\cos 31.3 + j \sin 31.3) = 283 + j11.4$$

$$= \sqrt{283^2 + 11.4^2} \angle \tan^{-1}\frac{11.4}{283} = 283 \angle 2.29 \text{ V} = 490 \text{ V}$$

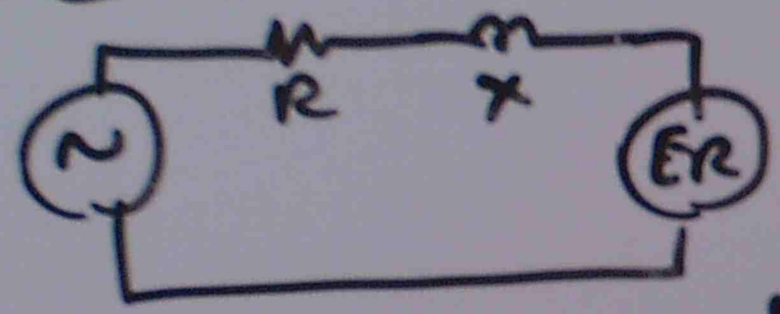
LEADING PF $265 + 4.08 \angle +36.8 \times 5.385 \angle 63.5$

$$265 + 21.97 \angle 100.3 = 265 + 21.97\,(\cos 100.3 + j \sin 100.3)$$

$$= 259 + j21.22 = 257 \angle 4.7 \text{ V} \rightarrow 445 \text{ V}$$

POWER LINE CALCULATION

Pb



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$= 265 + 4.08 \angle -36.8 \times 5.385 \angle 63.5 = 265 + 21.97 \angle 31.3$

$E_S = 265 + 21.97(\cos 31.3 + j \sin 31.3) = 283 + j11.4$

$= \sqrt{283^2 + 11.4^2} \angle \tan^{-1}\frac{11.4}{283} = 283 \angle 2.29$ V $= 490$ V

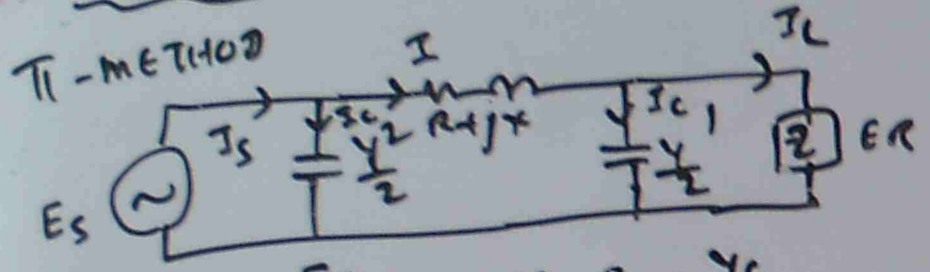
LEADING PF $265 + 4.08 \angle +36.8 \times 5.385 \angle 63.5$

$265 + 21.97 \angle 109.9 = 265 + 21.97(\cos 109.9 + j \sin 109.9)$

$= 259 + j21.22 = 257 \angle 4.7$ V → 445 V

LONG TRANSMISSION LINE

π-METHOD



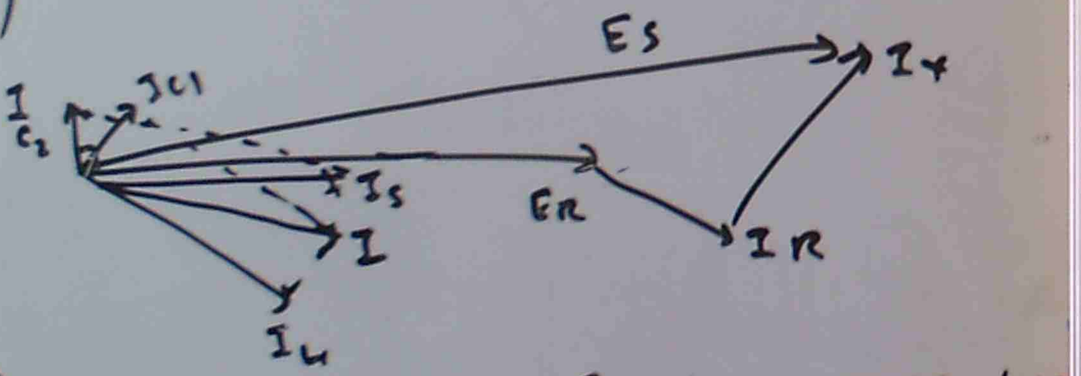
$$I_{c_1} = \frac{E_R}{\frac{X_c}{2}} \quad (\text{OR}) \quad E_R \times \frac{Y_c}{2}$$

$$\bar{I} = \bar{I}_{c_1} + \bar{I}_L$$

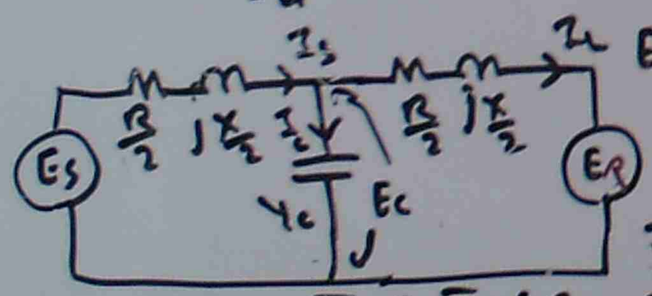
$$\bar{E}_S = \bar{E}_R + \bar{I}(R+jX), \quad I_{c_2} = \frac{E_S}{\frac{X_c}{2}} \ (\text{OR}) \ E_S \frac{Y_c}{2}$$

$$\bar{I}_S = I + \bar{I}_{c_2}$$

(11)



(T)

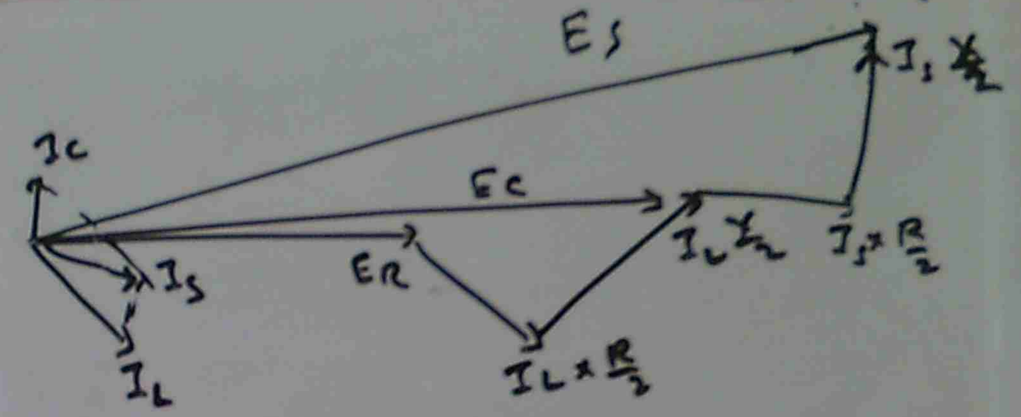


$$E_c = E_R + I_L\left(\frac{R}{2} + j\frac{X}{2}\right)$$

$$I_c = \frac{E_c}{X_c} \ (\text{OR}) \ E_c Y$$

$$\bar{I}_S = \bar{I}_c + I_L$$

$$\bar{E}_S = \bar{E}_c + \bar{I}_S\left(\frac{R}{2} + j\frac{X}{2}\right)$$



ECONOMIC CHOICE OF EQUIPMENT AND POWER SYSTEM PLANNING

- CONNECTED LOAD (OR) INSTALLED LOAD
- DEMAND FACTOR } LOAD FACTOR
- DIVERSITY FACTOR }

DISTRIBUTION PLANNING

SUBSTATION SIZE, FEEDER SIZE, VOLTAGE REGULATION LOAD CHARACTERISTICS, SIZE OF TRANSMISSION LINE,

SUB TRANSMISSION SYSTEM PLANNING

TRADING POLICY, CAPITAL, ORGANIZATIONAL AGREEMENT

PLANNING

- LOAD FORECAST PLANNING FOR FUTURE DEMAND
- RELIABILITY OF SUPPLY
- TYPE OF LOADS
- SUBSTATION DESIGN
- CUSTOMER LOAD CONTROL
  - LOCAL CONTROL
  - REMOTE CONTROL

TIME VALUE OF MONEY

P = Lump sum of money
i = INTEREST (m) - 'm' YEARS
S = SUM AFTER (m) YEARS

$$S = P(1+i)^m$$

$$S = \frac{R(1+i)^m - 1}{i}$$

R = REGULAR SUM OF MONEY INVESTED AT COMPOUND INTEREST "i"

$$P = \frac{R(1+i)^m - 1}{i(1+i)^m}$$

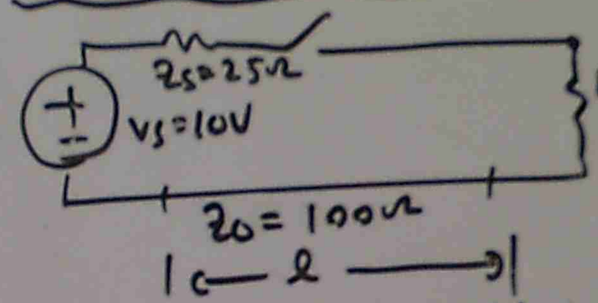
↑ CONVERSION OF ANNUAL INVESTMENT IN TO Lump Sum.

Pb THE SUM of $1000 IS INVESTED AT 6% FOR 10 YEARS AT COMPOUND INTEREST
(a) CALCULATE THE SUM AT THE END OF 10 YEARS
(b) IF INSTEAD of Lump SUM AT THE END OF 10 YEARS, THE LOAN of $ 1000 IS TO BE PAID BY FIXED AMOUNT EACH YEAR, CALCULATE ANNUAL AMOUNT

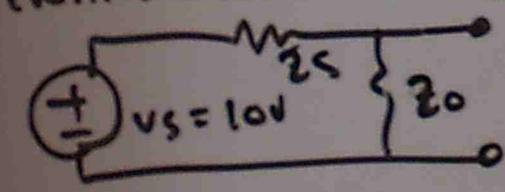
(a) $S = P(1+i)^m = 1000(1+0.06)^{10} = 179$

(b) $R = \frac{P[i(1+i)^m]}{[(1+i)^m - 1]} = \frac{1000[0.06(1+0.06)^{10}]}{[1+0.06]^{10} - 1} = \$135.90$

THE REFLECTION ON TRANSMISSION LINE



A 10V DC SOURCE WITH AN INTERNAL RESISTANCE OF 25Ω IS CONNECTED TO A TRANSMISSION LINE OF LENGTH 'l' HAVING AN IMPEDANCE OF 100Ω BY A SWITCH. THE TRANSMISSION IS TERMINATED WITH 400Ω RESISTOR
T = AMOUNT OF TIME REQUIRED FOR A SIGNAL TO TRAVEL THE LENGTH OF TRANSMISSION LINE.



$$V_{1+} = V_s \frac{Z_o}{Z_o + Z_s}$$

$$= 10 \times \frac{100}{100+25} = 8V$$

FIRST REFLECTION AT LOAD

$$V_{1(-)} = V_{1(+)} \times \Gamma_L \quad , \quad \Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o}$$

$$V_t = V_{1(+)} + V_{1(-)}$$

SECOND REFLECTION AT SOURCE

$$V_{2+} = V_{1-} \times \Gamma_s \quad , \quad \Gamma_s = \frac{Z_s - Z_o}{Z_s + Z_o}$$

$$V_t = V_{1(+)} + V_{1(-)} + V_{2(+)}$$

THIRD REFLECTION AT LOAD

$V_{2(-)} = V_{2(+)} \times \Gamma_L$ | $V_t = V_{1+} + V_{1-} + V_{2+} + V_{2-}$

$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{900 - 100}{900 + 100} = 0.8$

$V_{1-} = V_{1+}\,\Gamma_L = 8 \times 0.8 = 6.4\,V$

$V_T = V_{1+} + V_{1-} = 8 + 6.4 = 14.4\,V$

} FIRST REFLECTION AT LOAD

$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} = \frac{25 - 100}{25 + 100} = -0.6$

$V_{2+} = V_{1-} \times \Gamma_S = 6.4 \times (-0.6) = -3.84\,V$

$V_T = V_{1+} + V_{1-} + V_{2+} = 8 + 6.4 + (-3.84)$

$= 10.56\,V$

} 2ND REFLECTION AT SOURCE

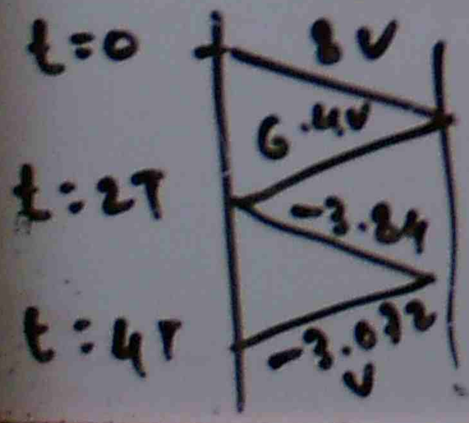
$V_{2-} = V_{2(+)}\,\Gamma_L = -3.84 \times 0.8 = -3.072\,V$

$V_T = V_{1+} + V_{1-} + V_{2+} + V_{2-}$

$= 8 + 6.4 + (-3.84) + (-3.072)$

$= 7.488\,V$

} THIRD REFLECTION AT LOAD

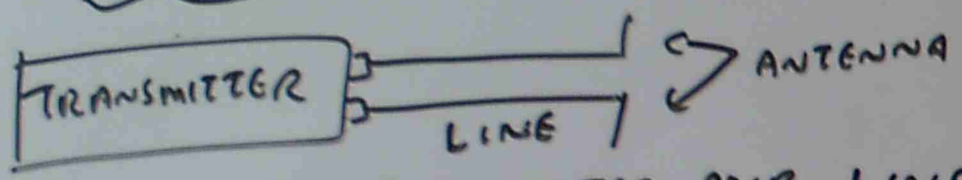


THE MATCHED TRANSMISSION LINE

$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} = \frac{100 - 100}{100 + 100} = 0$

NO REFLECTION, IF $Z_S = Z_0$

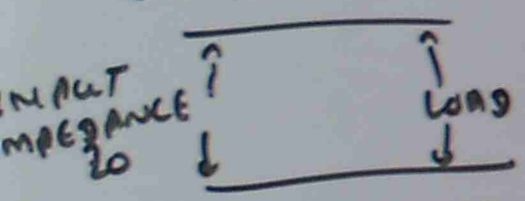
MODEL OF TRANSMISSION LINE



OPEN WIRE LINE, TWISTED PAIR LINE
CONCENTRIC CABLE / COAXIAL CABLE

ATTENUATION → RESISTANCE LOSS
DIELECTRIC LOSS
RADIATION LOSS

CHARACTERISTICS IMPEDANCE (Zo)



$Zo = \frac{E}{I}$

SURGE IMPEDANCE LOADING (SIL)

MVAR PRODUCED = $\frac{V^2}{X_C}$

MVAR USED: $I^2 X_L$

MVAR PRODUCED = MVAR USED

$\frac{V^2}{X_C} = I^2 X_L \rightarrow X_L X_C = \frac{V^2}{I^2}$

$2\pi f L \times \frac{1}{2\pi f C} = Z^2$

$\therefore Z = \frac{1}{2\pi\sqrt{LC}}$

$SIL = \frac{KV^2_{L-L}}{\text{SURGE IMPEDANCE}}$

BELOW SIL – LAGGING P.F

ABOVE SIL – LEADING PF

LONG & SHORT TRANSMISSION LINE

DC / LOW FREQUENCY AC CKT – CHARACTERISTICS OF PARALLEL WIRE IS IGNORED

LINE CONNECTED TO AC SOURCE

BEHAVE AS RESISTOR

LOW FREQUENCY AC POWER

VOLTAGE ALONG ALL RESPECTIVE POINTS ON A LOW FREQUENCY TWO CONDUCTOR LINE ARE EQUAL AND IN PHASE WITH ANOTHER AT ANY GIVEN POINT IN LINE

WAVE LENGTH & VELOCITY

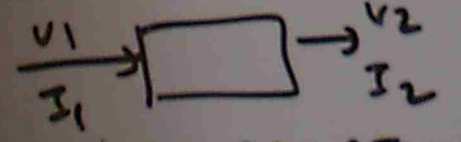
$\lambda = \frac{V}{f}$

λ = WAVE LENGTH
V = VELOCITY OF PROPAGATION
f = FREQUENCY OF SIGNAL

SHORT LINE – LOAD IMPEDANCE DOMINATES THE CIRCUIT

LONG LINE – LINE CHARACTERISTICS IMPEDANCE DOMINATES THE CIRCUIT

PROPAGATION CONSTANT



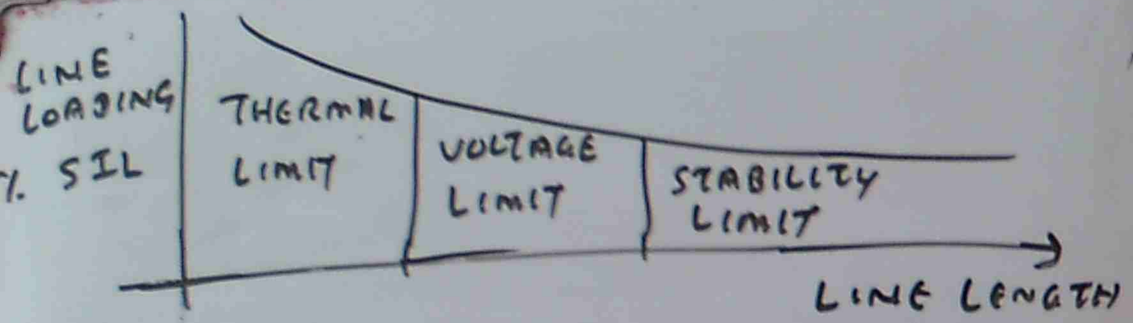
γ = PROPAGATION CONSTANT

α – REAL PART ATTENUATION CONSTANT

β – IMAGINARY PART PHASE CONSTANT

$\gamma = \alpha + i\beta$

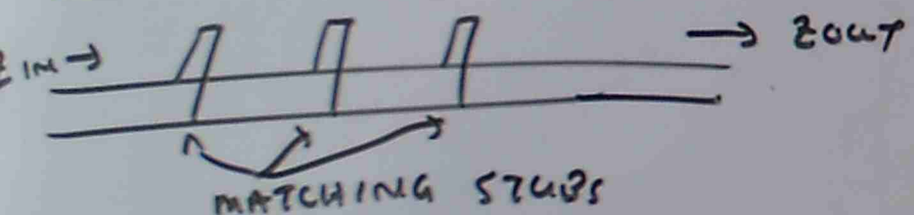
$\frac{V1}{V2} = \frac{I_1}{I_2} = e^{\gamma}$

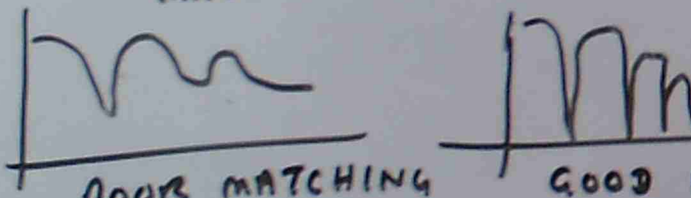


TRANSMISSION LINE MATCHING

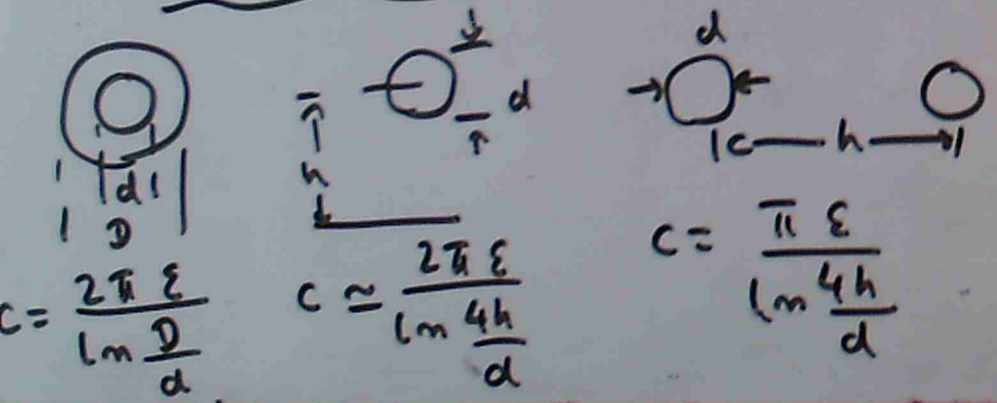
REFLECTION COEFFICIENT = $\frac{Z_L - Z_0}{Z_L + Z_0}$

MATCHING STUBS





EXAMPLES of TRANSMISSION LINE



$C = \frac{2\pi\varepsilon}{\ln \frac{D}{d}}$

$C \simeq \frac{2\pi\varepsilon}{\ln \frac{4h}{d}}$

$C = \frac{\pi\varepsilon}{\ln \frac{4h}{d}}$

AMPLITUDE

VOLTAGE AMPLITUDE, CURRENT AMPLITUDE
NORMALIZED AMPLITUDE

POSITIVE TRAVELLING WAVE

THE PHASE INCREASES WITH INCREASING DISTANCE FROM THE GENERATOR

NEGATIVE TRAVELLING WAVE

THE PHASE DECREASES WITH INCREASING DISTANCE FROM THE GENERATOR

DIRECTION of PROPAGATION

DIRECTION OF POWER FLOW FROM GENERATOR TO LOAD

WAVE GUIDES

CIRCULAR MODE

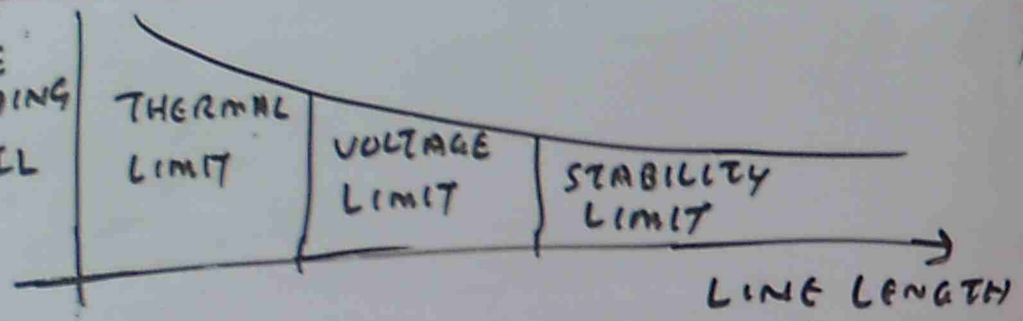


TE-MODE - NO ELECTRIC FIELD IN DIRECTION OF PROPAGATION (TRANSVERSE ELECTRIC)

TM-MODE - NO MAGNETIC FIELD IN DIRECTION OF PROPAGATION (TRANSVERSE MAGNETIC)

TEM-MODE - (TRANSVERSE ELECTRO MAGNETIC NO ELECTRIC OR MAGNETIC FIELD IN DIRECTION OF PROPAGATION

HYBRID - HAVE ELECTRIC/MAGNETIC IN DIRECTION OF PROPAGATION



TRANSMISSION LINE MATCHING

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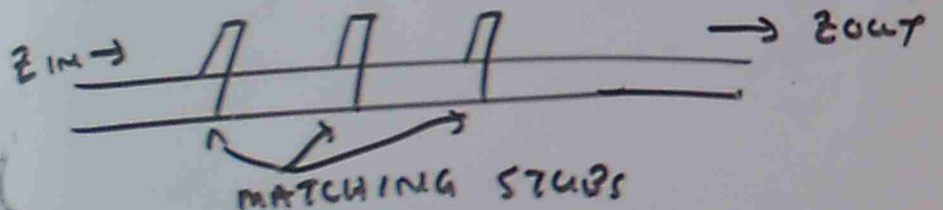
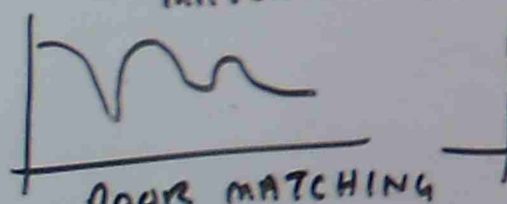
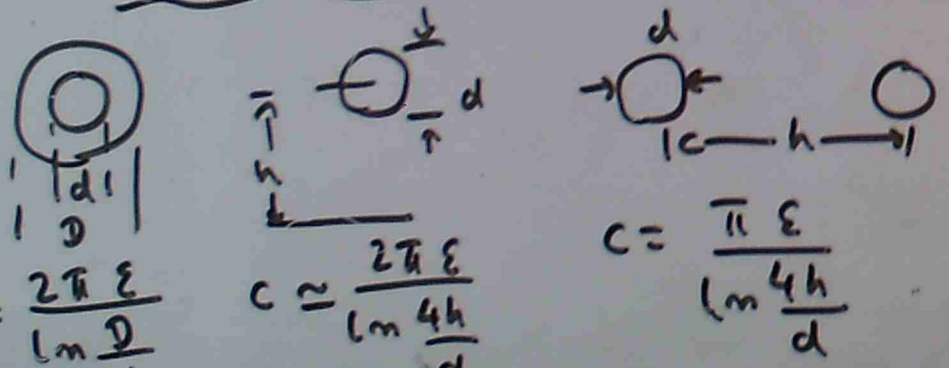
MATCHING STUBS





EXAMPLES OF TRANSMISSION LINE



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$C \simeq \frac{2\pi\varepsilon}{\ln \frac{4h}{d}}$

$C = \frac{\pi\varepsilon}{\ln \frac{4h}{d}}$

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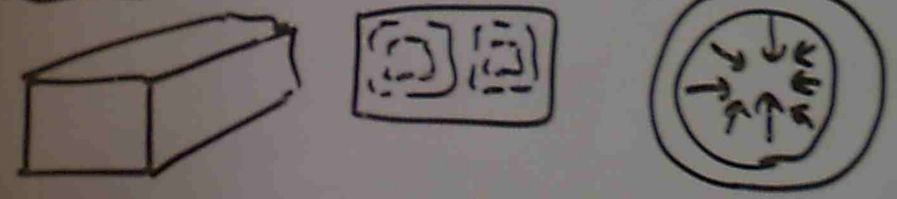
WAVE GUIDES

CIRCULAR MODE

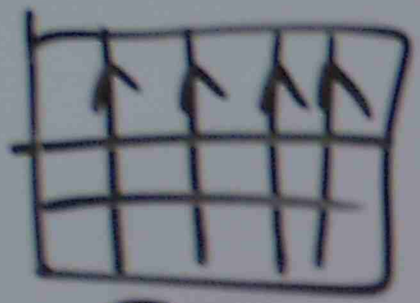


TE-MODE - NO ELECTRIC FIELD IN DIRECTION OF PROPAGATION (TRANSVERSE ELECTRIC)

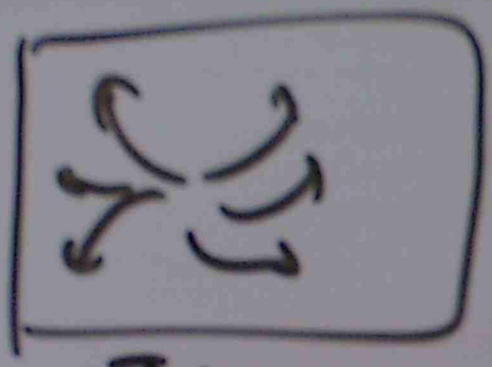
TM-MODE - NO MAGNETIC FIELD IN DIRECTION OF PROPAGATION (TRANSVERSE MAGNETIC)

TEM-MODE - (TRANSVERSE ELECTRO MAGNETIC NO ELECTRIC OR MAGNETIC FIELD IN DIRECTION OF PROPAGATION

HYBRID - HAVE ELECTRIC / MAGNETIC IN DIRECTION OF PROPAGATION

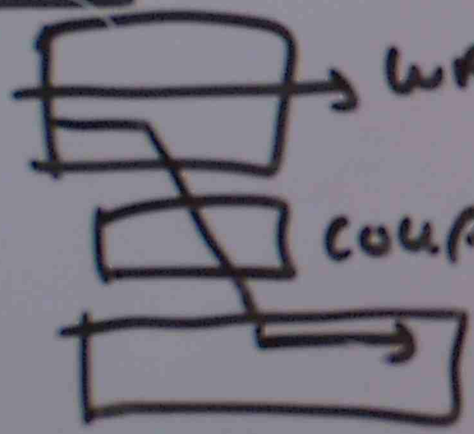


TG



TM

COUPLER

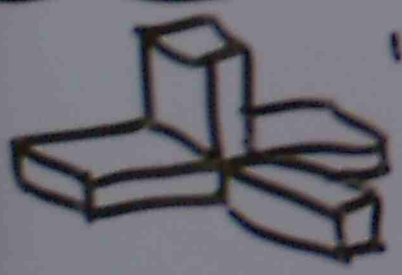


WAVE GUIDE(1)

COUPLER

WAVE GUIDE(2)

T-COUPLER



HYBRID



INPUT

BY PASS FILTER

OUTPUT

INPUT

LINE LENGTH_1

LINE LENGTH 2

STANDING WAVE



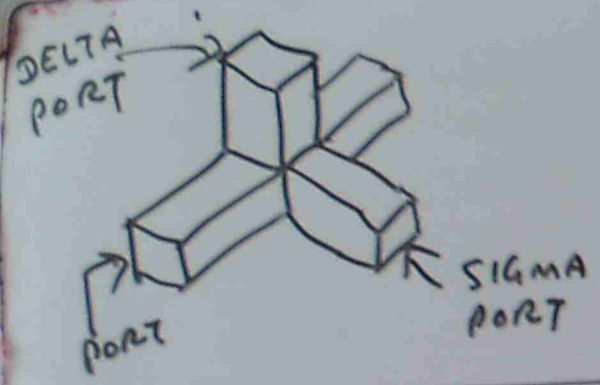
REMAIN IN CONSTANT POSITION

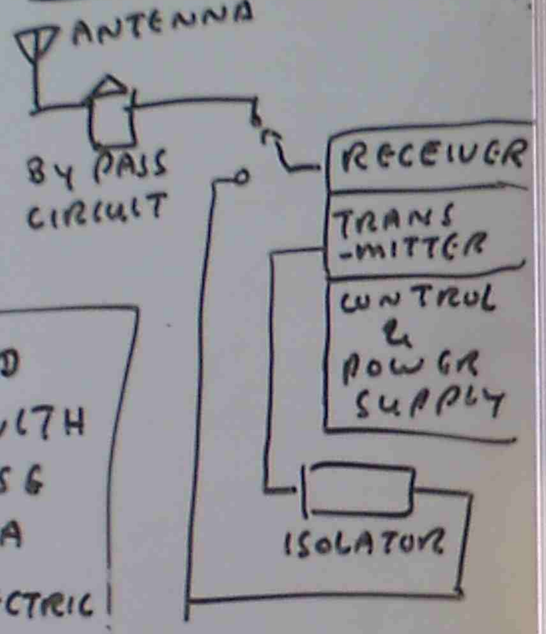
SECOND WAVE



EQUAL AMPLITUDE TRAVELLING IN OPPOSITE DIRECTION

CIRCULATOR





P1) DESIGN A SWITCHED LINE PHASE SHIFTER WITH A 22.5 DEGREE PHASE SHIFT AT 4 G.Hz ON A SUBSTRATE WITH A DIELECTRIC CONSTANT 9.9

$22.5^\circ \rightarrow \frac{22.5 \times \pi}{360} = 0.392$ RAD

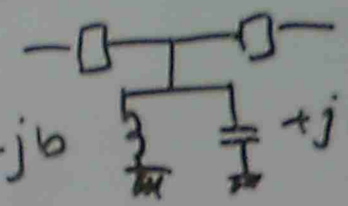
$\Delta\phi = \frac{\Delta\phi}{\beta}$

$4\,GHz \rightarrow \lambda_{AIR} = \frac{c}{f} = \frac{3\times10^8}{4\times10^9} = 0.075\,m$

$\lambda_g = \frac{\lambda_{AIR}}{\sqrt{\varepsilon_{EFF}}} = \frac{0.075}{\sqrt{9.9}} = 0.0238\,m$

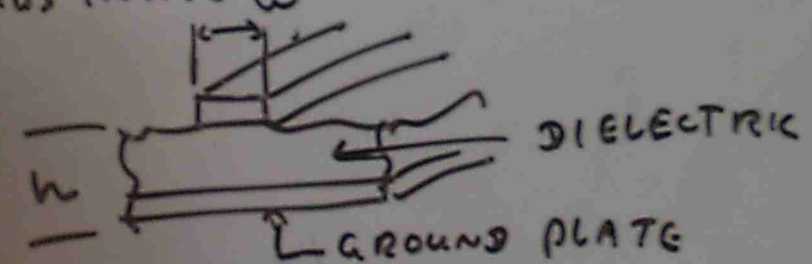
$\Delta\phi = \frac{\Delta\phi}{\beta} = \frac{\lambda_g \Delta\phi}{2\pi} = \frac{0.0238 \times 0.392}{2\pi} = 1.485\,mm$

DESIGN THE MICROSTRIP LINE SUCH THAT LINE LENGTH L IS 1.485m LONGER THAN LINE LENGTH



MICROSTRIP TRANSMISSION LINE

MICROSTRIP TRANSMISSION LINE IS A KIND OF HIGH GRADE PRINTED CIRCUIT CONSTRUCTION CONSISTING OF A TRACK OF COPPER AS OTHER CONDUCTOR ON AN INSULATING SUBSTRATE



SUBSTRATE MATERIAL

- ~ MICROWAVE DIELECTRIC CONSTANT
- ~ FREQUENCY DEPENDENCY
- - SURFACE FINISH & FLATNESS
- ~ THERMAL EXPANSION & CONDUCTIVITY
- ~ POROSITY

GaAs, SILICON

PCB STRIP LINE

CENTERED STRIP LINE
DUAL / OFFSET STRIP LINE

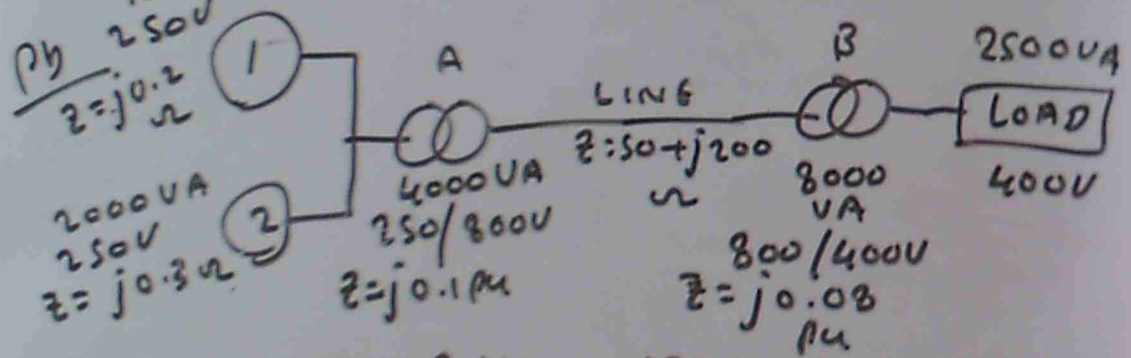
PER UNIT APPLICATION OF POWER LINE EQUIPMENTS

LINE ⇒ $Z_{(PU)} = \dfrac{Z_{(\Omega)} \times V.A\ BASE}{(BASE\ VOLTAGE)^2}$

Z_1 AT VA_1, V_1

TO FIND Z_2 AT VA_2, V_2

$$Z_2(PU) = Z_1(PU) \times \frac{V_1^2}{V_{BASE}^2} \times \frac{VA\text{-}BASE}{VA_1}$$



CALCULATE P.U IMPEDANCE REFERRED TO 5000 V.A, 250 V BASE

BASE 5000 VA, 250/800 V

GENERATOR (1)

$$Z_{PU}(5000) = j0.2 \times \frac{V_1^2}{V_{BASE}^2} \times \frac{VA\text{-}BASE}{VA_1}$$

$$= j0.2 \times \frac{250^2}{250^2} \times \frac{5000}{1000} = j1.0\ PU$$

GENERATOR (2)

$$Z_{PU}(5000) = j0.3 \times \frac{250^2}{250^2} \times \frac{5000}{2000} = j0.75\ PU$$

TRANSFORMER (A)

$$Z_{PU}(5000) = j0.1 \times \frac{250^2}{250^2} \times \frac{5000}{4000} = j0.125\ PU$$

TRANSFORMER (B)

$$Z_{PU}(5000) = j0.08 \times \frac{400^2}{250^2} \times \frac{5000}{8000} = j0.128\ PU$$

LINE

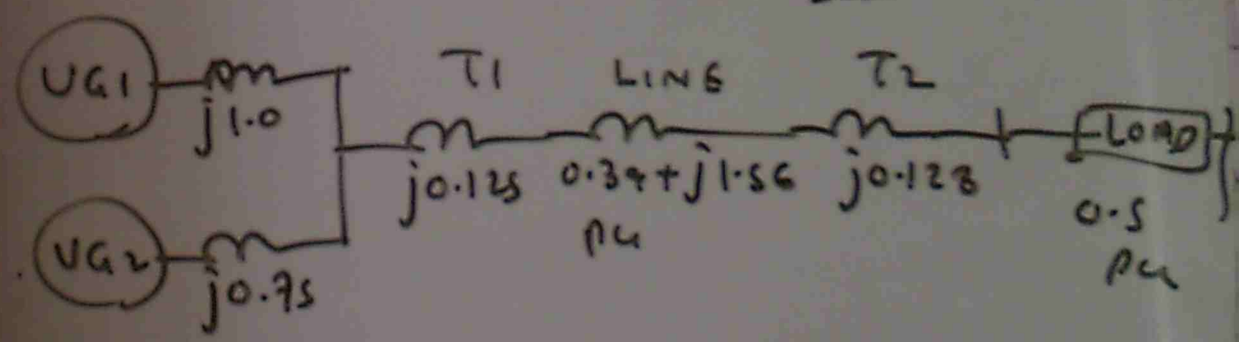
$$Z_{PU}(5000) = Z_{(\Omega)} \times \frac{VA\text{-}BASE}{V_{BASE}^2}$$

$$= (50 + j200) \times \frac{5000}{(800)^2}$$

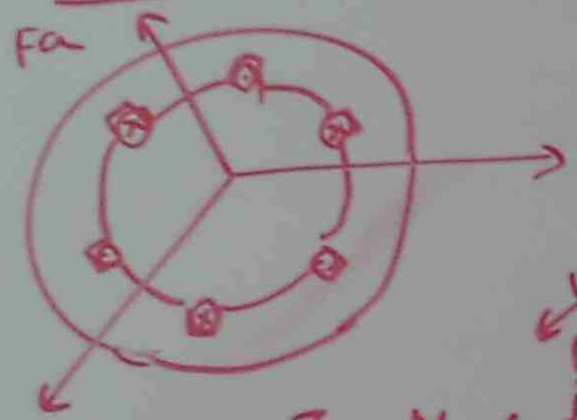
$$= 0.39 + j1.56\ PU$$

LOAD

$$Z(PU) = \frac{VA}{VA\text{-}BASE} = \frac{2500}{5000} = 0.5\ PU$$



(1) AC MACHINE INTRODUCTION

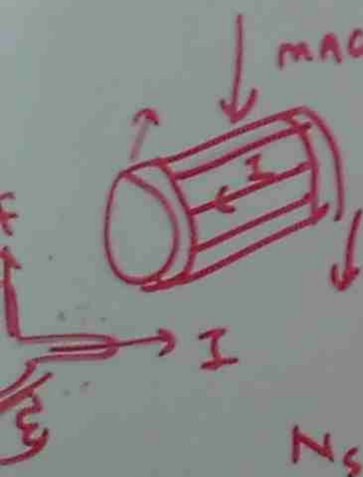


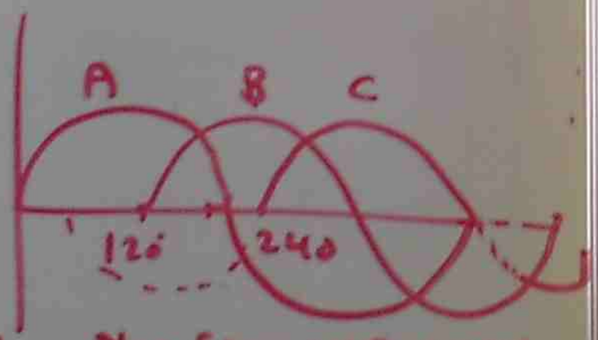
$$f_a = \frac{I_m N}{2}\left(e^{j\omega t} + e^{-j\omega t}\right) e^{j0}$$

$$f_b = \frac{I_m N}{2}\left(e^{j\omega t} + e^{-j\omega t}\right) e^{j(\omega t - \frac{4\pi}{3})}$$

$$f_c = \frac{I_m N}{2}\left(e^{j\omega t} + e^{-j\omega t}\right) e^{j(\omega t + \frac{4\pi}{3})}$$

$$F = 3\,\frac{I_m N}{2}\, e^{j\omega t}$$





$$N_s = \frac{120 f}{P}$$

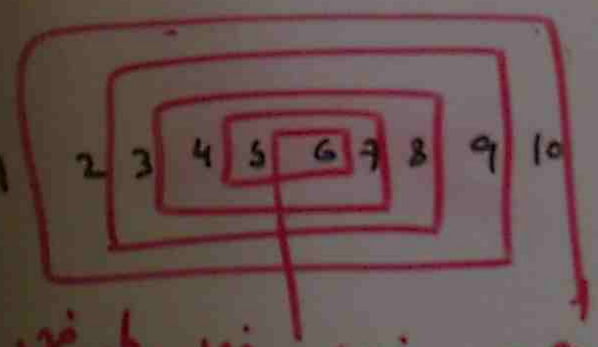
N_s = SYNCHRONOUS SPEED
f = FREQUENCY
P = NO. OF POLES

- THE REVOLVING FIELD CREATED BY THE STATOR CUTS ACROSS THE ROTOR BARS AND INDUCED VOLTAGES IN ALL OF THEM.
- BECAUSE THE ROTOR BARS ARE SHORT CIRCUITED BY END RINGS, THE VOLTAGE CAUSES A LARGE CURRENT TO FLOW.
- THE CURRENT CARRYING CONDUCTORS IN THE PATH OF FLUX CREATED BY THE STATOR, THEY ALL EXPERIENCE A STRONG MECHANICAL FORCE

DESIGN 3φ 4 POLES 36 SLOT 50HZ WINDING

$$\text{COIL SPAN} = \frac{\text{NO. OF SLOT}}{\text{NO. OF POLE}} = \frac{36}{4} = 9$$

1 (+9) 10 (+9) 20 (+9) 30 (+9) $40 - \frac{36}{4}$

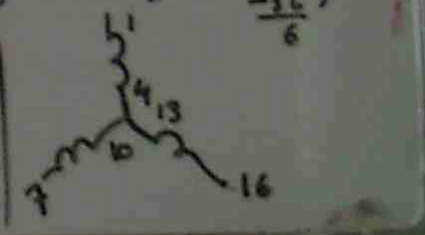


1 → 10, 11 → 20, 21 → 30, 31 → 4 (+6)
7 → 16, 17 → 26, 27 → 36, 1 → 10 (+6)
13 → 22, 23 → 33, 33 → $\frac{42}{-36}$, 7 → 16 $\frac{}{6}$

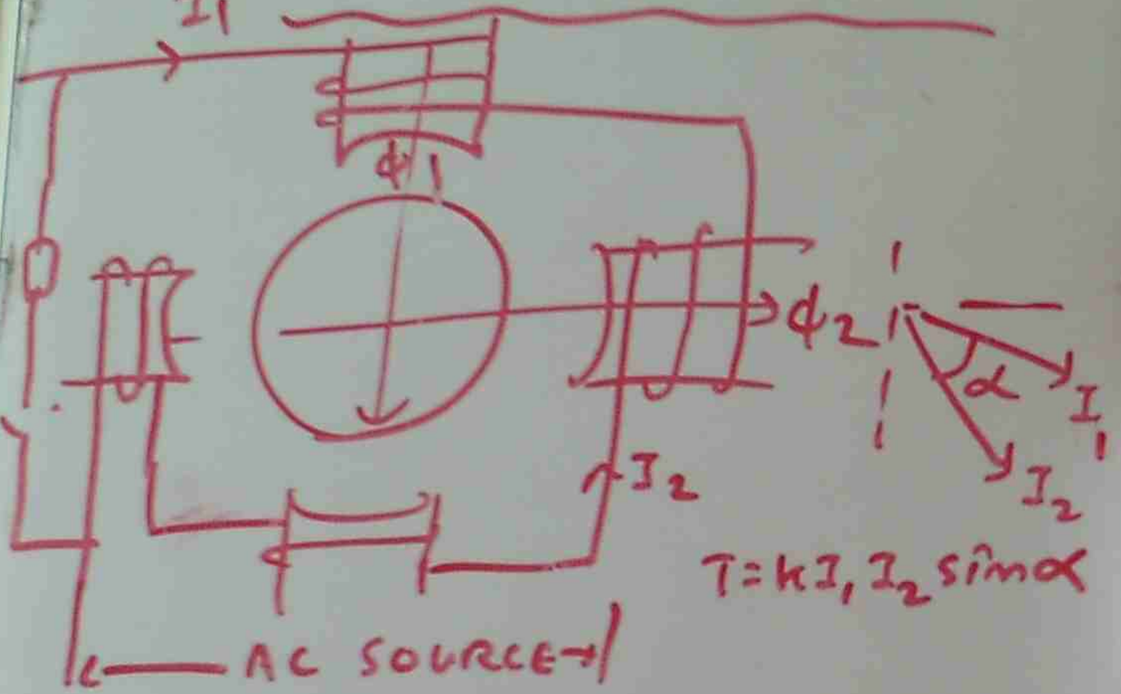


180° → 9 SLOT

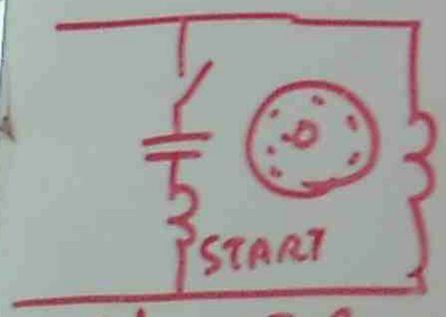
120° → $? = 9 \times \frac{120}{180} = 6$



SINGLE PHASE MOTOR



$T = kI_1 I_2 \sin\alpha$



1ϕ MOTOR

PRINCIPLE OF OPERATION

- CROSS FIELD THEORY
- REVOLVING FIELD THEORY

1ϕ MOTORS

SPLIT PHASE, CAPACITOR START / RUN
SHADED POLE, REPULSION, SYNCHRONOUS MOTOR
HYSTERESIS MOTOR

(16) SINGLE PHASE MOTOR

SLIDE 1 ⟶ 14
@ 88 ⟶ 094

(18) SINGLE PHASE MOTOR PROBLEMS

SLIDE 1 ⟶ 22
@ 105 ⟶ 109

FORCE ON MOTOR



$T = F \times r$ (T = TORQUE N-m, F = FORCE (N), r = RADIUS (m), N = RPM, m = MASS (kg), V = VELOCITY (m/s)

POWER of MOTOR $P = \frac{NT}{9.55}$

KINETIC ENERGY $= \frac{1}{2} m V^2$

MOMENT of INERTIA



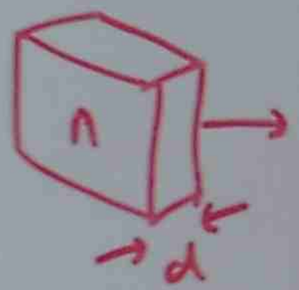
$J = \frac{m r^2}{2}$

$\Delta n = \frac{9.55 \times T \Delta t}{J}$

Δn = CHANGE IN SPEED | Δt = TIME

HEAT & TEMPERATURE

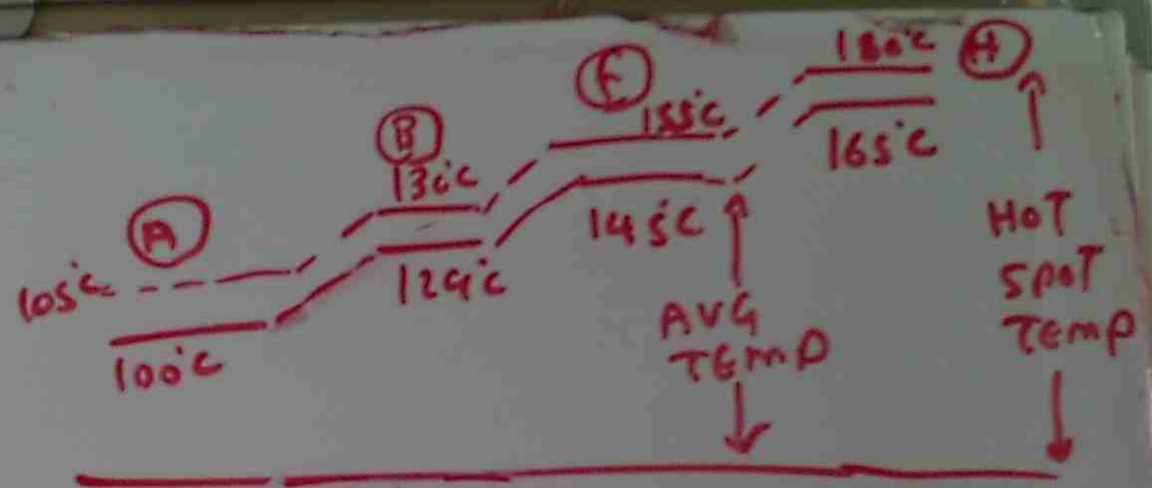
HEAT TRANSFER BY CONDUCTION $= \frac{KA\,(T_2 - T_1)}{d}$



HEAT LOSS BY CONVECTION $P = 3A\,(T_1 - T_2)^{1.25}$

HEAT TAKEN AWAY BY BLOWER $P = 1280\,V\,(t_2 - t_1)$

RADIATION LOSS $P = KA\,(T_1^4 - T_2^4)$



TEMPERATURE RISE BY RESISTANCE METHOD $T_2 = \frac{R_2}{R_1}(234 + t_1) - 234$

RELATION BETWEEN SPEED & SIZE OF MACHINE

HIGHER SPEED ⟶ HIGHER POWER
SIZE CAN BE REDUCED

(19) FORCE ON MOTOR
SLIDE 1 ⟶ 25
Θ 110 ⟶ Θ 123

$$\text{SLIP} = \frac{N_S - N_r}{N_S}$$

N_S = SYNCHRONOUS SPEED $= \frac{120 f}{P}$

N_r = ROTOR SPEED

f = FREQUENCY

P = NO. OF POLES

ROTOR FREQUENCY = SLIP × STATOR FREQUENCY

$$f_r = s \times f_s$$

ROTOR VOLTAGE PER PHASE = SLIP × STATOR VOLTAGE PER PHASE

$$E_r = s\, E_s$$

Ph THE 6 POLE WOUND ROTOR INDUCTION MOTOR IS EXCITED BY 3ϕ 60Hz SOURCE CALCULATE ROTOR FREQUENCY FOR

(a) STAND STILL (b) 500 RPM SAME DIRECTION

(c) 500 RPM OPPOSITE DIRECTION

$$N_S = \frac{120 f}{P} = \frac{120 \times 60}{6} = 1200 \text{ RPM}$$

(a) $s = \frac{N_S - N_r}{N_S} = \frac{1200 - 0}{1200} = 1$, $f_r = s f_s = 1 \times 60 = 60$ Hz

(b) $s = \frac{1200 - 500}{1200} = 0.583$, $f_r = 0.583 \times 60 = 35$ Hz

(c) $s = \frac{1200 - (-500)}{1200} = 1.417$, $f_r = 1.417 \times 60 = 85$ Hz

ESTIMATION OF CURRENT IN INDUCTION MOTOR

$$I = \frac{600\, P_h}{E}$$

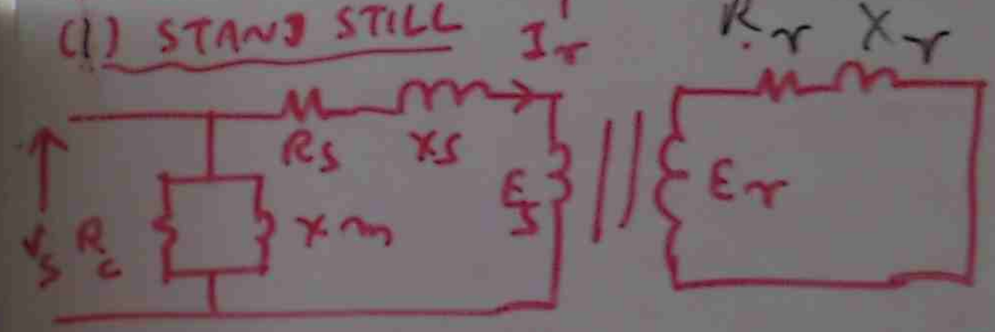
I = full load current

P_h = OUTPUT HORSE POWER

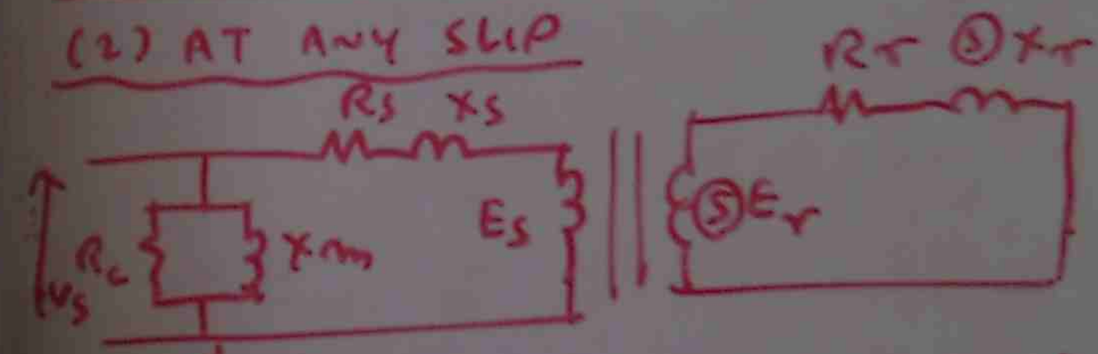
E = RATED LINE VOLTAGE

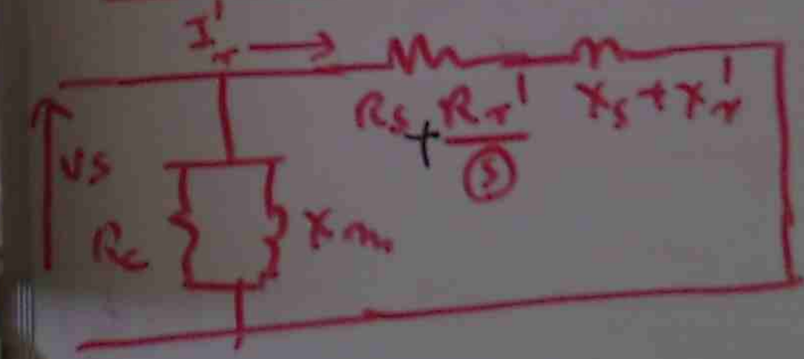
EQUIVALENT CIRCUIT OF INDUCTION MOTOR

(1) STAND STILL



(2) AT ANY SLIP





$$I'_r = \frac{V_s}{\sqrt{\left(R_s + \frac{R'_r}{s}\right)^2 + (X_s + X'_r)^2}}$$

Pb — A 440V, 4 POLE 3ϕ 50Hz SLIP RING MOTOR HAS STATOR Δ, ROTOR Y, STAND STILL VOLTAGE BETWEEN ROTOR SLIP RING IS 218V STATOR RESISTANCE /ph = 0.6Ω, ROTOR RESISTANCE /ph = 0.05Ω, STATOR REACTANCE /ph = 3Ω, ROTOR REACTANCE /ph = 0.25Ω FIND STATOR CURRENT



$$K_s = \frac{E_s(ph)}{E_r(ph)} = \frac{440}{218/\sqrt{3}} = 3.49$$

$$\frac{R_r'}{(s)} = K_s^2 \times \frac{R_r}{(s)} = 3.49^2 \times \frac{0.05}{1} = 0.609$$

$$X_r' = K_s^2 \times X_r = 3.49^2 \times 0.25 = 3.045$$

$$I_r' = \frac{V_s}{\sqrt{\left(R_s + \frac{R_r'}{(s)}\right)^2 + (X_s + X_r')^2}}$$

$$= \frac{440}{\sqrt{(0.6+0.609)^2 + (3+3.045)^2}} = 71.42 \text{ Amp}$$

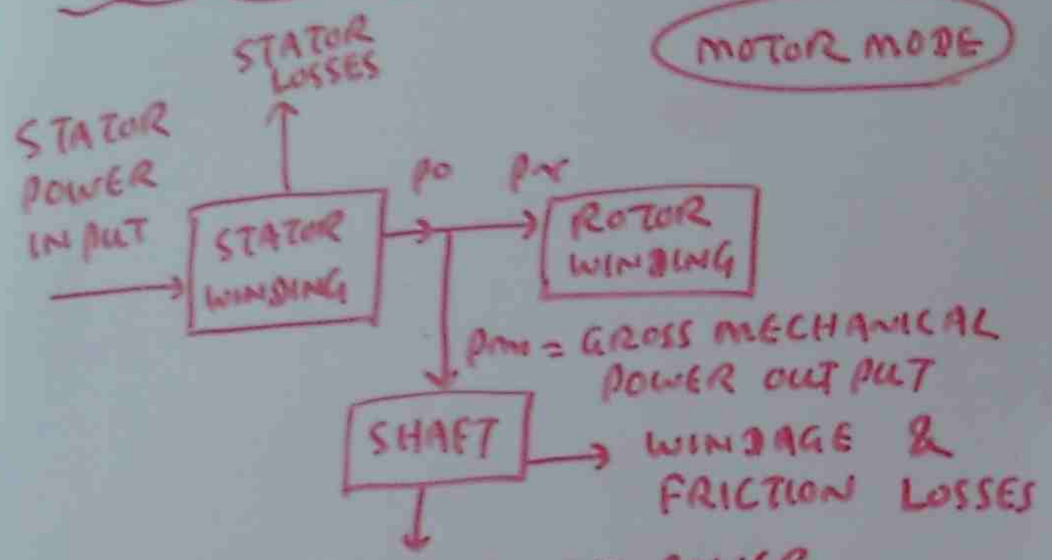
$$PF = \cos\tan^{-1}\frac{X_s + X_r'}{R_s + \frac{R_r'}{(s)}}$$

$$= \cos\tan^{-1}\frac{3+3.045}{0.6+0.609}$$

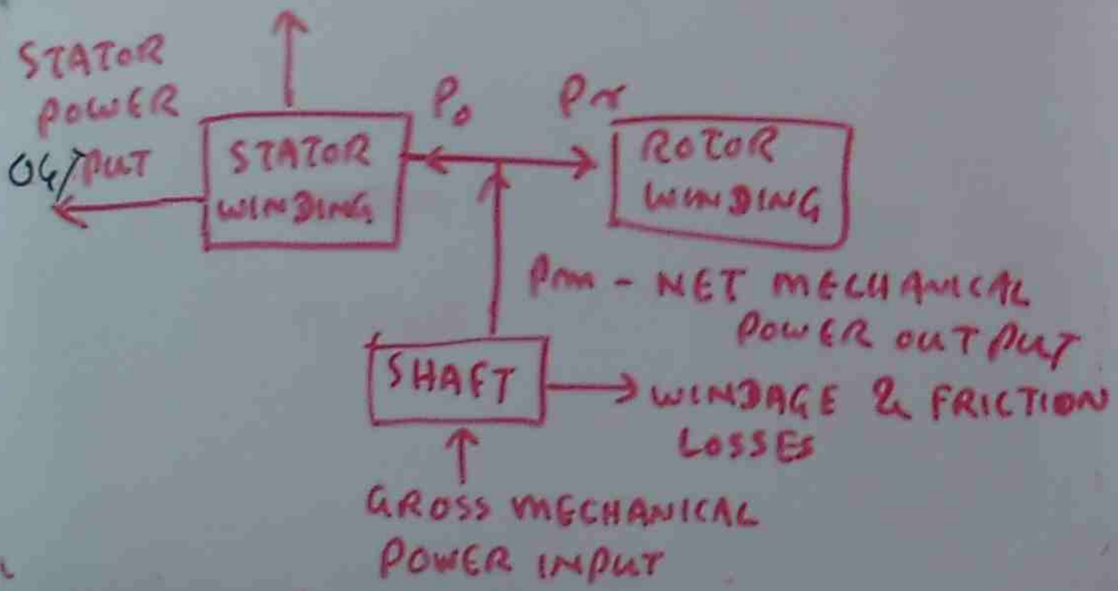
$$= 0.196$$

POWER TRANSFER IN INDUCTION MOTOR

MOTOR MODE



GENERATOR MODE



POWER ABSORBED BY STATOR WINDING $\Rightarrow P_o = 3 E_s I'_r \cos\phi_r$

POWER DISSIPATED IN ROTOR CIRCUIT $\Rightarrow 3\,(s)\, E_r I_r \cos\phi_r$

MECHANICAL POWER $(P_m) = P_o - P_r$
$= (1-s)\, P_o$

POWER DISSIPATED IN ROTOR RESISTANCE $= 3 I_r^2 R_r \left(\frac{1-s}{s}\right)$

ROTOR CIRCUIT POWER LOSS $= 3 (I'_r)^2 R'_r$

POWER ABSORBED BY IDEAL STATOR WINDING $= 3 (I'_r)^2 \frac{R'_r}{s}$

GROSS MECHANICAL POWER OUTPUT $= P_m = 3 (I'_r)^2 R_r \frac{(1-s)}{s}$

GROSS TORQUE DEVELOPED $= T = \frac{3}{2\pi n_r} (I'_r)^2 R'_r \frac{1-s}{s}$

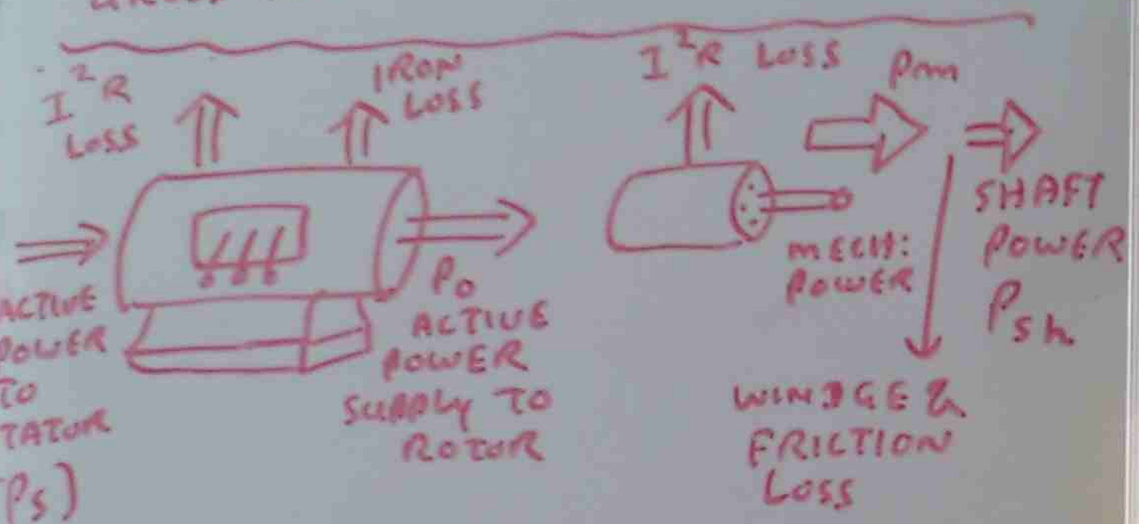
$N_r = (1-s) N_s$

(4) WOUND ROTOR motor SLIDE (9)

$T = \frac{3 V_s^2}{2\pi n_0} \times \frac{s R'_r}{(R'_r)^2 + s^2 (X'_r)^2}$ (MAX. TORQUE)

$s_m = \frac{R'_r}{\sqrt{R_s^2 + (X_s + X'_r)^2}}$ (MAX SLIP)

CALCULATION OF AIRGAP POWER, LOSSES, GROSS AND NET TORQUE



I^2R Loss = SLIP × ACTIVE POWER TRANSMITTED TO ROTOR = SLIP × P_o

MECHANICAL POWER DEVELOPED BY MOTOR (P_m) = ACTIVE POWER TO ROTOR − ROTOR I^2R LOSS

$= P_o - (s) P_o$

$P_m = (1-(s)) P_o$

MECHANICAL TORQUE $(T_m) = \dfrac{P_m \times 9.55}{(1-(s)) \times n_s}$

$n_s = \dfrac{f}{P/2}$

Ex: A 3ϕ INDUCTION MOTOR HAVING A SYNCHRONOUS SPEED OF 1200 RPM DRAWS 80 KW FROM A 3ϕ FEEDER. COPPER LOSS AND IRON LOSS IS 5 KW. IF THE MOTOR RUNS AT 1152 RPM. CALCULATE (a) ACTIVE POWER TO ROTOR (b) ROTOR I^2R LOSS (c) MECHANICAL POWER DEVELOPED (d) MECHANICAL POWER TO LOAD (e) EFFICIENCY

WINDAGE LOSS = 2 KW

(a) P_o = P_s − IRON + I^2R LOSS

$= 80 - 5 = 75$ KW

SLIP = $\dfrac{N_s - N_r}{N_s} = \dfrac{1200 - 1152}{1200} = 0.04$

(b) ROTOR I^2R LOSS = (s) × P_o = 0.04 × 75 = 3 KW

(c) MECHANICAL POWER DEVELOPED = $(1-(s))\, P_o$

$= (1 - 0.04) \times 75 = 72$ KW

(d) MECHANICAL POWER TO LOAD = MECHANICAL POWER DEVELOPED − WINDAGE & FRICTION LOSS

$= 72 - 2 = 70$ KW

(e) EFFICIENCY = $\dfrac{\text{MECH: POWER TO LOAD}}{\text{INPUT POWER}} \times 100$

$= \dfrac{70}{80} \times 100 = 87.5\%$

(1) AC MACHINE INTRODUCTION

SLIDE 1 ⟶ 12 , Q1 → Q5

(2) INDUCTION MOTOR

SLIDE 1 ⟶ 10, Q6 ⟶ Q11

(3) MOTOR EQUIVALENT CIRCUIT

SLIDE 1+2 Q 12

(4) WOUND ROTOR MOTOR

SLIDE 1+2, Q 13 ⟶ 25

(5) TORQUE + MOTOR TEST

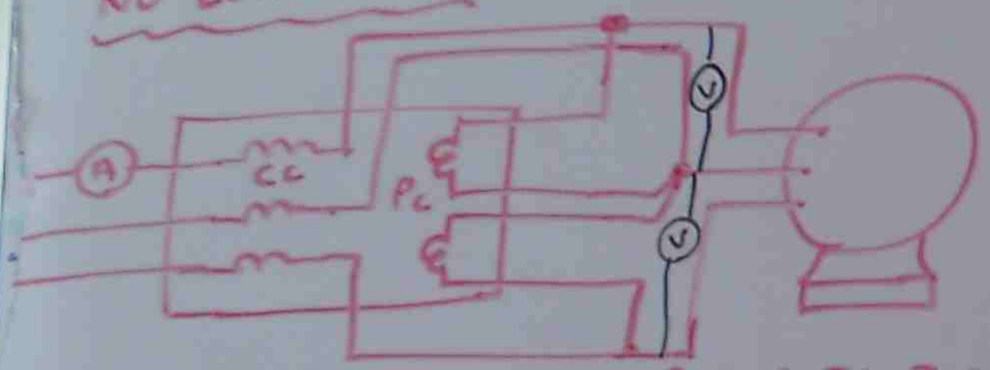
SLIDE 1 , Q 26+27

(6) SYNCHRONOUS SPEED + POWER OF MOTOR

SLIDE 1 ⟶ 4 Q 28 → 30

TEST TO DETERMINE THE EQUIVALENT CIRCUITS

NO LOAD TEST



C_c - CURRENT COIL, P_c - POTENTIAL COIL

E_{NL} - RATED LINE TO LINE VOLTAGE

I_{NL} - NO LOAD CURRENT

Q_{NL} - REACTIVE POWER

S_{NL} - APPARENT POWER

$$S_{NL} = \sqrt{3}\, E_{NL}\, I_{NL}$$

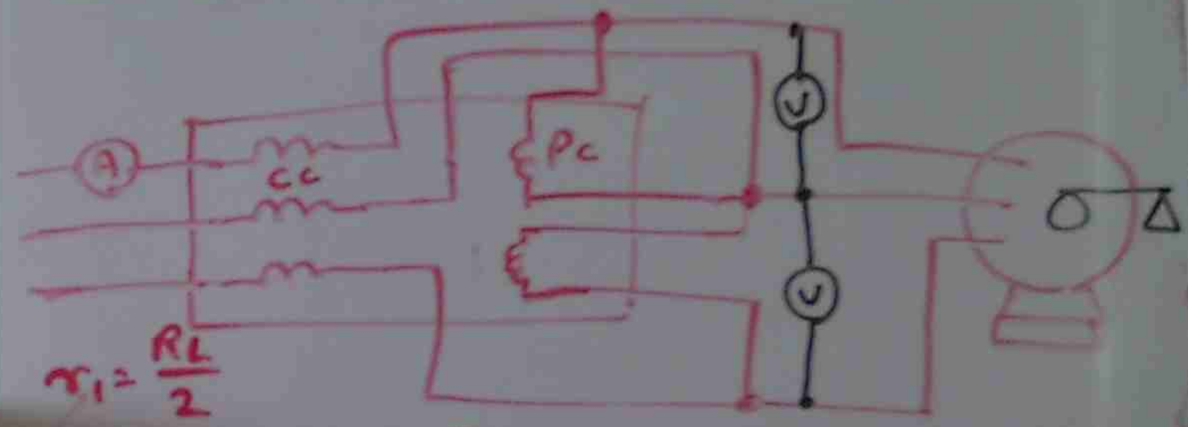
$$Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2}$$

$$R_m = \frac{E_{NL}^2}{\text{WINDAGE} + \text{FRICTION} + \text{IRON LOSS}}$$

$$\text{WINDAGE} + \text{FRICTION} + \text{IRON LOSS} = P_{NL} - 3 I_{NL}^2 r$$

$$X_m = \frac{E_{NL}^2}{Q_{NL}}$$

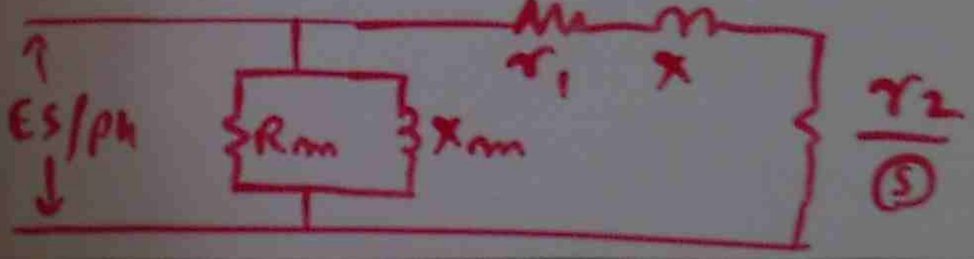
LOCKED ROTOR TEST



$$r_1 = \frac{R_L}{2}$$

$$S_{LF} = \sqrt{3}\, E_{LF}\, I_{LF}, \quad Q_{LF} = \sqrt{S_{LF}^2 - P_{LF}^2}$$

$$X = \frac{Q_{LF}}{3 I_{LF}^2}, \quad r_2 = \frac{P_{LF}}{3 I_{LF}^2} - r_1$$

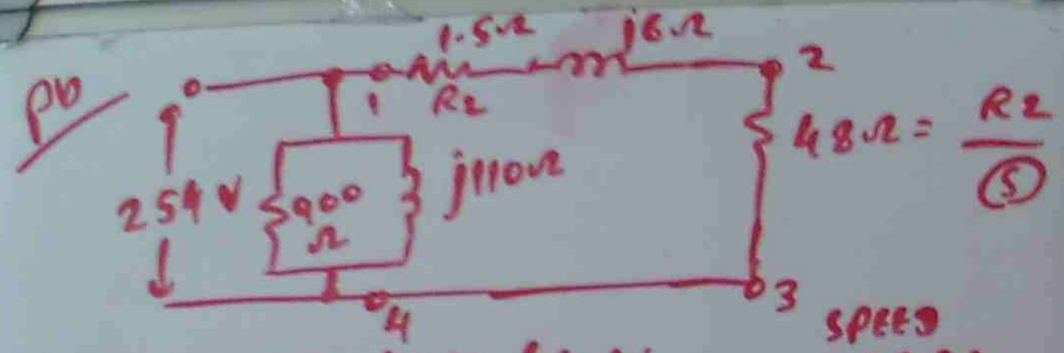


(8) THREE PHASE MOTOR EQUIVALENT CIRCUIT

SLIDE 1 ⟶ 5

Q 33 + Q 34

P10



STATOR COPPER LOSS = 44 W

SPEED = 1854 RPM

CALCULATE (a) ACTIVE POWER DELIVERED TO ROTOR

WINDAGE LOSS 70W

(b) MECHANICAL POWER INPUT TO SHAFT

(c) STATOR POWER INPUT

(d) INPUT LINE CURRENT

(e) SHAFT TORQUE

TOTAL RESISTANCE 1-2-3-4 = 1.5 + 48 = 49.5Ω

$$Z_{1234} = \sqrt{49.5^2 + 6^2} = 49.86\,\Omega$$

$$I_{1234} = \frac{254}{49.86} = 5.09\ \text{Amp}$$

(a) ACTIVE POWER DELIVERED TO ROTOR $= I^2 \frac{R_2}{2(5)}$

$= 5.09 \times 48$

$= 1243.5$ W

I^2R LOSS IN ROTOR $= I^2 R_2 = 5.09^2 \times 1.5 = 38.86$ W

(b) MECHANICAL POWER INPUT TO SHAFT = I^2R LOSS + ACTIVE POWER TO ROTOR

$= 38.86 + 1243.5$

$= 1282.36$ W

STATOR CORE LOSS $= \frac{V^2}{R_m} = \frac{254^2}{900} = 71.68$ W

(c) STATOR POWER INPUT = CORE LOSS + STATOR COPPER LOSS + MECH. POWER TO SHAFT

$= 71.68 + 44 + 1282.36$

$= 1398.04$ W

(d) REACTIVE POWER INPUT $= \frac{V^2}{X_m} = \frac{254^2}{110} = 586$ VAR

TOTAL APPARENT POWER $= \sqrt{\text{ACTIVE POWER}^2 + \text{REACTIVE POWER}^2}$

$= \sqrt{1398.04^2 + 586^2} = 1515.8$ VAR

P.F of MOTOR $= \frac{\text{ACTIVE POWER}}{\text{APPARENT POWER}} = \frac{1398.04}{1515.8} = 0.922$ LAG

SHAFT POWER = ACTIVE POWER TO ROTOR − WINDAGE FRICTION LOSS

$= 1243.5 - 70 = 1173$ W

SHAFT TORQUE $= \frac{9.55 \times \text{POWER}}{N_s} = \frac{9.55 \times 1173}{1854} = 6.04$ N-m

INDUCTION MOTOR CHARACTERISTICS UNDER VARIOUS LOAD CONDITION

$$\frac{S_1 E_1^2}{T_1 R_1} = \frac{S_2 E_2^2}{T_2 R_2} = \frac{S_3 E_3^2}{T_3 R_3}$$

S - SLIP
E - VOLTAGE
T - TORQUE
R - ROTOR RESISTANCE

Pb A 3ϕ 208V INDUCTION MOTOR HAVING SYN: SPEED 1200 RPM, RUNS AT 1140 RPM, WHEN CONNECTED TO 215V. DRIVING CONSTANT LOAD. CALCULATE SPEED IF VOLTAGE IS 240V

$$215V - S_1 = \frac{N_S - N_r}{N_S} = \frac{1200 - 1140}{1200} = 0.05$$

$$\frac{S_1 E_1^2}{T_1 R_1} = \frac{S_2 E_2^2}{T_2 R_2}$$

$$S_1 E_1^2 = S_2 E_2^2$$

$$0.05 \times 215^2 = S_2 \times 240^2$$

$$S_2 = 0.04$$

$$N_2 = (1 - S_2) N_S$$

$$= (1 - 0.04) \times 1200$$

$$= 1152 \text{ RPM}$$

(8) THREE PHASE MOTOR EQUIVALENT CIRCUIT

SLIDE 1 → 32

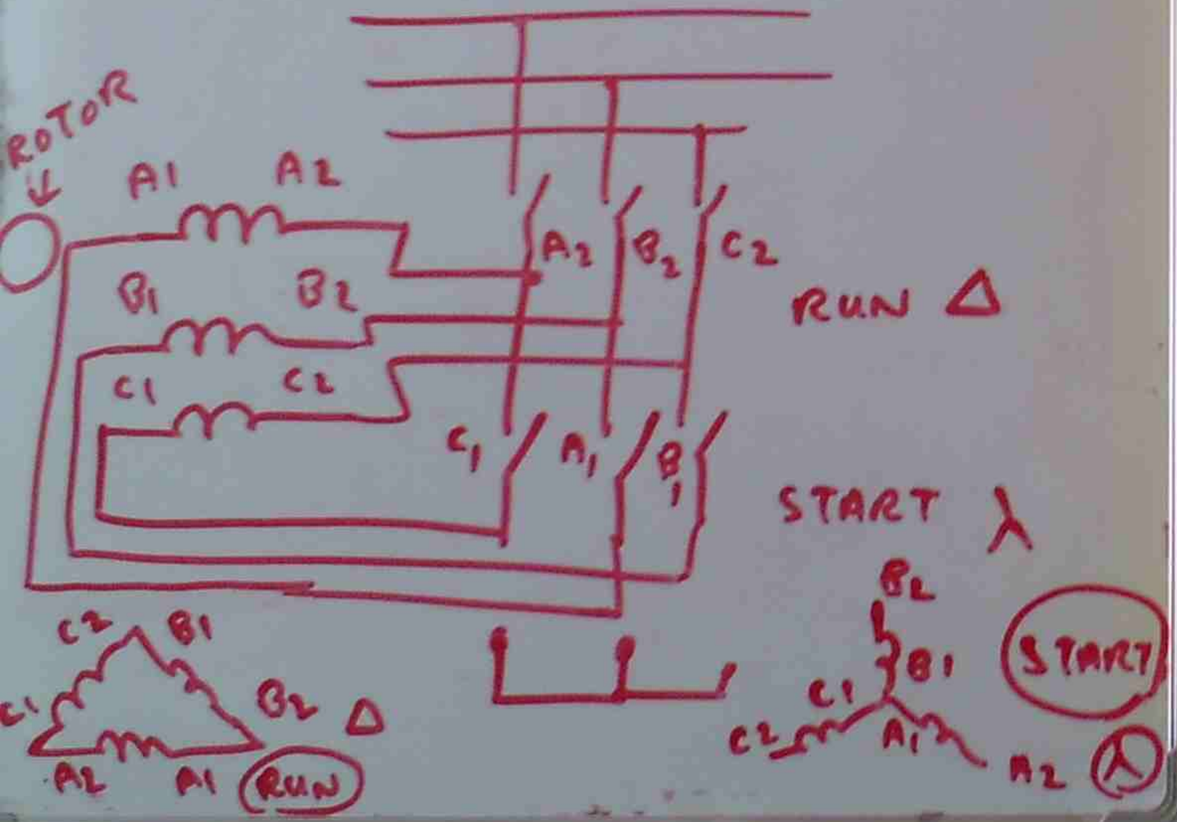
Q 33 → @ 45

REDUCED VOLTAGE STARTING METHODS

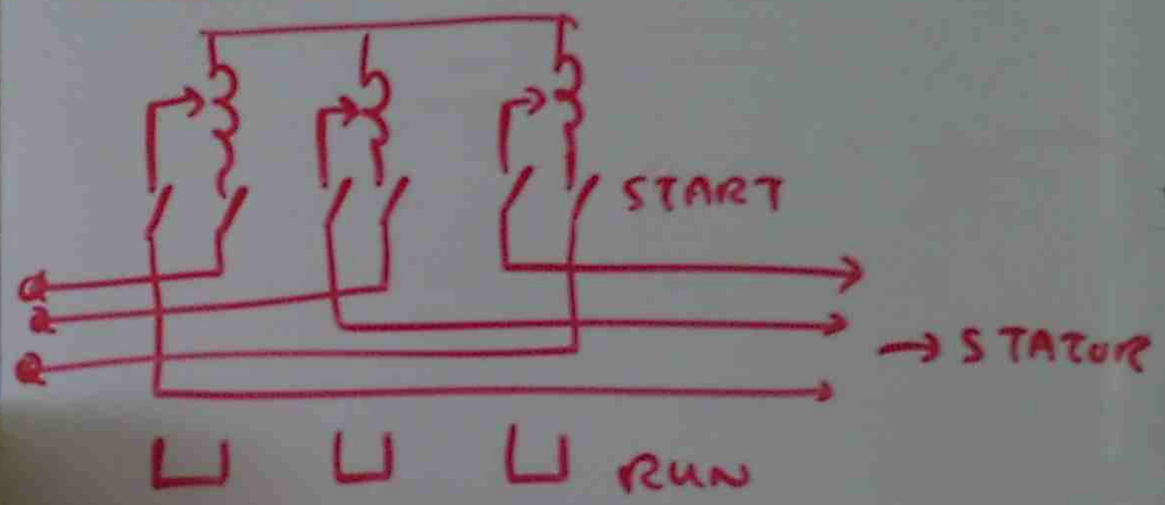
DOL - DIRECT ON LINE STARTING
IT DRAWS LINE CURRENT
4 → 5 TIMES RATED CURRENT

REDUCED VOLTAGE STARTERS

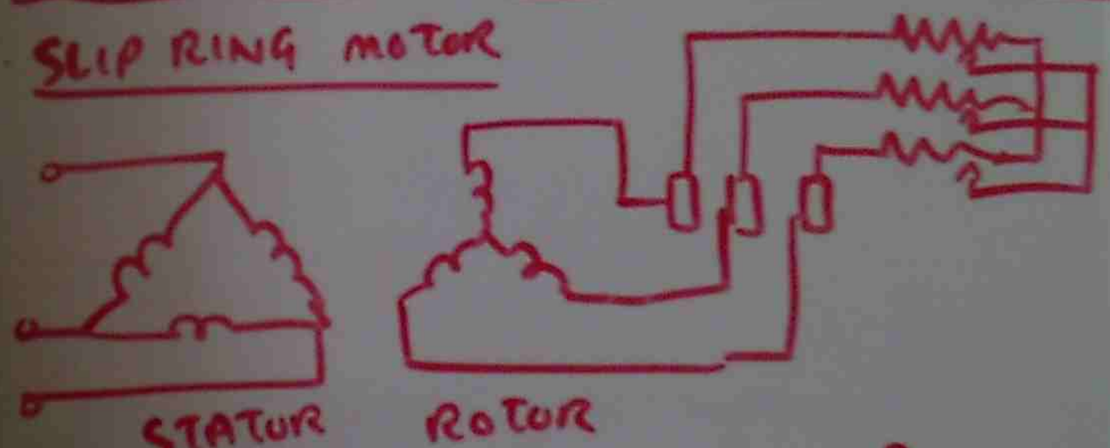
- STAR DELTA STARTING



AUTO TRANSFORMER STARTING



SLIP RING MOTOR



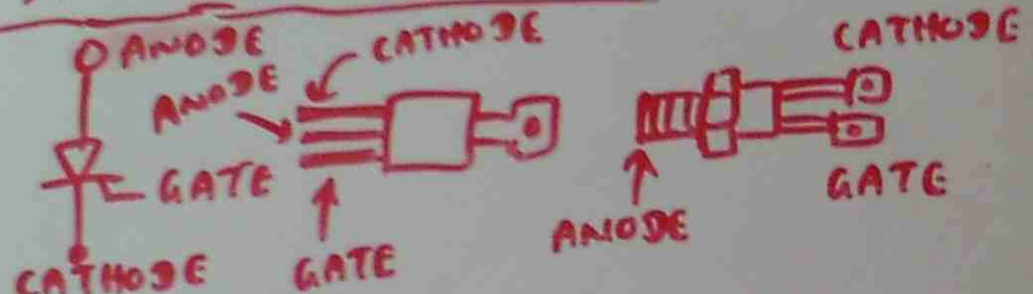
STAR/Δ STARTING

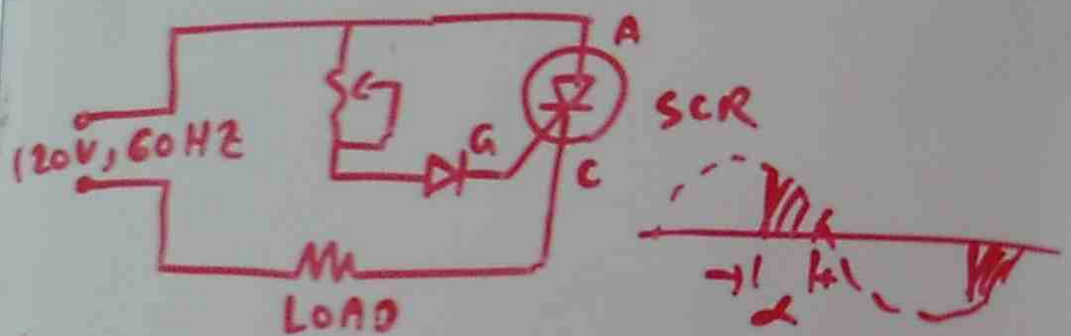
$$T_{\lambda\Delta} = \left(\frac{1}{\sqrt{3}}\right)^2 \times T_{DOL}$$

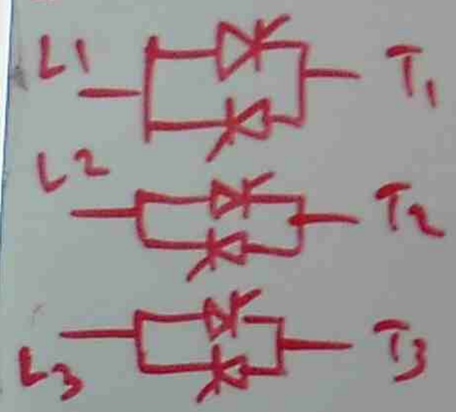
AUTO TRANSFORMER STARTING

$$T_{AUTO} = \left(\%\ TAPPING\right)^2 \times T_{DOL}$$

SOLID STATE CONTROL (SCR)

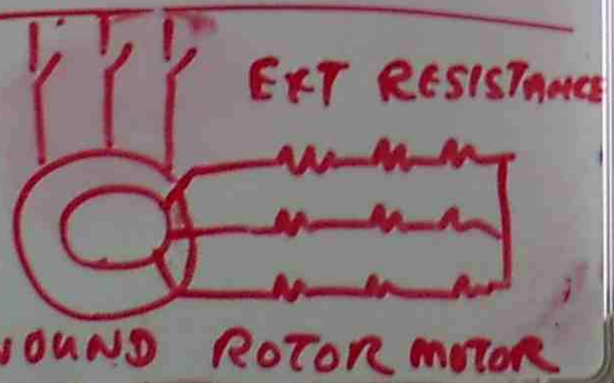




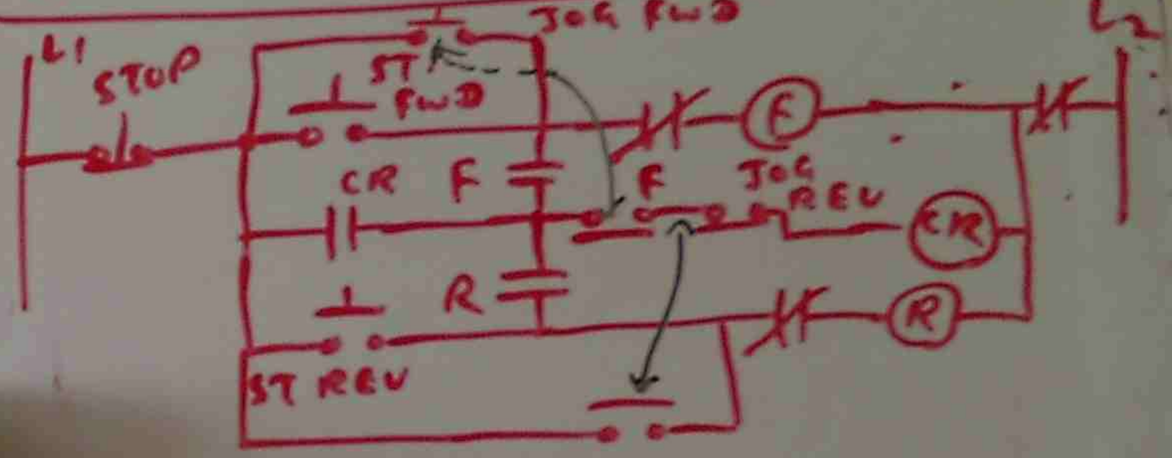


PROTECTION

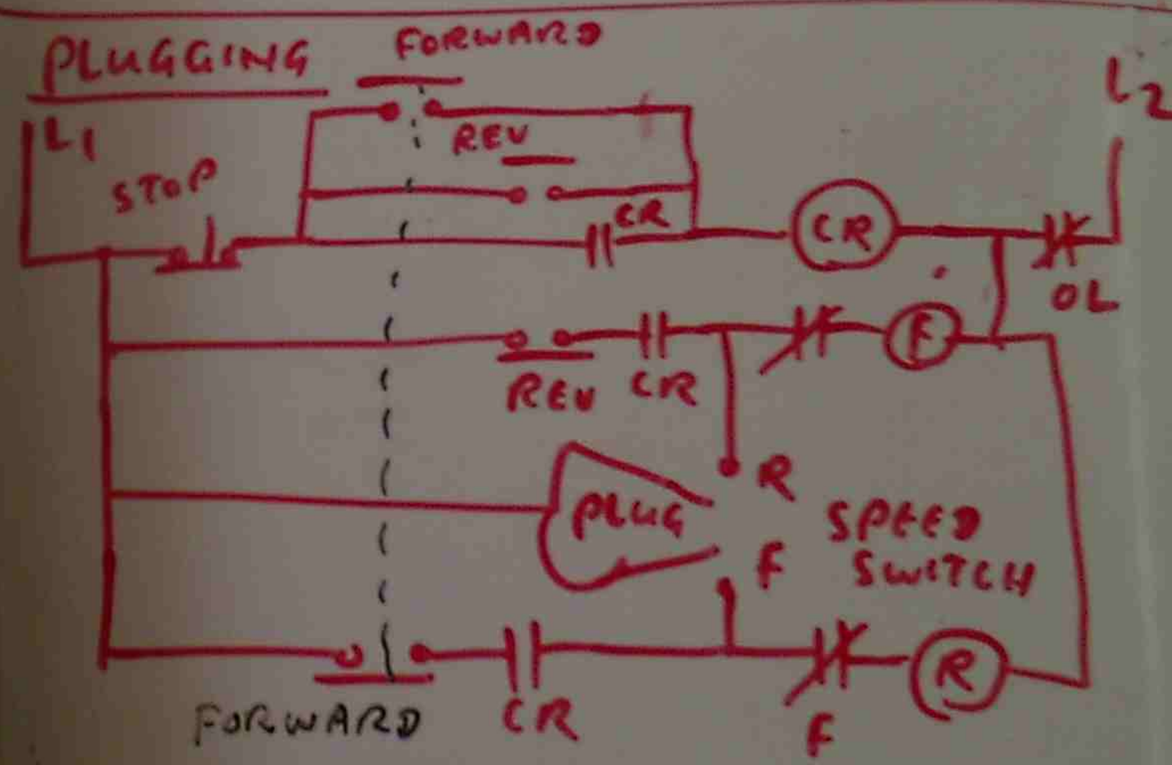
- LOW VOLTAGE
- TIME DELAY
- SURGE



JOGGING USING FORWARD/REVERSE STARTER

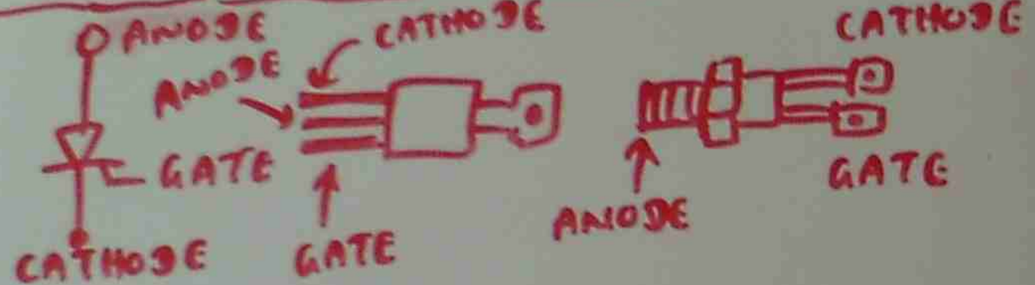


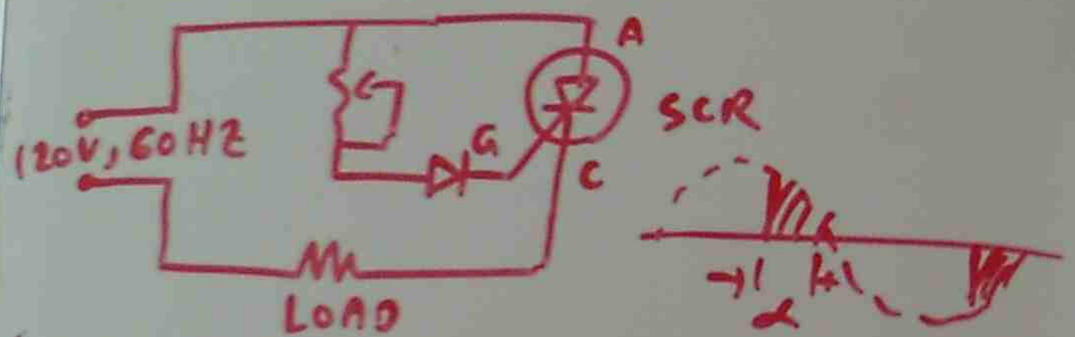
PLUGGING

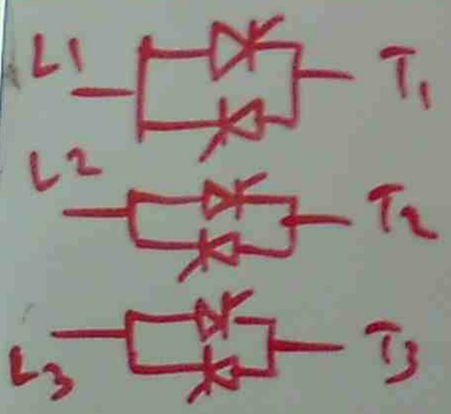


A SYSTEM OF BRAKING IN WHICH THE MOTOR CONNECTIONS ARE REVERSED SO THAT THE MOTOR DEVELOPS A COUNTER TORQUE

SOLID STATE CONTROL (SCR)

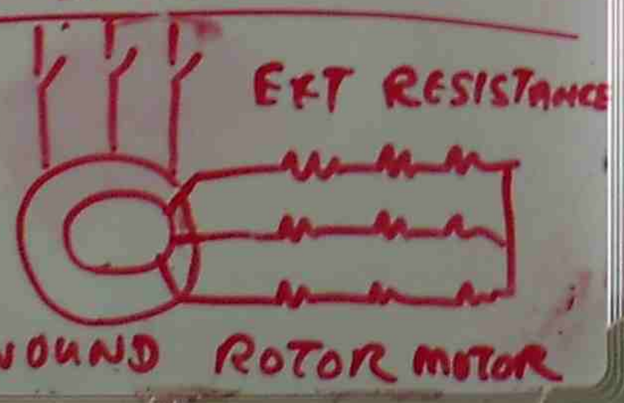




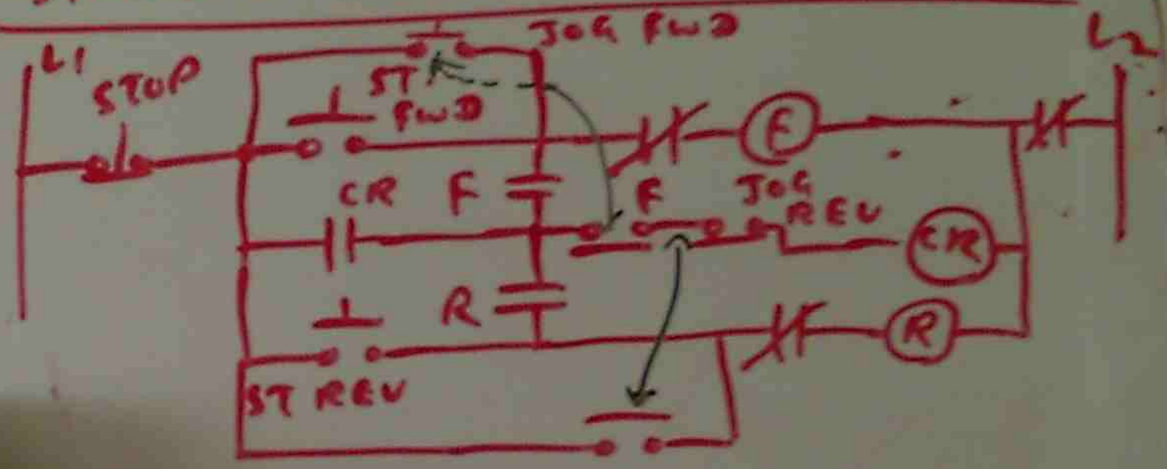


PROTECTION

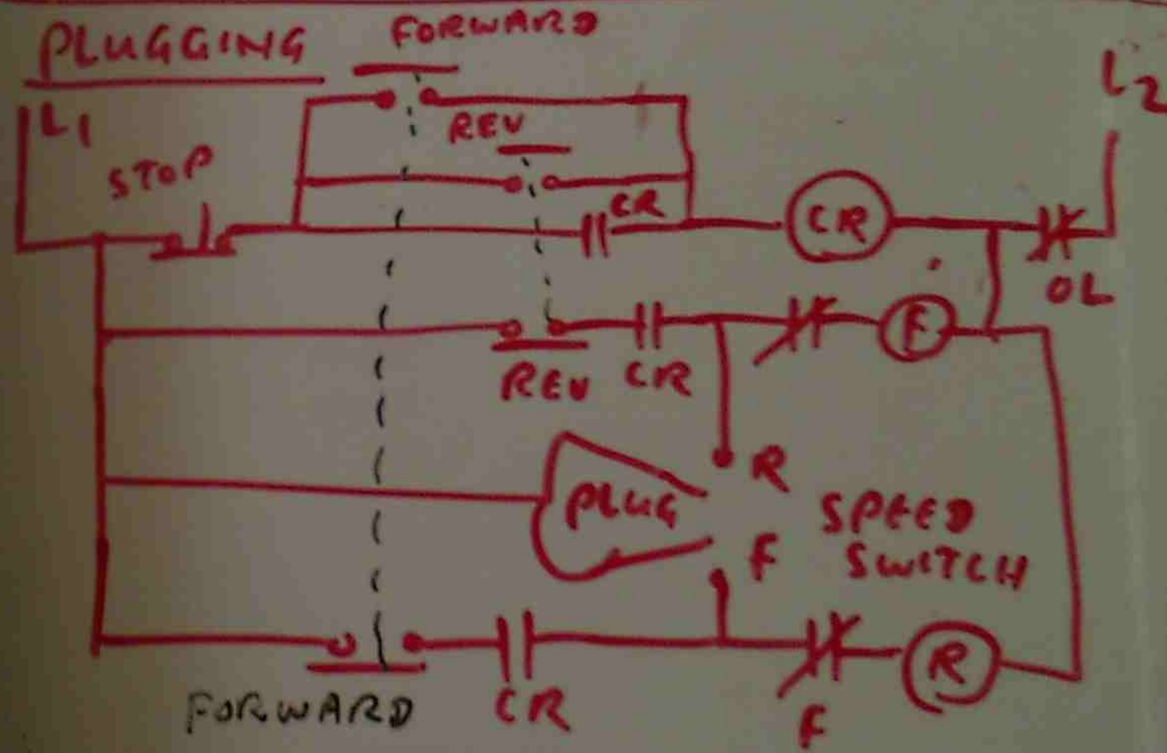
- LOW VOLTAGE
- TIME DELAY
- SURGE



JOGGING USING FORWARD/REVERSE STARTER



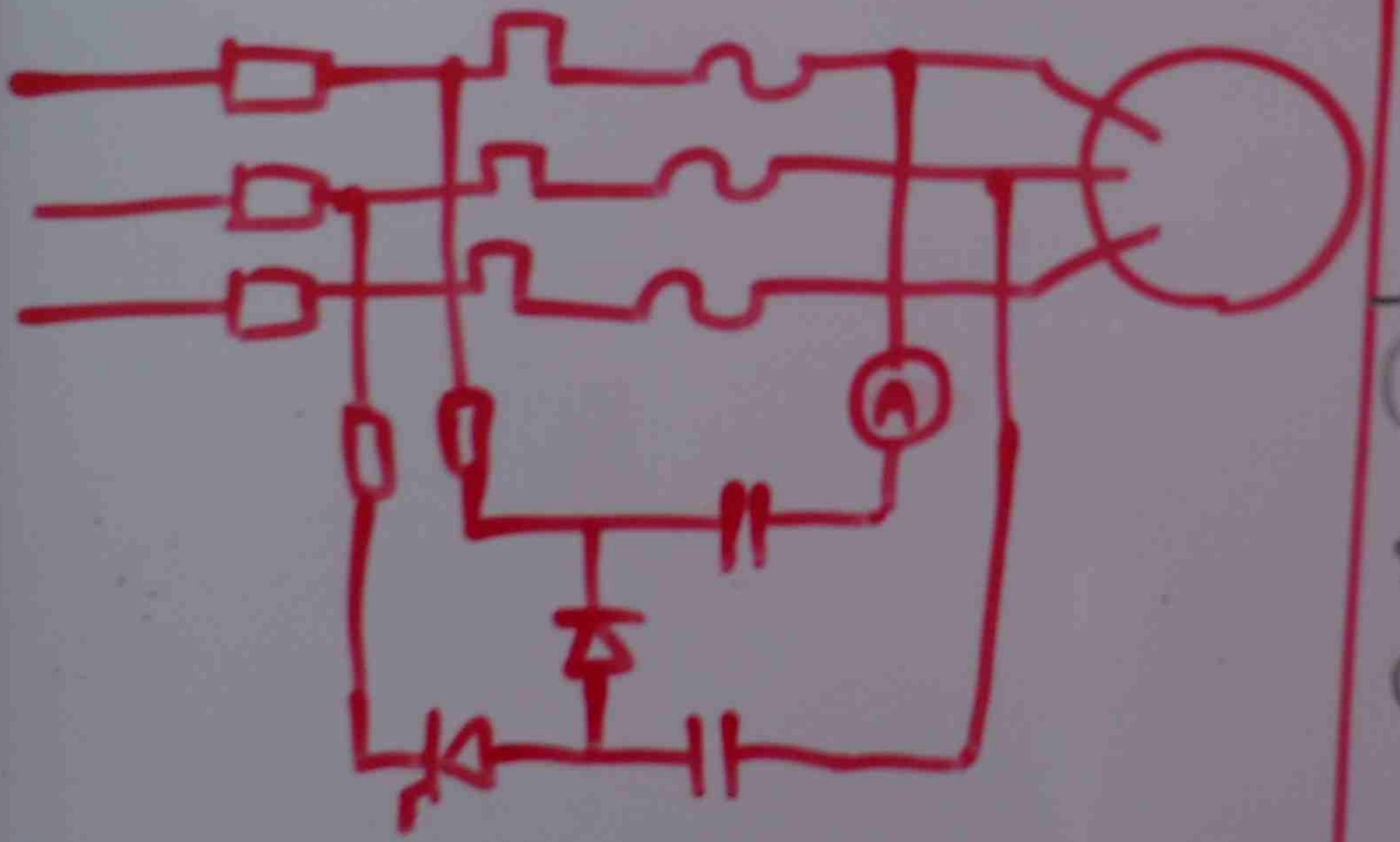
PLUGGING



A SYSTEM OF BRAKING IN WHICH THE MOTOR CONNECTIONS ARE REVERSED SO THAT THE MOTOR DEVELOPS A COUNTER TORQUE.

DYNAMIC BRAKING

DYNAMIC BRAKING OF AN AC INDUCTION MOTOR IS GENERALLY ACCOMPLISHED BY EXCITING IT'S STATOR WINDING WITH DC CURRENT.



OTHER BRAKE

HYDRAULIC BRAKE

(9) REDUCED VOLTAGE STARTING METHOD

SLIDE 1 → 7

Q 46 → 49

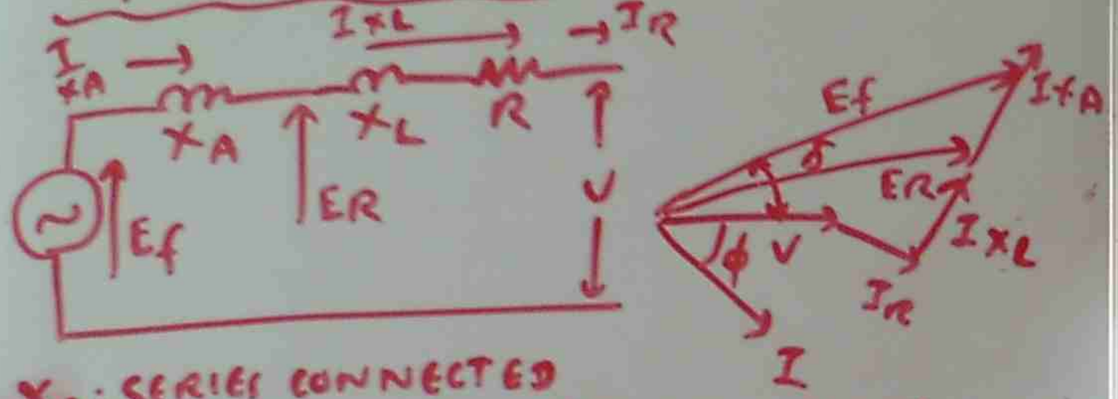
(10) REDUCED VOLTAGE STARTING

SLIDE 1 → 28

Q 50 → 63

SYNCHRONOUS MACHINES

SYNCHRONOUS GENERATOR



X_A: SERIES CONNECTED REACTANCE OF VOLTAGE WINDING

X_L - LEAKAGE REACTANCE OF VOLTAGE WINDING

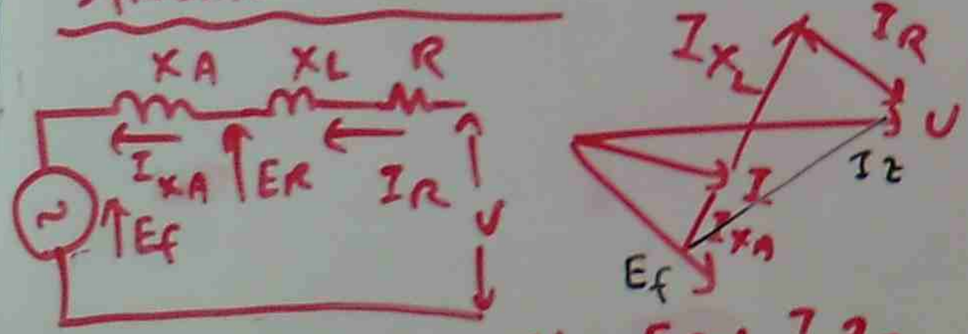
R - RESISTANCE OF VOLTAGE WINDING

V - TERMINAL VOLTAGE, E_f - GENERATED VOLTAGE

$$E_f = V + I Z_s = V + I (R + j(X_L + X_A))$$

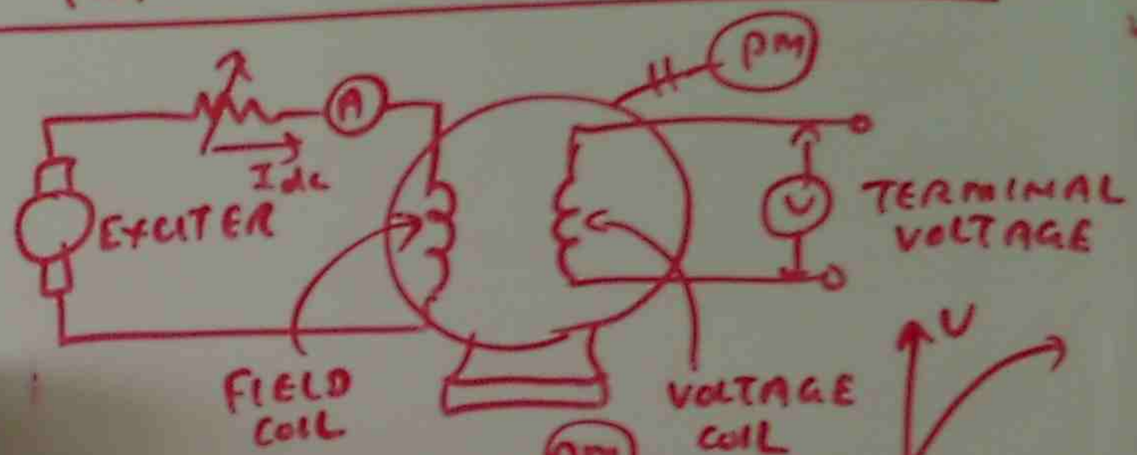
$$Z_s = R + j(X_L + X_A)$$

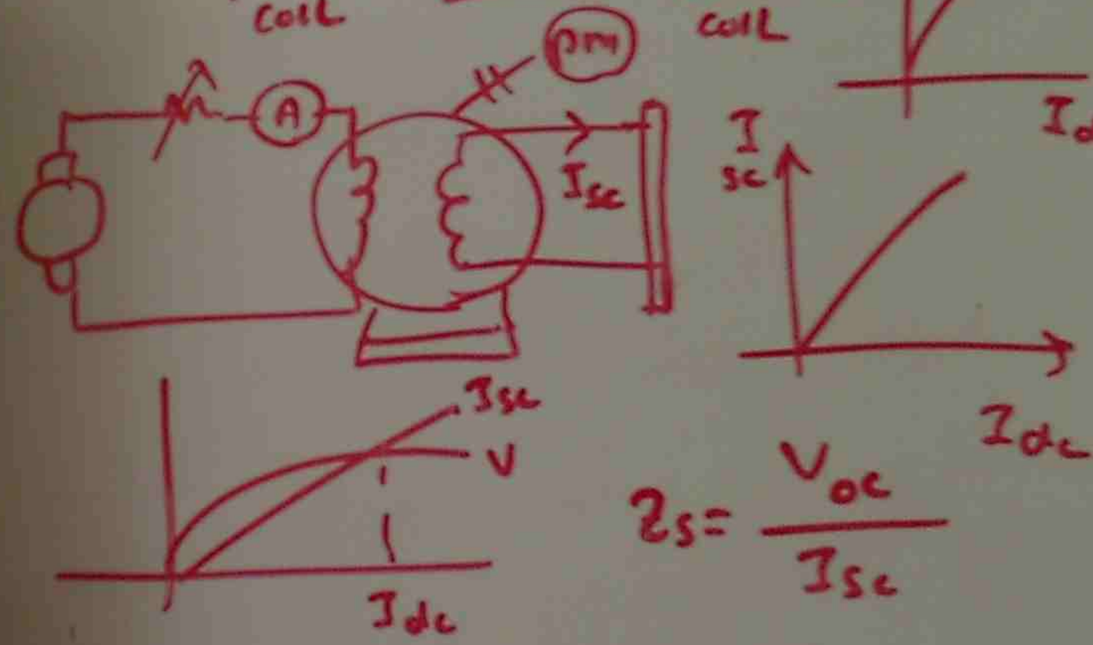
SYNCHRONOUS MOTOR



$$V = E_f + I Z_s$$

DETERMINATION of SYNCHRONOUS IMPEDANCE





$$Z_s = \frac{V_{oc}}{I_{sc}}$$

$$Z_s = \frac{E_f - V}{I}$$

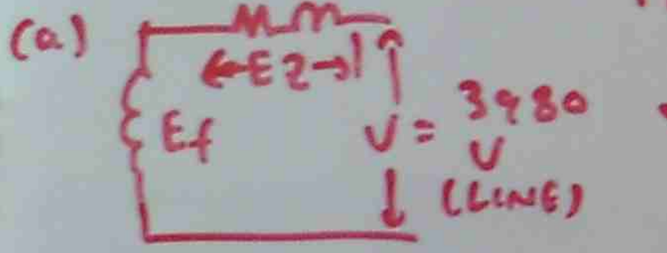
$$\text{VOLTAGE REGULATION} = \frac{E_f - V}{V} \times 100\ \%$$

Pb A 500 HP, 720 RPM SYNCHRONOUS MOTOR CONNECTED TO A 3980 V 3φ LINE GENERATES AN EXCITATION VOLTAGE E_f OF 1790 V (L-N) WHEN THE DC EXCITATION CURRENT IS 25 A. THE SYNCHRONOUS REACTANCE IS 22Ω AND THE TORQUE ANGLE BETWEEN E_f & V IS 30°.

CALCULATE (a) THE VALUE of IMPEDANCE DROP (b) AC LINE CURRENT (c) P.F (d) HP (e) TORQUE

$$P_{phase} = \frac{3980}{\sqrt{3}} = 2300 \text{ V}$$

(a)



$$V = E_f + E$$

$$2300 = 1790\angle -30 + E$$

$$\therefore E = 2300 - 1790\angle -30$$

$$= 2300 - 1790(\cos 30 - j\sin 30)$$

$$= 750 + j895 = \sqrt{750^2 + 895^2}\angle \tan^{-1}\frac{895}{750}$$

(b)

$$I = \frac{E_z}{z} = \frac{1168\angle 50}{22\angle 90} = 53\angle -40^\circ \text{ A}$$

(c) $pf = \cos 40 = 0.766$ LAGGING

(d)

$$HP = \frac{3EI\cos\theta}{746} = \frac{3 \times 2300 \times 53 \times 0.766}{746}$$

$$= \frac{280142}{746} = 375 \text{ HP}$$

(e)

$$\text{TORQUE} = \frac{9.55 \times P}{n} = \frac{9.55 \times 280142}{720}$$

$$= 3715 \text{ N-m}$$

POWER & TORQUE

$$P = \frac{E_f \times V}{X_s}\sin\delta$$

$$\delta = \frac{P\alpha}{2}$$

δ = ELECTRICAL ANGLE, P = NO. OF POLE, α = MECHANICAL ANGLE

P - MECHANICAL POWER / PH

V = LINE TO NEUTRAL VOLTAGE

X_s = SYNCHRONOUS REACTANCE

Pb A 3φ 6000 KW, 4 KV, 180 RPM 60 HZ MOTOR HAS $X_s = 1.2\Omega$ MECHANICAL ANGLE IS 1 DEGREE. $E_f = 2.4$ KV. CALCULATE MECHANICAL POWER

$$P = \frac{120f}{N_s} = \frac{120 \times 60}{180} = 40$$

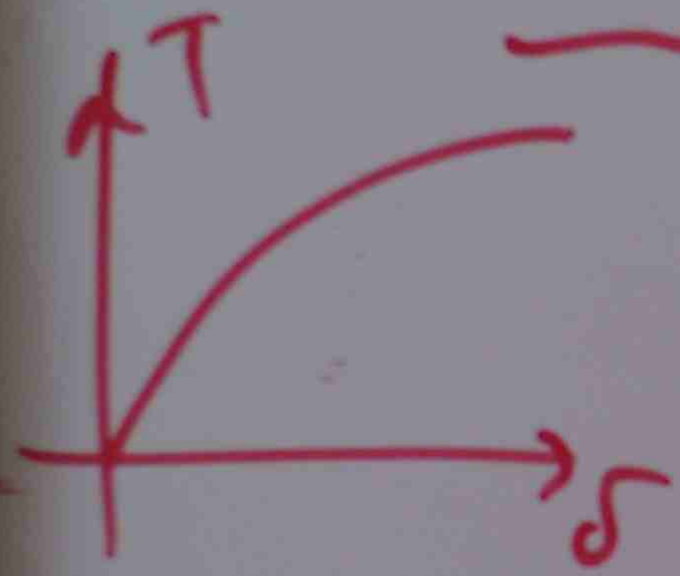
$$\delta = \frac{P\alpha}{2} = \frac{40 \times 1}{2} = 20$$

$$V = \frac{4 \text{ KV}}{\sqrt{3}} = 2.3 \text{ KV}$$

$$P = \frac{E_f V}{X_s}\sin\delta = \frac{2.3 \times 2.4}{1.2}\sin 20$$

$$3\phi \text{ HP} = \frac{3 \times 1573}{0.746} = 6300 \text{ HP}$$

OSCILLATION OF SYNCHRONOUS MACHINES



$$J\frac{d^2\delta}{dt^2} = -T_y\,\delta^2$$

J = MOMENT OF INERTIA OF ROTATING SYSTEM ($kg\text{-}m^2$)

T_y = SYNCHRONIZING TORQUE COEFFICIENT

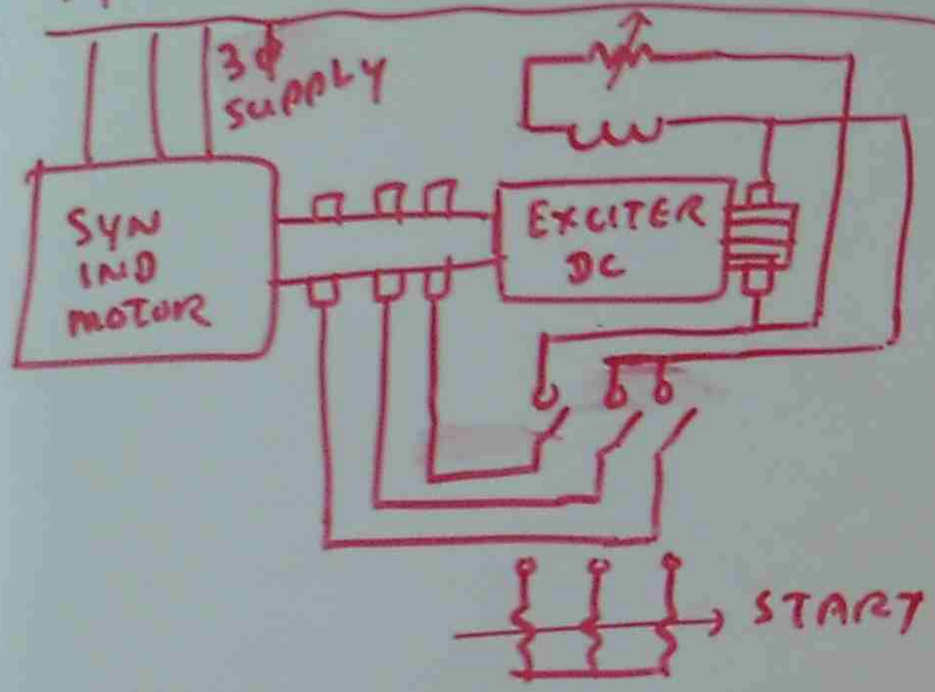
δ = COUPLING ANGLE $\quad f = \frac{1}{2\pi}\sqrt{T_y/J}$

f = FREQUENCY of OSCILLATION

HUNTING — VARIATION IN SPEED DUE TO CHANGE IN DRIVING TORQUE

(11) SYNCHRONOUS MACHINE	(12) SYNCHRONOUS GENERATOR	(13) EFFECT OF FIELD EXCITATION
SLIDE 1 → 6	SLIDE 1+2	SLIDE 1 → 10
@ 64 → 65	@ 66+67	@ 68 → 70

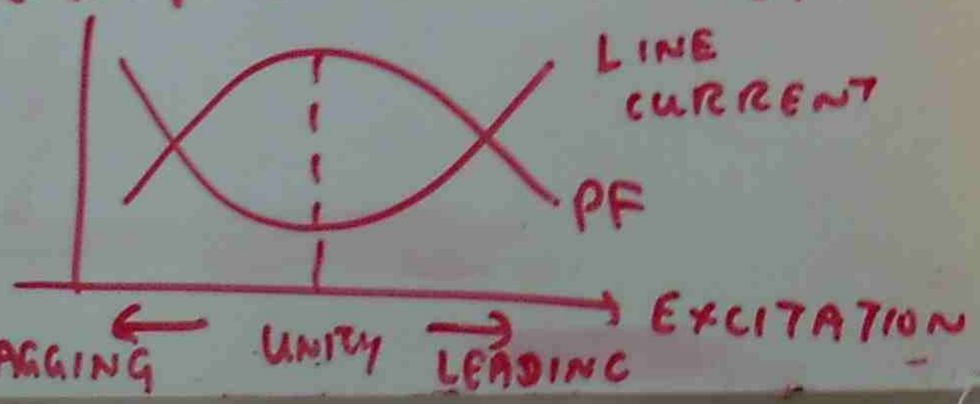
SYNCHRONOUS INDUCTION MOTOR



SYNCHRONOUS MOTOR – NO SELF STARTING TORQUE

(1) START BY SMALL DC MOTOR

(2) SQUIRREL CAGE BAR INSERTED IN ROTOR POLE . INDUCTION STARTING



pb A SYNCHRONOUS CAPACITOR RATED AT 160 MUAR, 16 KV, 1200 RPM IT HAS SYNCHRONOUS REACTANCE 0.8 Pu AND IS CONNECTED TO 16 KV LINE. CALCULATE THE VALUE of E_f SO THAT THE MACHINE (a) ABSORBS 160 MUAR (b) DELIVERS 120 MUAR

NOMINAL IMPEDANCE $Z_s = \frac{E^2}{S} = \frac{16000^2}{160 \times 10^6}$

$X_s = 0.8\ Pu = 0.8 \times 1.6 = 1.28\ \Omega$ $= 1.6\ \Omega$

TO ABSORB 160 MUAR

$V = \frac{16000}{\sqrt{3}} = 9250\ V$, $I = \frac{S}{\sqrt{3}E} = \frac{160 \times 10^6}{1.7321 \times 16 \times 10^3} = 5780\ A$

$E_f = V - IZ_s$

TO ABSORB (I) LAG (E) BY 90°

$E_f = V - IZ = 9250 \angle 0 - 5780 \angle -90 \times 1.28 \angle 90$

$= 1850 \angle 0\ V$

TO DELIVER 120 MUAR

$I = \frac{S}{\sqrt{3}E} = \frac{120 \times 10^6}{\sqrt{3} \times 16 \times 10^3} = 4335 \angle +90$

$E_f = 9250 \angle 0 - 4335 \angle 90 \times 1.28 \angle 90$

$= 9250 \angle 0 - 5550 \angle 180$

$= 9250 - 5550(\cos 180 + j \sin 180)$

$= 11480\ V = 11.48\ kV$

(13) EFFECT of FIELD EXCITATION

SLIDE 1 ⟶ 10

@ 68 ⟶ @ 71

(14) OSCILLATION of SYNCHRONOUS MACHINES

SLIDE 1 ⟶ 12

@ 72 ⟶ @ 76

(15) GENERATOR CONTROL

SLIDE 1 ⟶ 24

@ 77 ⟶ @ 87

(17) SYNCHRONOUS IMPEDANCE

SLIDE 1 ⟶ 17 @ 95 ⟶ @ 104

(13) EFFECT of FIELD EXCITATION

SLIDE 1 ⟶ 10

@ 68 → @ 71

(14) OSCILLATION of SYNCHRONOUS MACHINES

SLIDE 1 ⟶ 12

@ 72 ⟶ @ 76

(15) GENERATOR CONTROL

SLIDE 1 ⟶ 24

@ 77 ⟶ @ 87

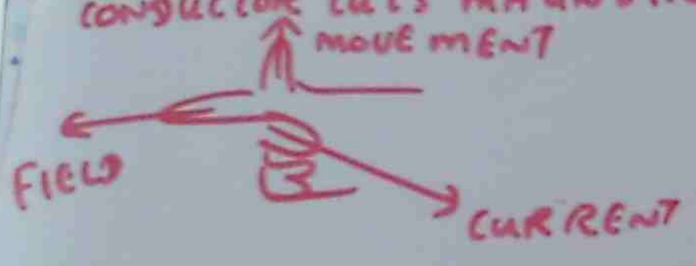
(17) SYNCHRONOUS IMPEDANCE

SLIDE 1 ⟶ 17 @ 95 → @ 104

DC MACHINE PRINCIPLE

GENERATOR ACTION

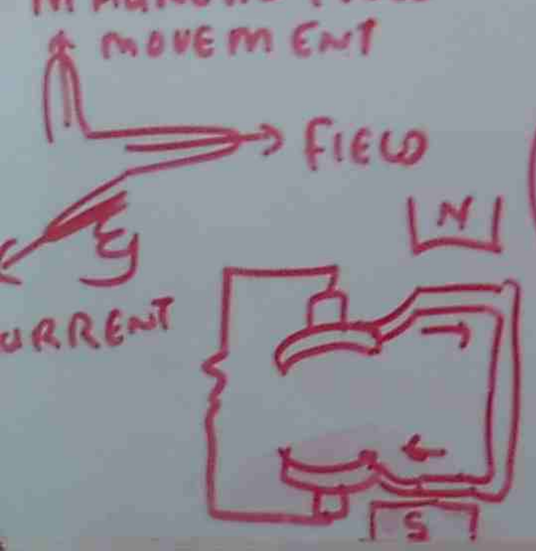
AN EMF IS INDUCED IN A CONDUCTOR WHEN THE CONDUCTOR IN SUCH A DIRECTION RELATIVE TO A MAGNETIC FIELD THAT THE CONDUCTOR CUTS MAGNETIC FIELD

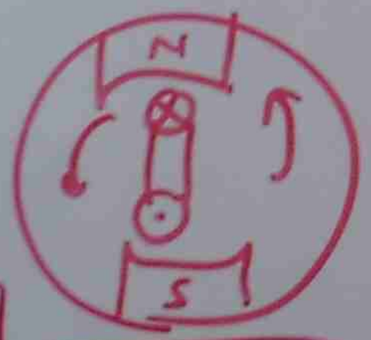




MOTOR ACTION

MOTOR ACTION IS BASED UPON THE FACT THAT A MECHANICAL FORCE IS EXERTED ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD





$e = BLV$

VOLT

L = COIL LENGTH

B = FIELD FLUX DENSITY

V = VELOCITY

$P = BLV \times I$

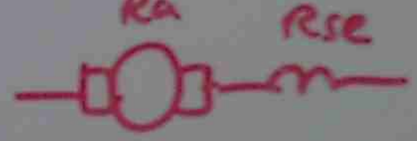
PARTS of DC MACHINE

YOKE, MAIN POLE, INTERPOLE, ARMATURE CORE, COMMUTATOR, BRUSH, BRUSH HOLDER ROCKER ARM,

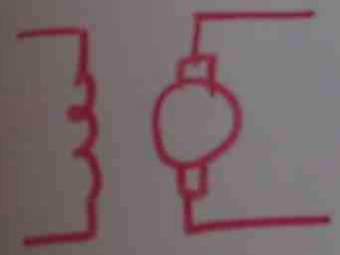
CONNECTION of DC MACHINE



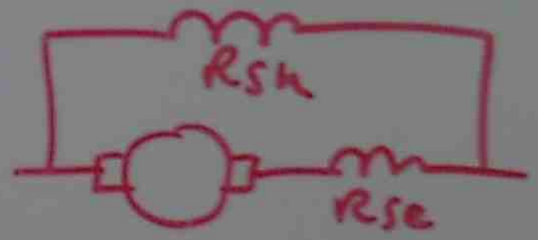
SHUNT CONNECTION



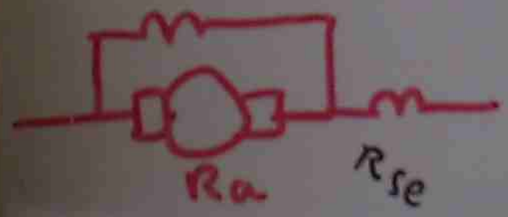
SERIES CONNECTION



SEPARATELY EXCITED

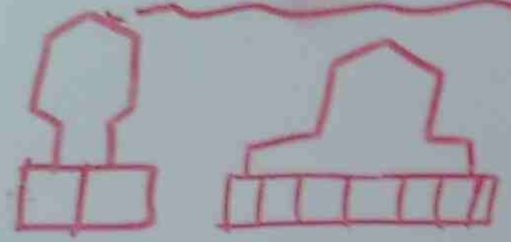


LONG SHUNT COMPOUND



SHORT SHUNT COMPOUND

TYPES of DC WINDINGS



LAP WAVE

$Y_S = \frac{S}{P} - K$ (LAP)

Y_S = COIL SPAN
P = NO. of POLE
S = NO. of SLOTS

$a = m \times P$ (LAP)

a = NO. of ARMATURE PARALLEL PATHS
m = PLEX NO.
SIMPLEX m = 1
DUPLEX m = 2

$Y_C = \frac{C \pm m}{P/2}$

C = NO. of COMMUTATOR
m = PLEX NO
P = NO. of POLE
Y_C = COMMUTATOR PITCH

$a = 2 \times m$ (WAVE)

Pb CALCULATE COIL SPAN FOR
(a) 36 SLOT, 4 POLE LAP
(b) 36 COIL, 2 POLE DUPLEX WAVE

(a) $Y_S = \frac{S}{P} - K = \frac{36}{4} - 0 = 9$ $1 \rightarrow 10$

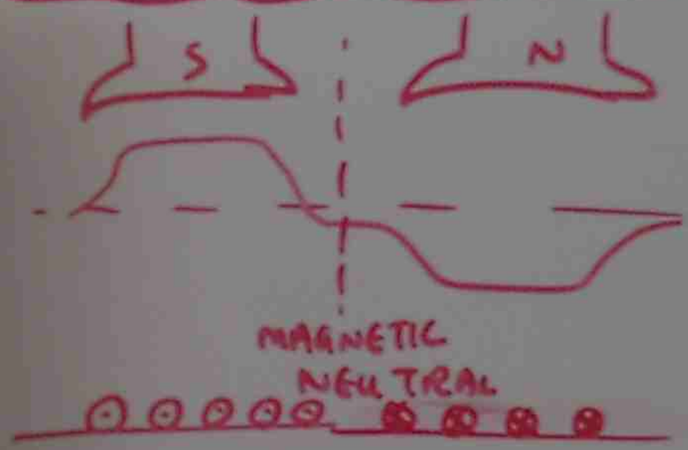
(b) $Y_C = \frac{C \pm m}{P/2} = \frac{36 \pm 2}{2/2} = 38$ (OR) 34
$1 \rightarrow 39$ $1 \rightarrow 35$
PROGRESSIVE RETRO-GRESSIVE

$T = I\alpha$

$\omega_2 = \omega_1 + \alpha t$

T = TORQUE (N-m)
α = ANGULAR ACCELERATION RAD/S^2
I = MOMENT OF INERTIA
ω = ANGULAR VELOCITY
t = TIME

MAGNETIC ACTION of ARMATURE FIELD DISTORTION



DE-MAGNETIZING - ARMATURE FLUX OPPOSES MAIN FLUX (A_{Td})
CROSS-MAGNETIZING - ARMATURE FLUX CROSS MAIN FLUX (A_{Tc})

$A_{Ta} = \frac{\beta Z I_a}{2a P}$ β = BRUSH SHIFTING ANGLE

$A_{T_c} = \frac{Z I_a}{2P}\left(\frac{360 - 2P\beta}{720}\right)$ (AMP-TURN)

Pb THE BRUSHES ON A 0.4m DIAMETER COMMUTATOR ARE ROCKED 0.03 m CIRCUMFERENTIALLY, CALCULATE A_{Td} & A_{Tc} NO. OF CONDUCTORS = 378, ARMATURE CURRENT = 800 AMP, 6 POLES, SIMPLEX LAP

$$\beta = \frac{x}{\pi D} \times 360^\circ = \frac{0.03}{3.14 \times 0.4} \times 360 = 8.6^\circ$$

$$a = m \times p = 1 \times 6 = 6$$

$$A_{Td} = \frac{\beta Z I_a}{360 a} = \frac{8.6 \times 378 \times 800}{360 \times 6} = 1210 \text{ AT/POLE}$$

$$A_{Tc} = \frac{Z I_a}{a \times p}\left(\frac{360 - 2p\beta}{720}\right) = \frac{378 \times 800}{6 \times 6}\left(\frac{360 - 2 \times 6 \times 8.6}{720}\right)$$

$$= 3000 \text{ AT/POLE}$$

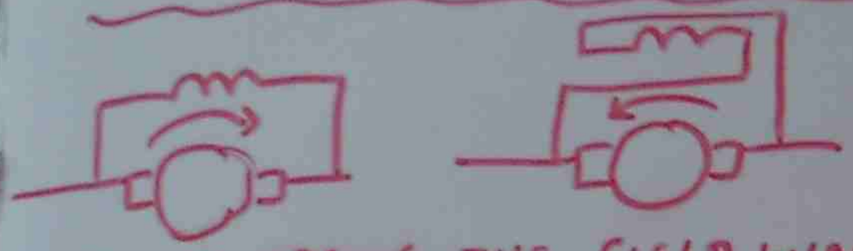
(1) DC MACHINE
SLIDE 1 → 6
@1 → @5

(2) ARMATURE WINDING
SLIDE 1 → 4
@6 → @10

(3) TORQUE PRODUCTION
SLIDE 1 → 13
@11 → @18

(4) ARMATURE REACTION
SLIDE 14 → 17
@18 → @20

FACTORS INFLUENCING THE SPEED AND DIRECTION OF ROTATION



BY REVERSING THE FIELD WINDING CONNECTION, THE DIRECTION OF ROTATION CAN BE CHANGED

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{a}$$

E_g - GENERATED VOLTAGE
Z = NO. OF CONDUCTOR
N = SPEED
P = NO. of POLE
a = NO. of ARMATURE PARALLEL PATHS

$$E_g = V_t - I_a R_a$$

$$\therefore \frac{\phi Z N}{60} \times \frac{P}{a} = V_t - I_a R_a$$

$$\frac{Z}{60}\frac{P}{a} = K \rightarrow K\phi N = V_t - I_a R_a$$

$$N = \frac{V_t - I_a R_a}{K\phi}$$

$$P = \frac{2\pi N T}{60}$$

Pb MOTOR PARTICULARS 3.75KW, 230V, 18 Amp, 1750 RPM, $R_a = 0.3\Omega$ BRUSH DROP 2V ON LOAD
CALCULATE (a) FULL LOAD TORQUE
(b) INITIAL RUSH of CURRENT & CORRESPONDING MOMENTARY MAX: TORQUE IF FIELD FLUX IS REDUCED TO 96%
(c) FINAL ARMATURE CURRENT, SPEED, POWER

(a) $$T_a = \frac{60P}{2\pi N_{FL}} = \frac{60 \times 3.75 \times 10^3}{2 \times 3.14 \times 1750} = 20.4 \text{ N-m}$$

(b) $$N = \frac{V_t - I_a R_a - \text{BRUSH DROP}}{K\phi} = \frac{230 - 18 \times 0.3 - 2}{K\phi}$$

$$1750 = \frac{228 - 5.4}{K\phi} \rightarrow K\phi = \frac{228 - 5.4}{1750} = 0.1273$$

FLUX DROP - 96%

$$0.96 \times 0.1273 = \frac{V_t - I_{a_2} R_a - \text{BRUSH DROP}}{N}$$

$$0.96 \times 0.1273 = \frac{230 - I_{a_2} \times 0.3 - 2}{1750}$$

$$I_{a_2} \times 0.3 = 0.96 \times 0.1273 \times 1750 + 2 - 230$$

$$I_{a_2} = 46.7 \text{ Amp}$$

(c) $$T = K\phi I_a$$

$$\frac{T_1}{T_2} = \frac{K\phi_1 I_{a1}}{K\phi_2 I_{a2}}$$

$$\frac{20.4}{T_2} = \frac{\phi \times 18}{0.96\phi \times 46.7}$$

$$T_2 = \frac{20.4 \times 0.96 \times 46.7}{18} = 50.56 \text{ N-m}$$

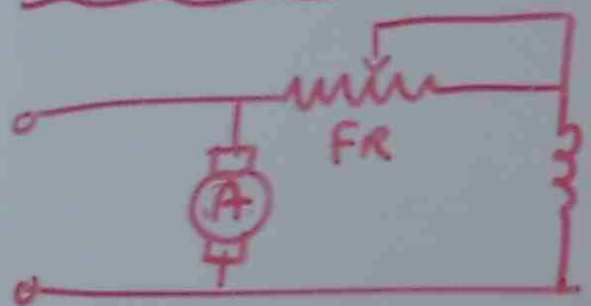
TORQUE & SPEED RELATION IN SERIES MOTOR

$T = K \phi I_a$

BUT $\phi \propto I_a$

$\therefore T = K I_a^2$

SHUNT FIELD RESISTANCE CONTROL



Pb A 7.5KW, 230V, 1750RPM SHUNT MOTOR ARMATURE RESISTANCE IS 0.35Ω SHUNT FIELD RESISTANCE 62.2Ω.

(a) IF NO LOAD CURRENT IS 7.7A, FULL LOAD EFFICIENCY 86%, BRUSH DROP 3V AT FULL LOAD, 1V AT NO LOAD, CALCULATE % REGULATION

FULL LOAD $I_1 = \dfrac{7.5 \times 10^3}{0.86 \times 230} = 37.7$ Amp

$I_{sh} = \dfrac{230}{62.2} = 3.7$ Amp

$I_{a_1} = 37.7 - 3.7 = 34$ Amp

FULL LOAD

$E_{g_1} = V_t - I_{a_1} R_{a_1} - \text{BRUSH DROP (1)}$

$= 230 - 34 \times 0.35 - 3 = 215.1$ V

NO LOAD $I_a = 7.7 - 3.7 = 4$ Amp

$E_{g_2} = V_t - I_{a_2} R_{a_2} - \text{BRUSH DROP 2}$

$= 230 - 4 \times 0.35 - 1 = 227.2$ V

$\dfrac{E_{g_1}}{E_{g_2}} = \dfrac{\phi_1 N_1}{\phi_2 N_2} \rightarrow \dfrac{215.1}{227.2} = \dfrac{\phi \times 1750}{\phi \times N_2}$

$\therefore N_2 = \dfrac{1750 \times 227.2}{215.1} = 1850$ RPM

% SPEED REG $= \dfrac{N_2 - N_1}{N_1} = \dfrac{1850 - 1750}{1750} \times 100$

$\times 100 = 5.7\%$

(7) EFFECT of FLUX ON VOLTAGE

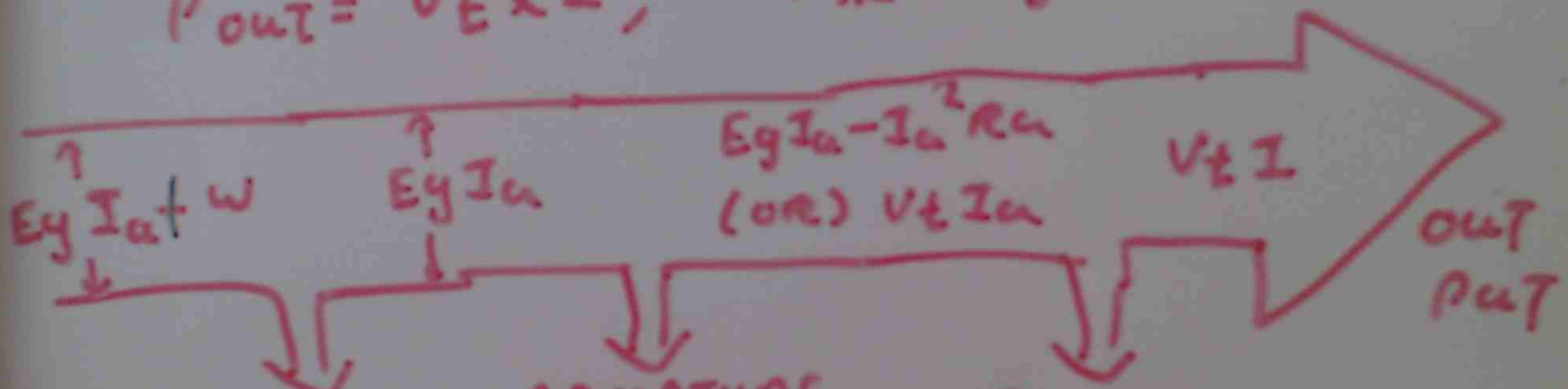
SLIDE 1 ⟶ 10

Q 40, Q 41

LOSSES AND EFFICIENCY IN DC MACHINE

DC GENERATOR

$P_{OUT} = V_t \times I$, $P_{IN} = E_g I_a + W$ ← LOSSES



$\eta = \dfrac{V_t I}{E_g I_a + W} \times 100$ η = EFFICIENCY

ROTATIONAL LOSSES

HEAT PRODUCED BY BEARING FRICTION

HEAT PRODUCED BY ARMATURE CONDUCTOR

HYSTERESIS LOSS

$P_h = K_h f B_m^{1.6}$ WATT

EDDY CURRENT LOSS

$P_e = K_e f^2 t^2 B^2 V$ . . .

COPPER LOSS

ARMATURE COPPER LOSS $I_a^2 R_a$

FIELD COPPER LOSS $I_{sh}^2 R_{sh}$, $I_{se}^2 R_{se}$

BRUSH LOSSES

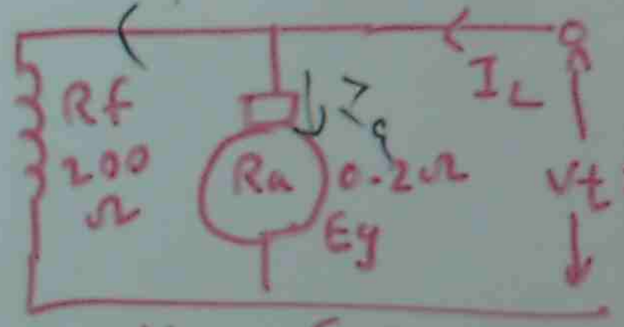
STRAY LOSSES

WINDAGE LOSS, FRICTION LOSS

PD. THE WINDING RESISTANCE OF A 500V, 60KW DC SHUNT MOTOR ARE $R_a = 0.2\Omega$, $R_f = 200\Omega$

IF ROTATIONAL LOSSES ARE TAKEN 1.4KW DETERMINE THE EFFICIENCY OF THE MACHINE (a) WHEN LINE CURRENT IS 102.5 Amp

I_f (b) AT FULL LOAD.



$I_f = \frac{V}{R_f} = \frac{500}{200} = 2.5A$

SHUNT FIELD COPPER LOSS = $V \times I_f$
$= 500 \times 2.5 = 1250W$

$I_a = I - I_f = 102.5 - 2.5 = 100A$

ARMATURE COPPER LOSS = $I_a^2 R_a = 100^2 \times 0.2$
$= 2000W$

TOTAL LOSS = ARMATURE COPPER LOSS + FIELD COPPER LOSS + ROTATIONAL LOSS
$= 2000 + 1250 + 1400 = 4650W$

OUTPUT POWER = INPUT − TOTAL LOSSES
$= VI - 4650 = 500 \times 102.5 - 4650$

EFFICIENCY $= \frac{500 \times 102.5 - 4650}{500 \times 102.5} \times 100 = 90.93\%$

(b) FULL LOAD $P_{out} = 60000$ WATT

$P_{out} = E_g I_a - W$

$60,000 = (V_t - I_a R_a) I_a - W$

$60,000 = (500 - I_a \times 0.2) I_a - 1400$

$I_a^2 - 2500 I_a + 30700 = 0$

$I_a = \frac{-(-2500) \pm \sqrt{(2500)^2 - 4 \times 1 \times 30700}}{2 \times 1}$

$= \frac{254}{2}$ (or) $\frac{4741}{2} \Rightarrow I_a = 129.5A$

$\%\eta = \frac{P_o}{P_i} \times 100 = \frac{60,000}{(129.5 + 2.5) \times 500} \times 100 = 90.9\%$

$P_{IN} = VI \rightarrow I = I_a + I_{SH}$

MACHINE TEMPERATURE RISE

CAN BE MEASURED BY
(a) THERMOMETER
(b) EMBEDDED THERMOCOUPLE (OR) THERMISTOR
(c) COMPUTATION FROM HOT & COLD RESISTANCE

$$\frac{R_f}{R_{RT}} = \frac{234.5 + T_f}{234.5 + T_{RT}}$$

Pb THE RESISTANCE of AN ARMATURE AT 25°C WAS FOUND TO BE 0.26Ω. AFTER A HEAT RUN, IT BECOMES 0.296Ω CALCULATE TEMPERATURE RISE OF WINDING

$R_{RT} = 0.26\Omega$, $R_f = 0.296\Omega$

$T_{RT} = 25°C$ $T_f = ?$

$$\frac{R_f}{R_{RT}} = \frac{234.5 + T_f}{234.5 + T_{RT}}$$

$$\frac{0.296}{0.26} = \frac{234.5 + T_f}{234.5 + 25}$$

$T_f = 61°C$

$\Delta T = 61 - 25 = 36°C$

Pb A 75 KW, 500V GENERATOR HAS 4% VOLTAGE REGULATION. CALCULATE (a) OPEN CKT VOLTAGE (b) KW OUTPUT AT 510V

$$\%.REg = \frac{E_g - V}{V} \times 100 \rightarrow 4 = \frac{E_g - 500}{500} \times 100$$

$$\therefore E_g = \frac{4 \times 500}{100} + 500 = 520V$$

$$I_{fL} = \frac{P}{V} = \frac{75 \times 10^3}{500} = 150 Amp$$

$$I_{fL_2} = \frac{E_g - V_{fL2}}{E_g - V_{fL1}} \times I_{fL_1}$$

$$= \frac{520 - 510}{520 - 500} \times 150 = 75A$$

$$OUTPUT = V_{fL_2} \times I_{fL_2} = 75 \times 510 = 38250 W$$

(4) ARMATURE REACTION + COMMUTATION

SLIDE 19 ⟶ 28
@20 ⟶ @25

(5) VOLTAGE REGULATION + EFFICIENCY

SLIDE 1 ⟶ 21
@26 ⟶ 35

(6) DC MACHINE PROBLEM

SLIDE 1 ⟶ 2
@36 ⟶ @39

(4) ARMATURE REACTION + COMMUTATION

SLIDE 19 ⟶ 28
Q 20 ⟶ Q 25

(5) VOLTAGE REGULATION + EFFICIENCY

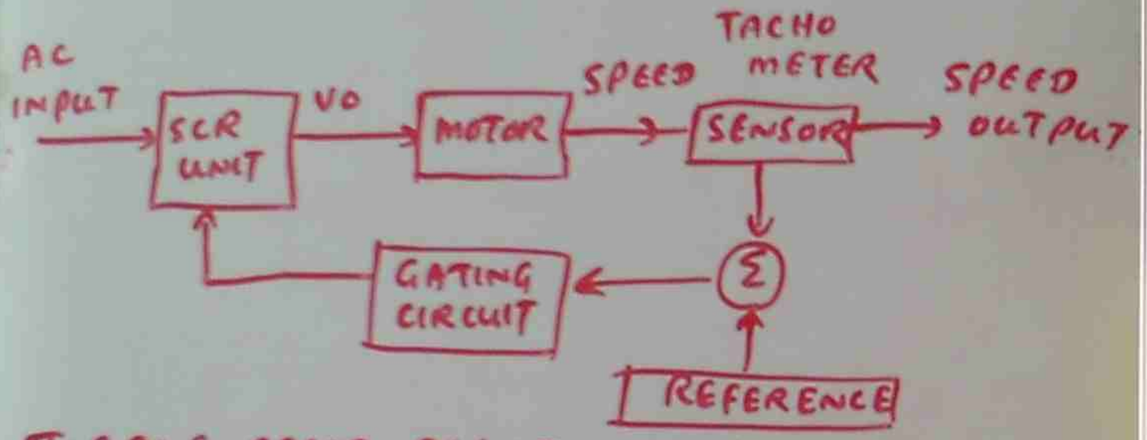
SLIDE 1 ⟶ 21
Q 26 ⟶ 35

(6) DC MACHINE PROBLEM

SLIDE 1 ⟶ 2
Q 36 ⟶ Q 39

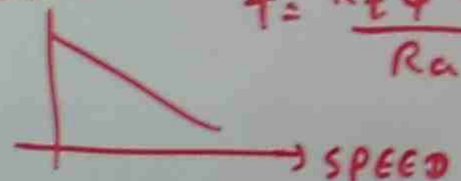
DC MOTOR CONTROL

BLOCK DIAGRAM OF SCR CONTROLLED MOTOR



TORQUE SPEED RELATIONSHIP

TORQUE



$$T = \frac{K_t \phi V_t}{R_a}$$

ϕ = FLUX

R_a = ARMATURE RESISTANCE

V_t - TERMINAL VOLTAGE

$E_g = K_e \phi N$

HEATING EFFECT OF RIPPLE

RIPPLE → HEATING
→ HARMONIC → NEED TO ELIMINATE BY FILTER
→ VIBRATION

→ DERATE THE MACHING
→ DERATE THE INSULATION

PWM



PRODUCED BY HIGH FREQUENCY SWITCHING SUCH AS PWM

$$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$$

WHERE $K_t = \frac{PZ}{2\pi a}$, $K_e = \frac{PZ}{60a}$

pb/ A 4 POLE WAVE WOUND ARMATURE OPERATING IN A FIELD OF FLUX 0.01 wb IN WOUND WITH 360 ARMATURE CONDUCTORS. DETERMINE THE EXPRESSION OF TORQUE AS FUNCTION OF SPEED. $V_t = 250V$, $R_a = 0.1\Omega$

$$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$$

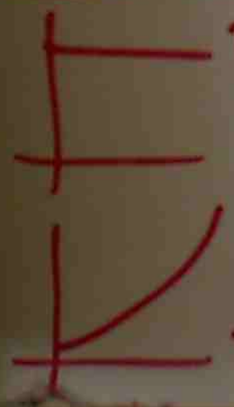
$a = 2 \times m$
$= 2 \times 1 = 2$

$$K_t = \frac{PZ}{2\pi a} = \frac{4 \times 360}{2 \times 3.1416 \times 2} = 114.5$$

$$K_e = \frac{PZ}{60a} = \frac{4 \times 360}{60 \times 2} = 12$$

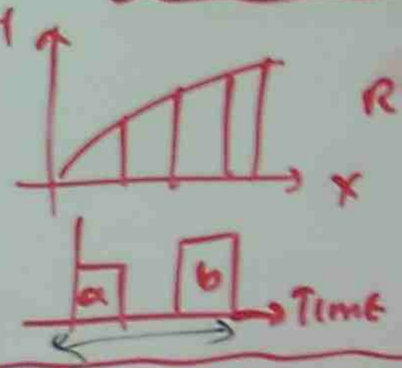
$$T = \frac{114.5 \times 0.01 \times 250}{0.1} - \frac{12 \times 114.5 \times (0.01)^2 N}{0.1}$$

$$T = 2860 - 1.38N$$



MATCH MOTOR & DRIVE SYSTEM

DUTY CYCLE CALCULATION



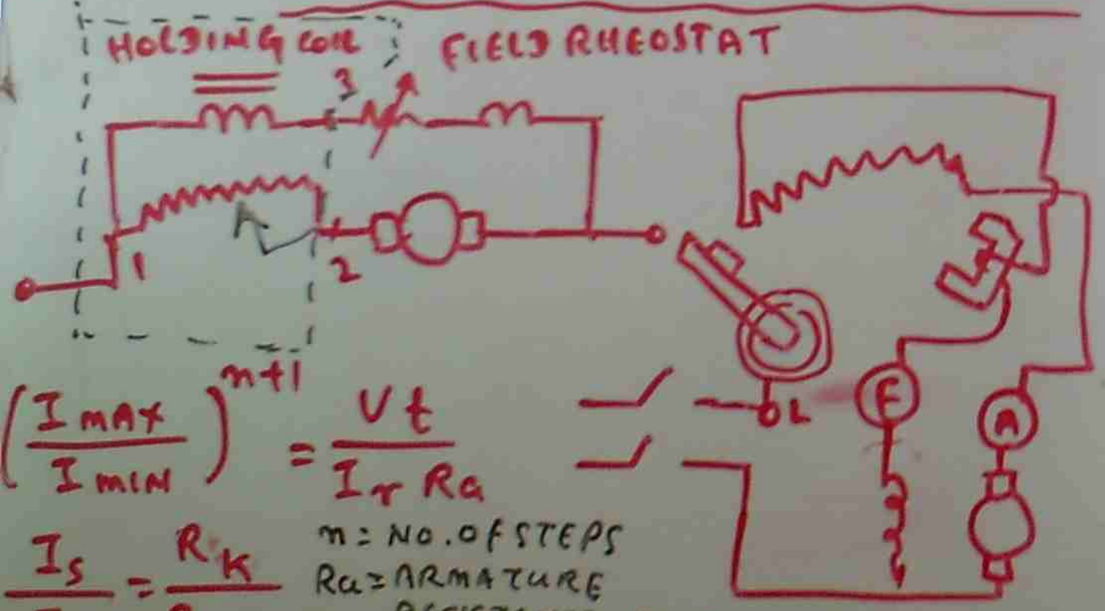
$$Rms = \sqrt{\frac{1}{y}\int_0^y y^2 dx}$$

$$AVERAGE = \frac{TOTAL\ AREA}{TOTAL\ DURATION}$$

DC MOTOR STARTING

DC MOTOR DRAWS HIGHER STARTING CURRENT RESISTANCES ARE INSERTED TO LIMIT THE CURRENT AND THEN THEY ARE GRADUALLY CUT OFF

MOTOR STARTER FOR DC MOTOR



$$\left(\frac{I_{MAX}}{I_{MIN}}\right)^{n+1} = \frac{V_t}{I_r R_a}$$

$$\frac{I_s}{I_r} = \frac{R_K}{R_{K+1}}$$

n = NO. OF STEPS
Ra = ARMATURE RESISTANCE
Ir = FULL LOAD CURRENT
Vt = TERMINAL VOLTAGE

3 POINTS STARTER

Pb THE RESISTANCE OF THE ARMATURE OF A 240V DC SHUNT MOTOR IS 0.5Ω. IT IS REQUIRED THAT THE CURRENT AT STARTING BE LIMITED TO 200% OF FULL LOAD CURRENT AND FULL LOAD CURRENT IS 15 Amp. DETERMINE (a) TOTAL RESISTANCE OF ARMATURE CURRENT AT STARTING (b) NO. OF STUDS (c) THE RESISTANCE OF EACH STUD

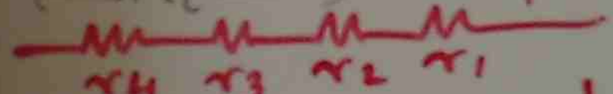
$R_a = 0.5\Omega$, $V_t = 240V$, $I_r = 15$ Amp (FULL LOAD)

$I_s = 200\%\ I_r = 2 \times 15 = 30$ Amp

$$\left(\frac{I_{MAX}}{I_{MIN}}\right)^{n+1} = \frac{V_t}{I_r R_a} \rightarrow \left(\frac{30}{15}\right)^{n+1} = \frac{240}{15 \times 0.5}$$

$$2^{n+1} = 32 \rightarrow (n+1)\log 2 = \log 32$$

$$n = \frac{\log 32}{\log 2} - 1 = 4$$



$$\frac{I_s}{I_r} = \frac{R_m}{R_{m+1}}$$

$$\frac{30}{15} = \frac{R_m}{R_{m+1}}$$

$$2 = \frac{R_m}{R_{n+1}}$$

$$R_1 = \frac{V_t}{I_1} = \frac{240}{30} = 8\Omega$$

$n = 1$

$$2 = \frac{R_1}{R_2} \rightarrow 2 = \frac{8}{R_2}$$

$\therefore R_2 = 4\Omega$

$n = 2$

$$2 = \frac{R_2}{R_3} \rightarrow 2 = \frac{4}{R_3}$$

$R_3 = 2\Omega$

$n = 3$

$$2 = \frac{R_3}{R_4} \rightarrow 2 = \frac{2}{R_4}$$

$R_4 = 1\Omega$

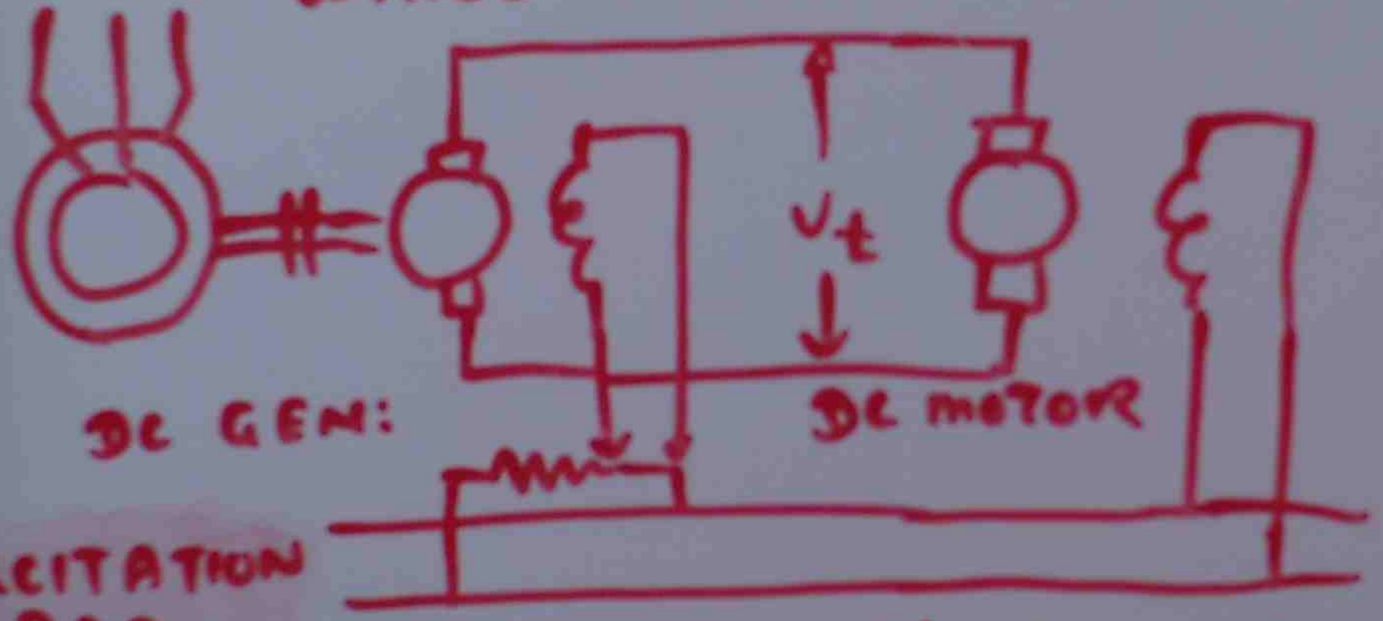
$r_1 = R_1 - R_2 = 8 - 4 = 4\Omega$

$r_2 = R_2 - R_3 = 2\Omega$

$r_3 = R_3 - R_4 = 1\Omega$

SPEED CONTROL

DC
- SHUNT FIELD CURRENT / FLUX
- ARMATURE CURRENT / FLUX
- WARD LEONARD CONTROL

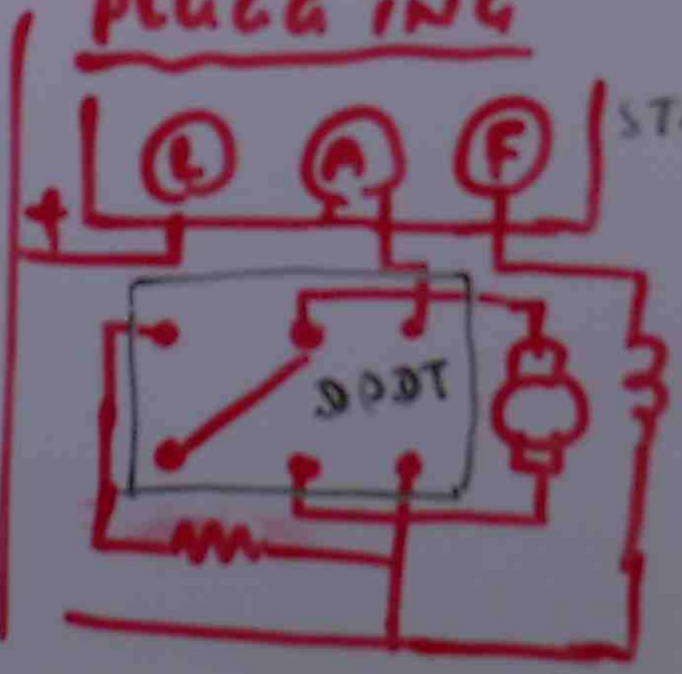


EXCITATION BAR

BRAKING

- PLUGGING
- DYNAMIC BRAKING
- MECHANICAL BRAKE

PLUGGING



STARTER

DYNAMIC BRAKING



SHUNT MOTOR

BRAKING RESISTOR

(8) DC MOTOR CONTROL + SCR

SLIDE 1 ⟶ 6

Q42 ⟶ Q48

(9) DC MOTOR STARTER

SLIDE 1 ⟶ 15

Q49 ⟶ Q57

(10) DC MOTOR STARTER CIRCUIT ANALYSIS

SLIDE 1 ⟶ 10

Q58 ⟶ Q62

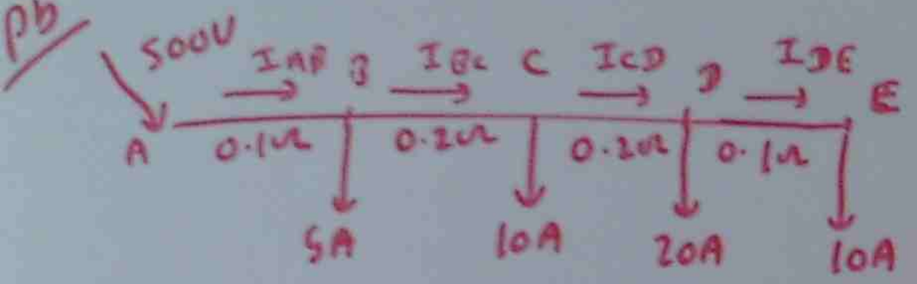
(11) DC MOTOR SPEED CONTROL

SLIDE 1 ⟶ 10

Q63 ⟶ Q71

(1) LINEAR & EXPONENTIAL FUNCTION

Pb



FIND THE LOAD VOLTAGES AT A, B, C, D, E AND LINE EFFICIENCY.

$I_{DE} = 10A$, $I_{CD} = 20+10 = 30A$, $I_{BC} = I_{CD} + 10 = 30+10 = 40A$

$I_{AB} = I_{BC} + 5 = 40+5 = 45A$

$V_B = 500 - I_{AB} R_{AB} = 500 - 45 \times 0.1 = 495.5V$

$V_C = V_B - I_{BC} R_{BC} = 495.5 - 40 \times 0.2 = 487.5V$

$V_D = V_C - I_{CD} R_{CD} = 487.5 - 30 \times 0.2 = 481.5V$

$V_E = V_D - I_{DE} R_{DE} = 481.5 - 10 \times 0.1 = 480.5V$

$P_{OUT} = V_B I_B + V_C I_C + V_D I_D + V_E I_E$

$= 495.5 \times 5 + 487.5 \times 10 + 481.5 \times 20 + 480.5 \times 10$

$= 21787.5W$

$P_{LOSS} = I_{AB}^2 R_{AB} + I_{BC}^2 R_{BC} + I_{CD}^2 R_{CD} + I_{DE}^2 R_{DE}$

$= 45^2 \times 0.1 + 40^2 \times 0.2 + 30^2 \times 0.2 + 10^2 \times 0.1$

$= 712.5$ WATT

$\% n = \frac{P_{OUT}}{P_{IN}} \times 100 = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}} \times 100 = \frac{21787.5 \times 100}{21787.5 + 712.5} = 96.8\%$

Pb THREE TOWNS A, B, C ARE LOCATED AS FOLLOWS. DETERMINE THE MOST SUITABLE PLACE TO LOCATE THE ELECTRIC POWER STATION TO SUPPLY THESE TOWNS

A = 1000 mW (10, 20) Km

B = 600 mW (5, 7) Km

C = 500 mW (10, 15) Km

$\bar{X} = \frac{P_A X_A + P_B X_B + P_C X_C}{P_A + P_B + P_C} = \frac{1000 \times 10 + 600 \times 5 + 500 \times 10}{1000 + 600 + 500}$

$= 8.57$ Km

$\bar{Y} = \frac{P_A Y_A + P_B Y_B + P_C Y_C}{P_A + P_B + P_C} = \frac{1000 \times 20 + 600 \times 7 + 500 \times 15}{1000 + 600 + 500}$

$= 15.09$ Km

POLAR → RECTANGULAR CONVERSION

$Z \angle \theta \rightarrow Z\cos\theta + jZ\sin\theta$

$Z \angle -\theta \rightarrow Z\cos(-\theta) + jZ\sin(-\theta)$

RECTANGULAR TO POLAR CONVERSION

$a + jb = \sqrt{a^2+b^2} \angle \tan^{-1} b/a$

$a - jb = \sqrt{a^2+b^2} \angle -\tan^{-1} b/a$

$-a + jb = \sqrt{a^2+b^2} \angle 180 - \tan^{-1} b/a$

$-a - jb = \sqrt{a^2+b^2} \angle -(180 - \tan^{-1} b/a)$

G047 - (1) LINEAR FUNCTI

SLIDE 1 → 9

Q1 → Q3

(2) RATIO & COMPARISON

COMPARISON OF ELECTRICITY SUPPLY SYSTEM

COPPER REQUIREMENT FOR DC 2WIRE THAN 3ϕ 3WIRE SYSTEM $= \frac{\text{NO. of AC CONDUCTOR}}{\text{NO. of DC CONDUCTOR}} \times \text{RATIO of } \frac{\text{AC-CSA}}{\text{DC-CSA}}$

FIRST PRINCIPLE

SAME POWER DELIVERED

DC POWER = AC POWER DELIVERED



$EI = 3 \times \frac{E_{MAX/PH}}{\sqrt{2}} I' \cos\theta$

$I = 3\frac{I' \cos\theta}{\sqrt{2}}$ —— ①

SECOND PRINCIPLE COMPARE LINE POWER LOSS

DC POWER LOSS : AC 3ϕ POWER LOSS

$2I^2R_1 : 3(I')^2 R_2$

$2\left(\frac{3I'}{\sqrt{2}}\cos\theta\right)^2 R_1 : 3(I')^2 R_2$

$9(I')^2\cos^2\theta\, R_1 : 3(I')^2 R_2$

$3\cos^2 R_1 : R_2$

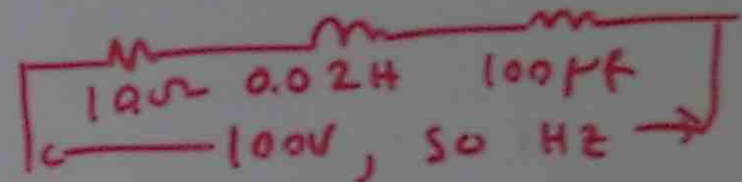
$3\cos^2\theta \frac{\rho L}{A_1} = \frac{\rho L}{A_2}$

$\frac{3\cos^2\theta}{\text{DC-CSA}} : \frac{1}{\text{AC-CSA}}$

$\frac{\text{AC-CSA}}{\text{DC-CSA}} = \frac{1}{3\cos^2\theta}$

(3) RLC CIRCUIT

Pb



FIND Z & I_t

$R = 10\Omega$, $X_L = 2\pi fL = 2\times3.1416\times50\times0.02 = 62.$

$X_C = \frac{1}{2\pi fc} = \frac{1}{2\times3.1416\times50\times100\times10^{-6}} = \frac{10^6}{31416} = 31$

$Z = \sqrt{R^2+(X_L-X_C)^2} \angle \tan^{-1}\frac{X_L-X_C}{R}$

$= \sqrt{(10)^2+(62.8-31.8)^2} \angle \tan^{-1}\frac{62.8-31.8}{10}$

$= 32.5 \angle 72.1\ \Omega$, $I = \frac{V}{Z} = \frac{100}{32.5\angle72.1} = 3.0$

$Z_1\angle\theta_1 \times Z_2\angle\theta_2 = Z_1Z_2\angle\theta_1+\theta_2$

$\frac{Z_1\angle\theta_1}{Z_2\angle\theta_2} = \frac{Z_1}{Z_2}\angle\theta_1-\theta_2$

(3) RLC CIRCUIT

SLIDE (1) → (9)

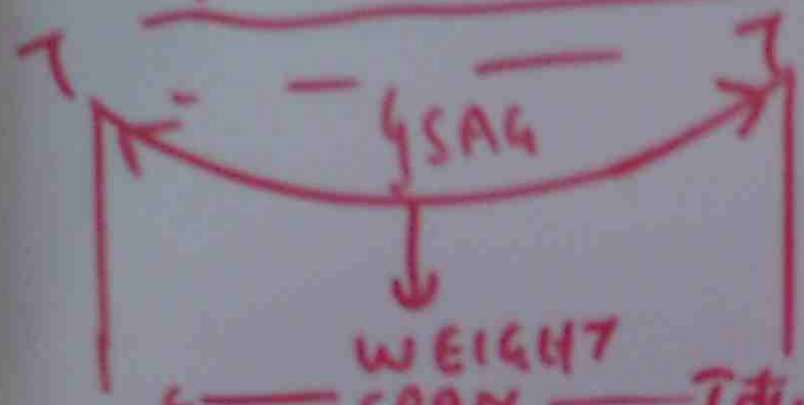
$\theta_{SA} \rightarrow \theta_{SC}$

(4) GRADIENT LOG FUNC

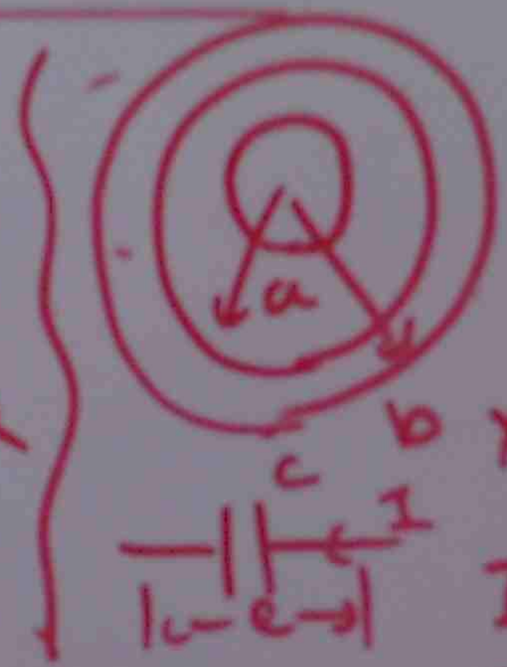
SLIDE (1) → 6

$\theta_6 \rightarrow \theta_7$

PARABOLIC FUNCTION



$$SAG = \frac{WL^2}{8T}$$



$b = e^{xa}$

$e = 2.712$

$a = \frac{\text{SYSTEM VOLTAGE}}{\text{SAFE VOLTAGE STRESS}}$

$X_c = \frac{1}{2\pi fc}$, $I_c = \frac{E}{X_c}$

$I = ce$

Ex A TRANSMISSION LINE HAS 200m SPAN BETWEEN SUPPORTS. THE CONDUCTOR WEIGHT IS 20N/m AND TENSION IN CONDUCTOR IS 20 kN CALCULATE SAG

$$SAG = \frac{WL^2}{8T} = \frac{20 \times 200^2}{8 \times 20 \times 10^3} = 5\,m$$

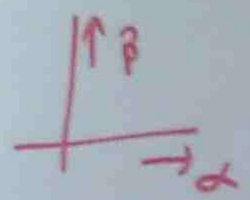
(4) GRADIENT LOG FUNCTION
SLIDE 7 → 11, Q8 → Q9

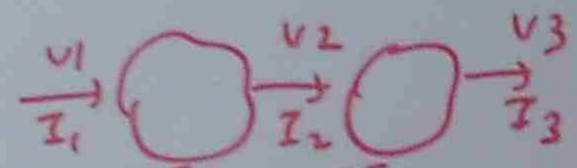
(5) GRADIENT APPLICATION
SLIDE 1 → 8
Q10 → Q11

OSCILLATION & EXPONENTIAL FUNCTION

γ = PROPAGATION CONSTANT

$\gamma = \alpha + i\beta$





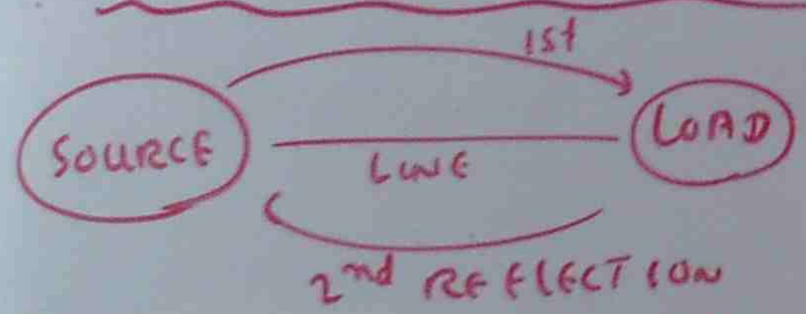
$$\frac{V_1}{V_2} = \frac{I_1}{I_2} = e^{\gamma}$$

$$\frac{V_1}{V_2} \times \frac{V_2}{V_3} \times \frac{V_3}{V_4} \times \cdots \frac{V_{n-1}}{V_n} = e^{\gamma}$$

$$e^{\gamma_1} \times e^{\gamma_2} \times e^{\gamma_3} = e^{\gamma}$$

$$e^{\gamma_1 + \gamma_2 + \gamma_3} = e^{\gamma} \rightarrow \gamma = \gamma_1 + \gamma_2 + \gamma_3 + \cdots$$

REFLECTION ON TRANSMISSION LINE



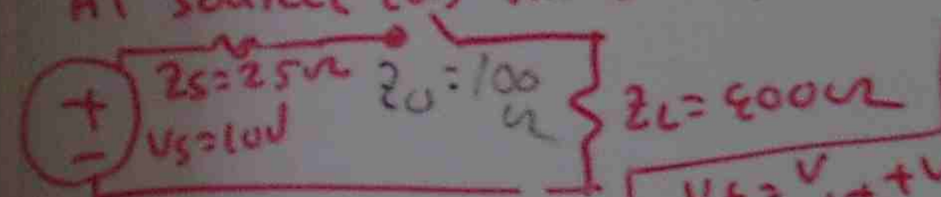
1st REFLECTION AT LOAD $V_t = V_{1+} + V_{1-}$

2nd RELECTION AT SOURCE $\Rightarrow V_t = V_{1+} + V_{1-} + V_{2-}$

$$V_{1+} = V_s \frac{Z_0}{Z_0 + Z_s}, \quad V_{1-} = V_{1+} \times \frac{Z_L - Z_0}{Z_L + Z_0}, \quad V_{2+} = V_{1-} \times \frac{Z_s - Z_0}{Z_s + Z_0}$$

THIRD REFLECTION AT LOAD $= V_{1+} + V_{1-} + V_{2+} + V_{2-}$

Pb A 10V DC SOURCE WITH AN INTERNAL RESISTANCE 25Ω IS CONNECTED TO A TRANSMISSION LINE OF LENGTH "L" HAVING AN IMPEDANCE OF 100Ω BY SWITCH. THE TRANSMISSION LINE IS TERMINATED WITH 900Ω RESISTOR. T = AMOUNT OF TIME REQUIRED FOR SIGNAL TO TRAVEL OVER THE LINE. CALCULATE (a) THE VOLTAGE WHEN THE SWITCH IS CLOSED AT (T=0), (b) FIRST REFLECTION AT LOAD (c) SECOND REFLECTION AT SOURCE (d) THIRD REFLECTION AT LOAD



(a) $t = 0$

$$V_{1+} = V_s \frac{Z_0}{Z_s + Z_0} = 10 \times \frac{100}{100+25} = 8V$$

(b) $$V_{(1-)} = V_+ \frac{Z_L - Z_0}{Z_L + Z_0} = 8\left(\frac{900-100}{900+100}\right) = 6.4V$$

$$V_t = V_{1+} + V_{1(-)} = 8 + 6.4 = 14.4$$

(c) $$V_{2(+)} = V_{1(-)} \times \frac{Z_s - Z_0}{Z_s + Z_0} = 6.4 \times \frac{25-100}{25+100} = -3.8$$

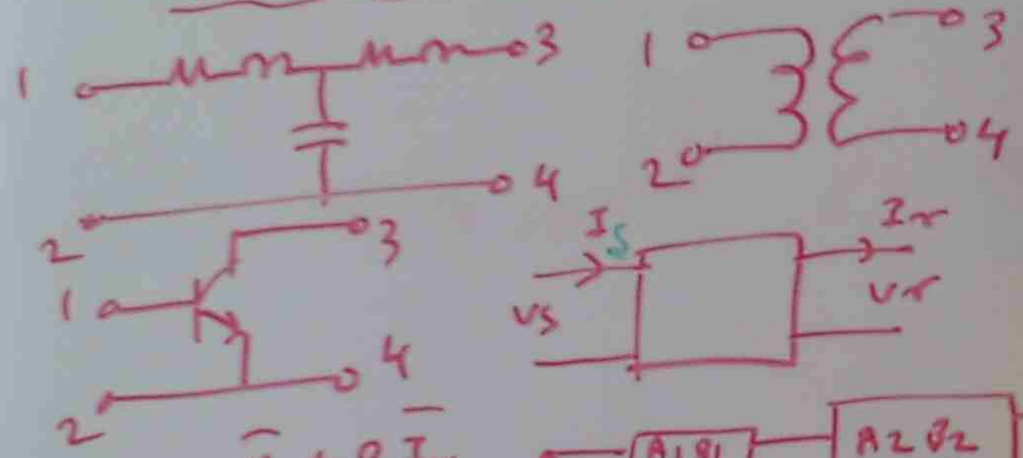
$$V_t = V_{1+} + V_{1-} + V_{2+} = 8 + 6.4 + (-3.84) = 10.56$$

(d) $$V_{2(-)} = V_{2(+)} \times \frac{Z_L - Z_0}{Z_L + Z_0} = -3.84 \times \frac{900-100}{900+100} = -3.072V$$

$$V_t = V_{1+} + V_{1-} + V_{2+} + V_{2-} = 8 + 6.4 + (-3.84) + (-3.072) = 7.488V$$

SIMULTANEOUS EQUATIONS

4 TERMINALS NETWORK



$$V_S = A\bar{V}_R + B\bar{I}_R$$
$$I_S = C\bar{V}_R + D\bar{I}_R$$

$$A_{eq} = A_1A_2 + B_1C_2$$
$$B_{eq} = A_1B_2 + B_1D_2$$
$$C_{eq} = C_1A_2 + D_1C_2$$
$$D_{eq} = C_1B_2 + D_1D_2$$

$$\boxed{\bar{V}_S = A_{eq}\bar{V}_R + B_{eq}\bar{I}_R \qquad \bar{I}_R = C_{eq}\bar{V}_R + D_{eq}\bar{I}_R}$$

(OPEN) $A = \frac{V_S}{V_R}$, $C = \frac{I_S}{V_S}$, (SHORT) $B = \frac{V_S}{I_R}$, $D = \frac{I_S}{I_R}$

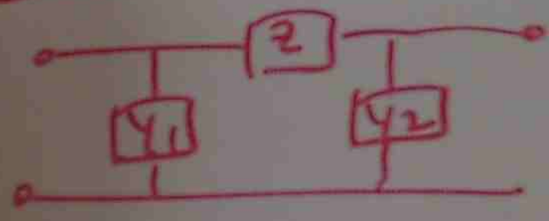
P9 DETERMINE THE A, B, C, D CONSTANTS OF THE NETWORK. THE RESULTS ARE AS FOLLOWS

(RECEIVER OPEN CKT)
$\bar{V}_S = 100\angle 0°\,V$
$\bar{V}_R = 70.7\angle -45°\,V$
$I_S = 1.41\angle 45°\,A$, $I_R = 0$

RECEIVER SHORT
$V_R = 0$, $I_R = 2\angle -90°$
$V_S = 100\angle 0°\,V$
$I_S = 2\angle -90°$

$$A = \frac{V_S}{V_R} = \frac{100\angle 0°}{70.7\angle -45°} = 1.41\angle 45° \quad \text{OPEN}$$
$$C = \frac{I_S}{V_S} = \frac{1.41\angle -45°}{100\angle 0°} = 0.0141\angle -45° \quad \text{SHORT}$$
$$B = \frac{V_S}{I_R} = \frac{100\angle 0°}{2\angle -90°} = 50\angle 90°$$
$$D = \frac{I_S}{I_R} = \frac{2\angle -90°}{2\angle -90°} = 1$$

Π EQUIVALENT NETWORK



$A = 1 + Y_1Z$
$B = Z$
$C = Y_1 + Y_2 + Y_1Y_2$
$D = 1 + ZY_1$

FURTHER STUDY & EXERCISE

(6) OSCILLATION FUNCTION
SLIDE 1 ⟶ 10
Q12 ⟶ Q14

(7) SIMULTANEOUS EQUATION
SLIDE 1 ⟶ 4
Q15

HARMONIC

$$\text{FREQUENCY} = \frac{1}{\text{TIME}}$$

2nd HARMONIC FREQUENCY = 2× FUNDAMENTAL FREQUENCY

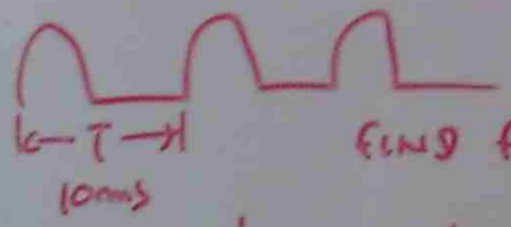
3rd HARMONIC FREQUENCY = 3× FUNDAMENTAL FREQUENCY

P9 A WAVEFORM $T = 100\text{ms}$ FIND 3rd AND 4th HARMONIC

$$f = \frac{1}{T} = \frac{1}{100\times10^{-3}} = \frac{10^3}{100} = 10\text{Hz}$$

$f_3 = 3f = 3\times10 = 30\text{Hz}$, $f_4 = 4f = 4\times10 = 40\text{Hz}$

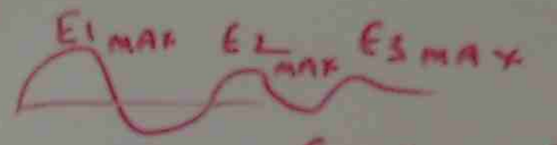
P12



FIND FREQUENCY

$$f = \frac{1}{T} = \frac{1}{10\times10^{-3}} = 100\text{Hz}$$

⑧ WAVE FORMS SLIDE 4 → 10 { Q.17 → Q.19

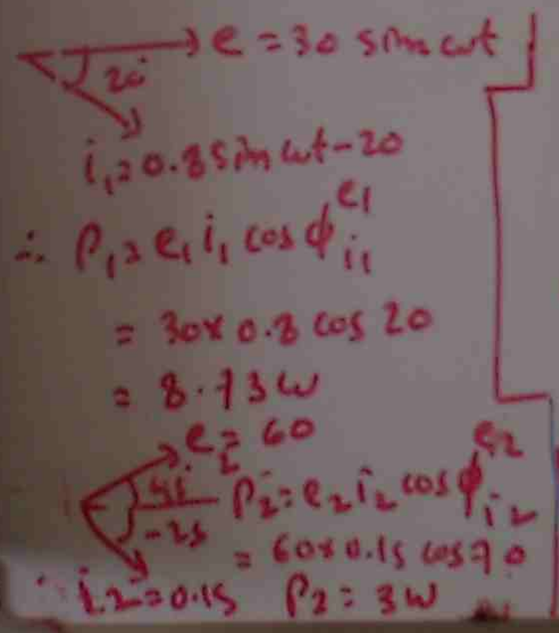


$$E_{1rms} = \frac{E_{1MAX}}{\sqrt{2}}, \quad E_{2rms} = \frac{E_{2MAX}}{\sqrt{2}}$$

$$E_{3rms} = \frac{E_{3MAX}}{\sqrt{2}}$$

$$E_{rms} = \sqrt{E_{1rms}^2 + E_{2rms}^2 + E_{3rms}^2}$$

P10 A VOLTAGE IS GIVEN BY $e = 30\sin\omega t + 60\sin(3\omega t + 45) + 10\sin(5\omega t - 60)$ VOLT IS APPLIED TO A CIRCUIT. THE CURRENT IS $i = 0.8\sin(\omega t - 20) + 0.15\sin(3\omega t - 25) + 0.09\sin(5\omega t - 120)$ FIND TOTAL POWER AND POWER FACTOR



$$\therefore P_1 = e_1 i_1 \cos\phi_{i1}^{e1}$$

$$= 30\times0.8\cos20$$

$$= 8.73\text{W}$$

$$P_2 = e_2 i_2 \cos\phi_{i2}^{e2}$$

$$= 60\times0.15\cos70$$

$$P_2 = 3\text{W}$$

$$P_3 = e_3 i_3 \cos\phi_{i3}^{e3}$$

$$= 10\times0.09\cos60$$

$$= 0.45\text{W}$$

$$P_T = P_1 + P_2 + P_3 = 8.73 + 3 + 0.45$$

$$= 12.18\text{W}$$

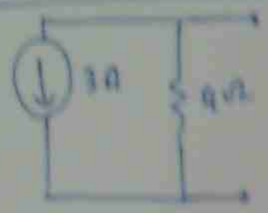
$$e_{rms} = \sqrt{\left(\frac{30}{\sqrt2}\right)^2 + \left(\frac{60}{\sqrt2}\right)^2 + \left(\frac{10}{\sqrt2}\right)^2} = 47.95\text{V}$$

$$i_{rms} = \sqrt{\left(\frac{0.8}{\sqrt2}\right)^2 + \left(\frac{0.15}{\sqrt2}\right)^2 + \left(\frac{0.09}{\sqrt2}\right)^2} \Rightarrow 0.574$$

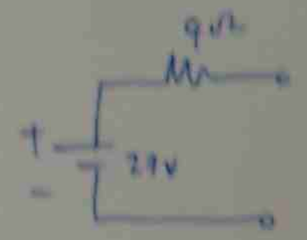
$$PF = \frac{P_T}{e_{rms}\, i_{rms}} = \frac{12.18}{47.95\times0.574} = 0.43$$

CIRCUIT ANALYSIS LESSON (1)

SOURCE CONVERSION

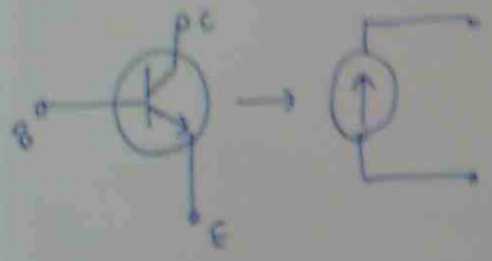


$\longrightarrow V = I \times R$
$= 3 \times 9$
$= 27V$



CURRENT SOURCE

VOLTAGE SOURCE

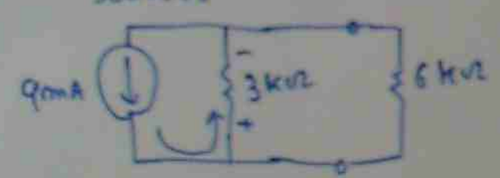


VOLTAGE SOURCE

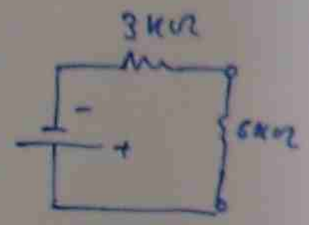


EXAMPLE OF CURRENT SOURCE

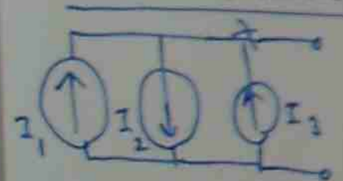
Pb CONVERT THE FOLLOWING CURRENT SOURCE TO VOLTAGE SOURCE



$V = I \times R$
$= 9 \times 10^{-3} \times 3 \times 10^{3}$
$= 27V$

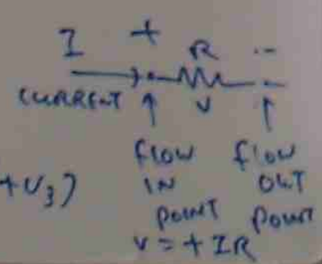


COMBINING CURRENT SOURCES



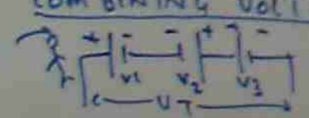
Flow IN: +
Flow OUT: −

$I_T = (+I_1) + (-I_2) + (+I_3)$



$V = +IR$

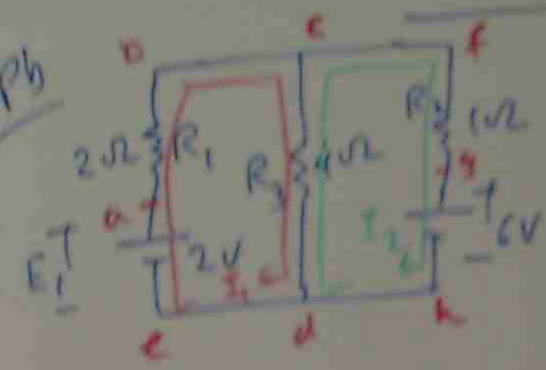
COMBINING VOLTAGE SOURCES



$V_T = (+V_1) + (-V_2) + (+V_3)$

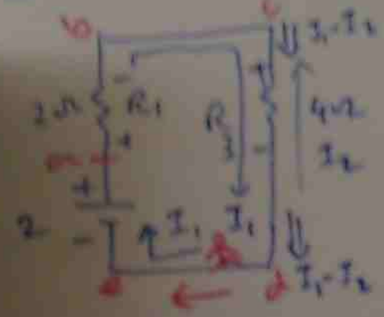
MESH ANALYSIS

Pb



FIND I_1 & I_2

Loop a, b, c, d, e



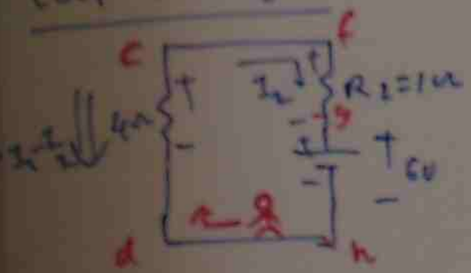
$(-2) + (+I_1 \times 2) + (+4(I_1 - I_2) = 0$

$-2 + 2I_1 + 4I_1 - 4I_2 = 0$

$6I_1 - 4I_2 = 2$

$3I_1 - 2I_2 = 1$ — (1)

Loop d c f g h



$-((I_1 - I_2) \times 4) + (+I_2 \times 1) + (+6) = 0$

$-4I_1 + 4I_2 + I_2 = -6$

$-4I_1 + 5I_2 = -6$ — (2)

(1) × 5 ⇒ $15I_1 - 10I_2 = 5$

(2) × 2 ⇒ $-8I_1 + 10I_2 = -12$

$7I_1 = -7 \longrightarrow I_1 = -1$

$3 \times (-1) - 2I_2 = 1$

$-2I_2 = 1 + 3$

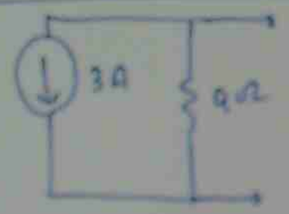
$I_2 = \frac{4}{-2} = -2$

$$\boxed{\begin{aligned} a_1 I_1 + a_2 I_2 &= m_1 \\ b_1 I_1 + b_2 I_2 &= m_2 \end{aligned}}$$

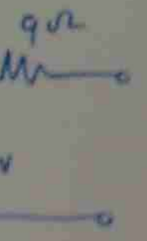
$$I_1 = \frac{\begin{vmatrix} m_1 & a_2 \\ m_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}} \qquad I_2 = \frac{\begin{vmatrix} a_1 & m_1 \\ b_1 & m_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}}$$

CIRCUIT ANALYSIS LESSON(1)

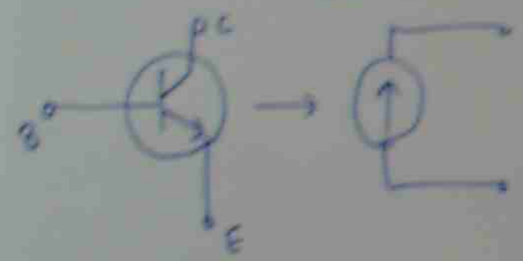
SOURCE CONVERSION



$\rightarrow V = I \times R$
$= 3 \times 9$
$= 27V$



CURRENT SOURCE — VOLTAGE SOURCE

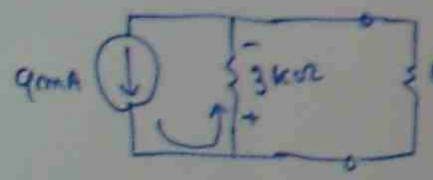


EXAMPLE of CURRENT SOURCE

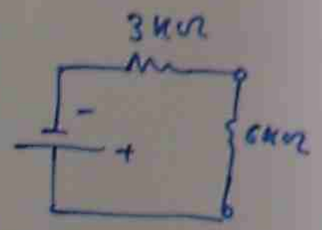
VOLTAGE SOURCE

$\frac{+\,|\,\uparrow}{-\,|}$

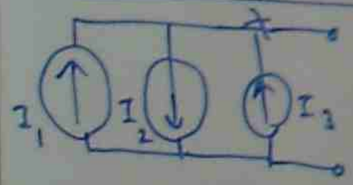
Pb — CONVERT THE FOLLOWING CURRENT SOURCE TO VOLTAGE SOURCE



$V = I \times R$
$= 9 \times 10^{-3} \times 3 \times 10^{3}$
$= 27V$



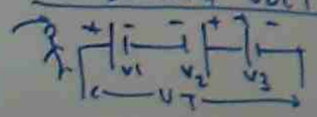
COMBINING CURRENT SOURCES



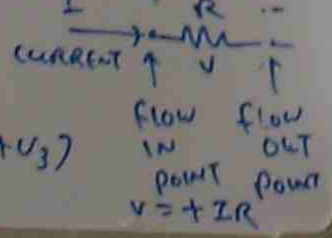
Flow IN: +
Flow OUT: −

$I_T = (+I_1) + (-I_2) + (+I_3)$

COMBINING VOLTAGE SOURCES

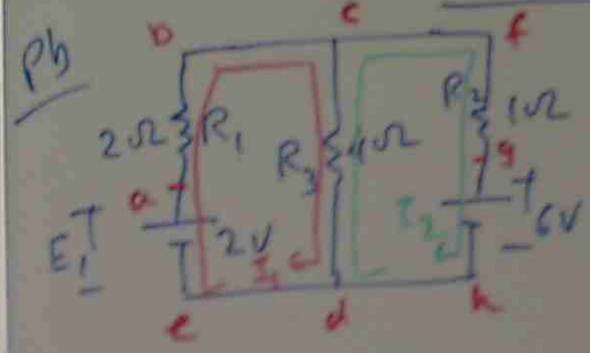


$V_T = (+V_1) + (-V_2) + (+V_3)$



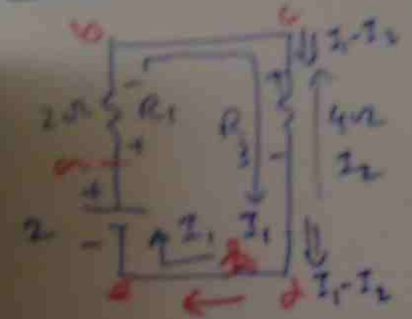
MESH ANALYSIS

Pb



FIND I_1 & I_2

Loop a, b, c, d, e



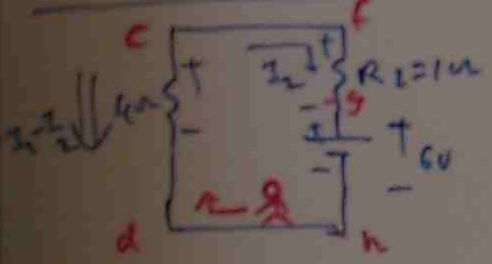
$(-2) + (+I_1 \times 2) + (+4(I_1 - I_2)) = 0$

$-2 + 2I_1 + 4I_1 - 4I_2 = 0$

$6I_1 - 4I_2 = 2$

$3I_1 - 2I_2 = 1$ ——— (1)

Loop d c f g h



$-((I_1 - I_2) \times 4) + (+I_2 \times 1) + (+6) = 0$

$-4I_1 + 4I_2 + I_2 = -6$

$-4I_1 + 5I_2 = -6$ ——— (2)

(1) × 5 ⇒ $15I_1 - 10I_2 = 5$

(2) × 2 ⇒ $-8I_1 + 10I_2 = -12$

$7I_1 = -7 \longrightarrow I_1 = -1$

$3 \times (-1) - 2I_2 = 1$

$-2I_2 = 1 + 3$

$I_2 = \frac{4}{-2} = -2$

$a_1 I_1 + a_2 I_2 = m_1$

$b_1 I_1 + b_2 I_2 = m_2$

$I_1 = \dfrac{\begin{vmatrix} m_1 & a_2 \\ m_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}}$

$I_2 = \dfrac{\begin{vmatrix} a_1 & m_1 \\ b_1 & m_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}}$

$3I_1 - 2I_2 = 1$ $\quad a_1 = 3,\ a_2 = -2$

$a_1 I_1 + a_2 I_2 = m_1$ $\quad m_1 = 1$

$-4I_1 + 5I_2 = -6$ $\quad b_1 = -4,\ b_2 = 5$

$b_1 I_1 + b_2 I_2 = m_2$ $\quad m_2 = -6$

$$I_1 = \frac{\begin{vmatrix} m_1 & a_2 \\ m_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}} = \frac{\begin{vmatrix} 1 & -2 \\ -6 & 5 \end{vmatrix}}{\begin{vmatrix} 3 & -2 \\ -4 & 5 \end{vmatrix}} = \frac{1\times 5 - (-6)(-2)}{3\times 5 - (-4)(-2)}$$

$$= \frac{5 - 12}{15 - 8} = \frac{-7}{7} = -1\ A$$

$$I_2 = \frac{\begin{vmatrix} a_1 & m_1 \\ b_1 & m_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}} = \frac{\begin{vmatrix} 3 & 1 \\ -4 & -6 \end{vmatrix}}{7} = \frac{3(-6) - (-4)\times 1}{7} = \frac{-18 + 4}{7}$$

$$= \frac{-14}{7} = -2\ A$$

$$a_1 I_1 + a_2 I_2 + a_3 I_3 = m_1$$

$$b_1 I_1 + b_2 I_2 + b_3 I_3 = m_2$$

$$c_1 I_1 + c_2 I_2 + c_3 I_3 = m_3$$

$$I_1 = \frac{\begin{vmatrix} m_1 & a_2 & a_3 \\ m_2 & b_2 & b_3 \\ m_3 & c_2 & c_3 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix}} \qquad I_2 = \frac{\begin{vmatrix} a_1 & m_1 & a_3 \\ b_1 & m_2 & b_3 \\ c_1 & m_3 & c_3 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix}}$$

$$I_3 = \frac{\begin{vmatrix} a_1 & a_2 & m_1 \\ b_1 & b_2 & m_2 \\ c_1 & c_3 & m_3 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix}}$$

$c_1 \quad c_2 \quad c_3 \quad c_1$

$m_1 \quad a_2 \quad a_3 \quad m_1 \quad a_2$

$m_2 \quad b_2 \quad b_3 \quad m_2 \quad b_2$

$m_3 \quad c_2 \quad c_3 \quad m_3 \quad c_2$

$$I_1 = \frac{+(m_1 b_2 c_3 + a_2 b_3 m_3 + a_3 m_2 c_2) - (m_3 b_2 a_3 + c_2 b_3 m_1 + c_3 m_2 a_2)}{+(a_1 b_2 c_3 + a_2 b_3 c_1 + a_3 b_1 c_2) - (c_1 b_2 a_3 + c_2 b_3 a_1 + c_3 b_1 a_2)}$$

$a_1 \quad a_2 \quad a_3 \quad a_1 \quad a_2$

$b_1 \quad b_2 \quad b_3 \quad b_1 \quad b_2$

$c_1 \quad c_2 \quad c_3 \quad c_1 \quad c_2$

FURTHER LESSONS, EXPLANATIONS & EXERCISES

STUDY OPTION (1)

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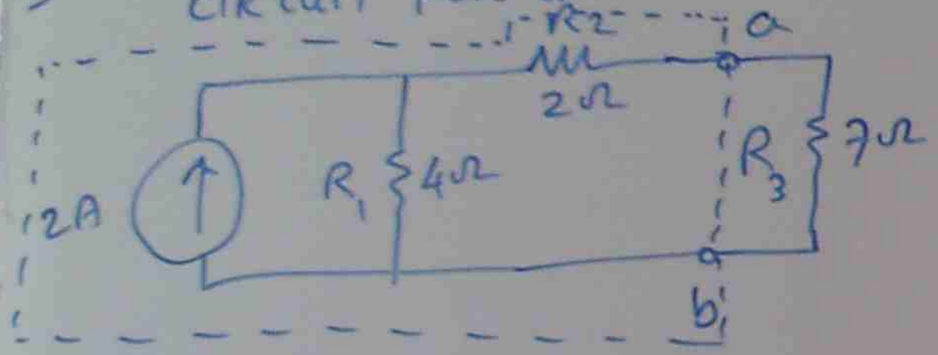
1. CURRENT SOURCE & VOLTAGE SOURCE
2. CIRCUIT SOLUTION

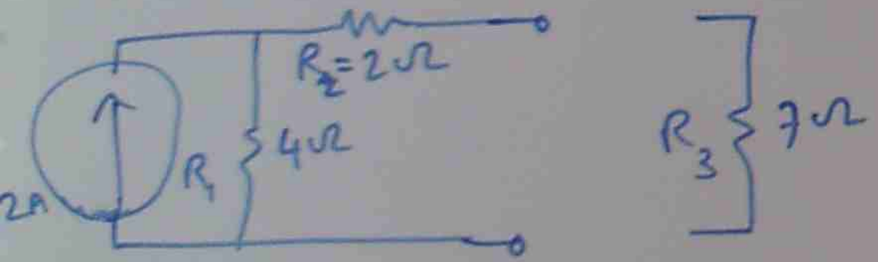
- READ THE LESSONS, LISTEN THE AUDIO FILE
- DO THE EXERCISES GIVEN IN EXERCISE LINK

(3) THEVENIN'S THEOREM

pb FIND THE THEVENIN'S EQUIVALENT CIRCUIT FOR GIVEN AREA OF NETWORK



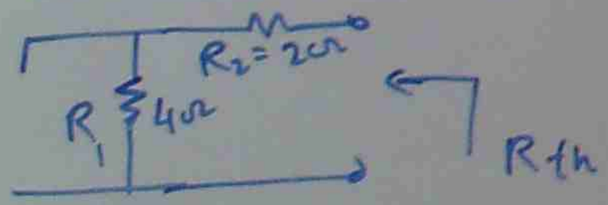
STEP(1) REMOVE THE EXTERNAL RESISTOR



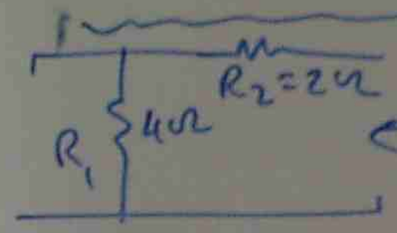
STEP(2) KILL THE SOURCE

(a) CURRENT SOURCE ⟶ REMOVE

(b) VOLTAGE SOURCE ⟶ SHORT CIRCUIT

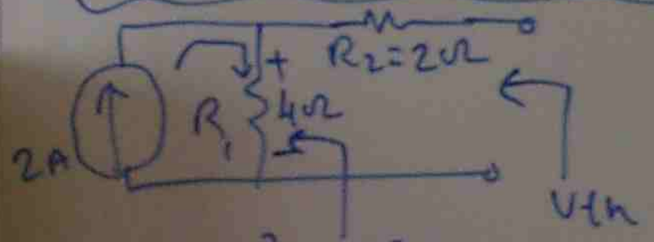


STEP(3) FIND EQUIVALENT RESISTANCE



$R_{th} = R_1 + R_2 = 4 + 2 = 6\Omega$

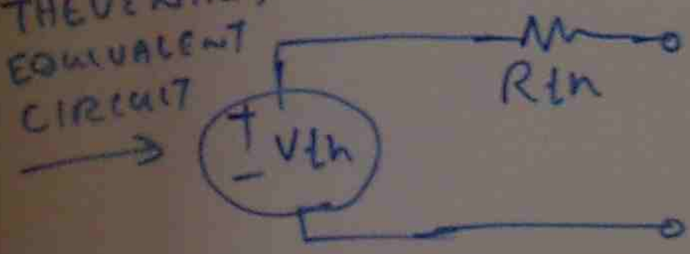
STEP(4) RECONNECT THE SOURCE & FIND VOLTAGE ACROSS TERMINAL

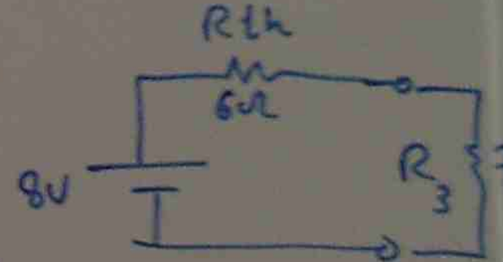


$V_{R_1} = (2A) \times (4\Omega) = 8V$

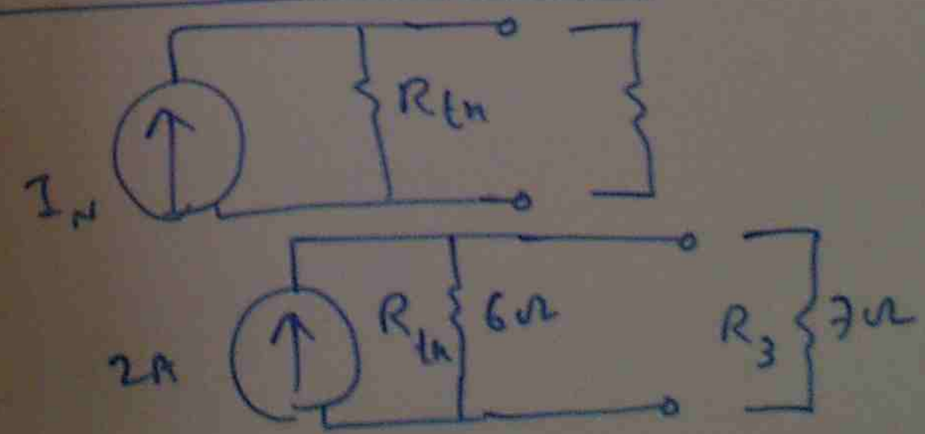
$V_{th} = 8V$

THEVENIN'S EQUIVALENT CIRCUIT



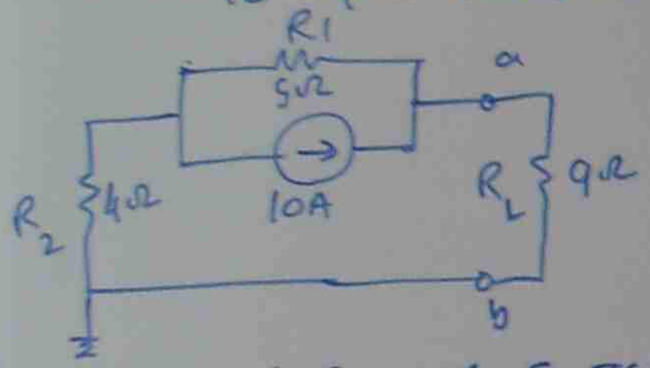


NORTON EQUIVALENT CIRCUIT

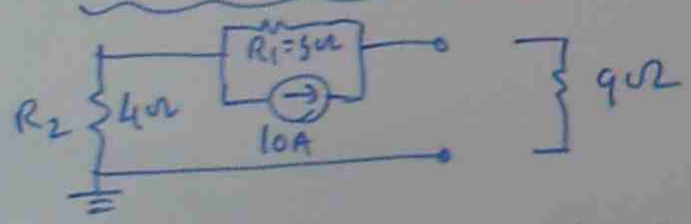


NORTON'S THEOREM

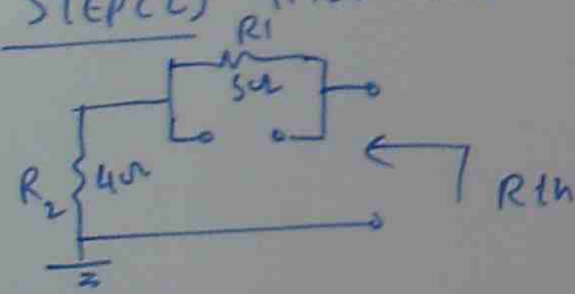
Pb FIND THE NORTON EQUIVALENT CIRCUIT FOR THE NETWORK EXTERNAL TO 9Ω RESISTOR.



STEP(1) REMOVE EXTERNAL RESISTOR



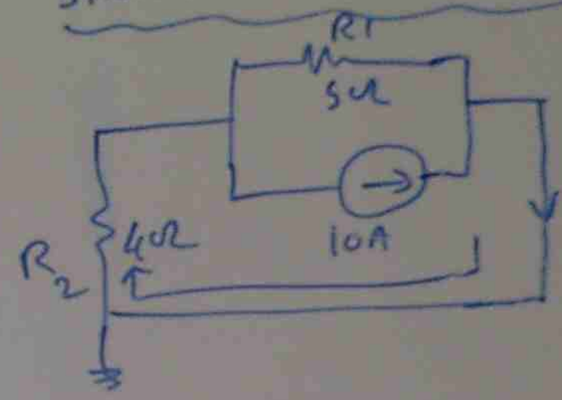
STEP(2) KILL THE SOURCE



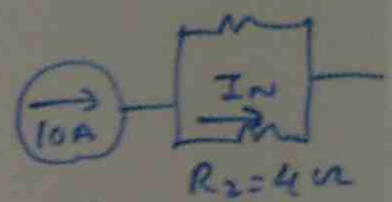
STEP(3) FIND EQUIVALENT RESISTANCE (Rth)

$R_{th} = 4 + 5 = 9\Omega$

STEP(4) RECONNECT THE SOURCE SHORT THE TERMINAL, FIND CURRENT FLOW



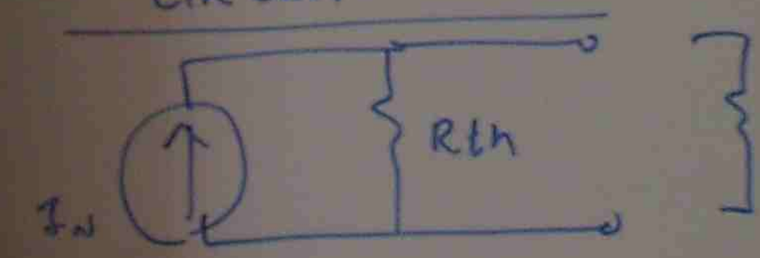
$I_N \equiv$

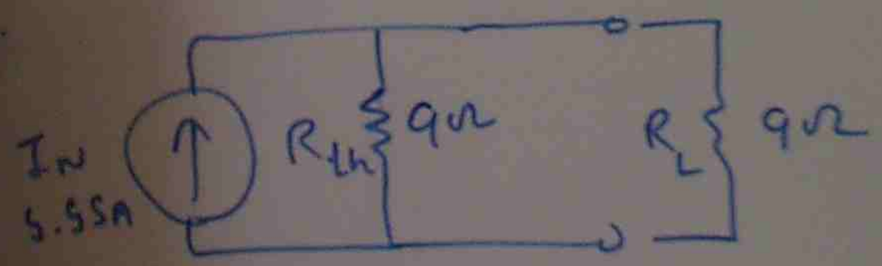


$$I_N = 10 \times \frac{R_1}{R_1 + R_2}$$

$$= 10 \times \frac{5}{5+4} = 5.55\,A$$

NORTON EQUIVALENT CIRCUIT





STUDY G048 (2) CIRCUIT SOLUTION & DO THE EXERCISES IN

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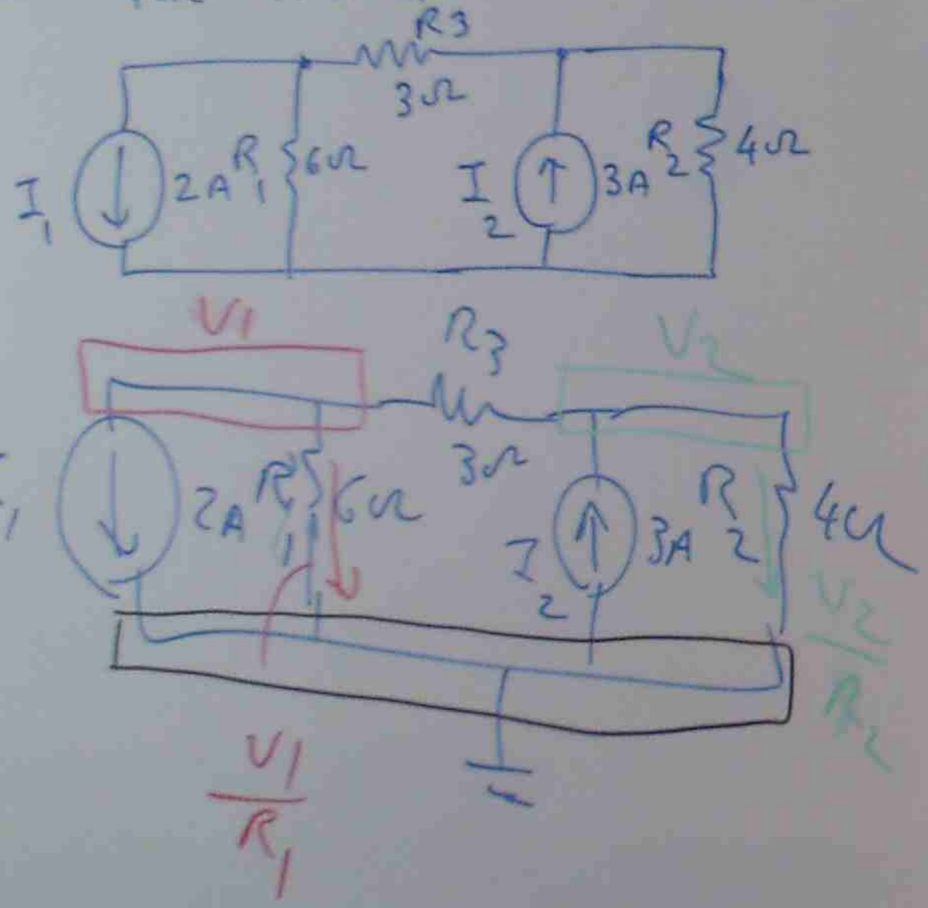
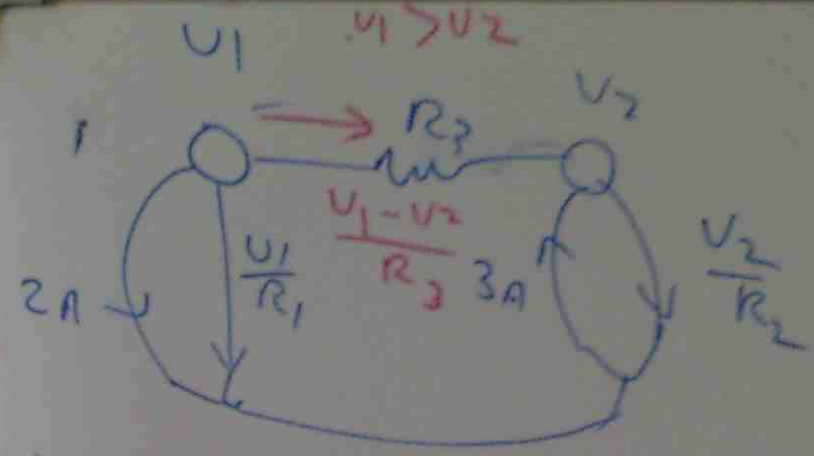
(3) NODAL ANALYSIS

Pb WRITE THE NODAL EQUATION FOR THE GIVEN NETWORK.





V_1 NODE Flow in (+) Flow out (−)

$$(-2)+\left(-\frac{V_1}{R_1}\right)+\left(-\frac{V_1-V_2}{R_3}\right)=0$$

$$-2-\frac{V_1}{6}-\frac{(V_1-V_2)}{3}=0 \quad -(1)$$

V_2 NODE

$$\left(+\left(\frac{V_1-V_2}{R_3}\right)\right)+(+3)+\left(-\frac{V_2}{R_2}\right)=0$$

$$\frac{V_1-V_2}{3}+3-\frac{V_2}{4}=0 \quad -(2)$$

$$-2 - \frac{v_1}{6} - \frac{(v_1 - v_2)}{3} = 0 \quad \text{— (1)}$$

$$\frac{-2\times 6 - v_1 - 2(v_1 - v_2)}{6} = 0$$

$$-12 - v_1 - 2v_1 + 2v_2 = 0$$

$$-3v_1 + 2v_2 = 12$$

$$3v_1 - 2v_2 = -12 \quad \text{— (I)}$$

$$\frac{v_1 - v_2}{3} + 3 - \frac{v_2}{4} = 0 \quad \text{— (2)}$$

$$\frac{4(v_1 - v_2) + 12\times 3 - 3v_2}{12} = 0$$

$$4(v_1 - v_2) + 36 - 3v_2 = 0$$

$$4v_1 - 4v_2 - 3v_2 = -36$$

$$4v_1 - 7v_2 = -36 \quad \text{— (II)}$$

(I) $\times 4 \Rightarrow$ $12v_1 - 8v_2 = -48$

(II) $\times 3 \Rightarrow$ $12v_1 - 21v_2 = -108$

$$+13v_2 = +60$$

$$v_2 = 4.615$$

SUBSTITUTE IN (I)

$$3v_1 - 2(4.615) = -12$$

$$3v_1 = -12 + 2\times 4.615$$

$$3v_1 = -2.77$$

$$v_1 = -0.92$$

EXERCISE

DO NODAL ANALYSIS PROBLEMS IN (2) CIRCUIT SOLUTION

DETERMINANT METHOD

$$a_1 I_1 + a_2 I_2 = m_1$$

$$3v_1 - 2v_2 = -12$$

$a_1 = 3$, $a_2 = -2$, $m_1 = -12$

$$b_1 I_1 + b_2 I_2 = m_2$$

$$4v_1 - 7v_2 = -36$$

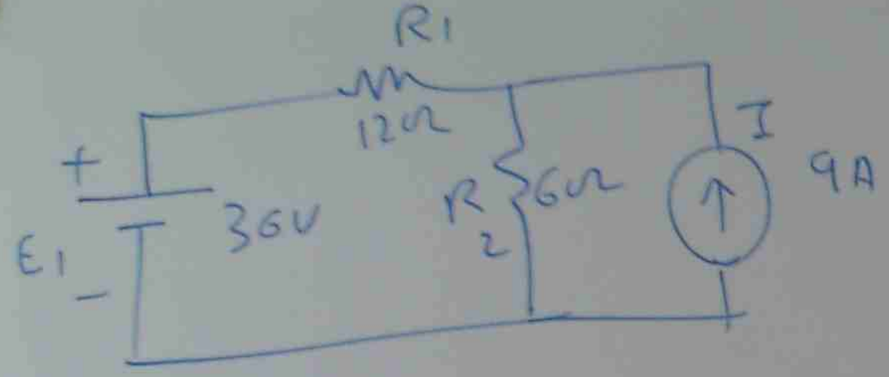
$b_1 = 4$, $b_2 = -7$, $m_2 = -36$

$$v_1 = \frac{\begin{vmatrix} m_1 & a_2 \\ m_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}} = \frac{\begin{vmatrix} -12 & -2 \\ -36 & -7 \end{vmatrix}}{\begin{vmatrix} 3 & -2 \\ 4 & -7 \end{vmatrix}} = \frac{(-12)(-7) - (-36)(-2)}{3(-7) - 4(-2)}$$

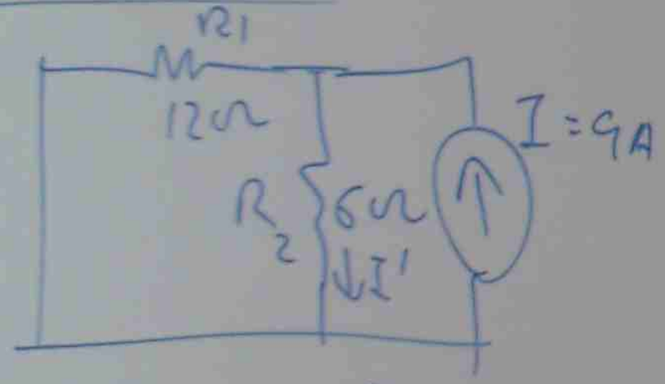
$$= \frac{84 - 72}{-21 + 8} = \frac{12}{-13} = -0.92$$

$$v_2 = \frac{\begin{vmatrix} a_1 & m_1 \\ b_1 & m_2 \end{vmatrix}}{\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}} = \frac{\begin{vmatrix} 3 & -12 \\ 4 & -36 \end{vmatrix}}{-13} = \frac{3(-36) - 4(-12)}{-13} = \frac{-108 + 48}{-13}$$

$$= \frac{-60}{-13} = 4.615$$



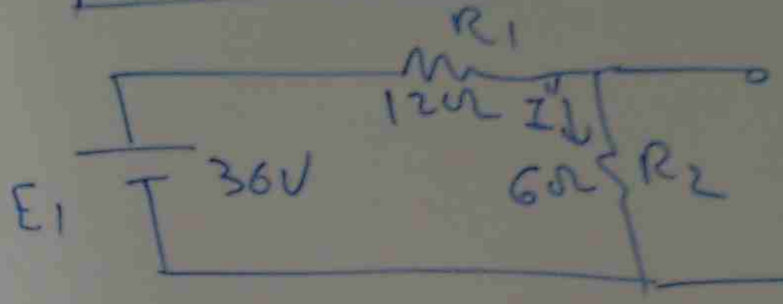
KILL(E1) 36V



$$I' = I \times \frac{R_1}{R_1+R_2} = 9 \times \frac{12}{12+6}$$

$$= 6A \downarrow$$

KILL 9A



$R_T = R_1 + R_2 = 12+6 = 18\Omega$

$$I'' = \frac{E_1}{R_T}$$

$$= \frac{36}{18} = 2A \downarrow$$

$\downarrow +$

$I = I' + I'' = 6 + 2 = 8A$

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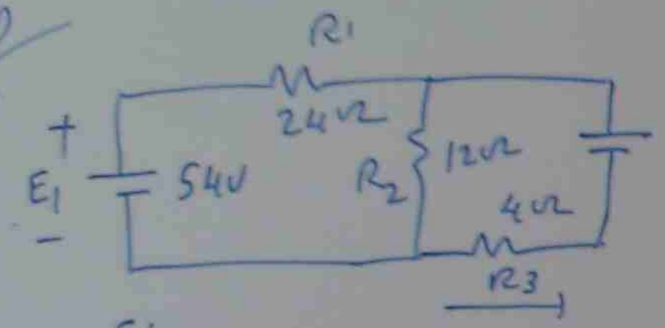
G048

(3) NODAL ANALYSIS
SUPER POSITION
THEOREM
STUDY & EXERCISES

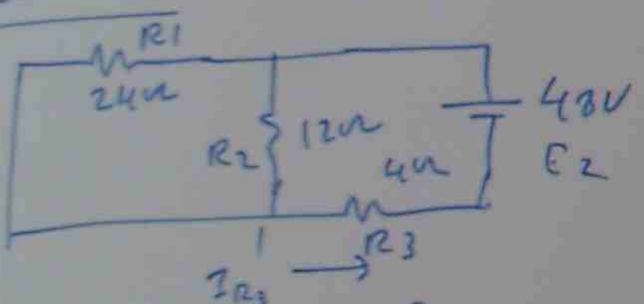
(4) SUPER POSITION THEOREM

Pb



FIND THE CURRENT " " THROUGH R_3

KILL E1



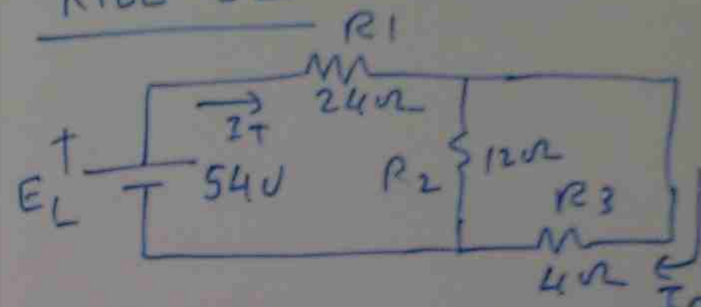
$$R_T = R_3 + \frac{R_1 R_2}{R_1 + R_2} = 4 + \frac{24 \times 12}{24+12}$$

$$= 12\ \Omega$$

$$I'_{R_3} = I'_T = \frac{E_2}{R_T} = \frac{48}{12}$$

$$= 4\ A \longrightarrow$$

KILL E2



$$R_T = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

$$= 24 + \frac{12 \times 4}{12+4}$$

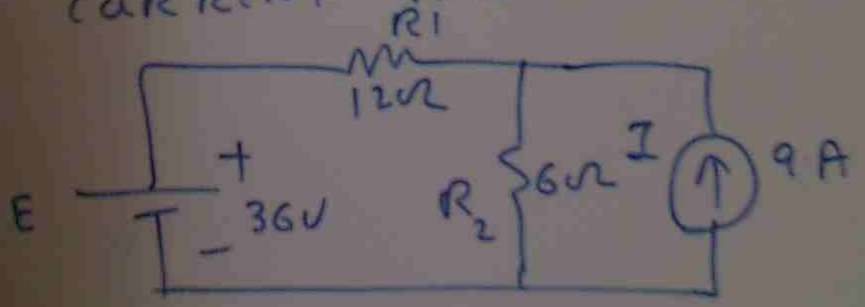
$$= 27\Omega$$

$$I''_T = \frac{E_1}{R_T} = \frac{54}{27} = 2\ A$$

$$I''_{R_3} = I_T \times \frac{R_2}{R_2 + R_3} = 2 \times \frac{12}{12+4} = 1.5\ A \longleftarrow$$

$$I_{R_3} = I'_{R_3} + I''_{R_3} = \underset{\longrightarrow}{4} + \underset{\longleftarrow}{(-1.5)} = \underset{\longrightarrow}{2.5\ A}$$

Pb / USING SUPER POSITION, FIND THE CURRENT THROUGH 6Ω RESISTOR.



AC NETWORK THEOREM

RECTANGULAR FORM — POLAR FORM



$a+jb \rightarrow \sqrt{a^2+b^2} \angle \tan^{-1}\frac{b}{a}$

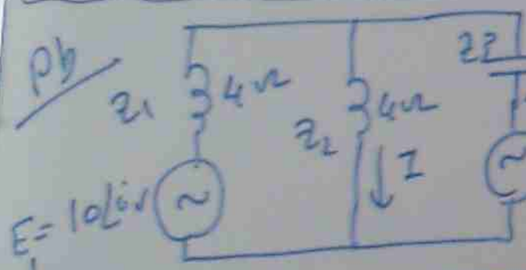
$a-jb \rightarrow \sqrt{a^2+b^2} \angle -\tan^{-1}\frac{b}{a}$

$-a+jb \rightarrow \sqrt{a^2+b^2} \angle 180-\tan^{-1}\frac{b}{a}$

$-a-jb \rightarrow \sqrt{a^2+b^2} \angle -(180-\tan^{-1}\frac{b}{a})$

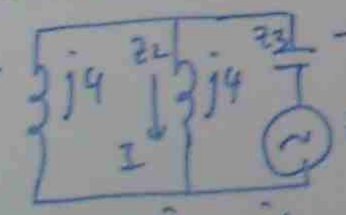
POLAR $z\angle\theta \rightarrow z\cos\theta + jz\sin\theta$ (RECTANGULAR)

Pb



FIND I BY SUPERPOSITION THEOREM

KILL E1



$Z_T = (-j3) + \frac{j4 \times j4}{j4+j4} = -j3 + \frac{4\angle 90 \times 4\angle 90}{j8}$

$= -j3 + \frac{4\times 4 \angle 90+90}{8\angle 90} = -j3 + \frac{16\angle 180}{8\angle 90}$

$= -j3 + 2\angle 90 = -j3 + 2(\cos 90 + j\sin 90)$

$= -j3 + j2 = -j1$

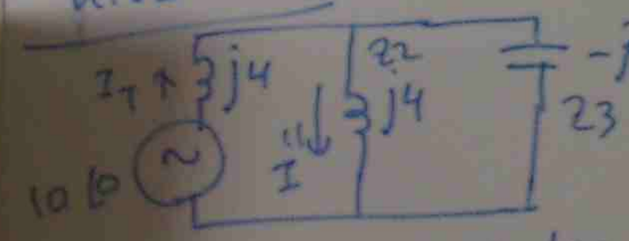
$I_T = \frac{E_2}{Z_T} = \frac{5\angle 0}{-j1} = \frac{5\angle 0}{1\angle -90} = 5\angle 90$

$I' = I_T \times \frac{Z_1}{Z_1+Z_2} = 5\angle 90 \times \frac{j4}{j4+j4}$

$= 5\angle 90 \times \frac{4\angle 90}{j8} = 5\angle 90 \times \frac{4\angle 90}{8\angle 90} = 2.5\angle 90$ ↓

$j2.5$ ↓

KILL E2



$Z_T = j4 + \frac{(-j3)(j4)}{(-j3)+(j4)}$

$= j4 + \frac{3\angle -90 \times 4\angle 90}{j1}$

$Z_T = j4 + \frac{3\angle -90 \times 4\angle 90}{1\angle 90} = j4 + 12\angle -90$

$= j4 + 12(\cos(-90) + j\sin(-90))$

$= j4 - j12 = -j8 = 8\angle -90$

$I_T = \frac{E}{Z_T} = \frac{10\angle 0}{8\angle -90} = 1.25\angle 90$

$I'' = I_T \times \frac{Z_3}{Z_2+Z_3} = 1.25\angle 90 \times \frac{-j3}{j4+(-j3)}$

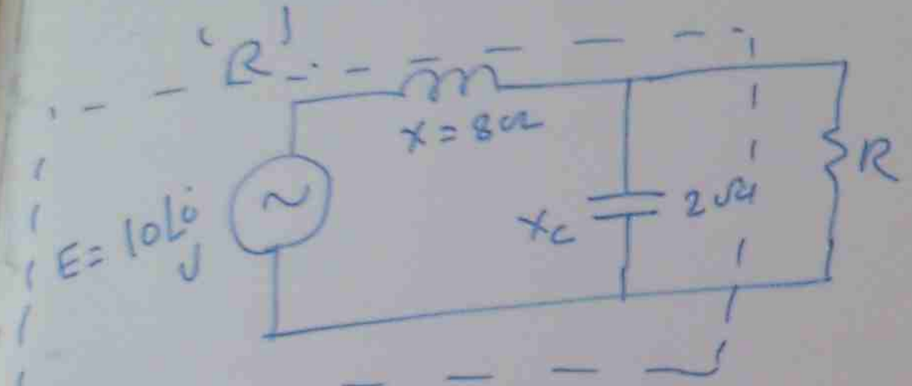
$= 1.25\angle 90 \times \frac{3\angle -90}{1\angle 90} = 3.75\angle 90$ ↓

$= j3.75$ ↓

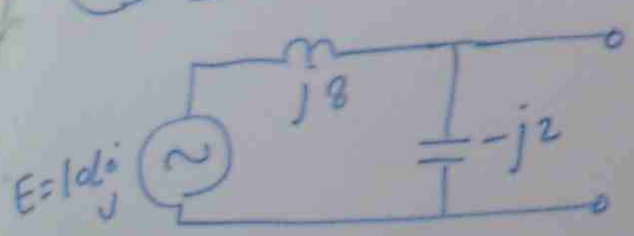
$I = I' + I'' = j2.5 + j3.75 = j6.25$

$= 6.25\angle 90$ ↓

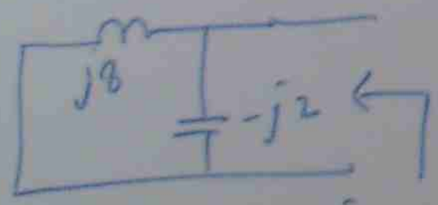
Pb FIND THE THEVENIN EQUIVALENT NETWORK EXTERNAL TO RESISTOR 'R'



(I) REMOVE "R"



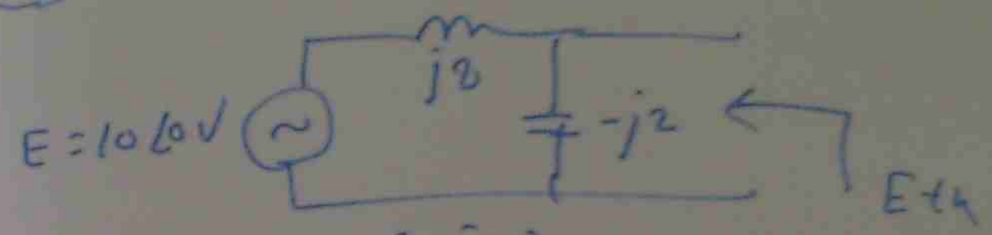
(II) KILL THE SOURCE



(III) FIND $Z_{th} = \frac{j8 \times (-j2)}{j8 + (-j2)} = \frac{8\angle 90 \times 2\angle -90}{j6}$

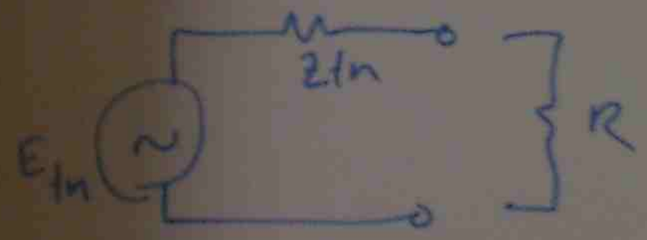
$= \frac{16\angle 0}{6\angle 90} = 2.67\angle -90\ \Omega$

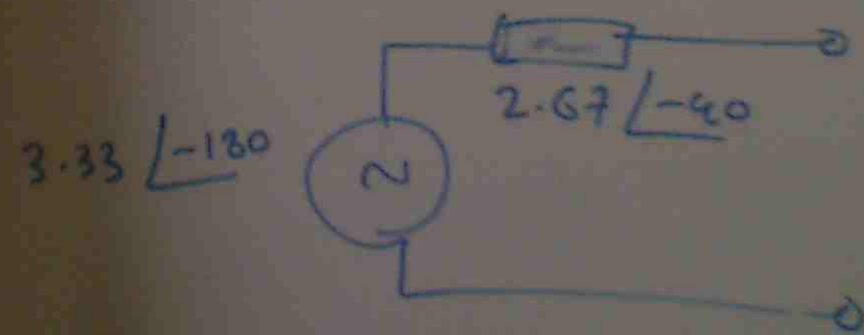
(IV) RECONNECT SOURCE, FIND E_{th}



$E_{th} = E \times \frac{(-j2)}{j8 + (-j2)} = \frac{E(-j2)}{j6}$

$= 10\angle 0 \times \frac{2\angle -90}{6\angle 90} = 3.33\angle -180$





AC NETWORK THEOREM

RECTANGULAR FORM — POLAR FORM



$a+jb \longrightarrow \sqrt{a^2+b^2} \angle \tan^{-1}\frac{b}{a}$

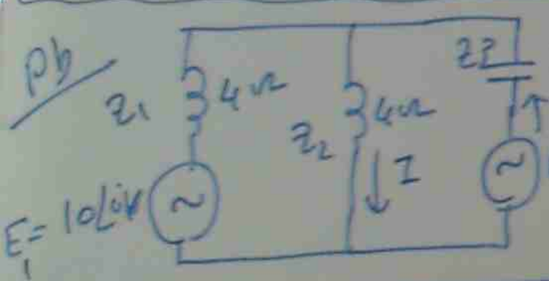
$a-jb \longrightarrow \sqrt{a^2+b^2} \angle -\tan^{-1}\frac{b}{a}$

$-a+jb \longrightarrow \sqrt{a^2+b^2} \angle 180-\tan^{-1}\frac{b}{a}$

$-a-jb \longrightarrow \sqrt{a^2+b^2} \angle -(180-\tan^{-1}\frac{b}{a})$

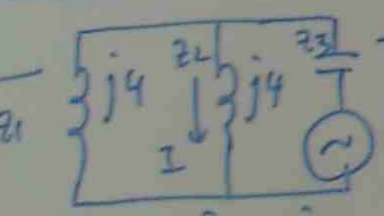
POLAR $Z\angle\theta \longrightarrow Z\cos\theta + jZ\sin\theta$ (RECTANGULAR)

Pb



FIND I BY SUPER POSITION THEOREM

KILL E1



$Z_T = (-j3) + \frac{j4 \times j4}{j4+j4} = -j3 + \frac{4\angle 90 \times 4\angle 90}{j8}$

$= -j3 + \frac{4\times 4 \angle 90+90}{8\angle 90} = -j3 + \frac{16\angle 180}{8\angle 90}$

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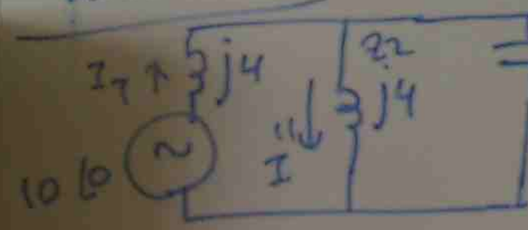
$I_T = \frac{E_2}{Z_T} = \frac{5\angle 0}{-j1} = \frac{5\angle 0}{1\angle -90} = 5\angle 90$

$I' = I_T \times \frac{Z_1}{Z_1+Z_2} = 5\angle 90 \times \frac{j4}{j4+j4}$

$= 5\angle 90 \times \frac{4\angle 90}{j8} = 5\angle 90 \times \frac{4\angle 90}{8\angle 90} = 2.5\angle 90$ ↓ 2.5 ↓

KILL E2



$Z_T = j4 + \frac{(-j3)(j4)}{(-j3)+(j4)}$

$= j4 + \frac{3\angle -90 \times 4\angle 90}{j1}$

$Z_T = j4 + \frac{3\angle -90 \times 4\angle 90}{1\angle 90}$

$= j4 + 12\angle -90$

$= j4 + 12(\cos(-90) + j\sin(-90))$

$= j4 - j12 = -j8 = 8\angle -90\ \Omega$

$I_T = \frac{E}{Z_T} = \frac{10\angle 0}{8\angle -90} = 1.25\angle 90$

$I'' = I_T \times \frac{Z_3}{Z_2+Z_3} = 1.25\angle 90 \times \frac{-j3}{j4+(-j3)}$

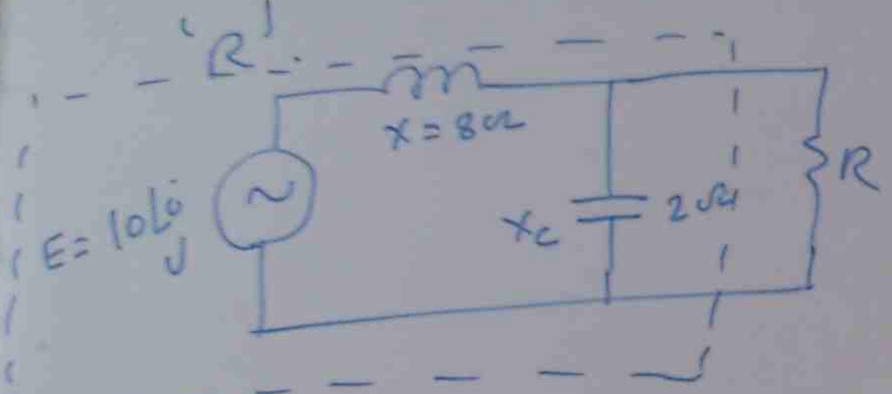
$= 1.25\angle 90 \times \frac{3\angle -90}{1\angle 90} = 3.75\angle 90$ ↓

$= j3.75$ ↓

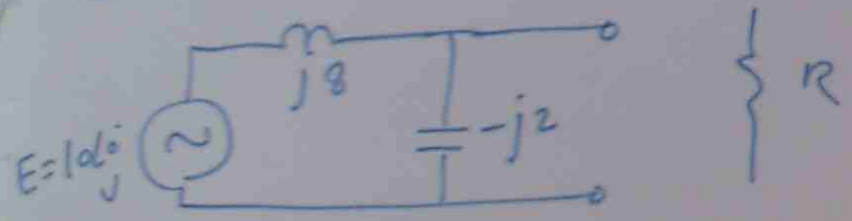
$I = I' + I'' = j2.5 + j3.75 = j6.25$

$= 6.25\angle 90$ ↓

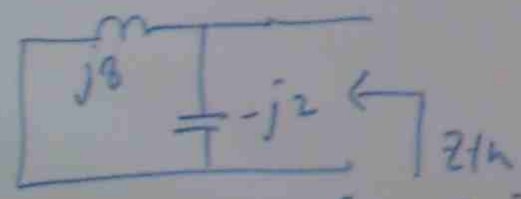
Pb / FIND THE THEVENIN EQUIVALENT NETWORK EXTERNAL TO RESISTOR



(I) REMOVE "R"



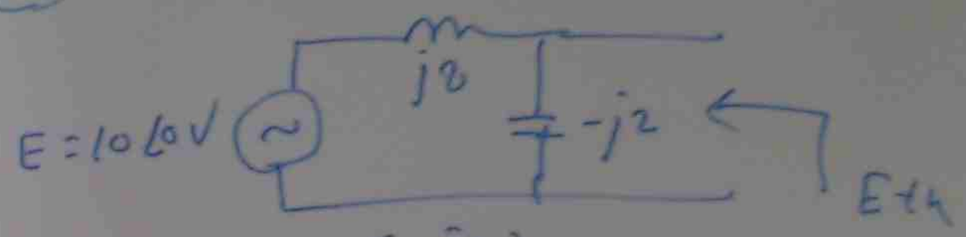
(II) KILL THE SOURCE



(III) FIND $Z_{in} = \frac{j8 \times (-j2)}{j8 + (-j2)} = \frac{8\angle 90 \times 2\angle -90}{j6}$

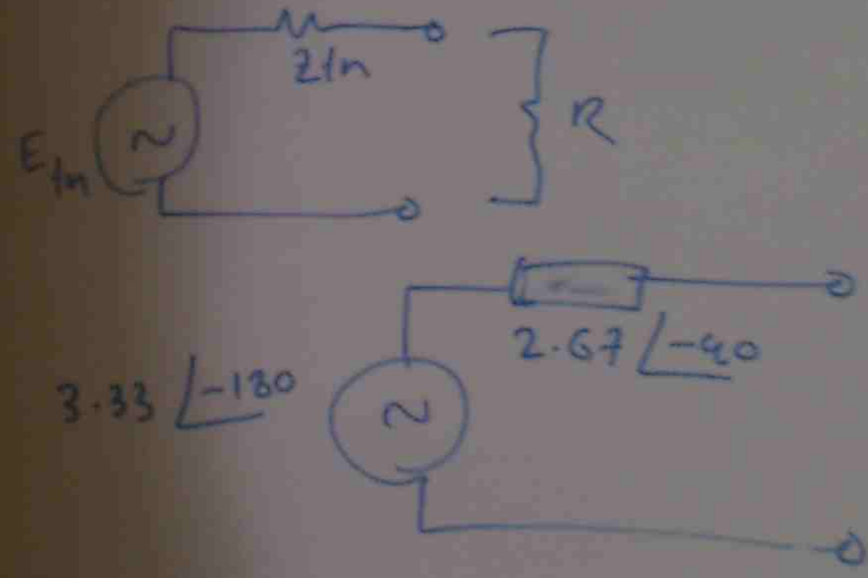
$= \frac{16\angle 0}{6\angle 90} = 2.67\angle -90\ \Omega$

(IV) RECONNECT SOURCE, FIND E_{th}



$E_{th} = E \times \frac{(-j2)}{j8 + (-j2)} = \frac{E(-j2)}{j6}$

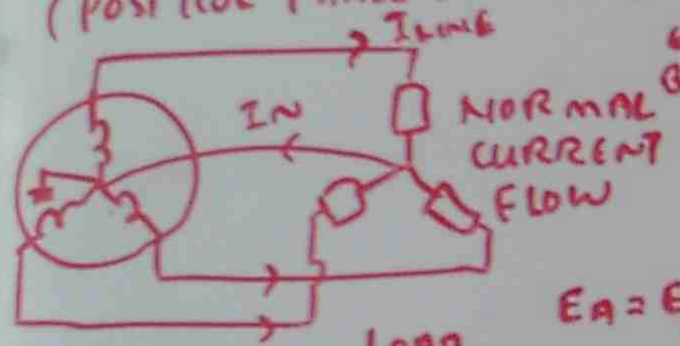
$= 10\angle 0 \times \frac{2\angle -90}{6\angle 90} = 3.33\angle -180$

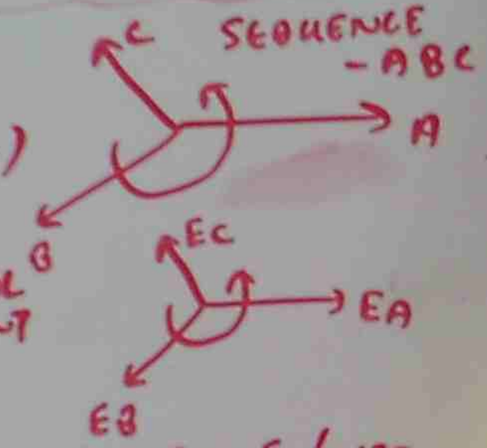


BASIC CONCEPT of 3φ SYSTEM

PHASE SEQUENCE

(POSITIVE PHASE SEQUENCE)



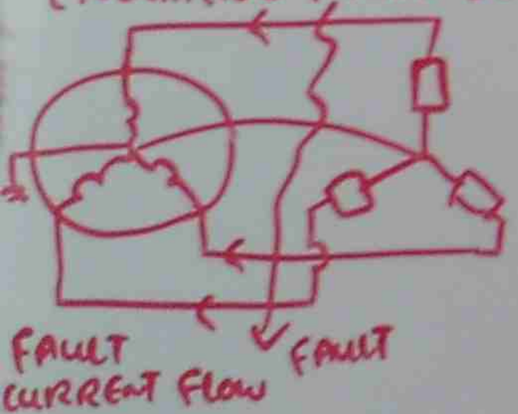


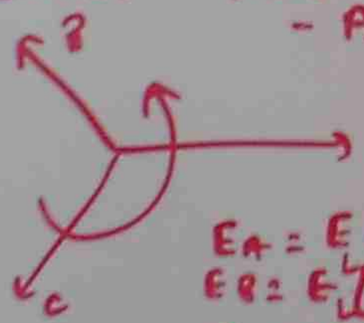
SEQUENCE -ABC

$E_A = E_L \angle 0$, $E_B = E_L \angle -120$

$E_C = E_L \angle -240$ (+120

(NEGATIVE PHASE SEQUENCE)





SEQUENCE -ACB

$E_A = E \angle 0$

$E_B = E \angle 120$

$E_C = E \angle 240$

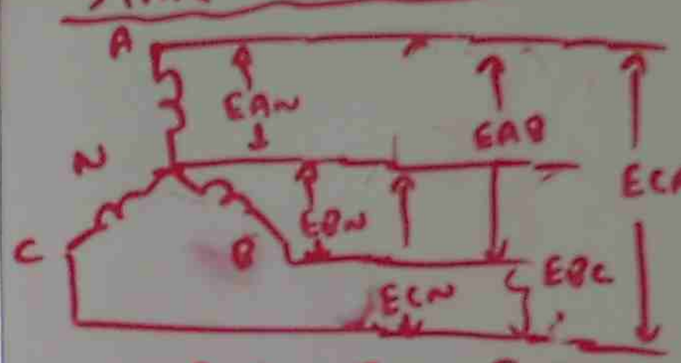
ZERO PHASE SEQUENCE

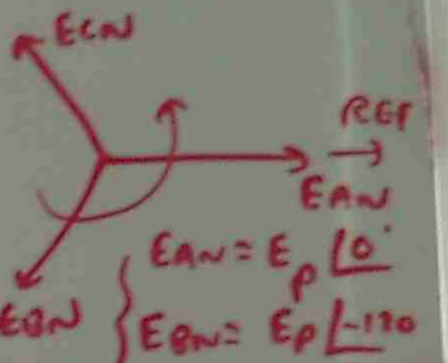


E_A, E_B, E_C

ZERO PHASE SEQUENCE CURRENT TO GROUND

STAR CONNECTION



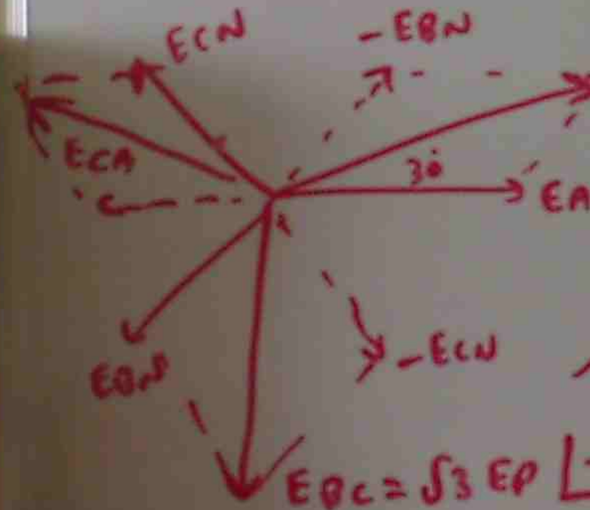


$E_{AN} = E_p \angle 0°$

$E_{BN} = E_p \angle -120$

$E_{CN} = E_p \angle -240$

$E_{AB} = \sqrt{3} E_p$, $E_{BC} = \sqrt{3} E_p$, $E_{CA} = \sqrt{3} E_p$



$E_{AB} = \sqrt{3} E_P \angle 30°$

$E_{CA} = \sqrt{3} E_P \angle 150°$

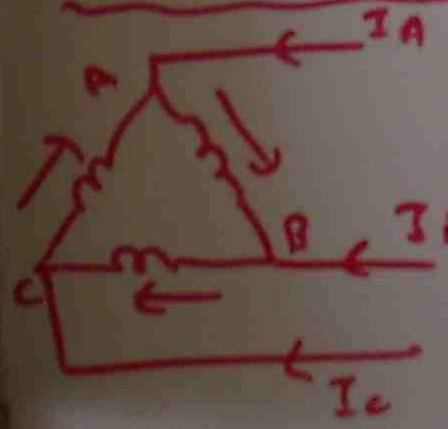
$E_{BC} = \sqrt{3} E_P \angle -90°$

$E_{AB} = E_{AN} - E_{BN}$

$E_{BC} = E_{BN} - E_{CN}$

$E_{CA} = E_{CN} - E_{AN}$

DELTA CONNECTION



A → B → C

Δ

AT (A) POINT

FLOW IN = FLOW OUT

$I_A + I_{CA} = I_{AB}$

$\therefore I_A = I_{AB} - I_{CA}$

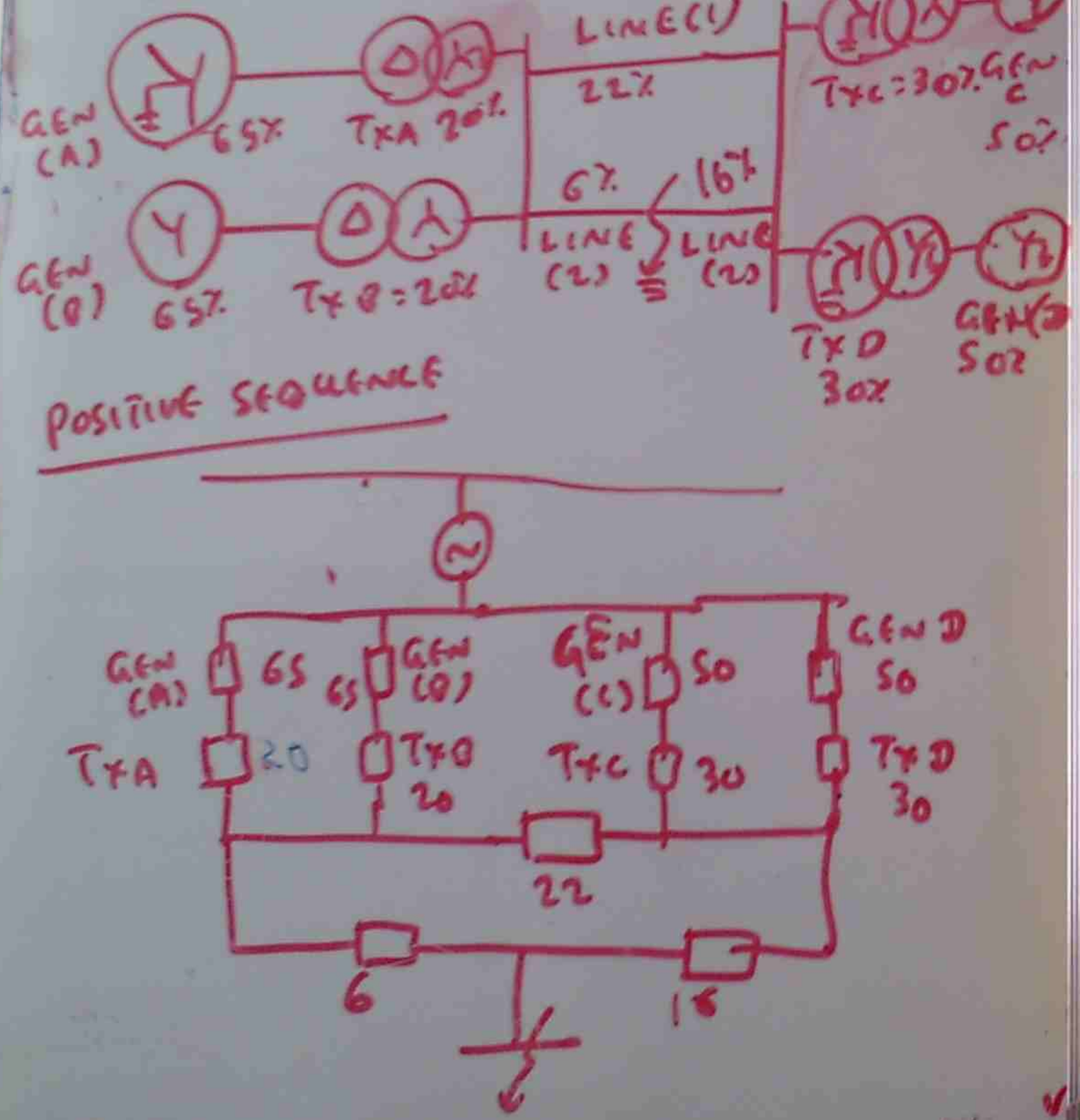
AT (B) POINT, FLOW IN = FLOW OUT

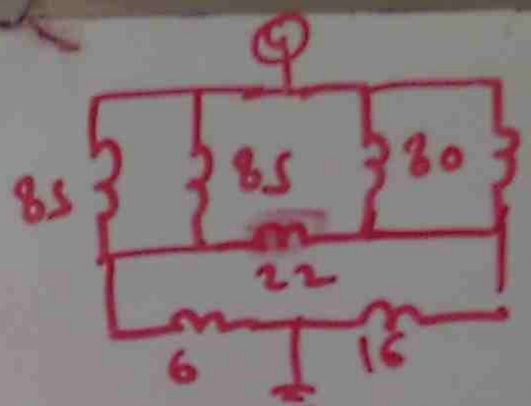
$I_B + I_{AB} = I_{BC} \rightarrow I_B = I_{BC} - I_{AB}$

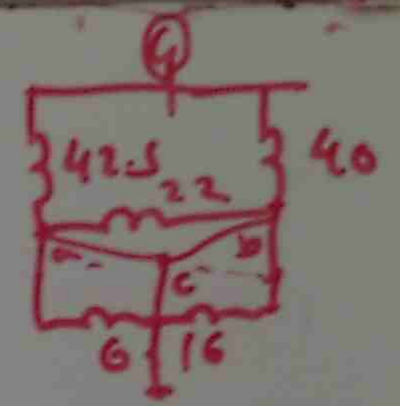
AT (C) POINT, FLOW IN = FLOW OUT

$I_C + I_{BC} = I_{CA} \rightarrow I_C = I_{CA} - I_{BC}$

Pb DRAW POSITIVE SEQUENCE, NEGATIVE SEQUENCE AND ZERO SEQUENCE EQUIVALENT DIAGRAM FOR GIVEN POWER SYSTEM

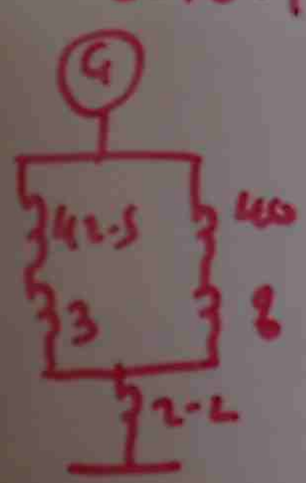


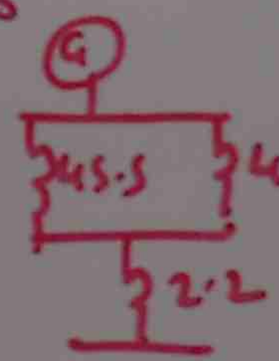


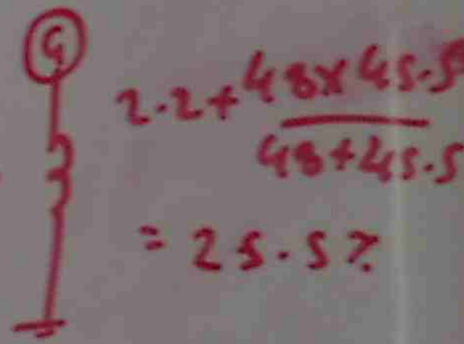


$a = \frac{22 \times 6}{22+6+16} = 3$, $b = \frac{22 \times 16}{6+22+16} = 8$

$c = \frac{6 \times 16}{22+6+16} = 2.2$



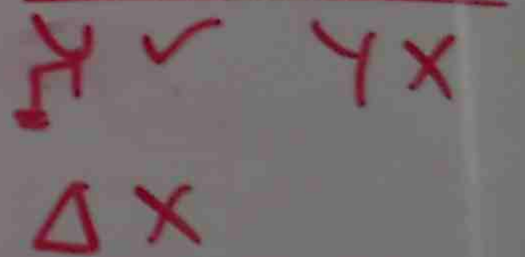




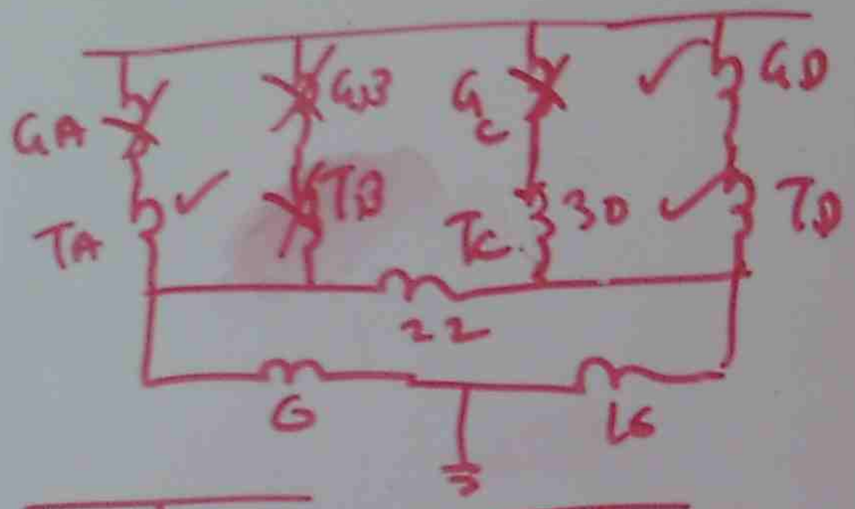
NEGATIVE SEQUENCE

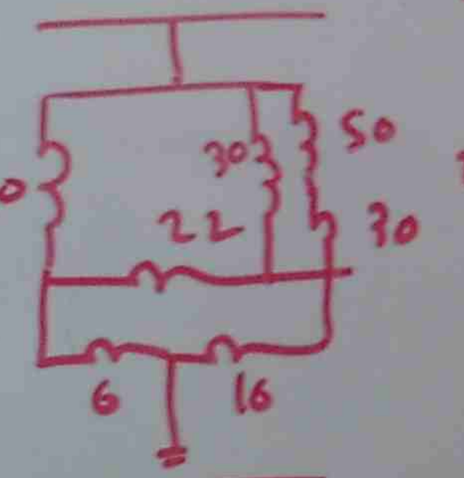


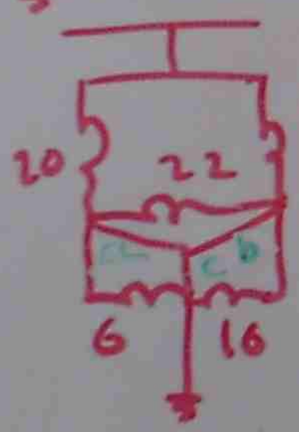
ZERO SEQUENCE



ZERO SEQUENCE

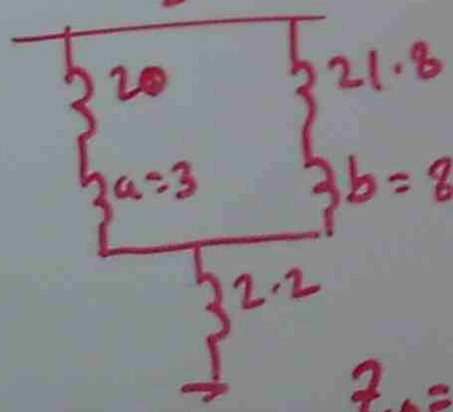


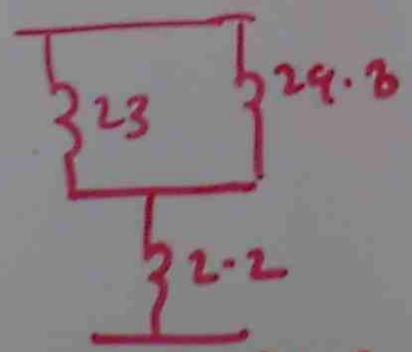




30//30

$\frac{30 \times 30}{30+30} = 21.8$





$Z_0 = 2.2 + \frac{23 \times 29.8}{23+29.8} = 15.1\ \Omega$

(9) AC CIRCUIT 3ϕ PROBLEM

SLIDE 1+2+3

Q17 → Q18

(10) J FORM

SLIDE 1 → 6

Q19 → Q20

(11) POSITIVE, NEGATIVE, ZERO SEQUENCE

SLIDE 1 → 8

Q21 → Q23

(12) PER UNIT SYSTEM

SLIDE 1 → 6

Q24

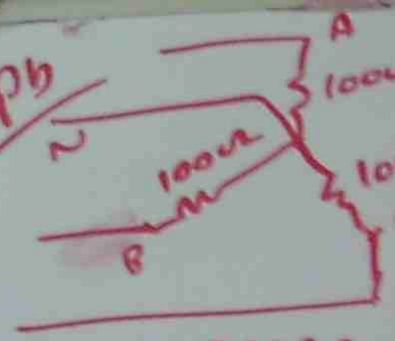
(13) FAULT CALCULATION

SLIDE 1 → 15, Q25

(14) 4 TERMINAL + FAULT CALCULATION

SLIDE 1 → 17 Q26 → Q31

Pb

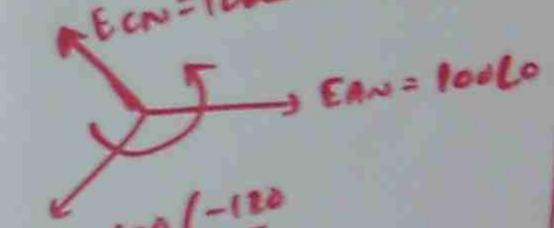


LINE TO LINE VOLTAGE = 173.21 V

FIND PHASE CURRENTS & NEUTRAL CURRENT

PHASE SEQUENCE - ABC

PHASE VOLTAGE = $\frac{\text{LINE VOLTAGE}}{\sqrt{3}} = \frac{173.21}{1.7321} = 100V$



$I_{AN} = \frac{E_{AN}}{Z_A} = \frac{100\angle 0}{100\angle 0} = 1\angle 0$ Amp

$I_{BN} = \frac{E_{BN}}{Z_B} = \frac{100\angle -120}{100\angle 0} = 1\angle -120$ A

$I_{CN} = \frac{E_{CN}}{Z_C} = \frac{100\angle 120}{100\angle 0} = 1\angle 120$ A

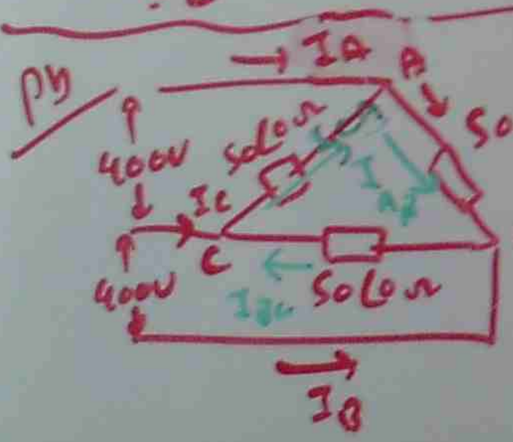
$I_N = I_A + I_B + I_C = 1\angle 0 + 1\angle -120 + 1\angle 120$

$= 1(\cos 0 + j\sin 0) + 1(\cos(-120) + j\sin(-120)) + 1(\cos(120) + j\sin(120))$

$= 1 + j0 - 0.5 - j0.866 + (-0.5) + j0.866$

$= 0$

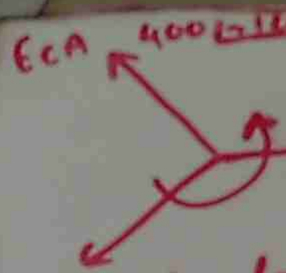
Pb



LINE VOLTAGE IS 400V

PHASE SEQUENCE A-B-C

FIND PHASE CURRENTS AND LINE CURRENTS.



$I_{AB} = \frac{E_{AB}}{Z_{AB}}$

$I_{AB} = \frac{400\angle 0}{50\angle 0} = 8\angle 0$ A

$I_{BC} = \frac{E_{BC}}{Z_{BC}} = \frac{400\angle -120}{50\angle 0} = 8\angle -120$ A

$I_{CA} = \frac{E_{CA}}{Z_{CA}} = \frac{400\angle 120}{50\angle 0} = 8\angle 120$ A

AT POINT (A)

$I_A + I_{CA} = I_{AB} \rightarrow I_A = I_{AB} - I_{CA} = 8\angle 0 - 8\angle 120$

$I_A = 8(\cos 0 + j\sin 0) - 8(\cos 120 + j\sin 120)$

$= 8 + j0 + 4 - j7 = 12 - j7 = \sqrt{12^2 + 7^2}\angle -\tan^{-1}\frac{7}{12}$

$= 13.9\angle -30$ A

AT POINT (B)

$I_B + I_{AB} = I_{BC} \rightarrow I_B = I_{BC} - I_{AB} = 8\angle -120 - 8\angle 0$

$I_B = 8(\cos(-120) + j\sin(-120)) - 8(\cos 0 + j\sin 0)$

$= -4 - j7 - 8 = -12 - j7$

$= \sqrt{12^2 + 7^2}\angle -(180 - \tan^{-1}\frac{7}{12})$

$= 13.9\angle -150$ A

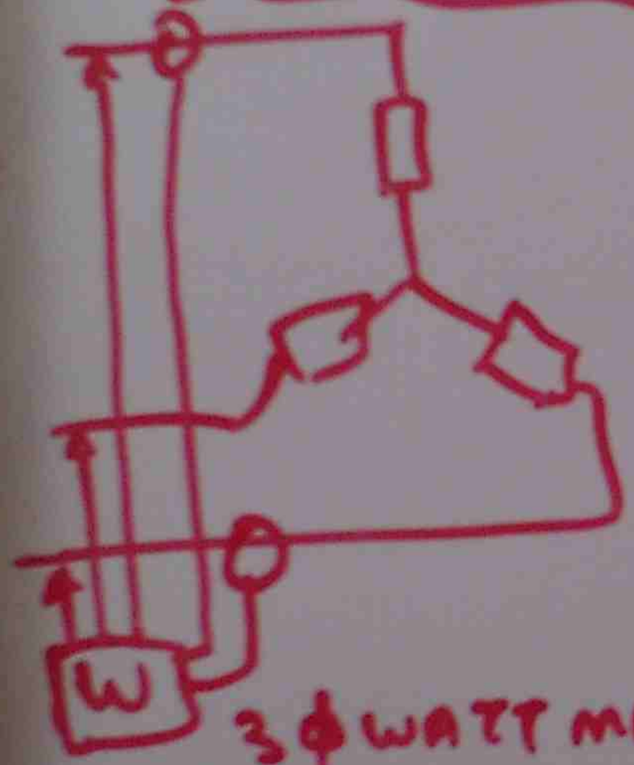
AT POINT (C)

$I_C + I_{BC} = I_{CA} \rightarrow I_C = I_{CA} - I_{BC} = 8\angle 120 - 8\angle -120$

$I_C = 8(\cos 120 + j\sin 120) - 8(\cos(-120) + j\sin(-120))$

$= -j13.4 = 13.9\angle -90$ A

3φ POWER MEASUREMENT



3φ WATT METER

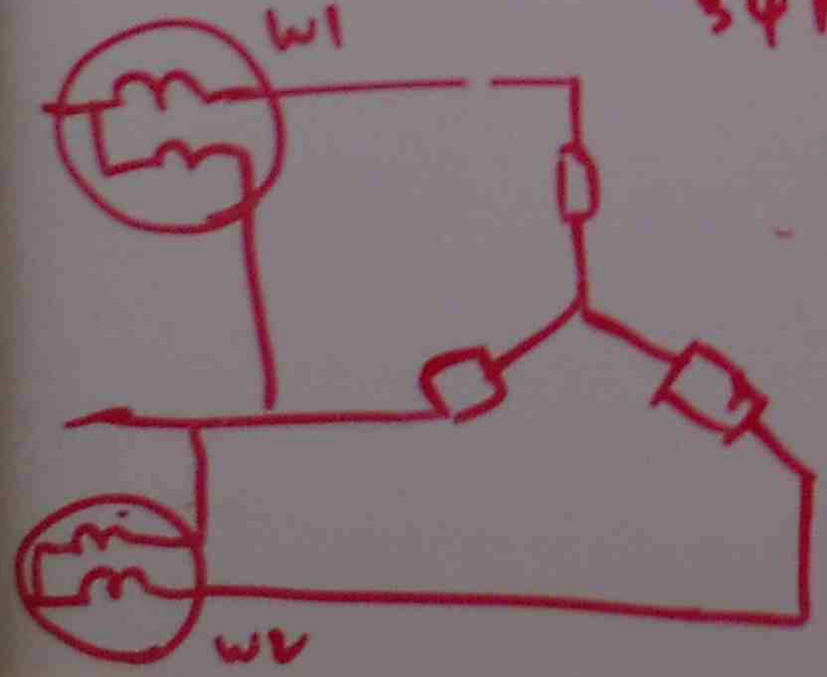
BALANCED



3φ POWER = 3× WATT METER

3φ POWER = $W_1 + W_2$, $\phi = \tan^{-1}\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$

PF = $\cos\phi$



(1) DELTA REVERSE SEQUENCE:- @1

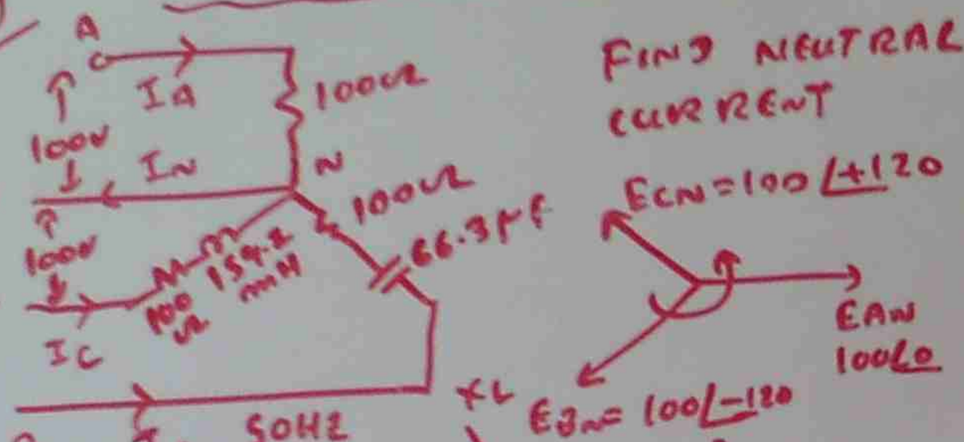
(2) 3φ POWER MEASUREMENT SLIDE 1 → 6, @2, @3

(3) 3φ 4WIRE SLIDE 1 → 5, @ 4 → 5

(4) 3φ 4WIRE SLIDE 1 → 12 | @ → @ 6 → 12

3φ 4 WIRES UNBALANCED LOAD

Ph



FIND NEUTRAL CURRENT

$E_{CN} = 100\angle +120$

E_{AN} $100\angle 0$

$E_{BN} = 100\angle -120$

X_L

$Z_A = 100\ \Omega$, $Z_L = 100 + j\,2\pi fL = 100 + j\,2\times 3.1416 \times 50 \times 159.2\times 10^{-3}$

$Z_C = 100 + j50 = \sqrt{100^2+50^2}\,\angle \frac{\tan^{-1}50}{100} = 111.8\angle 26.5^\circ\ \Omega$

$Z_B = 100 - j\frac{1}{2\pi fc} = 100 - j\frac{1}{2\times 3.1416\times 50\times 66.3\times 10^{-6}}$

X_C

$= 100 - j50 = \sqrt{100^2+50^2}\,\angle -\tan^{-1}\frac{50}{100} = 111.8\angle -26.5^\circ\ \Omega$

$I_A = \frac{E_{AN}}{Z_A} = \frac{100\angle 0}{100} = 1\angle 0\ A$

$I_B = \frac{E_{BN}}{Z_B} = \frac{100\angle -120}{111.8\angle -26.5} = 0.894\angle -120+26.5 = 0.894\angle -94.4^\circ\ A$

$I_C = \frac{E_{CN}}{Z_C} = \frac{100\angle 120}{111.8\angle 26.5} = 0.894\angle 120-26.5 = 0.894\angle 94.4^\circ\ A$

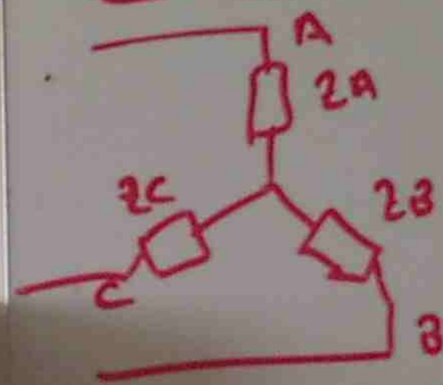
$I_N = I_A + I_B + I_C = 1\angle 0 + 0.894\angle -94.4 + 0.894\angle 94.4$

$= 1(\cos 0 + j\sin 0) + 0.894(\cos(-94.4) + j\sin(-94.4)) + 0.894(\cos 94.4 + j\sin 94.4)$

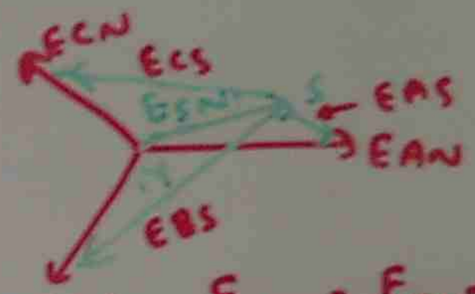
$= 0.878 + j0.0012 = \sqrt{0.878^2+0.0012^2}\,\angle \tan^{-1}\frac{0.0012}{0.878}$

$= 0.878\angle 0.973^\circ\ A$

BREAKING OF NEUTRAL WIRE IN 3φ 4WIRES SYSTEM



3φ 3WIRES SYSTEM



$E_{AS} = I_A \times Z_A$

$E_{BS} = I_B \times Z_B$

$E_{CS} = I_C \times Z_C$

$E_{AN} = E_{AS} + E_{SN}$

$E_{BN} = E_{BS} + E_{SN}$

$E_{CN} = E_{CS} + E_{SN}$

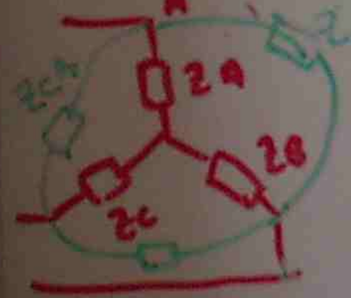
$E_{AN} = \frac{\text{LINE VOLTAGE}\angle 0^\circ}{\sqrt{3}}$

$E_{BN} = \frac{\text{LINE VOLTAGE}\angle -120}{\sqrt{3}}$

$E_{CN} = \frac{\text{LINE VOLTAGE}\angle +120^\circ}{\sqrt{3}}$

I_A, I_B, I_C

CHANGE TO Δ, FIND LINE CURRENTS



$Z_{AB} = \frac{Z_AZ_B + Z_BZ_C + Z_CZ_A}{Z_C}$

$Z_{BC} = \frac{Z_AZ_B + Z_BZ_C + Z_CZ_A}{Z_A}$

$Z_{CA} = \frac{Z_AZ_B + Z_BZ_C + Z_CZ_A}{Z_B}$

$I_A = I_{AB} - I_{CA}$, $I_B = I_{BC} - I_{AB}$, $I_C = I_{CA} - I_{BC}$

Py A 3ϕ 200V SYSTEM NEUTRAL WIRE IS BROKEN. THE FOLLOWING LINE CURRENTS ARE FLOWING.

$Z_A = 50\angle 0^\circ$, $I_A = 1.55\angle -8.5$ Amp

$Z_B = 50\angle 0^\circ$, $I_B = 2.47\angle -176.4^\circ$ Amp

$Z_C = 158\angle 71.6^\circ \Omega$, $I_C = 1.03\angle 26.88$ Amp

(i) WHAT ARE THE NEW PHASE VOLTAGES?

(ii) WHAT IS THE VOLTAGE BETWEEN NEW STAR POINT AND ORIGINAL POINT?

(iii) WHICH PHASE GOT OVER VOLTAGE?

NORMAL PHASE VOLTAGE $= \frac{\text{LINE VOLTAGE}}{\sqrt{3}}$

$= \frac{200}{1.7321} = 115\,V$

$E_{AS} = I_A \times Z_A = 1.55\angle -8.5 \times 50\angle 0 = 77.5\angle -8.5^\circ\,V$

$E_{BS} = I_B \times Z_B = 2.47\angle -176.4 \times 50\angle 0 = 123\angle -176.4^\circ\,V$

$E_{CS} = I_C \times Z_C = 1.03\angle 26.88 \times 158\angle 71.6$

$= 162.5\angle 92.7\,V$ (OVER VOLTAGE)

$E_{SN} = E_{AN} - E_{AS} = 115\angle 0 - 77.5\angle -8.5$

$= 115(\cos 0 + j\sin 0) - 77.5(\cos(-8.5) + j\sin(-8.5))$

$= 38.36 + j11.45$

$= \sqrt{38.36^2 + 11.45^2}\,\angle \tan^{-1}\frac{11.45}{38.36} = 40\angle 16.54\,V$

CALCULATION OF POWER IN FOUR WIRE STAR CONNECTED UNBALANCED LOAD

3ϕ BALANCED LOAD POWER $= \sqrt{3}\,E_{LINE}\,I_{LINE}\cos\phi$

3ϕ UNBALANCED LOAD POWER

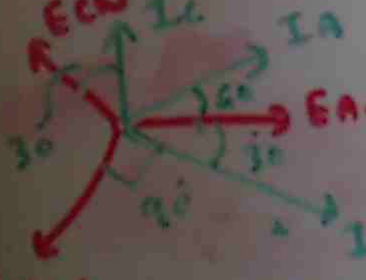
$3\phi\ \text{POWER} = E_{AN} I_A \cos\phi^{E_{AN}}_{I_A} + E_{BN} I_B \cos\phi^{E_{BN}}_{I_B} + E_{CN} I_C \cos\phi^{E_{CN}}_{I_C}$

Py 3ϕ 208V ABC, $Z_A = 10\angle -60$, $Z_B = 6\angle -40$, $Z_C = 12\angle 30$ FIND 3ϕ POWER

$E_{AN} = \frac{E_{LINE}}{\sqrt{3}} = \frac{208}{1.732} = 120\,V$

$I_A = \frac{E_{AN}}{Z_A} = \frac{120\angle 0}{10\angle -60} = 12\angle 60\,A$, $I_B = \frac{E_{BN}}{Z_B} = \frac{120\angle -120}{6\angle -40} = 20\angle -30$

$I_C = \frac{E_{CN}}{Z_C} = \frac{120\angle 120}{12\angle 30} = 10\angle 90\,A$



$P_A = E_{AN} I_A \cos\phi^{E_{AN}}_{I_A}$

$= 120 \times 12 \cos 60 = 720\,W$

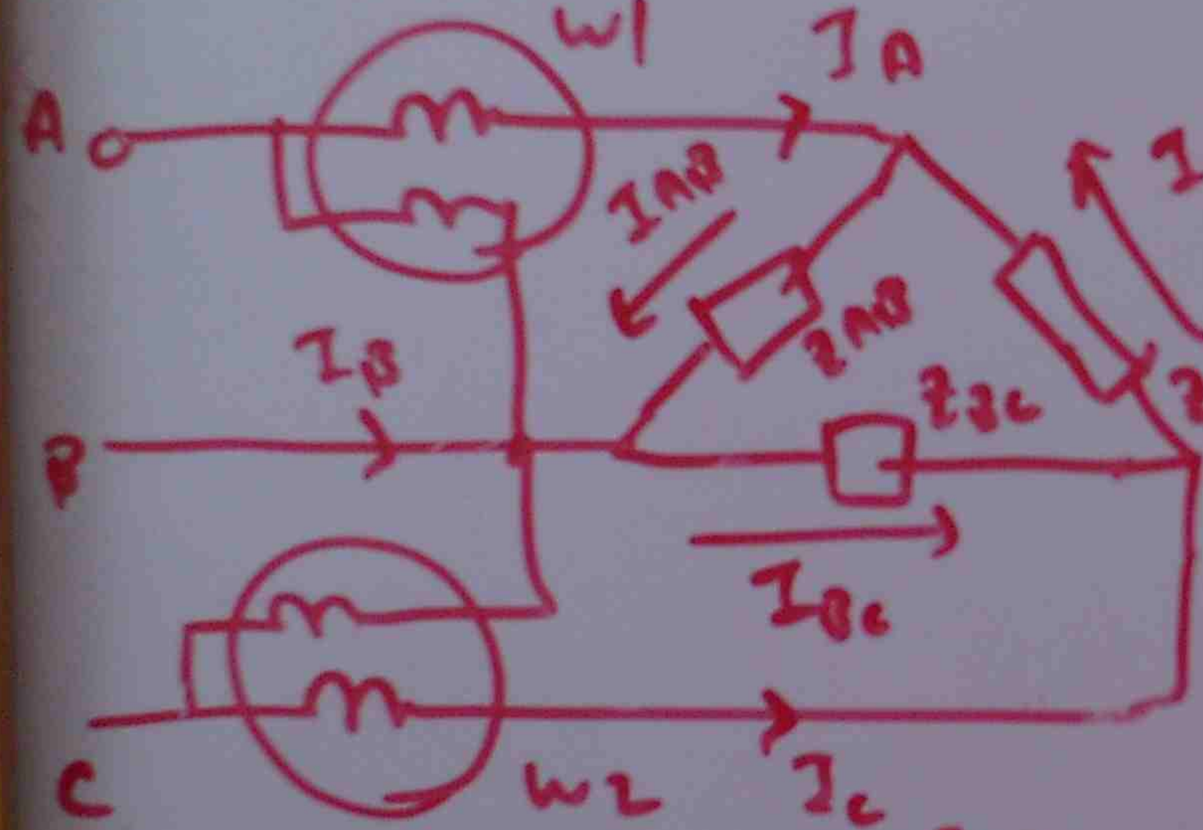
$P_B = E_{BN} I_B \cos\phi^{E_{BN}}_{I_B}$

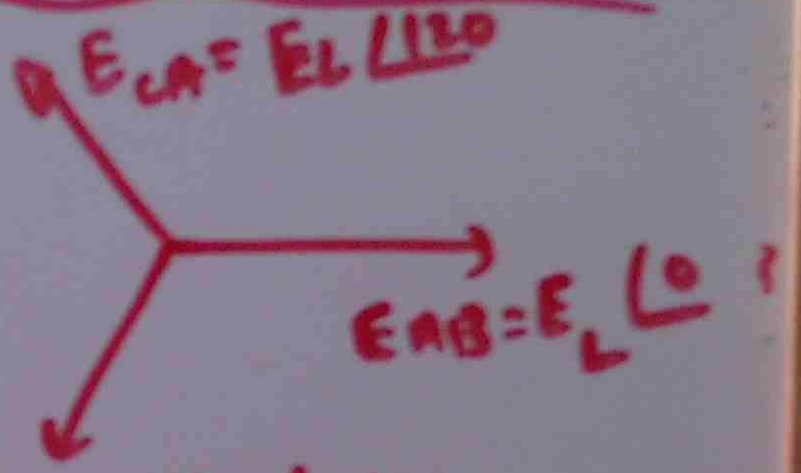
$= 120 \times 20 \cos 90 = 0$

$P_C = E_{CN} I_C \cos\phi^{E_{CN}}_{I_C} = 120 \times 10 \cos 30 = 1059$

$P_T = P_A + P_B + P_C = 720 + 0 + 1059 = 1779\,W$

3φ POWER BY 2 WATT METER METHOD





$$W_1 = E_{AB} I_A \cos \phi_{I_A}^{E_{AB}}$$

$$W_2 = E_{BC} I_C \cos \phi_{I_C}^{E_{BC}}$$

$$W_T = W_1 + W_2$$

$$I_{AB} = \frac{E_L \angle 0}{Z_{AB} \angle \phi_{AB}}$$

$$I_{BC} = \frac{E_L \angle -120}{Z_{BC} \angle \phi_{BC}}$$

$$I_{CA} = \frac{E_L \angle 120}{Z_{CA} \angle \phi_{CA}}$$

$$I_A = I_{AB} - I_{CA}$$

$$I_B = I_{BC} - I_{AB}$$

$$I_C = I_{CA} - I_{BC}$$

(7) 3φ STAR UNBALANCED
SLIDE 1 → 6 @ 14

(8) 3φ Δ POWER
SLIDE 1 → 3 @ 16

3φ FAULT CALCULATION

FAULT

SYMMETRICAL
3φ FAULT

UNSYMMETRICAL
L → L FAULT
L → G FAULT
2L → G FAULT

POSITIVE SEQUENCE → CURRENT FROM GENERATOR TO LOAD

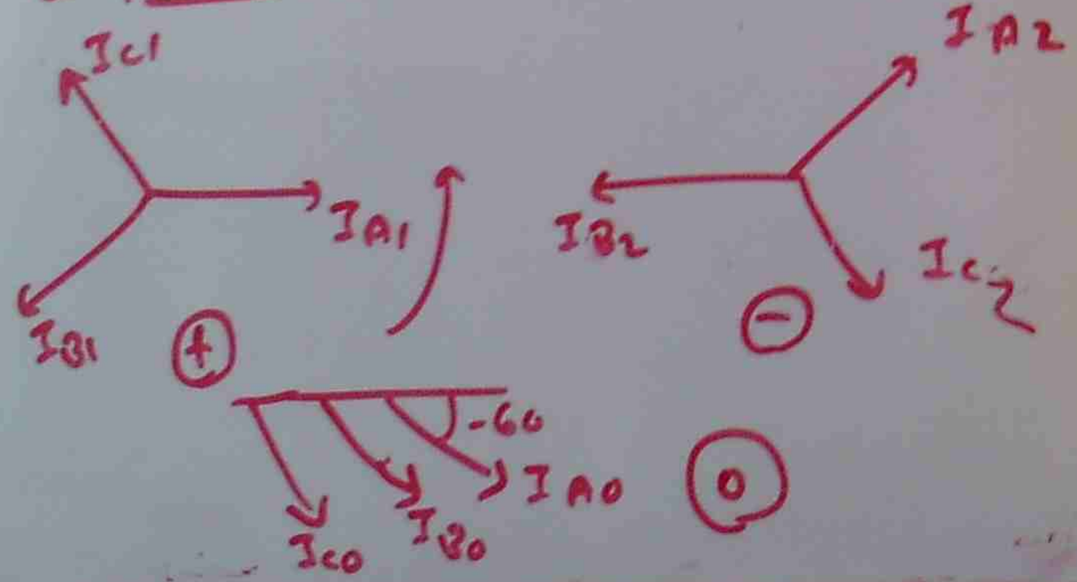
NEGATIVE SEQUENCE → CURRENT FROM FAULT POINT TO GENERATOR

$I_A \; E_0^+ \quad I_0 \; E_0^- \quad I_C \; E_0^+$

$j = 1\angle 90 \quad j^2 = 1\angle 180 \quad j^3 = 1\angle 270, \quad j = \sqrt{-1}$

a = PHASE DISPLACEMENT $= 1\angle 120$

$a^2 = 1\angle 240$



$I_A = I_{A_1}^+ + I_{A_2}^- + I_{A_0}^0, \quad I_B = I_{B_1}^+ + I_{B_2}^- + I_{B_0}^0$

$I_C = I_{C_1}^+ + I_{C_2}^- + I_{C_0}^0$

$I_{A_1} = \frac{1}{3}(I_A + aI_B + a^2 I_C)$

$I_{A_2} = \frac{1}{3}(I_A + a^2 I_B + aI_C)$

$I_{A_0} = \frac{1}{3}(I_A + I_B + I_C)$

I_{B_1} = SAME MAGNITUDE AS I_{A_1} $\angle -120°$ DIFFERENCE

I_{C_1} = SAME MAGNITUDE AS I_{A_1} $\angle +120°$ DIFFERENCE

I_{B_2} = SAME MAGNITUDE AS I_{A_2} $\angle +120°$ DIFFERENCE

I_{C_2} = SAME MAGNITUDE AS I_{A_2} $\angle -120°$ DIFFERENCE

$I_{A_0} = I_{B_0} = I_{C_0} = \angle -60°$

Pb $I_A = 100\angle 0°$ Amp, $I_B = 100\angle +120°$ A
$I_C = 0$ FIND $I_{A_1}, I_{B_1}, I_{C_1}$

$I_{A_1} = \frac{1}{3}(I_A + aI_B + a^2 I_C)$

$= \frac{1}{3}(100\angle 0° + 1\angle 120° \times 100\angle 120° + 1\angle 240° \times 0)$

$= \frac{1}{3}(100 + j0 + 100\angle 300°)$

$= \frac{1}{3}(150 - j86.6)$

$= \frac{1}{3} \times 173.2\angle -30°$

$\rightarrow 57.7\angle -30°$

$I_{B_1} = 57.7\angle -30 - 120$

$= 57.7\angle -150$ A

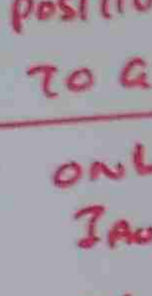
$I_{C_1} = 57.7\angle -30 + 120$

$= 57.7\angle 90$ A

BALANCED 3φ SHORT CIRCUIT

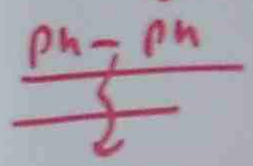
ONLY POSITIVE SEQUENCE $I_{A_1}, I_{B_1}, I_{C_1}$

3 LINES TO GROUND



ONLY ZERO SEQUENCE
I_{A0}, I_{B0}, I_{C0}

Ph-Ph

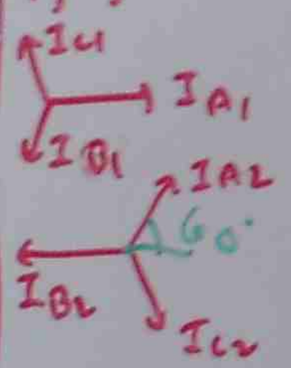
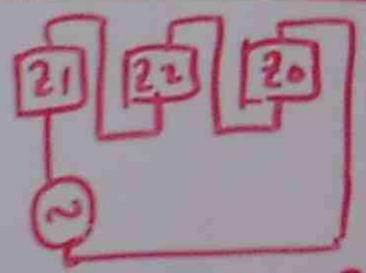


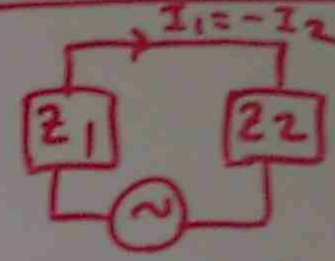
2L→G



ALL $I_{A_1}, I_{B_1}, I_{C_1}$
$I_{A_2}, I_{B_2}, I_{C_2}$
I_{A0}, I_{B0}, I_{C0}
PRESENT

FAULT CURRENT CALCULATION TABLE

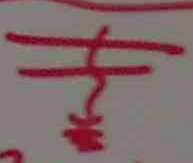
TYPE OF FAULT	COMPONENT	CIRCUIT
1φ→G	+, −, 0 	 $Z_T = Z_0 + Z_1 + Z_2$ $I_{A_1} = I_{A_2} = I_{A_0} = \frac{VA(BASE)}{\sqrt{3}\, V_{LINE}} \times \frac{100}{\%ZT}$ $I_A = I_{A_1} + I_{A_2} + I_{A_0}$ $I_A = 3 I_{A_1}$

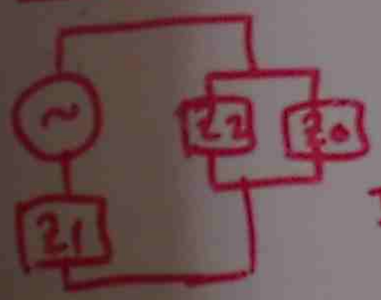
TYPE OF FAULT	COMPONENT	CIRCUIT
L→L 	+, −IVE $I_B \rightarrow I_A$ $I_C = 0$ $I_A = -I_B$ $V_A = V_B$	 $Z_T = Z_1 + Z_2$

$I_1 = \frac{VA\ BASE}{\sqrt{3}\, V_{LINE}} \times \frac{100}{\%ZT}$, $(-I_2) = \frac{VA\ BASE}{\sqrt{3}\, V_{LINE}} \times \frac{100}{\%ZT}$

$I_A = I_B = \sqrt{3}\, I_1$

TYPE OF FAULT 2L→G



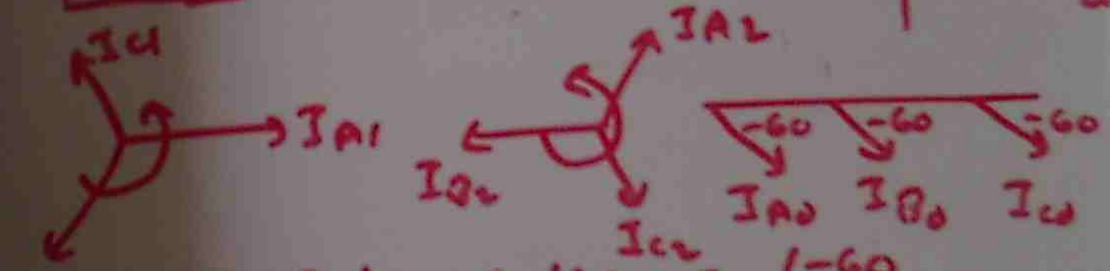


$Z_T = Z_1 + \frac{Z_2 Z_0}{Z_2 + Z_0}$

$I_{1,2} = \frac{VA\ BASE}{\sqrt{3}\, V_{LINE}} \times \frac{100}{\%ZT}$

$I_2 = \frac{I_1 Z_0}{Z_0 + Z_2}$

$I_0 = I_1 \frac{Z_2}{Z_0 + Z_2}$



$I_A = I_1 \angle 0 + I_2 \angle 60 + I_0 \angle -60$

$I_B = I_1 \angle -120 + I_2 \angle 180 + I_0 \angle -60$

$I_C = I_1 \angle 120 + I_2 \angle -60 + I_0 \angle -60$

$I_{FAULT} = I_A + I_B + I_C$

Pb $Z_1 = 65\%$, $Z_2 = 69\%$ $Z_0 = 40\%$ BASE = 100 MVA

$E = 132$ KV 2L → G FAULT, FIND I_{FAULT}

$$Z_T = Z_1 + \frac{Z_2 Z_0}{Z_2 + Z_0}$$

$$= 65 + \frac{69 \times 40}{69 + 40}$$

$$= 90\%$$

$$I_1 = \frac{VA\ BASE}{\sqrt{3}\, V_{LINE}} \times \frac{100}{\%Z_T}$$

$$= \frac{100 \times 10^6}{\sqrt{3} \times 132 \times 10^3} \times \frac{100}{90}$$

$$= 486\ A$$

$$I_2 = \frac{I_1 Z_0}{Z_0 + Z_2} = \frac{486 \times 40}{69 + 40}$$

$$= 178.3\ A$$

$$I_0 = \frac{I_1 Z_2}{Z_0 + Z_2} = \frac{486 \times 69}{69 + 40}$$

$$= 307.6\ A$$

$$I_A = I_{A1} \angle 0 + I_{A2} \angle 60 + I_{A0} \angle -60$$

$$= I_1 \angle 0 + I_2 \angle 60 + I_0 \angle -60$$

$$= 486 \angle 0 + 178.3 \angle 60 + 307 \angle -60$$

$$= 486 (\cos 0 + j \sin 0) + 178.3 (\cos 60 + j \sin 60) + 307 (\cos 60 - j \sin 60)$$

$$= 728 - j 111.96 = 737.4 \angle -8.7\ A$$

$$I_B = I_{B1} \angle -120 + I_{B2} \angle 120 + I_{B0} \angle -60$$

$$= I_1 \angle -120 + I_2 \angle 120 + I_0 \angle -60$$

$$= 746.7 \angle -111.8\ A$$

$$I_C = I_{C1} \angle 120 + I_{C2} \angle -60 + I_{C0} \angle -60$$

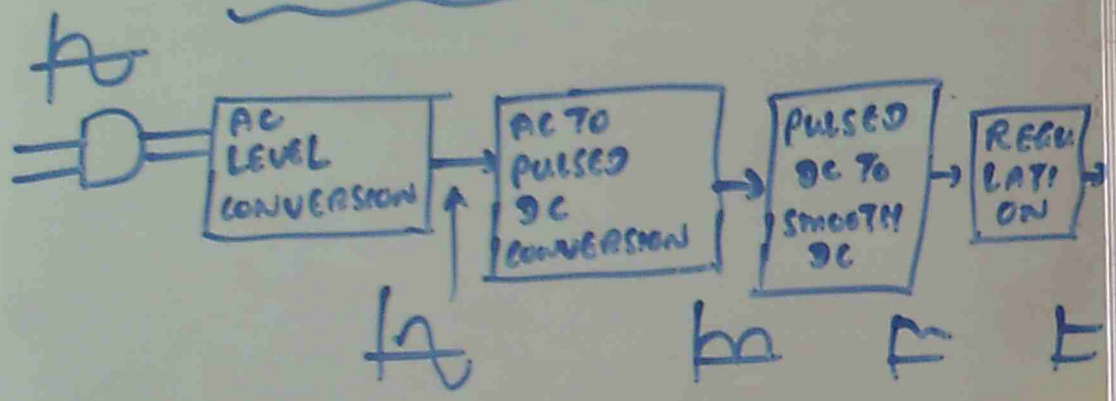
$$= I_1 \angle 120 + I_2 \angle -60 + I_0 \angle -60$$

$$= 0$$

$$I_{FAULT} = I_A + I_B + I_C$$

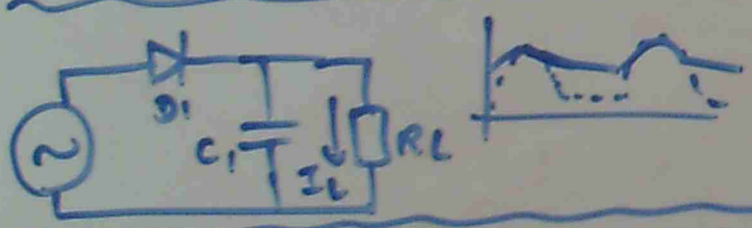
$$= 737.4 \angle -8.7 + 746 \angle -111 + 0 = 918 \angle -60\ A$$

DC POWER SUPPLIES

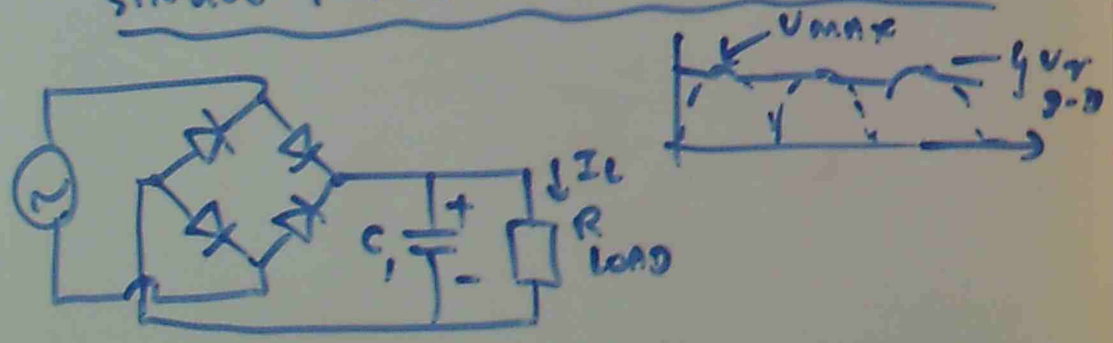


BLOCK DIAGRAM OF A REGULATED POWER SUPPLY

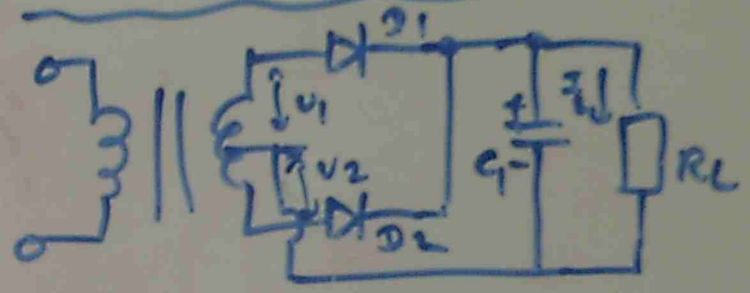
SINGLE PHASE HALF WAVE RECTIFIER



SINGLE PHASE FULL WAVE RECTIFIER



THE CENTRE TAPPED FULL WAVE RECTIFIER



DC OUTPUT VOLTAGE = 0.636 × V_{MAX}

PIV DIODES MUST WITHSTAND 2× V_{MAX}

CIRCUIT OPERATION

* FOR (+) HALF CYCLE OF THE INPUT, DIODE (D_1) CONDUCTS. CURRENT FLOWS IN TOP SECTION OF TRANSFORMER.
* FOR (−) HALF CYCLE OF THE INPUT, DIODE (D_2) CONDUCTS. CURRENT FLOWS IN BOTTOM SECTION OF TRANSFORMER.

CIRCUIT	V_{DC}	PIV of DIODES	RIPPLE FREQUENCY
½ WAVE	V_{MAX}	V_{MAX}	f SUPPLY
BRIDGE	V_{MAX}	V_{MAX}	$2 \times f$ SUPPLY
CT FULLWAVE	V_{MAX}	$2\,V_{MAX}$	$2\,f$ SUPPLY

CALCULATING THE SIZE OF FILTER CAPACITOR

$$C = \frac{V_{DC}}{V_r f_r R_L}$$

V_{DC} - DC OUTPUT VOLTAGE
V_r - P-P RIPPLE VOLTAGE
f_r - RIPPLE FREQUENCY

Pb CALCULATE THE LOAD RESISTANCE AND CAPACITOR SIZE OF A FULL WAVE RECTIFIER THAT SUPPLIES 40V DC WITH A 2% RIPPLE 'V' (PEAK TO PEAK) AT 250mA TO A RESISTIVE LOAD. ASSUME THE RECTIFIER CIRCUIT IS SUPPLIED WITH 50HZ AC

$R_L = \frac{V_{dc}}{I_L} = \frac{40}{0.25} = 160\Omega$

$V_r = V_{dc} \times \text{RIPPLE} = 40 \times \frac{2}{100} = 0.8V$

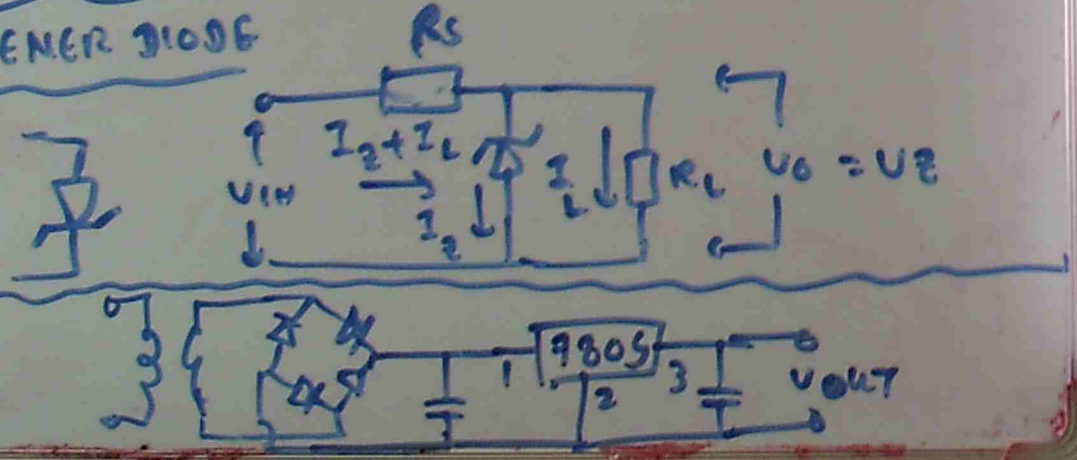
$V_{dc} = V_r f_r R_L C \rightarrow C = \frac{V_{dc}}{V_r f_r R_L}$

$C = \frac{40}{0.8 \times 100 \times 160} = 3125\,\mu F$

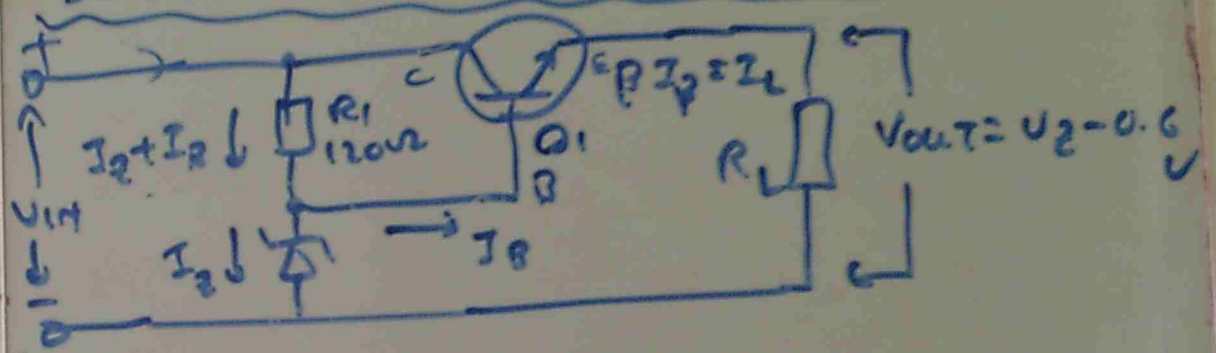
LOAD REGULATION

$\%\text{ LOAD REGULATION} = \frac{V_{dc}(\text{NO LOAD}) - V_{dc}(\text{FULL LOAD})}{V_{dc}(\text{FULL LOAD})} \times 100$

ZENER DIODE



SERIES TRANSISTOR REGULATOR

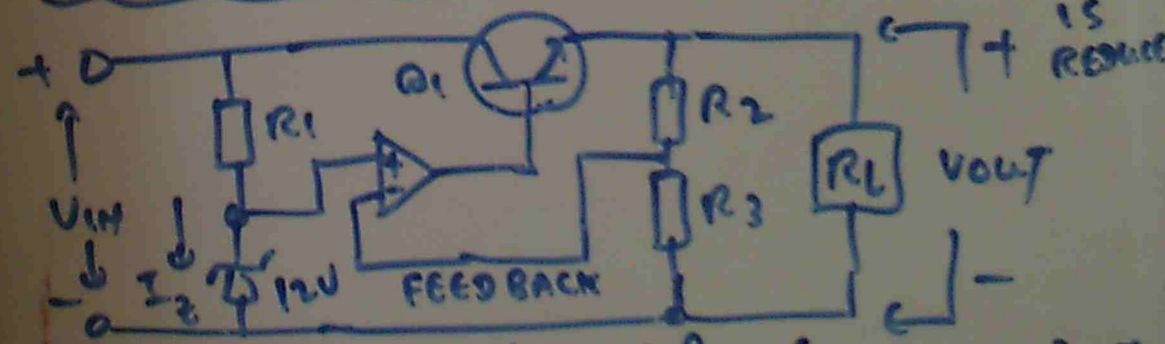


$V_{CE} = V_{IN} - V_{OUT}$

AN INCREASE IN THE LOAD CURRENT WILL CAUSE ZENER CURRENT TO REDUCE AS MORE BASE CURRENT IS REQUIRED BY TRANSISTOR. IF THE INPUT VOLTAGE CHANGES, THE ZENER CURRENT WILL ALSO CHANGE, BUT THE ZENER VOLTAGE WILL REMAIN CONSTANT KEEPING THE OUTPUT VOLTAGE CONSTANT

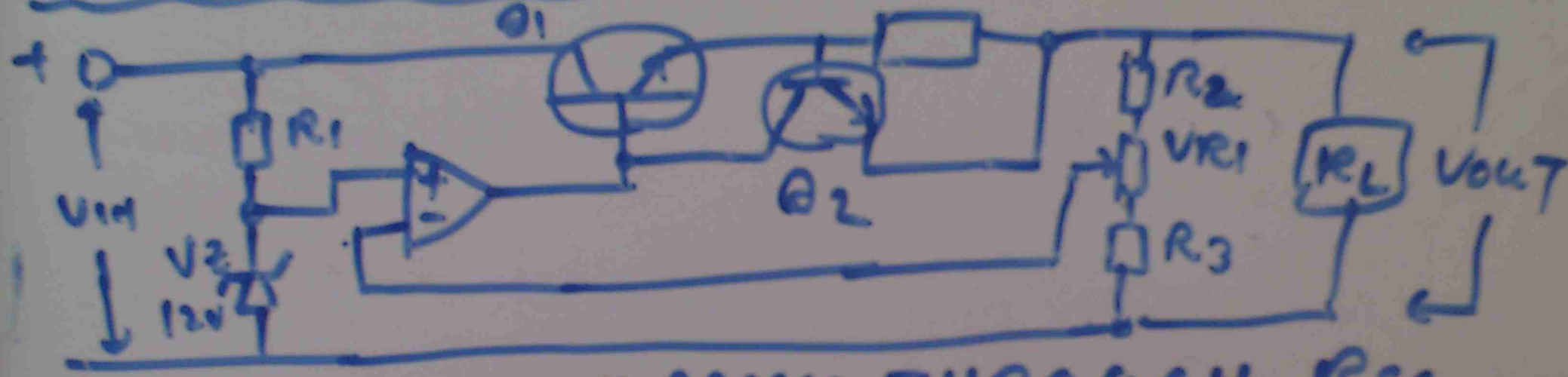
POWER DISSIPATED BY SERIES TRANSISTOR $= I_L \times V_{CE}$

REGULATOR WITH FEED BACK



$V_{OUT} = \left(\frac{R_2}{R_3} + 1\right) \times V_{REF}$ | $P_d = (V_{IN} - V_{OUT}) \times I_L$

CURRENT LIMITING



- THE LOAD CURRENT PASSES THROUGH Rsc
- IF THE VOLTAGE DEVELOPED ACROSS Rsc EXCEEDS 0.6V, Q2 WILL BE TURNED ON AS FORWARD BIAS VOLTAGE ACROSS Rsc. VE=VREF
- WHEN Q2 TURNS ON, IT WILL ROB Q1 OF BASE CURRENT TURNING OFF Q1. AS RESULT, THE LOAD CURRENT IS LIMITED $I_{sc} = \frac{0.6V}{R_{sc}}$

Pb $V_{IN}=30V$, $R_2=1K$, $R_3=1K$, $V_{R1}=2K$, $R_{sc}=0.6\Omega$ FIND V_{OMIN}, V_{OMAX}, P_d

$V_O = \left(\frac{R_2}{R_3}+1\right) \times V_{REF}$

$V_{OMIN} = \left(\frac{1}{3}+1\right) \times 6$

$= 8V$

$V_{O_{MAX}} = \left(\frac{3}{1}+1\right) \times 6 = 24V$

$I_{sc} = \frac{0.6V}{R_{sc}} = \frac{0.6}{0.6} = 1A$

$P_d = (V_{IN} - V_O) * I_L = (30-0) \times 1 = 30W$

3 TERMINAL REGULATOR LM338

HOLL

(1) POWER SUPPLIES

SLIDE (1) ⟶ (7)

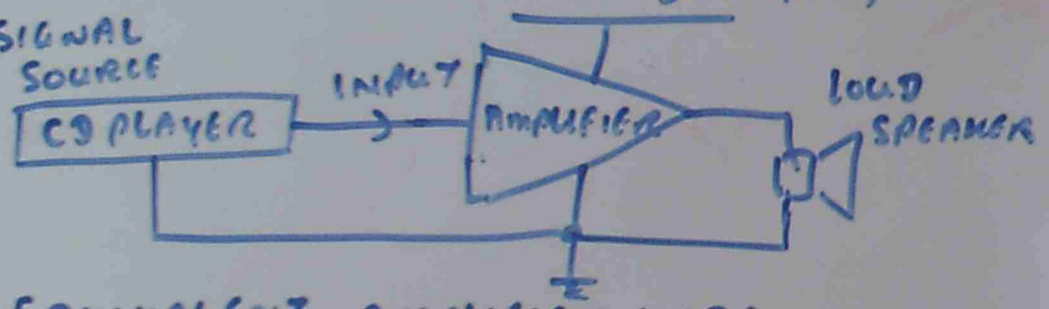
Q1 ⟶ Q7

AMPLIFIER

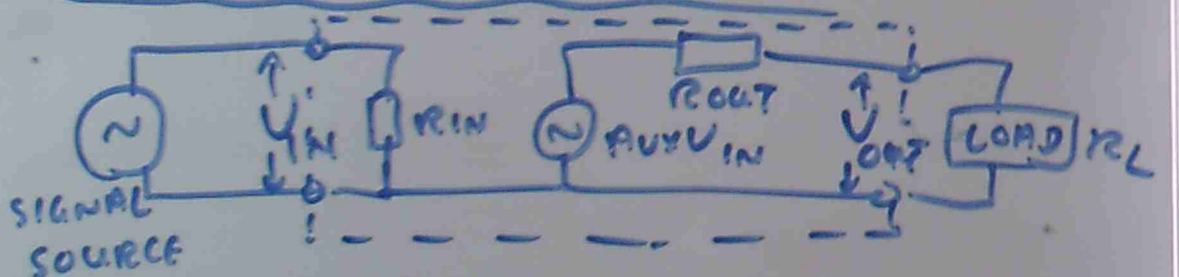
www.17908 17794.zoomshare.com H013

AN AMPLIFIER IS AN ELECTRONIC CIRCUIT THAT TAKES AN INPUT SIGNAL AND PRODUCES A LARGER VERSION OF THAT SIGNAL AT IT'S OUTPUT





EQUIVALENT AMPLIFIER MODEL



GAIN :- $A_V = \frac{V_{OUT}}{V_{IN}} \rightarrow V_{OUT} = A_V \times V_{IN}$

$A_I = \frac{I_{OUT}}{I_{IN}}$

$A_P = \frac{P_{OUT}}{P_{IN}}$

A_V - VOLTAGE GAIN
A_I - CURRENT GAIN
A_P - POWER GAIN

$dB_{AV} = 20 \log \frac{V_{OUT}}{V_{IN}}$

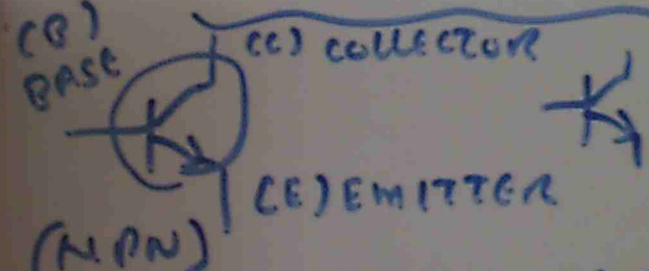
$dB_{AI} = 20 \log \frac{I_{OUT}}{I_{IN}}$

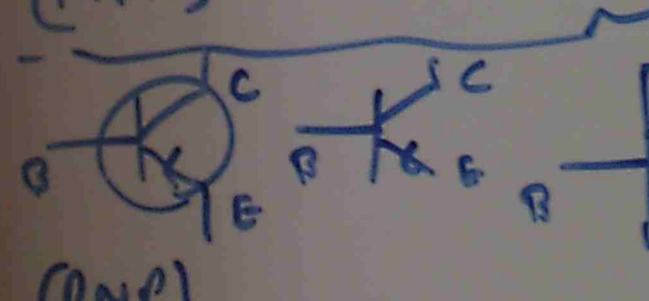
$dB_{AP} = 10 \log \frac{P_{OUT}}{P_{IN}}$

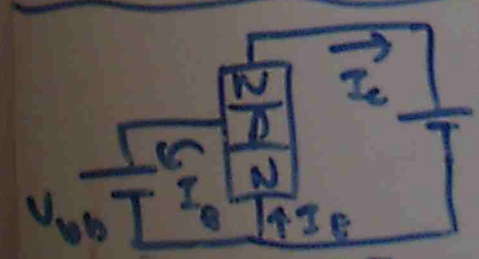
Pb AN AMPLIFIER FED WITH A GAIN OF 25 IS FED WITH 10mV INPUT SIGNAL WHAT IS OUTPUT SIGNAL

$V_{OUT} = V_{IN} \times A_V = 10mV \times 25 = 250mV$

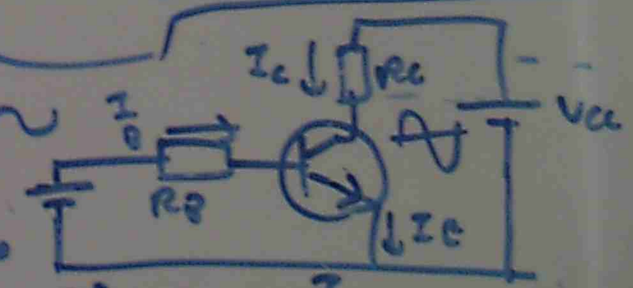
BIPOLAR JUNCTION TRANSISTORS





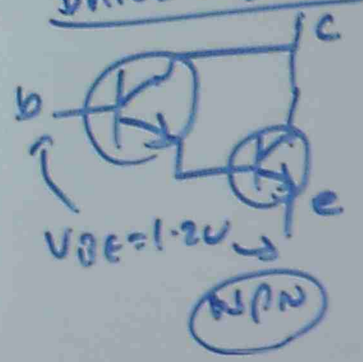


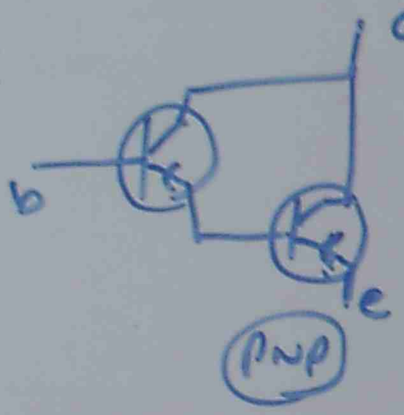
$I_E = I_C + I_B$



$\alpha = \frac{I_C}{I_E}$, $\beta = \frac{I_C}{I_B}$

DARLINGTON



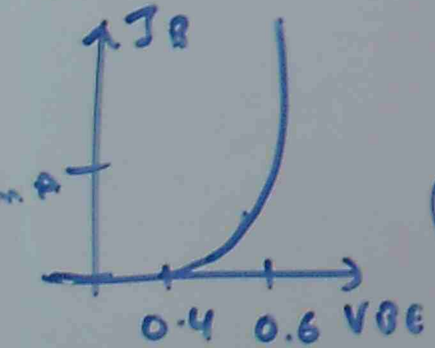


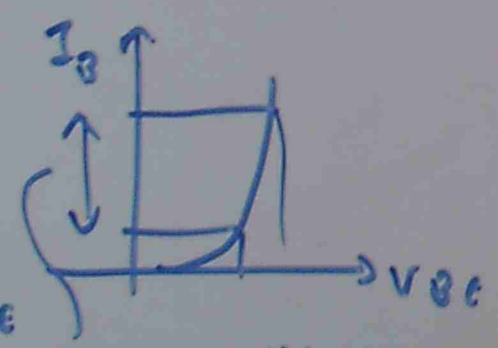
CLASS (A) PRODUCE AN OUT PUT OVER FULL CYCLE (360°)

CLASS (B) (POWER STAGE) PRODUCE AN OUT PUT FOR ½ OF IN PUT CYCLE (180°)

CLASS (AB) COMPROMISE BETWEEN CLASS A AND B. OUTPUT FOR MORE THAN 180° LESS THAN 360°. REDUCE DISTORTION.

CLASS (C) TRANSISTORS CONDUCT FOR LESS THAN 180° OF INPUT WAVE FORM. SWITCHING CIRCUIT. HIGH FREQUENCY TUNED CIRCUITS

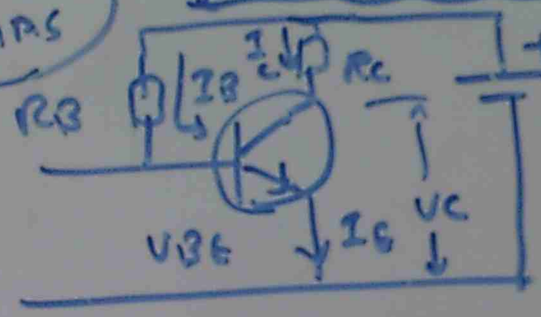




LARGE CHANGE IN BASE CURRENT

TRANSISTOR BIASING CIRCUIT

BASE BIAS



$I_B = \frac{V_{CC} - 0.6}{R_B}$

$I_C = \beta I_B$

V_C - COLLECTOR VOLTAGE TO GROUND, V_B - BASE VOLTAGE TO GROUND

V_E - EMITTER VOLTAGE TO GROUND, V_{CE} - COLLECTOR TO EMITTER VOLTAGE

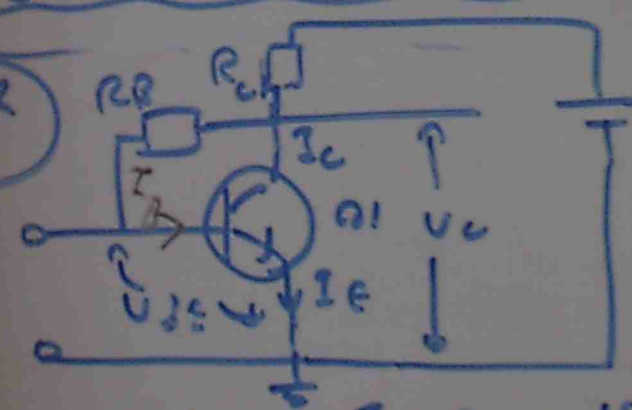
I_B - BASE CURRENT, I_E - EMITTER CURRENT

I_C - COLLECTOR CURRENT

$I_E \simeq I_C$, $V_E = 0V$, $V_B = 0.6V$

$V_C = V_{CC} - I_C \times R_C$

COLLECTOR BIAS



$I_B = \frac{V_{CC} - 0.6}{R_B}$

$V_{CC} = (I_B + I_C)R_C + I_B R_B + V_{BE}$

$V_{CC} = \left(\frac{1+\beta}{\beta}\right) I_B R_C + I_B R_B + V_{BE}$

$I_B = \frac{V_{CC} - V_{BE}}{[(1+\beta)R_C + R_B]}$

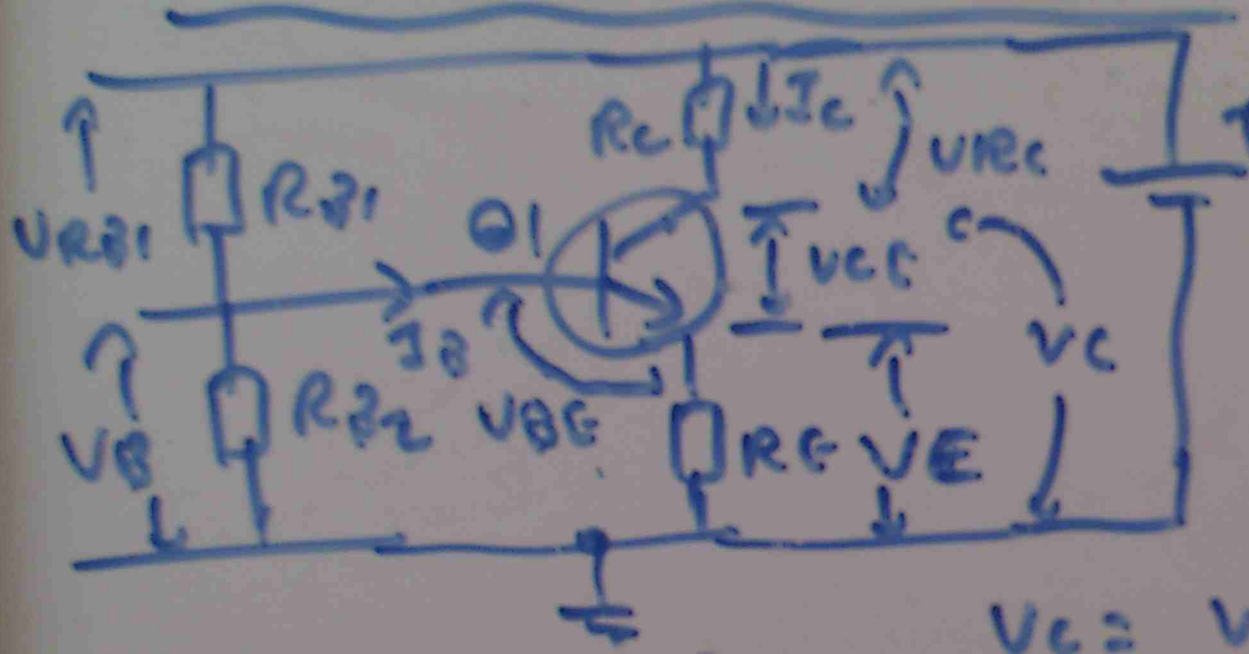
$I_E = I_C$

$V_{BE} = 0$

$V_B = 0.6V$

$V_C = V_{CC} - I_C R_C$

VOLTAGE DIVIDER BIAS



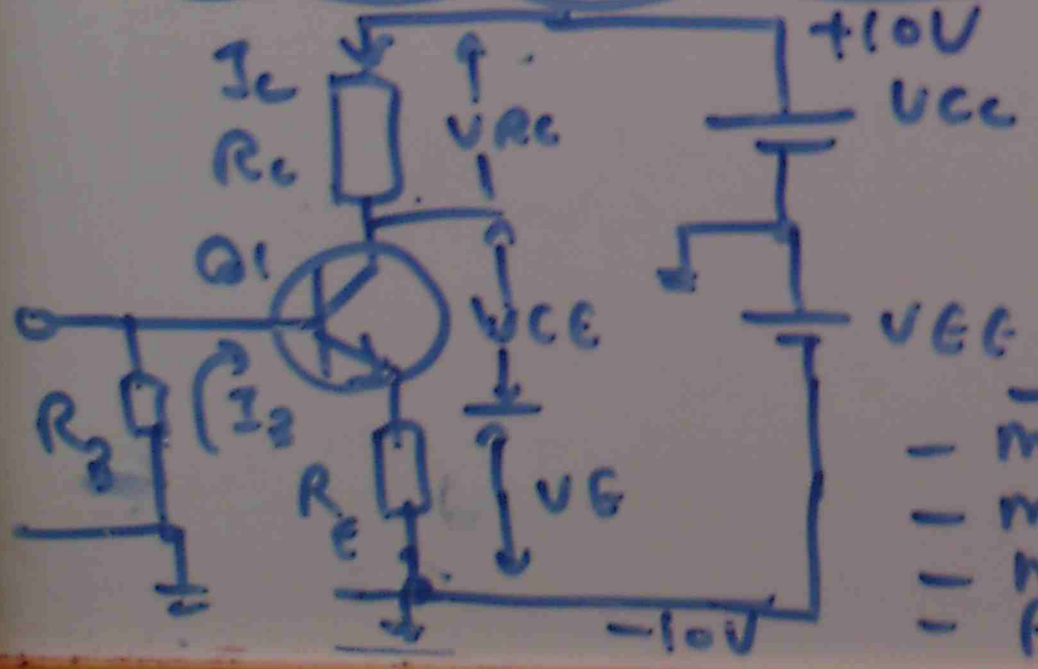
$$V_{B2} = V_{CC} \times \frac{R_{B2}}{R_{B1}+R_{B2}}$$

$$V_E = V_B - 0.6$$

$$I_C = \frac{V_E}{R_E}$$

$$V_C = V_{CC} - I_C R_C$$

DUAL SUPPLY BIAS



$V_B = 0V$

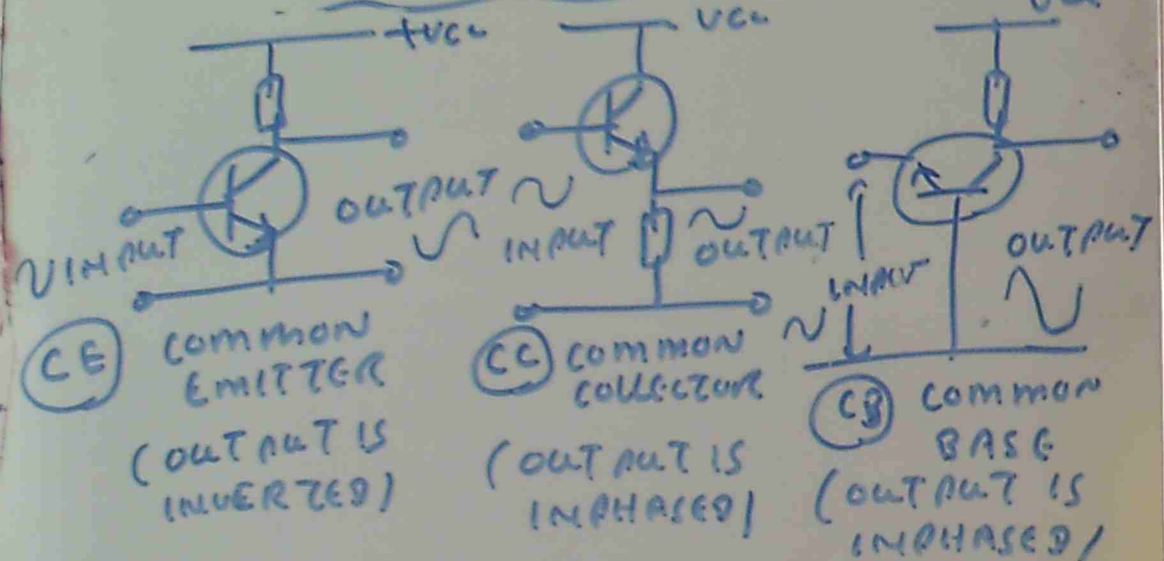
$V_E = -0.6V$

$$I_C = \frac{V_{EE} - 0.6}{R_E}$$

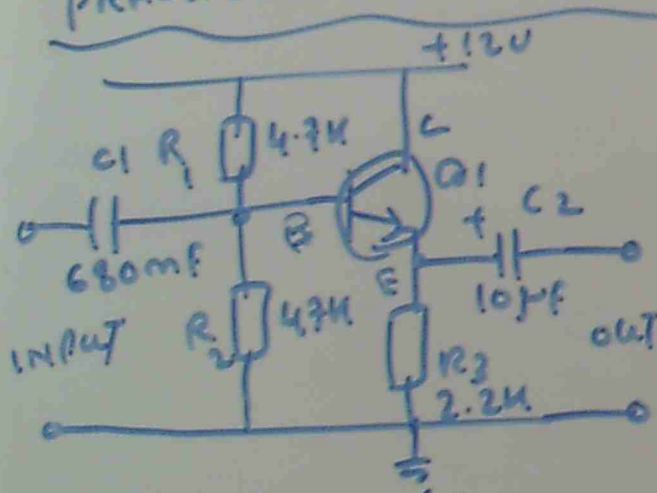
MAXIMUM RATING

- MAXIMUM COLLECTOR CURRENT
- MAXIMUM VCE
- MAXIMUM VBC
- POWER DISSIPATION

AMPLIFIER CONFIGURATION



PRACTICAL COMMON COLLECTOR CIRCUIT



INPUT → BASE

OUTPUT ← EMITTER

EMITTER FOLLOWER

VOLTAGE GAIN < 1

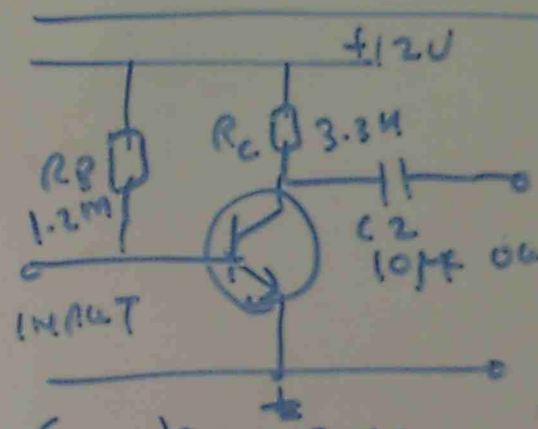
HIGH CURRENT POWER GAIN

MEDIUM → HIGH INPUT RESISTANCE (10K → 100 KΩ)

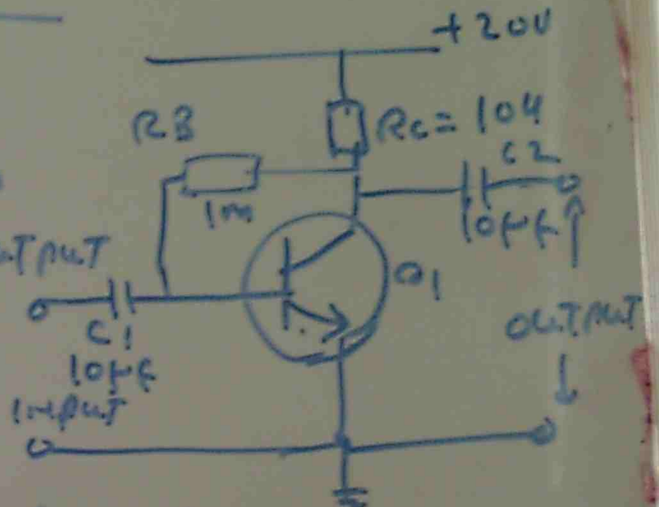
LOW OUTPUT RESISTANCE (10s of OHm)

BUFFER – ISOLATION STAGE

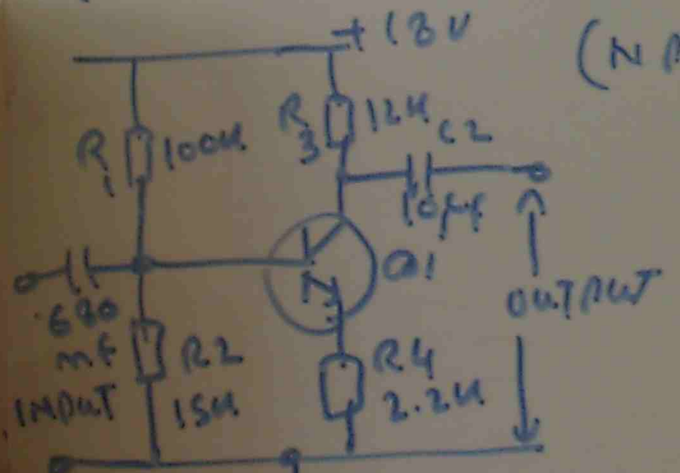
COMMON EMITTER



(NPN) BASE BIAS



(NPN) COLLECTOR BIAS



NPN COLLECTOR BIAS

INPUT → BASE

OUTPUT ← COLLECTOR

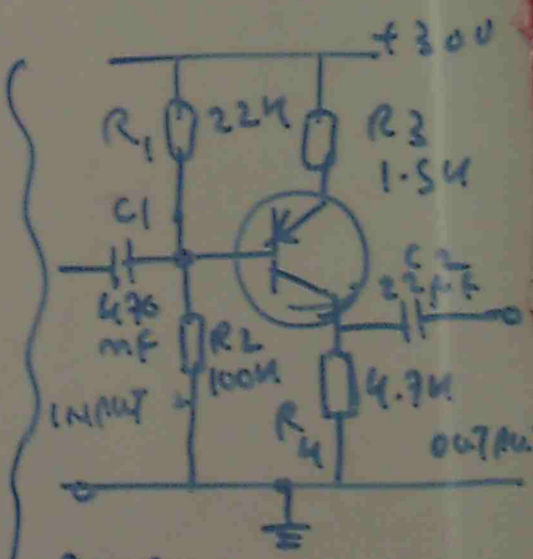
OUTPUT VOLTAGE IS INVERTED

LOW → HIGH VOLTAGE GAIN (3 → 300)

MEDIUM → HIGH INPUT RESISTANCE (3K → 300 K)

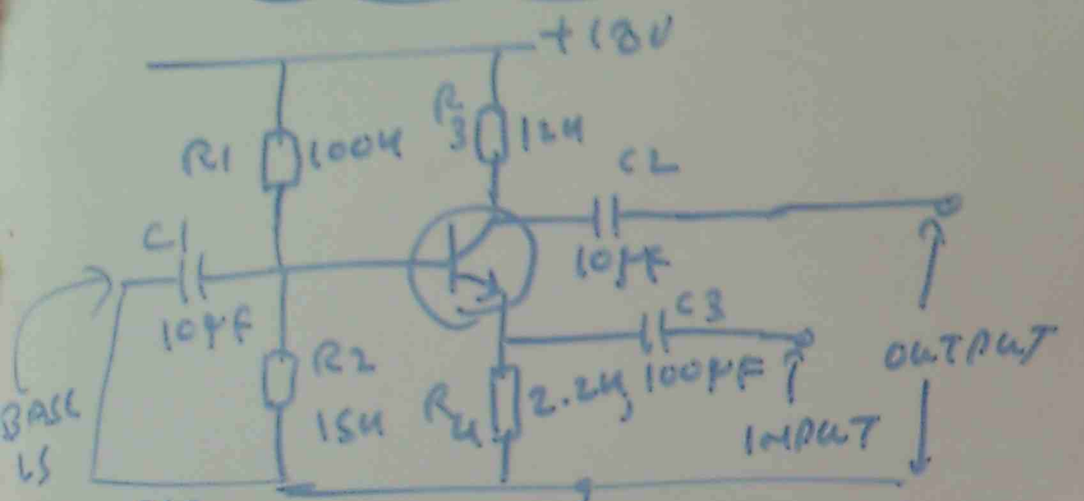
MEDIUM TO HIGH OUTPUT RESISTANCE (1K → 50KΩ)

TO AMPLIFY SMALL VOLTAGE SIGNAL



PNP DIVIDER VOLTAGE

COMMON BASE CIRCUIT

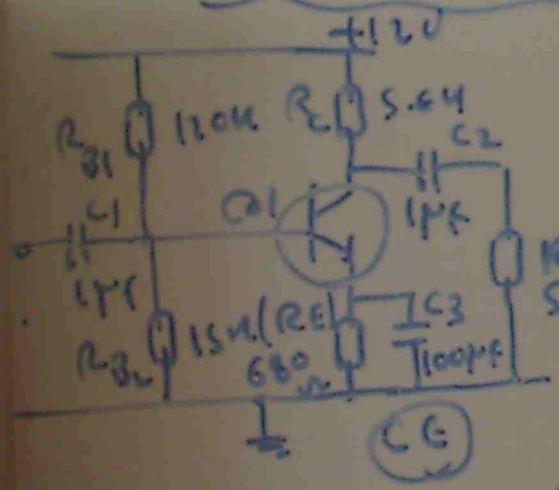


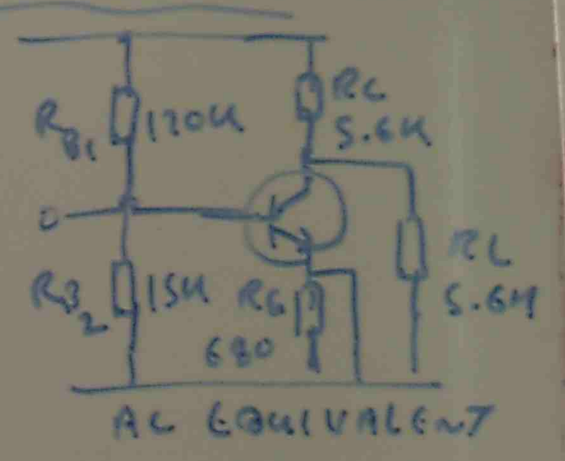
COMMON BASE VOLTAGE DIVIDER BIAS

INPUT → EMITTER
OUTPUT ← COLLECTOR
OUTPUT VOLTAGE IS IN-PHASE WITH INPUT
VOLTAGE GAIN STAYS CONSTANT
LOW CURRENT GAIN (LESS THAN 1)
VERY LOW INPUT RESISTANCE (AROUND 30Ω)
MEDIUM TO HIGH OUTPUT RESISTANCE
TO AMPLIFY SMALL SIGNAL VOLTAGES IN HIGH FREQUENCIES (RADIO) BECAUSE IT'S GAIN REMAINS HIGH AT THESE FREQUENCIES
INPUT CAPACITOR - AC COUPLED CAPACITOR

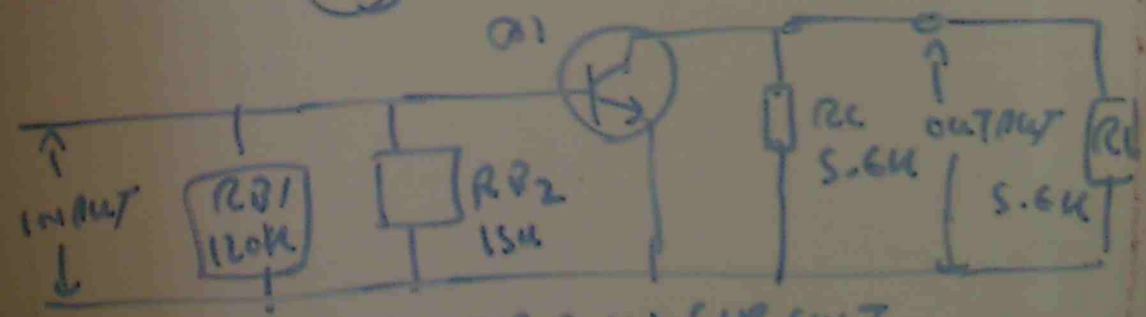
PARAMETER	CE	CC	CB
VOLTAGE GAIN	LOW → HIGH	< 1	HIGH
CURRENT GAIN	HIGH	HIGH	< 1
POWER GAIN	HIGH	HIGH	HIGH
INPUT RESISTANCE	MED → HIGH	MED → HIGH	VERY LOW
OUTPUT RESISTANCE	MED → HIGH	LOW	MED → HIGH

AMPLIFIER PARAMETERS





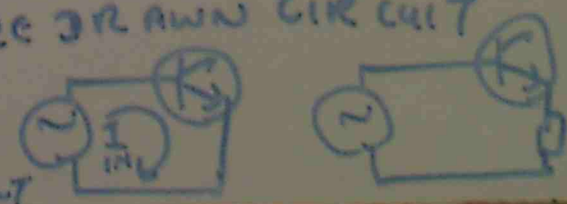
AC EQUIVALENT

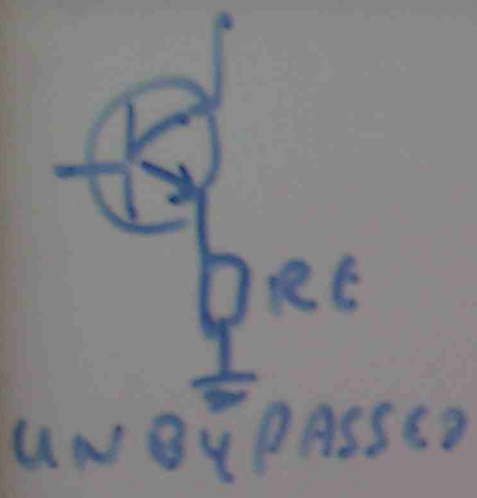


$r_e = \frac{26mV}{I_E}$

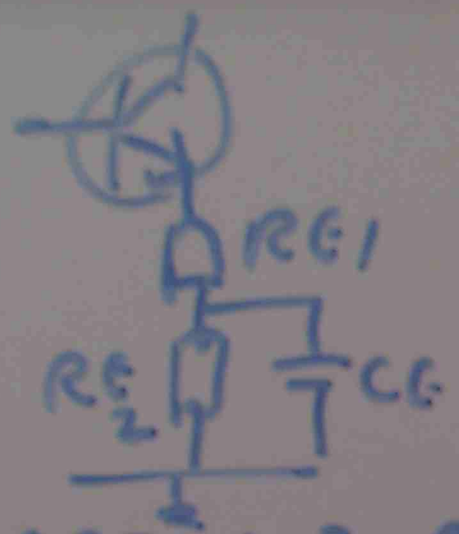
I_{IN} - INPUT CURRENT

REDRAWN CIRCUIT

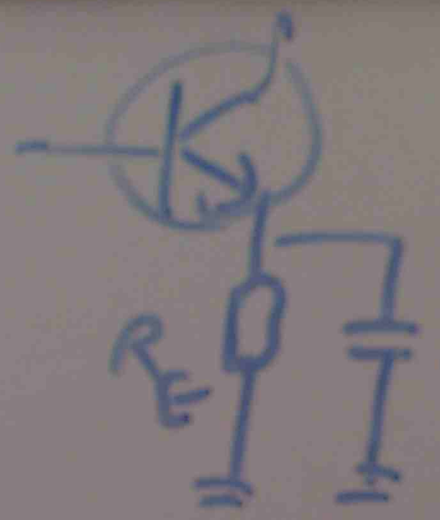




UNBYPASSED



PARTIAL BYPASS



FULLY BY PASS

$R_{IN} = \beta (r_e + R_E)$ (R_E NOT BY PASS

BASE

$R_{IN} = \beta (r_e + R_{E_1})$ R_{E_2} BY PASS

BASE

$R_{IN(BASE)} = \beta r_e$ (R_E IS BY PASSED

COMMON EMITTER

$$A_V = \frac{R_C \parallel R_L}{r_e}$$

$$R_{IN} = R_{B1} \parallel R_{B2} \parallel \beta r_e$$

$$R_{OUT} = R_C$$

COMMON COLLECTOR

$$A_V = \frac{R_E}{r_e + R_E}$$

$$A_V \approx 1$$

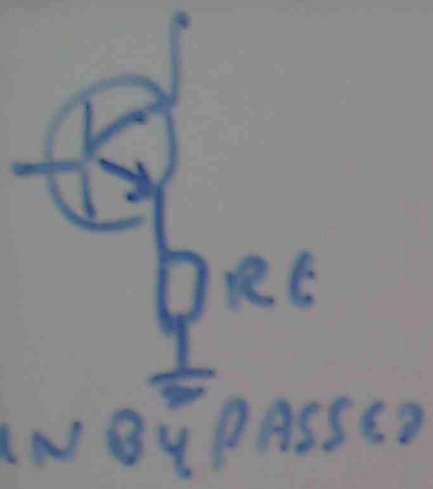
COMMON BASE

A_V - AS (CE)

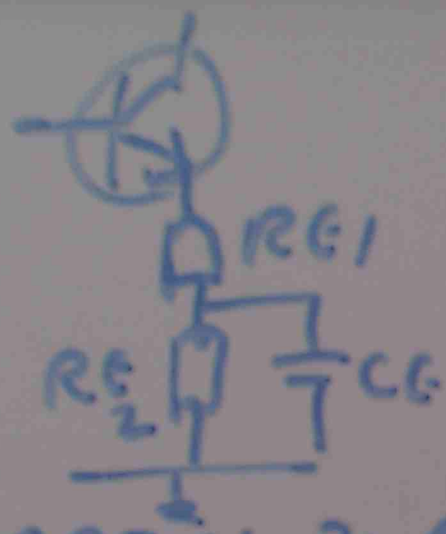
$$A_I = \frac{I_C}{I_E}$$

$$R_{IN} = r_e$$

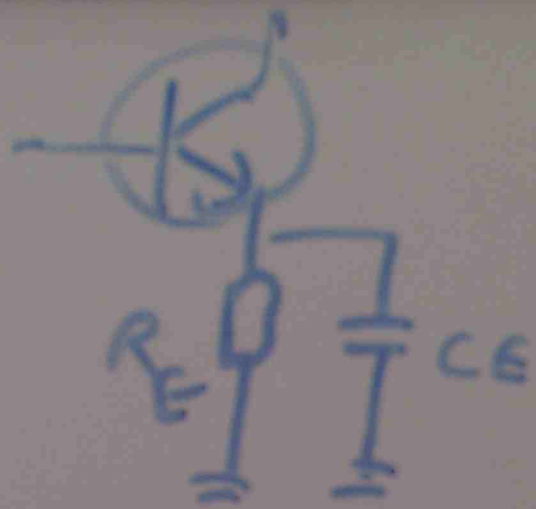
$$R_O = R_C$$



UNBYPASSED



PARTIAL BYPASS



FULLY BY PASS

R_{IN} = β (re + RE) (RE NOT BYPASS

BASE

R_{IN} = β (re + RE_1) RE_2 BYPASS

BASE

$R_{IN(BASE)}$ = β re (RE IS BYPASSED

COMMON EMITTER

$$A_V = \frac{R_C \parallel R_L}{r_e}$$

$$R_{IN} = R_{B1} \parallel R_{B2} \parallel \beta r_e$$

$$R_{OUT} = R_C$$

COMMON COLLECTOR

$$A_V = \frac{R_E}{r_e + R_E}$$

$$A_V \approx 1$$

COMMON BASE

A_V - AS (CE)

$$A_I = \frac{I_C}{I_E}$$

$$R_{IN} = r_e$$

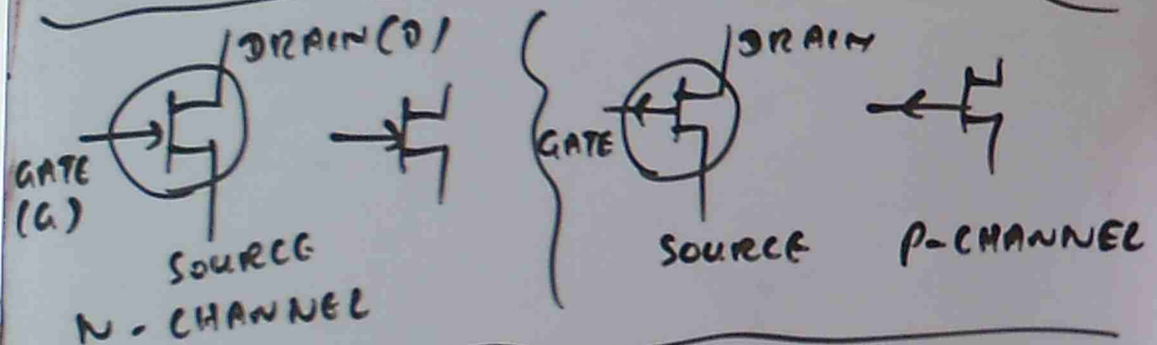
$$R_O = R_C$$

(JFET) JUNCTION FIELD EFFECT AMPLIFIERS

ADVANTAGE
- HIGH INPUT RESISTANCE
- NO THERMAL RUNAWAY

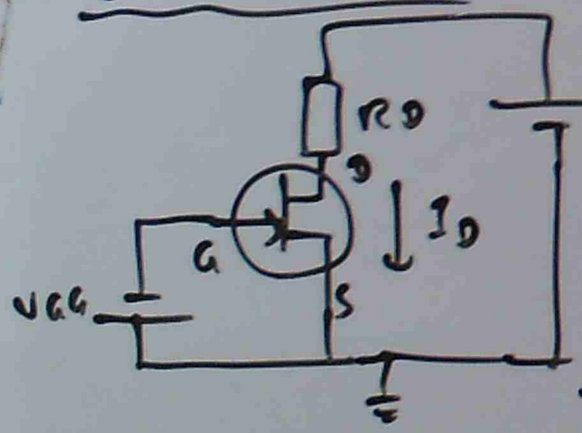
} LESS NOISY

DISADVANTAGE
LOW GAIN, LOW BANDWIDTH

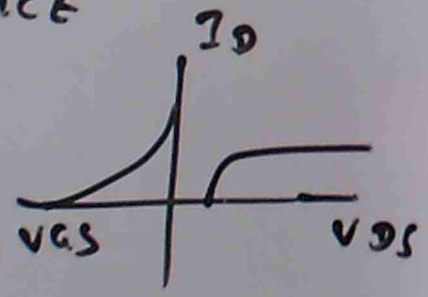


NO-GATE CURRENT IN JFET
VOLTAGE CONTROLLED DEVICE

JFET BIASING



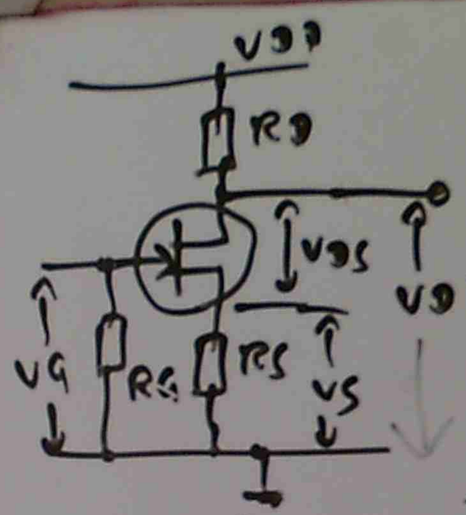
$V_{GS} = -5V$
$I_{DSS} = 8mA$



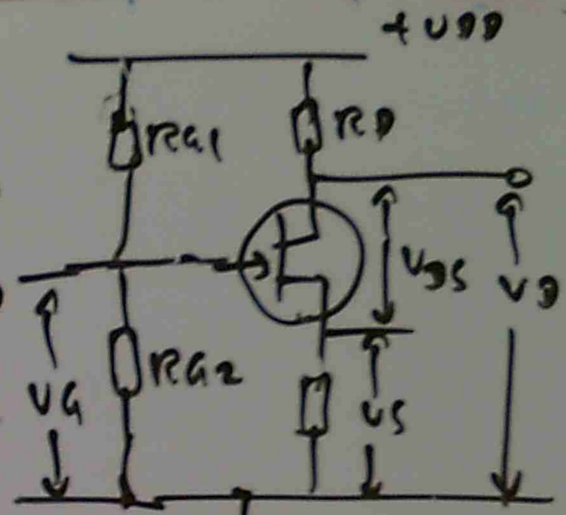
VOLTAGE CURRENT CURVE

BIASING CIRCUITS

SELF BIAS
VOLTAGE DIVIDER BIAS



SELF BIAS



VOLTAGE DIVIDER BIAS

J-FET AMPLIFIER CONFIGURATION

COMMON SOURCE

COMMON DRAIN

COMMON GATE →

	INPUT	OUTPUT	GAIN
COMMON SOURCE	GATE	DRAIN	180° MED
COMMON DRAIN	GATE	SOURCE	0° <1
COMMON GATE	SOURCE	DRAIN	0° MED

BLOCKING CAPACITOR PREVENTS AC SIGNAL

- VGS VALUE

TRANSCONDUCTANCE = $\frac{1}{re}$ 100Ps + 5000Ps

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(1) AMPLIFIER CONFIGURATION

SLIDE (1) ⟶ (6)

Q1 ⟶ Q6

(2) MULTI STAGE + FEED BACK + FET

SLIDE (1) ⟶ SLIDE (27)

Q7 ⟶ Q 21

(3) POWER OUTPUT STAGE

SLIDE (1) ⟶ SLIDE (15)

Q 22 ⟶ Q 33

(4) POWER SUPPLY

SLIDE (1) ⟶ SLIDE (4)

Q 34 ⟶ Q 39

(5) POWER AMPLIFIER

SLIDE (1) ⟶ SLIDE (11)

Q 40 ⟶ Q 44

(6) OPERATIONAL AMPLIFIER CALCULATION

SLIDE (1) ⟶ SLIDE (16)

Q 45 ⟶ Q 50

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OTHER REFERENCE URLS

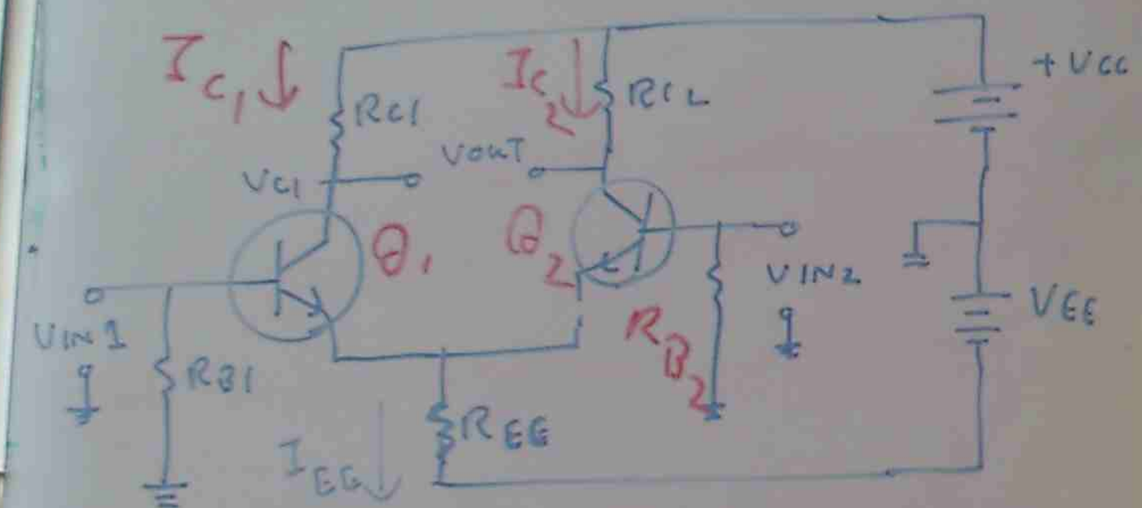
AMPLIFIER

AMPLIFIER (1) Amp(1) ⟶ Amp(6)

AMPLIFIER (2) Amp(a) ⟶ Amp(e)

1

DIFFERENTIAL AMPLIFIER



INFINITE GAIN
INFINITE INPUT IMPEDANCE
ZERO OUT PUT IMPEDANCE
INFINITE BAND WIDTH
HIGH NOISE REJECTION RATIO
HIGH STABILITY

$$I_{EE} = \frac{V_{REE}}{REE} \qquad V_c = V_{cc} - I_c R_c$$

$$I_{C_1} = I_{C_2} = \frac{I_{EE}}{2}$$

DIFFERENTIAL VOLTAGE GAIN (Ad) $= \frac{R_c}{2r_e}$

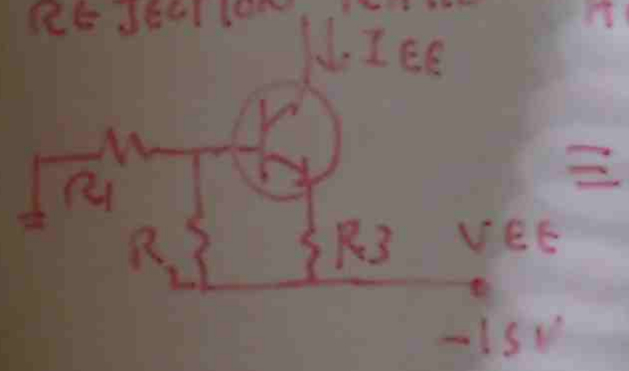
γ_{in} (INPUT RESISTANCE) $= 2\beta r_e$

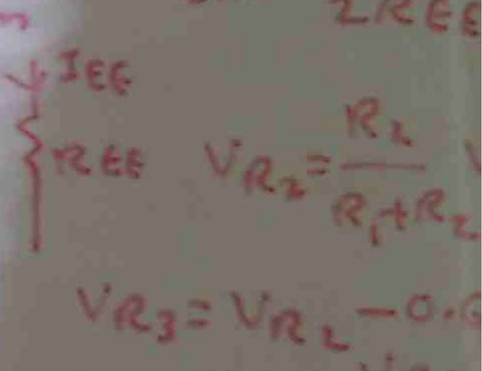
DIFFERENTIAL AMPLIFIER → CAN REJECT NOISE SIGNALS THAT ARE COMMON TO BOTH INPUTS

COMMON MODE REJECTION RATIO $= \frac{Ad}{ACm}$

WHERE

$A_{CM} = \frac{R_c}{2REE}$

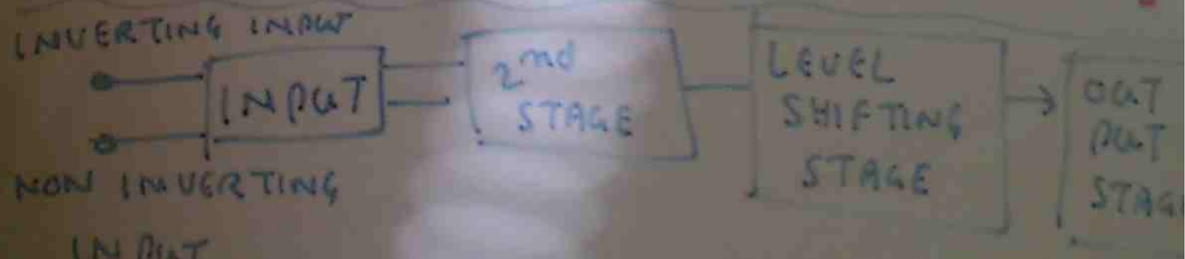




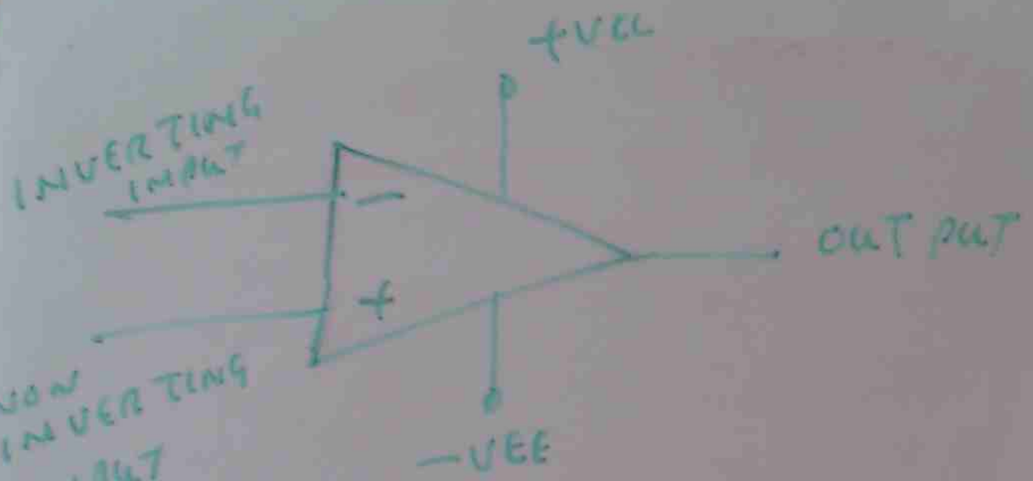
$V_{R_2} = \frac{R_2}{R_1+R_2}$

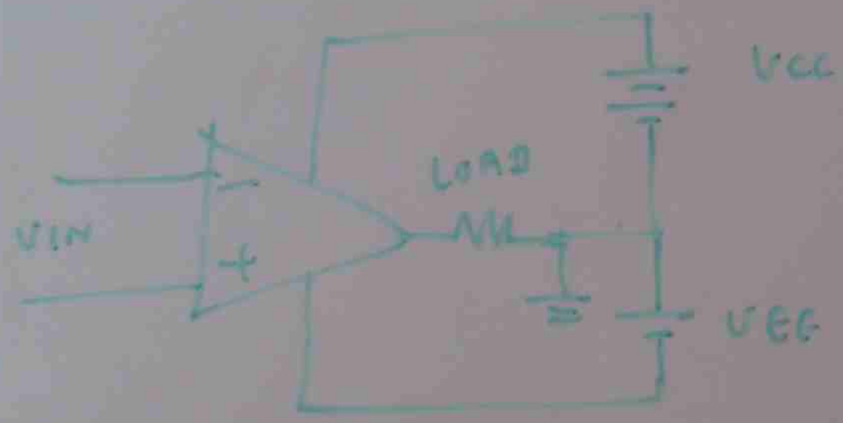
$V_{R_3} = V_{R_2} - 0.6$

$I_c = I_{EE} = \frac{V_{R_3}}{R_3}$



O/P - OUTPUT





POWER SUPPLY FOR OP-AMP

HO25

1. DC CONDITION OP-AMP

SLIDE 1 → 8

2. 1 → 6

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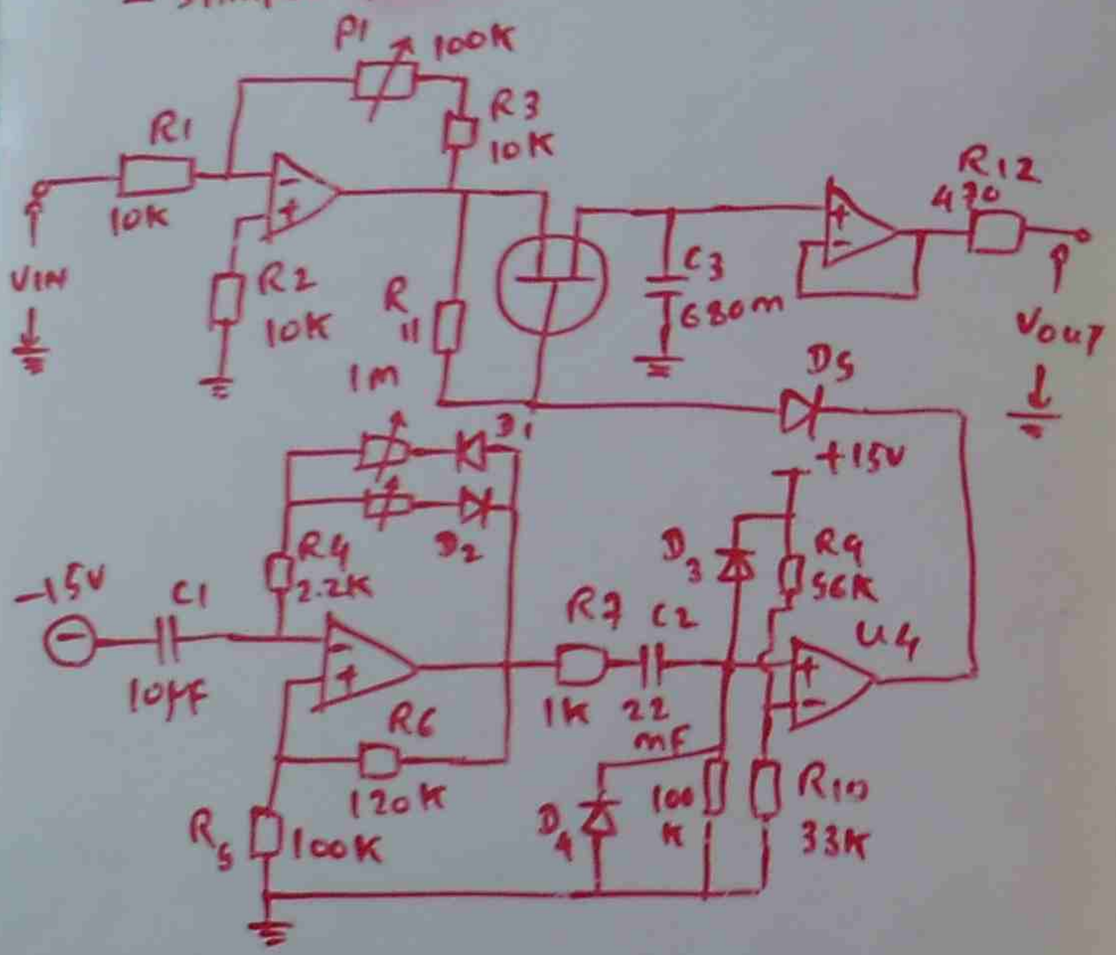
MULTI STAGE OP-AMP CIRCUITS

- LIGHT LEVEL INDICATOR
- SAMPLE AND HOLD CIRCUIT

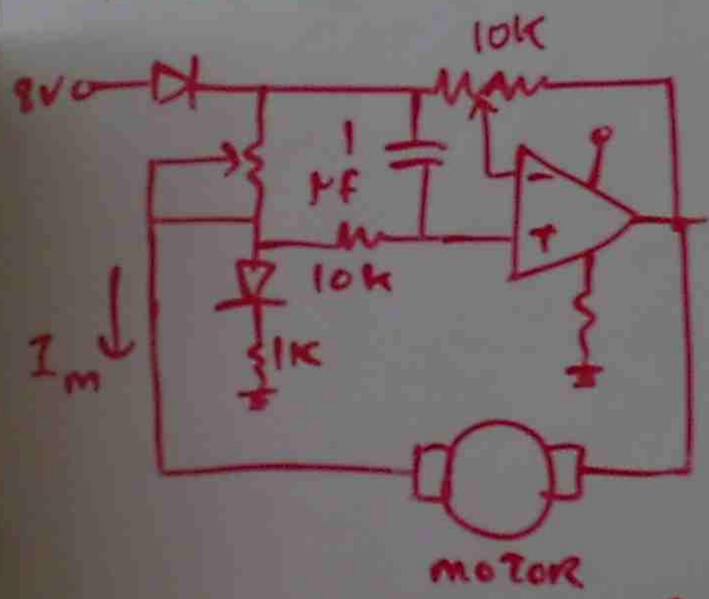


SAMPLE & HOLD CIRCUIT

POWER OP-AMP

- HIGH OUTPUT CURRENT
- HIGH OUTPUT VOLTAGE
- HIGH OUTPUT POWER

MOTOR SPEED CONTROL



$$V_{MOTOR} = \frac{R_2(V_{32} + I_3 R_3)}{R_1}$$

$+V_{31}$

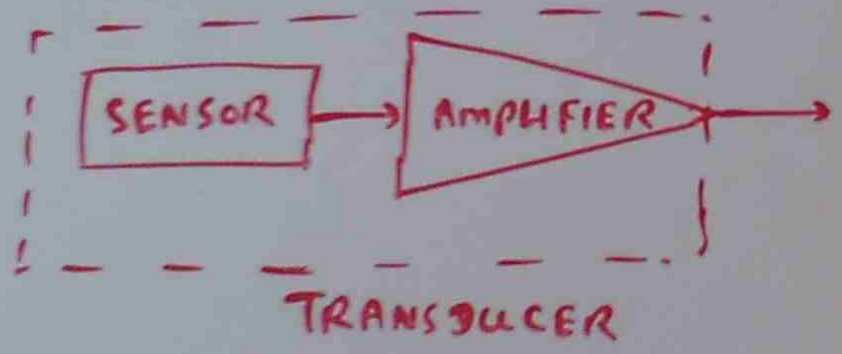
(4) OP-AMP DIODE - SLIDE 1 → 15
Q 43 → 50

(5) ACTIVE FILTER SLIDE 1 → 17
Q 51 → 58

TRANSDUCERS

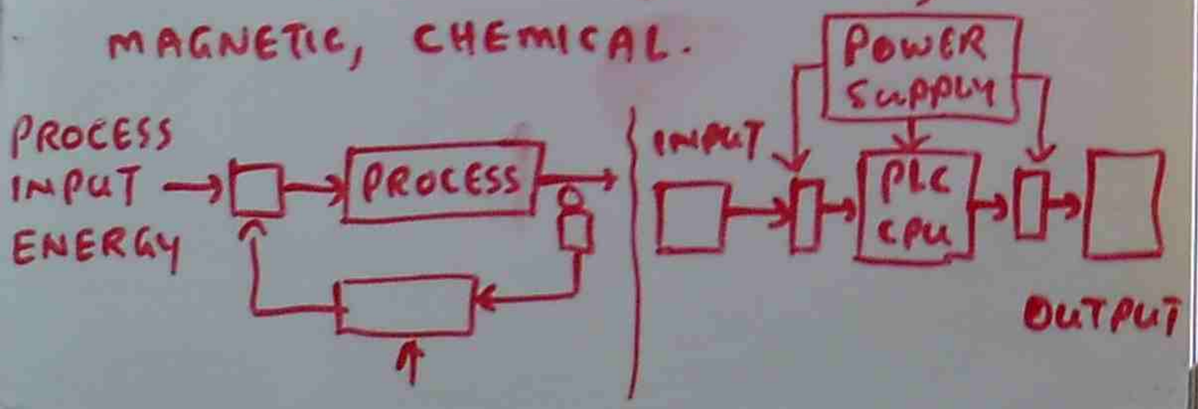
A TRANSDUCER CONSISTS OF THE SENSOR & IT'S ASSOCIATED CIRCUITRY TO PRODUCE AN OUTPUT SIGNAL.

A SENSOR IS A DEVICE THAT DETECTS A CHANGE IN PHYSICAL STIMULUS AND CONVERT THIS CHANGE TO A SIGNAL THAT CAN BE MEASURED.



TYPES OF SIGNALS

RADIANT, MECHANICAL, THERMAL, ELECTRICAL MAGNETIC, CHEMICAL.



TEMPERATURE MEASUREMENT

THERMOCOUPLE, RESISTANCE TEMPERATURE DETECTOR, THERMISTOR

FORCE MEASUREMENT

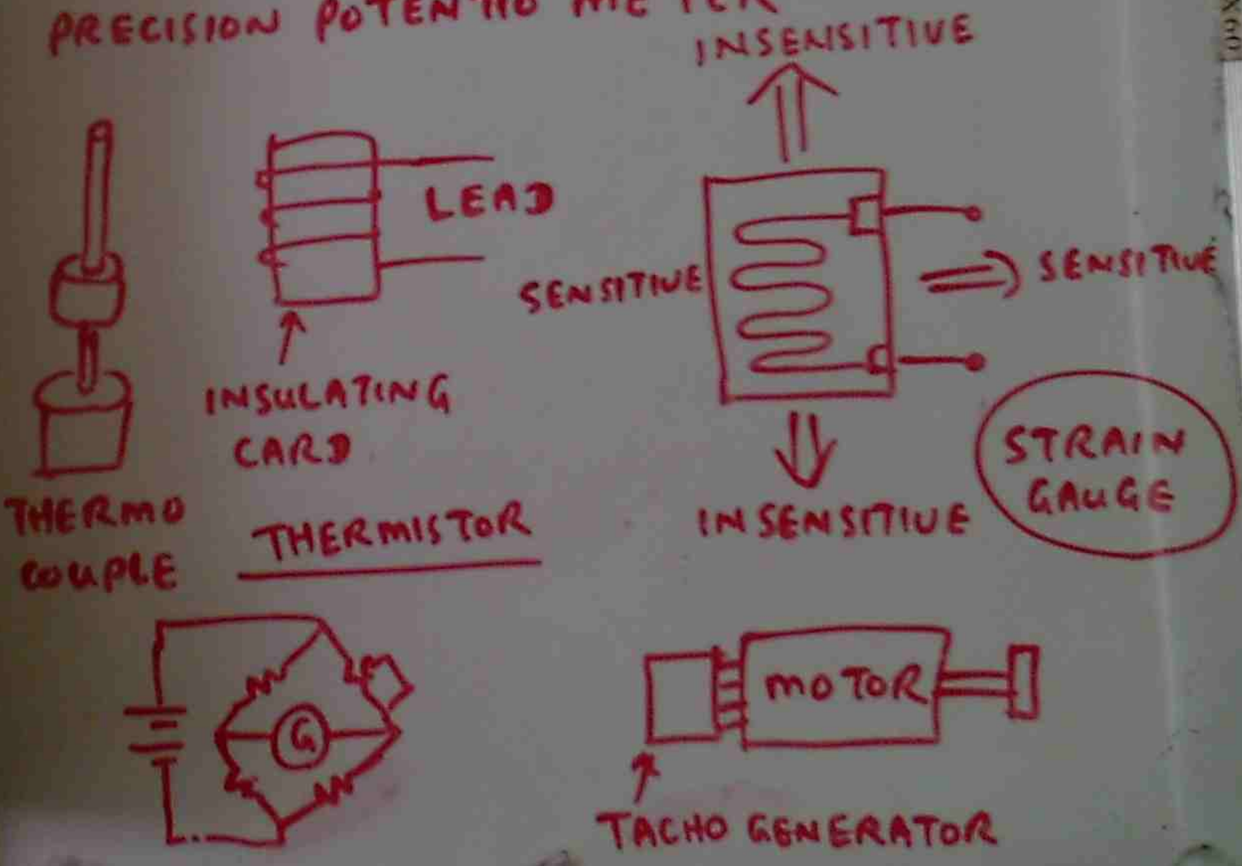
THE STRAIN GAUGE,

SPEED MEASUREMENT

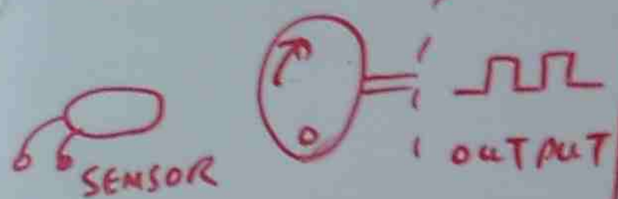
TACHO GENERATOR,

POSITION MEASURE MEASUREMENT

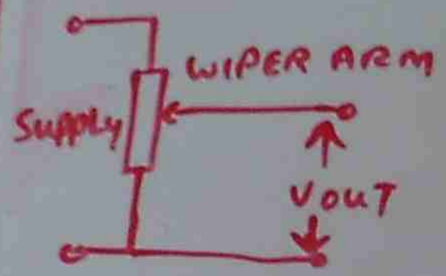
PRECISION POTENTIO METER



ENCODER

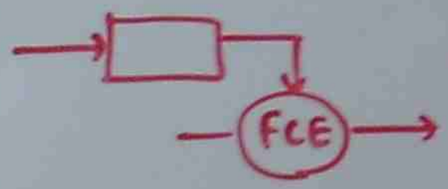


PRECISION POTENTIOMETER



FINAL CONTROL ELEMENTS

FINAL CONTROL ELEMENT (FCE) ARE IMPORTANT COMPONENTS IN ANY CONTROL SYSTEM AS THESE ELEMENTS CONVERT THE OUTPUT SIGNALS FROM THE CONTROLLERS TO CONTROL THE ACTUAL PROCESS



TYPES OF FINAL CONTROL ELEMENTS

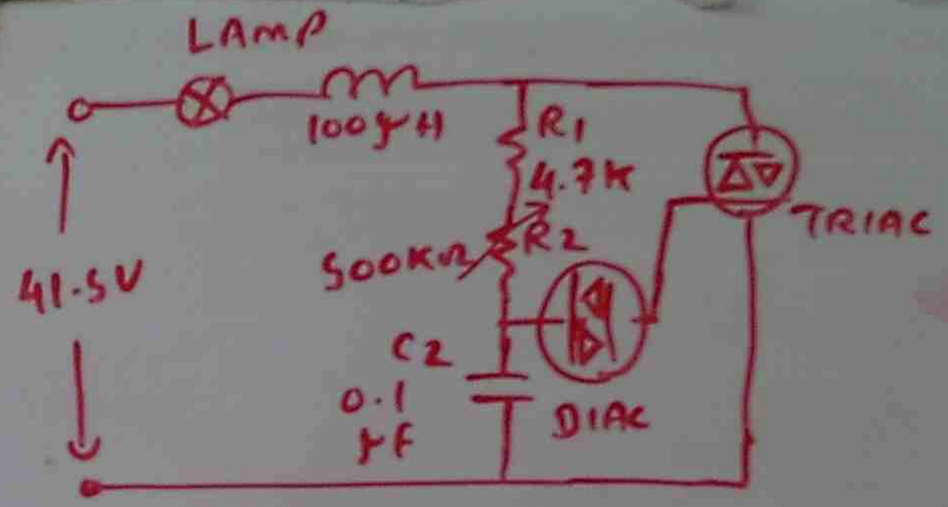
- SOLENOINDS
- RELAYS AND CONTACTORS
- VALVE
- SOLID STATE SWITCHING DEVICES



BJT

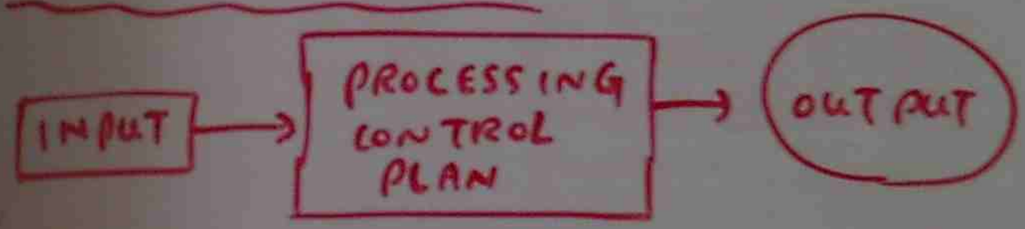


THYRISTOR (SCR)



CONTROL SYSTEM

AUTOMATIC CONTROL



OPEN LOOP CONTROL

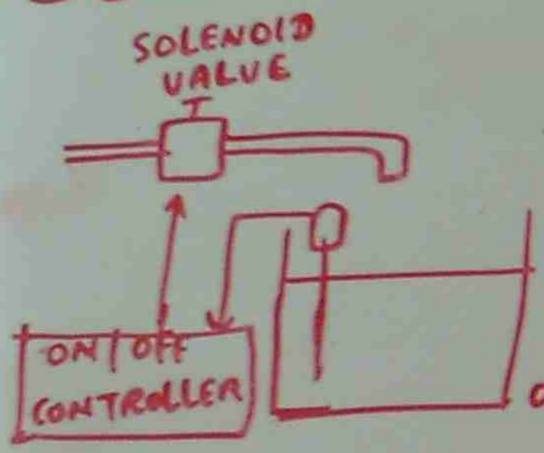
- DOES NOT USE A COMPARISON OF ACTUAL RESULT AND THE DESIRED RESULT TO DETERMINE THE CONTROL ACTION
  - WATER TANK, TIME LIMIT STARTER

CLOSED LOOP CONTROL

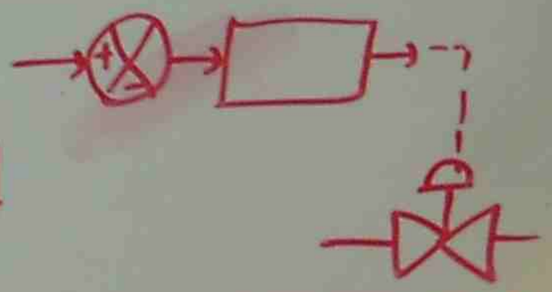
- TO ENSURE THE CONTROL SYSTEM RESPONDS CORRECTLY TO CHANGE IN LOAD
- THE OUTPUT DOES NOT VARY TOOMUCH FROM SET POINT

TYPES OF CONTROLS

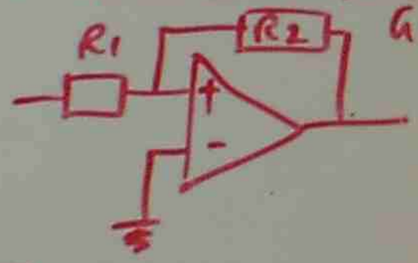
ON/OFF



PROPORTIONAL CONTROL

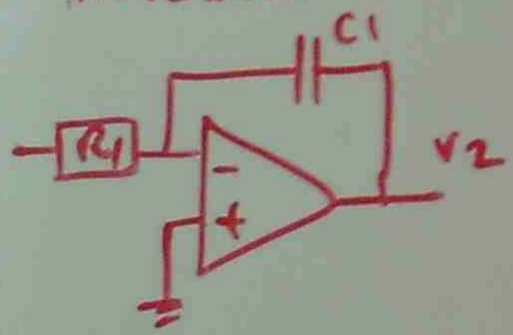


OUTPUT = ERROR × CONTROLLER GAIN

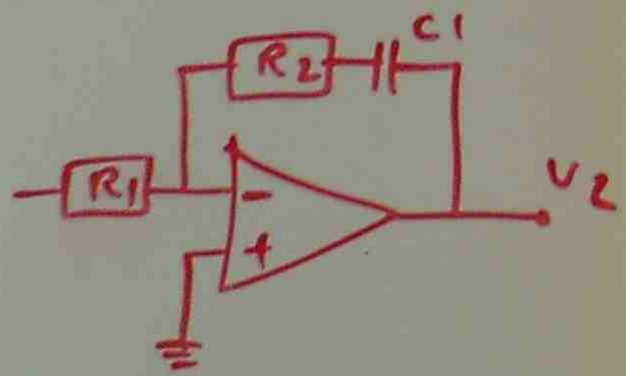


PROPORTIONAL + INTEGRAL CONTROL

INTEGRAL CONTROL IS KNOWN AS RESET



INTEGRAL CONTROL



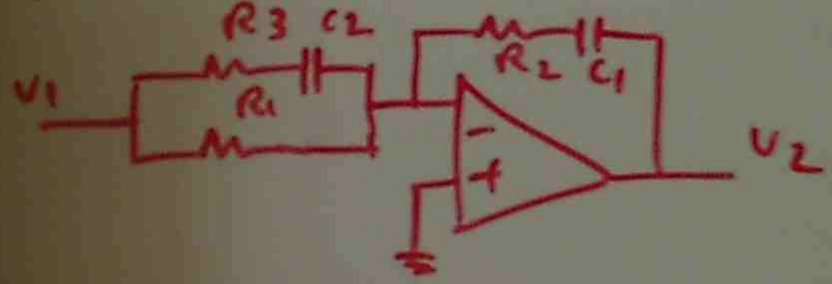
PROPORTIONAL CONTROL

DERIVATIVE CONTROL

DERIVATIVE CONTROL PROVIDES A CORRECTION PROPORTIONAL TO THE RATE OF CHANGE of THE ERROR.

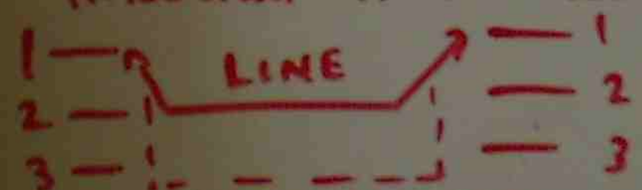
PROPORTIONAL + INTEGRAL + DERIVATIVE CONTROL (PID)

SUITABLE FOR CONTROLLING SUDDEN LARGE LOAD CHANGE



MULTIPLEXING

TRANSMITTING MORE THAN ONE SIGNAL THROUGH A SINGLE LINE



SYNCHRONIZED

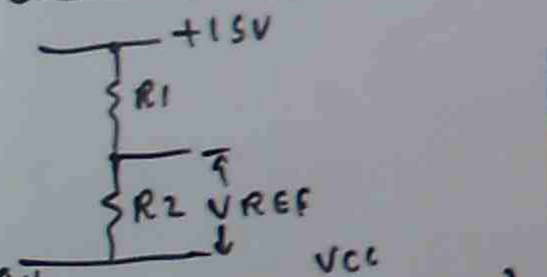
(6) INDUSTRIAL TRANSDUCER - SLIDE 1 → 19 & 59 → 71

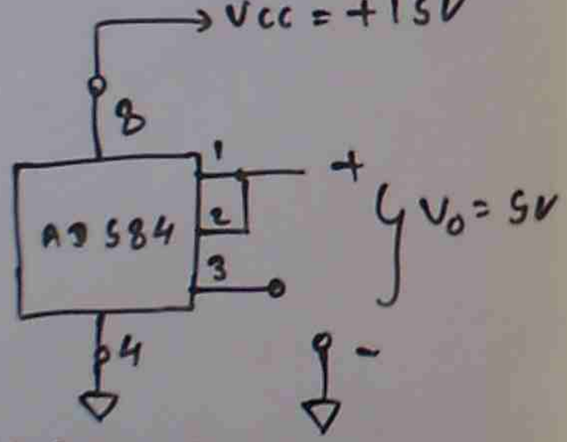
(7) SOLID STATE SWITCHING CONTROL → SLIDE 1 → 24 & 72 → 80

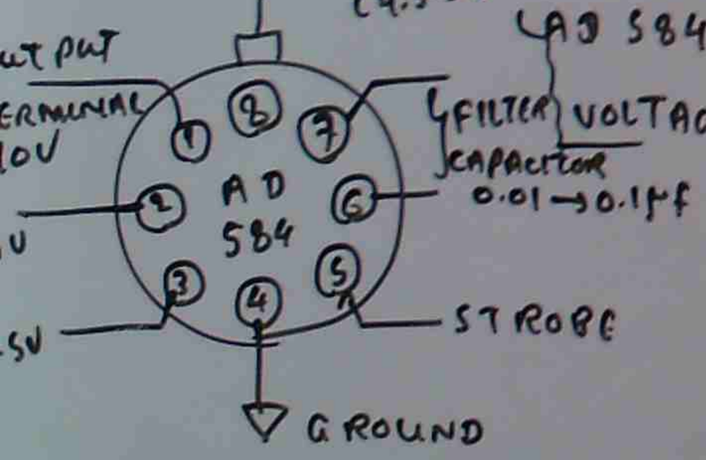
COMPARATORS

IN INDUSTRY, IT IS OFTEN NECESSARY TO COMPARE AN UNKNOWN QUANTITY TO A REFERENCE. THE COMPARISON IS MADE A CONTROL CIRCUIT CAN INDICATE WHETHER A MEASURED QUANTITY IS HIGHER, EQUAL TO (OR) LESS THAN THE PRESCRIBED REFERENCE

VOLTAGE REFERENCE







AD 584 PIN PROGRAMMA-BLE VOLTAGE REFERENCE

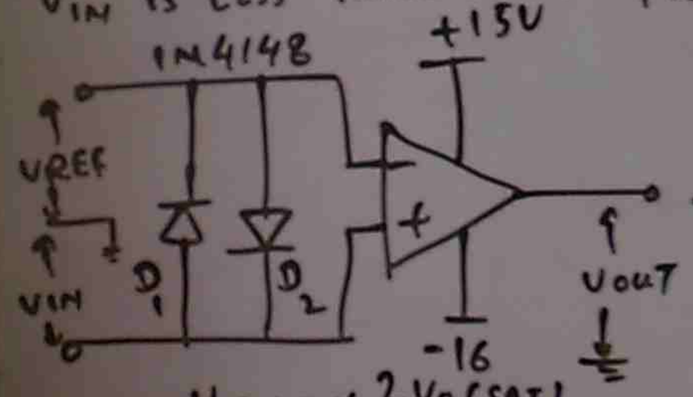
STABLE OUTPUT VOLTAGE
+2.5; +5; +7.5; +10V

THE BASIC COMPARATOR

$$A_{OUT} = AV_{OI} \times V_{IN}$$

NON INVERTING COMPARATOR

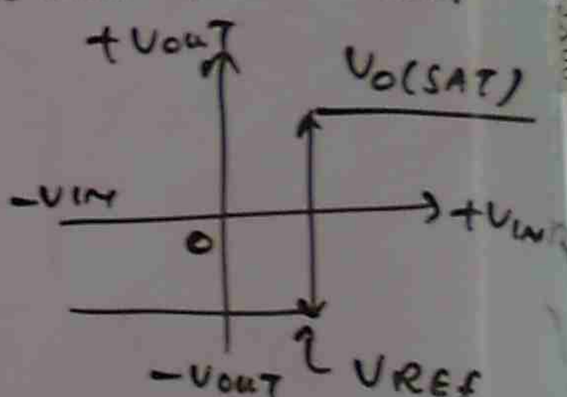
$+V_{O(SAT)}$ WHEN VIN EXCEEDS VREF &
$-V_{O(REF)}$ WHEN V_{IN} IS LESS THAN VREF



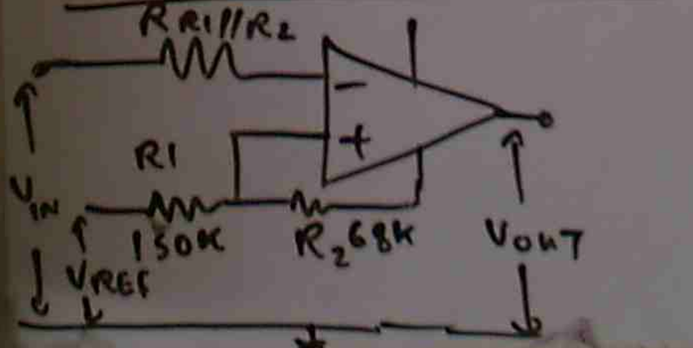
$$V_{IN} = V_{REF} + \frac{2V_{O(SAT)}}{AV_{OI}}$$

INVERTING COMPARATOR

$-V_{O(SAT)}$ WHEN V_{IN} EXCEEDS VREF
$+V_{O(SAT)}$ WHEN V_{IN} IS LESS THAN VREF



DIFFERENTIAL COMPARATOR



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H025

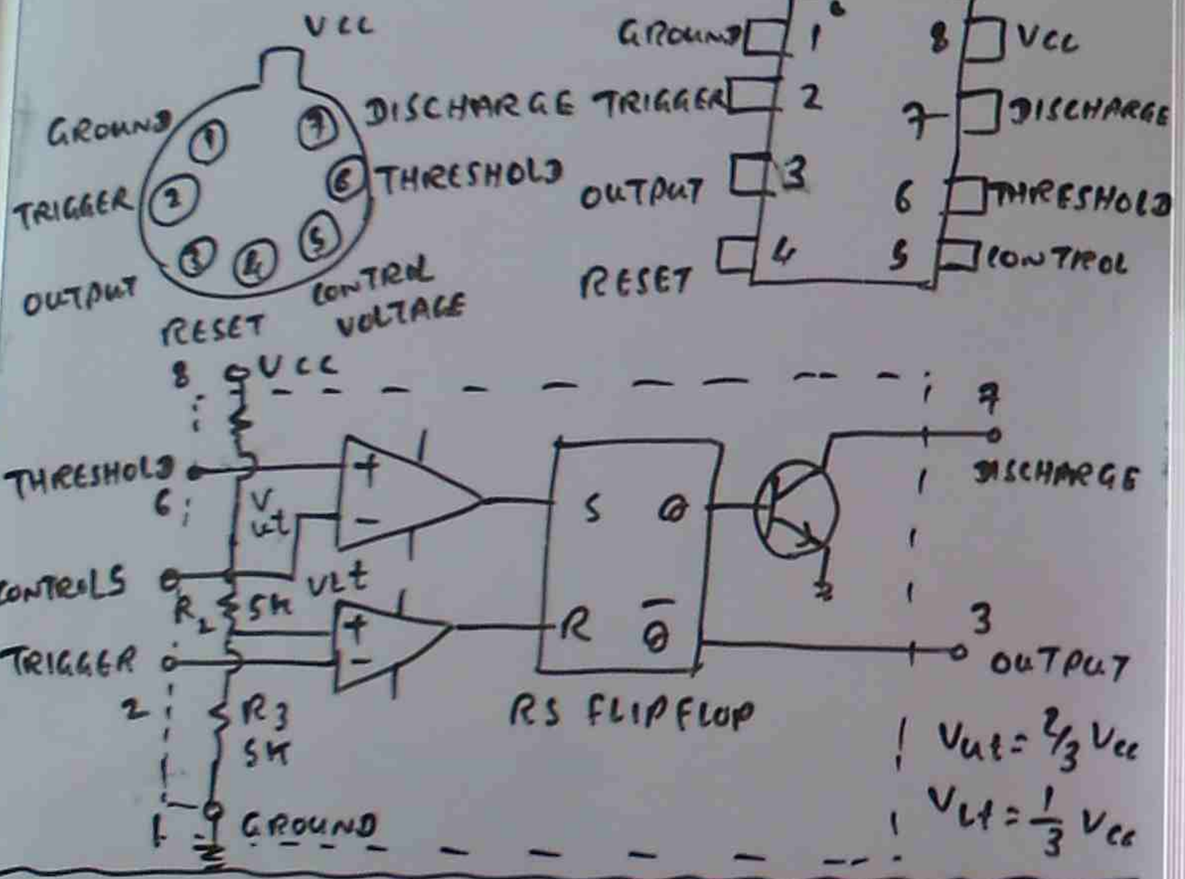
(1) DC CONDITION - op-amp

SLIDE ⑨ → ㉒

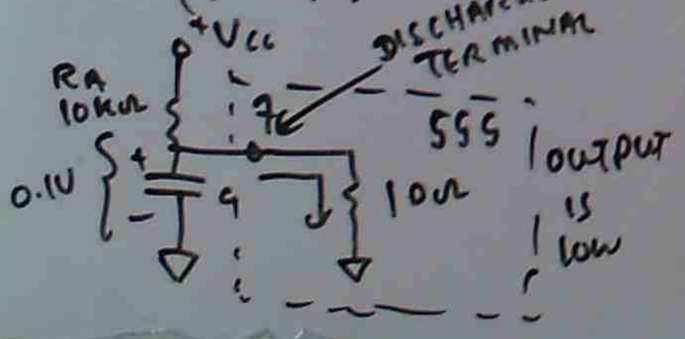
Q7 → Q13

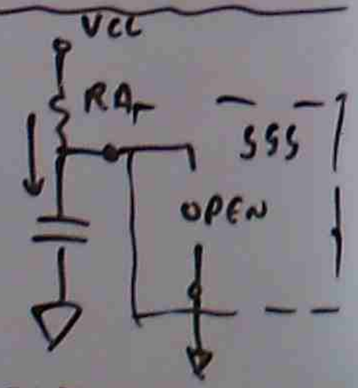
TIMER IC

555 TIMER IC



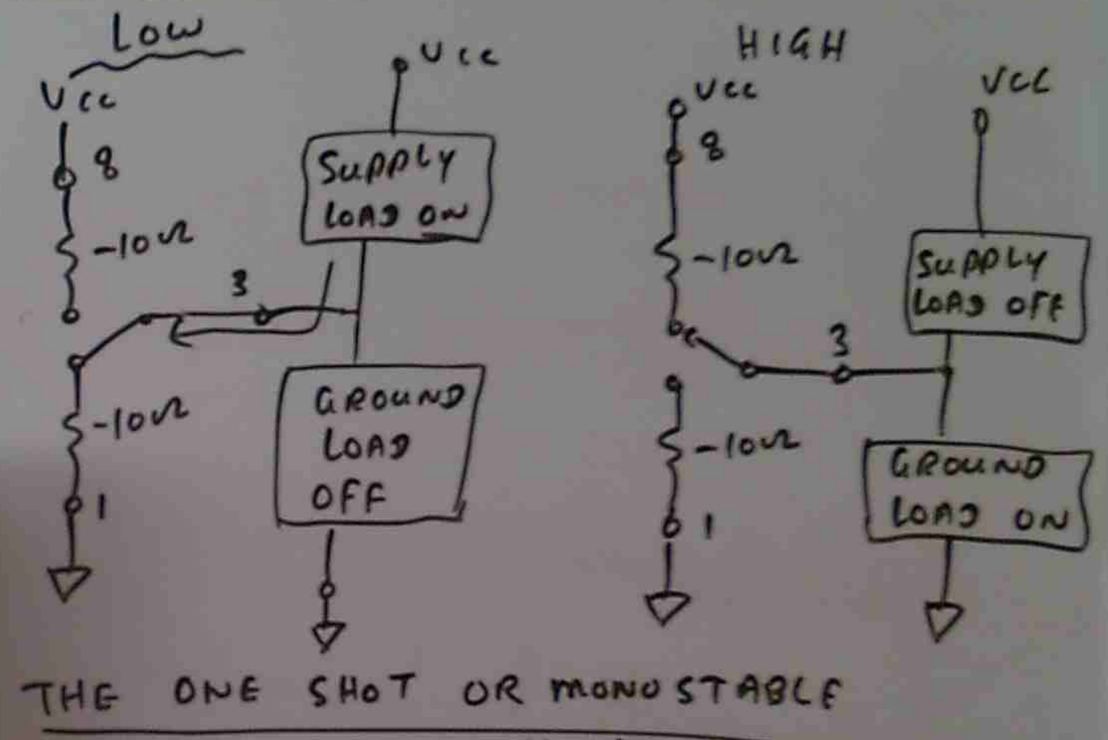
DISCHARGE TERMINAL (PIN 7)



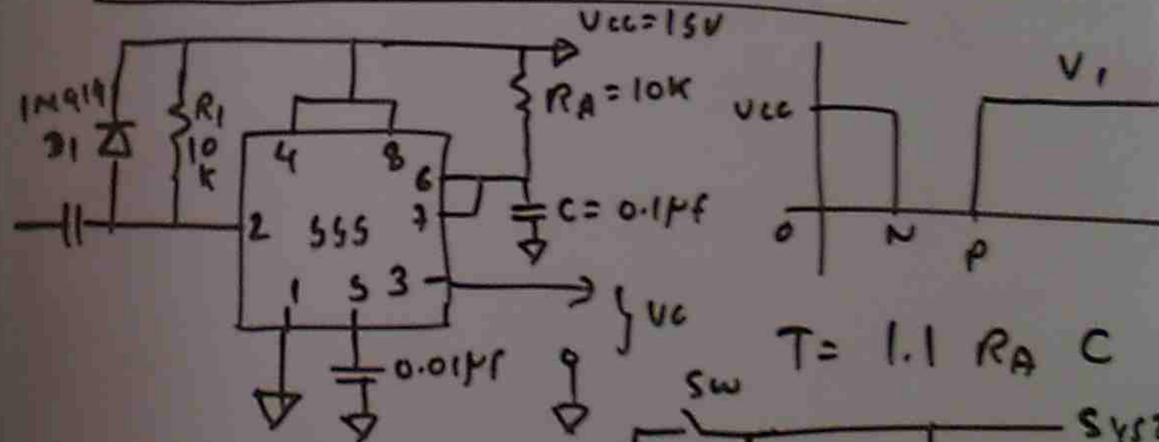


OUT PUT IS HIGH

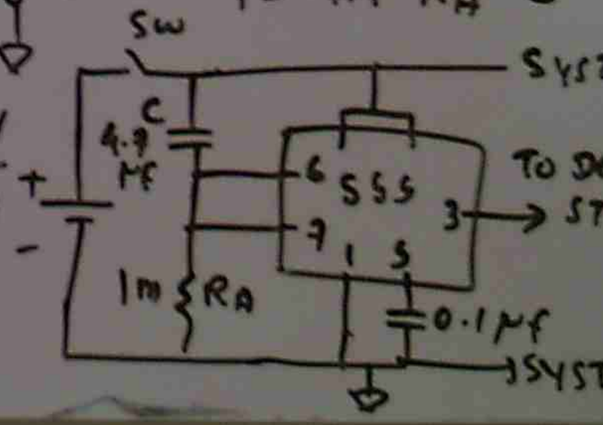
THE OUTPUT TERMINAL PIN 3



THE ONE SHOT OR MONOSTABLE



POWER ON TIME DELAY



HO25

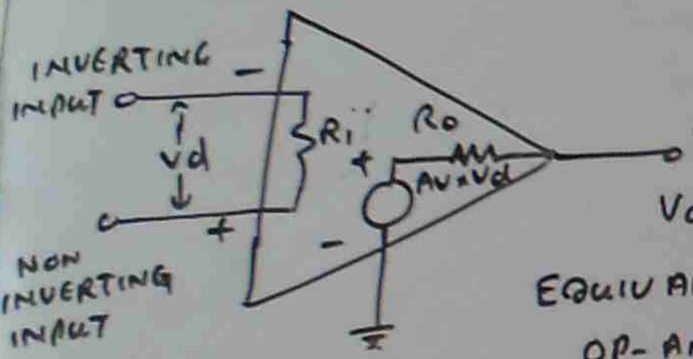
(2) MONOSTABLE CKT INVERTING

SLIDE 1 → 5

14 → 16

15V

OPERATIONAL AMPLIFIER CIRCUIT (1)

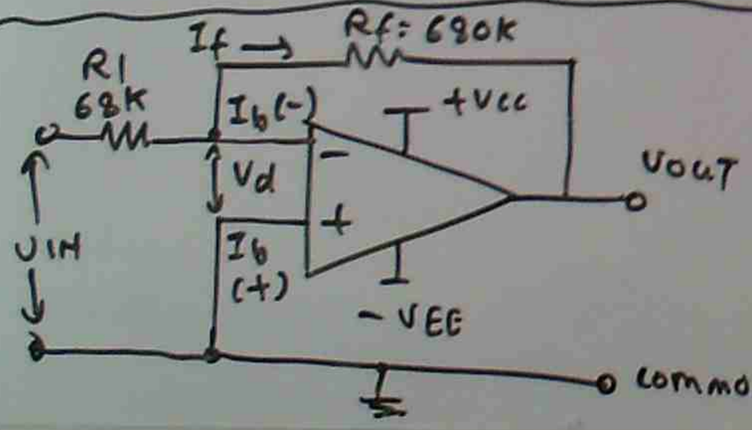


$V_o = A_V \times V_d$

EQUIVALENT CIRCUIT of OP-AMP

IDEAL CHARACTERISTICS

- INFINITE OPEN LOOP VOLTAGE GAIN A_{VOI}
- INFINITE INPUT RESISTANCE (R_{IN})
- ZERO OUT PUT RESISTANCE
- INFINITE BAND WIDTH
- A COMMON MODE REJECTION RATIO OF INFINITY
- OUT PUT VOLTAGE 0 V FOR IN PUT OF 0V.
- INFINITE SLEW RATE



INVERTING AMPLIFIER

FEED BACK FACTOR

$$\beta = \frac{R_1}{R_1 + R_f}$$

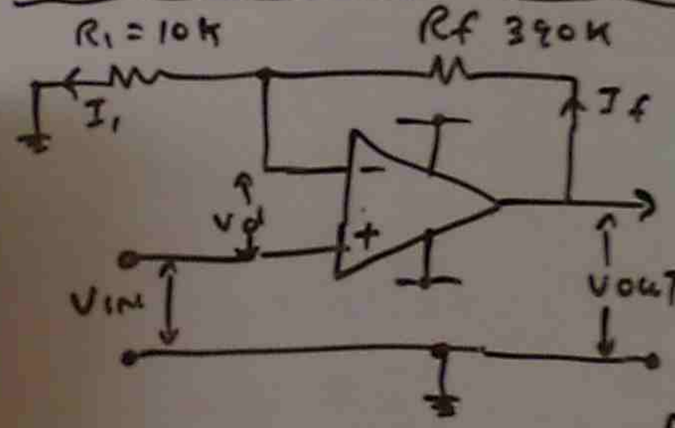
$$I_1 = \frac{V_{IN}}{R_1}, \quad V_{Rf} = I_f R_f = I_1 R_f$$

$$V_{OUT} = (-)\, I_1 R_f, \quad A_V = \frac{V_{OUT}}{V_{IN}} = \frac{-I_1 R_f}{I_1 R_1}$$

$$A_V = -\frac{R_f}{R_1}$$

$$R_{IN} = R_1$$

THE IDEAL NON INVERTING AMPLIFIER



$V_{IN} = V_{(+)} = V_{(-)}$

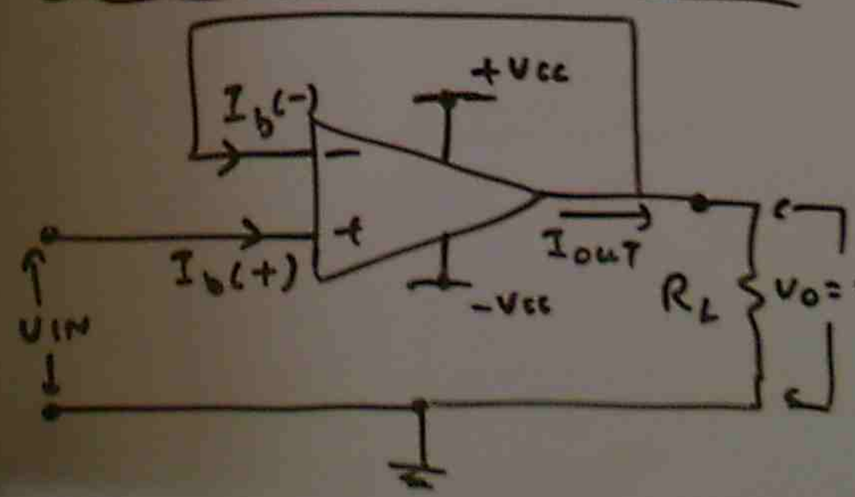
$I_1 = I_f$

$V_{OUT} = V_{R_1} + V_{Rf}$

$A_V = \frac{V_{OUT}}{V_{IN}}$

$A_V = \frac{R_f}{R_1} + 1$

THE IDEAL VOLTAGE FOLLOWER

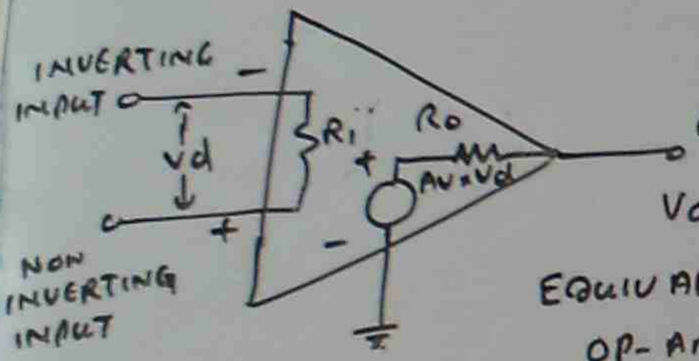


BUFFER
UNITY GAIN
AMPLIFIER

$V_{IN} = V_{(+)} = V_{(-)}$

$R_o = 0$

OPERATIONAL AMPLIFIER CIRCUIT (1)

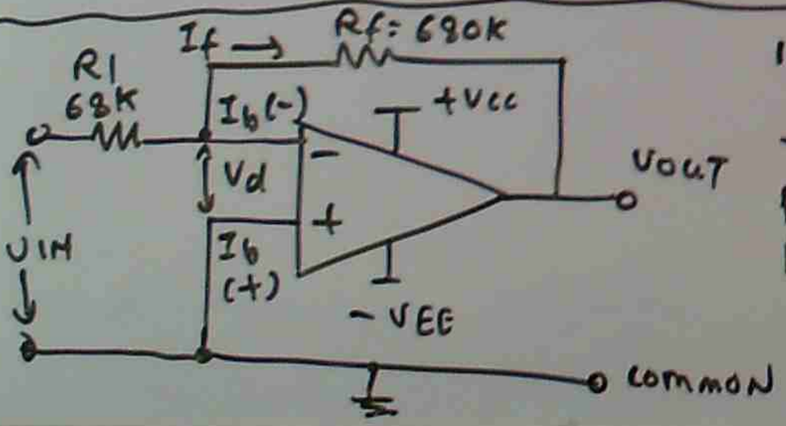


$V_o = A_V \times V_d$

EQUIVALENT CIRCUIT OF OP-AMP

IDEAL CHARACTERISTICS

- INFINITE OPEN LOOP VOLTAGE GAIN A_{VOI}
- INFINITE INPUT RESISTANCE (R_{IN})
- ZERO OUT PUT RESISTANCE
- INFINITE BAND WIDTH
- A COMMON MODE REJECTION RATIO OF INFINITY
- OUT PUT VOLTAGE 0 V FOR IN PUT OF 0V.
- INFINITE SLEW RATE



INVERTING AMPLIFIER

FEED BACK FACTOR

$$\beta = \frac{R_1}{R_1 + R_f}$$

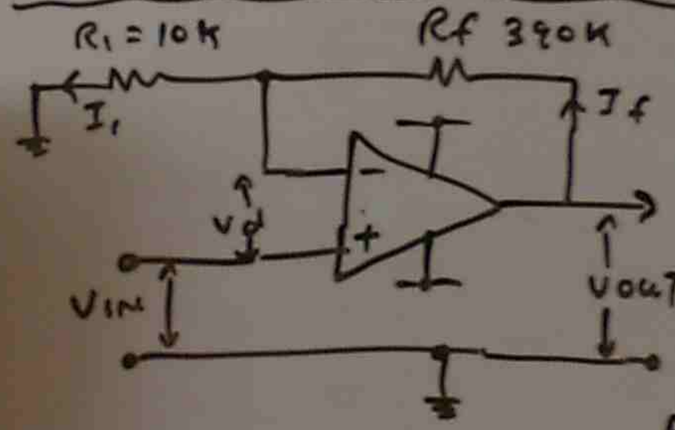
$$I_1 = \frac{V_{IN}}{R_1}, \quad V_{Rf} = I_f R_f = I_1 R_f$$

$$V_{OUT} = (-)\, I_1 R_f, \quad A_V = \frac{V_{OUT}}{V_{IN}} = \frac{-I_1 R_f}{I_1 R_1}$$

$$A_V = -\frac{R_f}{R_1}$$

$$R_{IN} = R_1$$

THE IDEAL NON INVERTING AMPLIFIER



$V_{IN} = V_{(+)} = V_{(-)}$

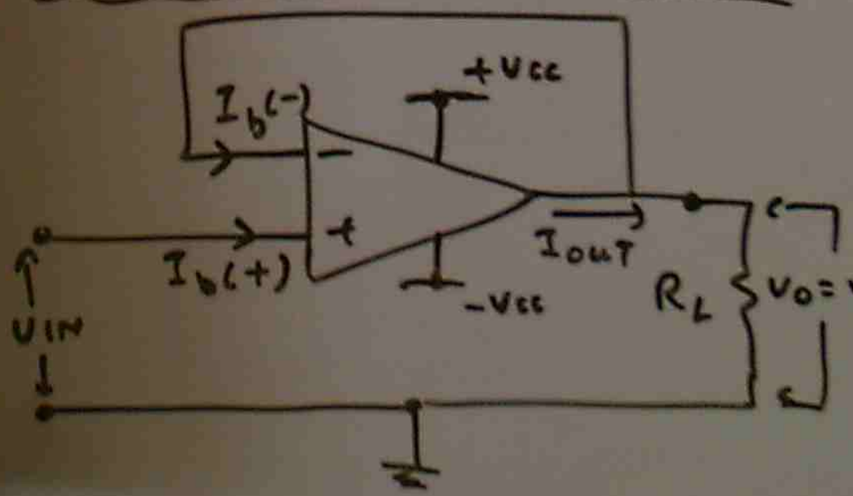
$I_1 = I_f$

$V_{OUT} = V_{R_1} + V_{Rf}$

$A_V = \frac{V_{OUT}}{V_{IN}}$

$A_V = \frac{R_f}{R_1} + 1$

THE IDEAL VOLTAGE FOLLOWER



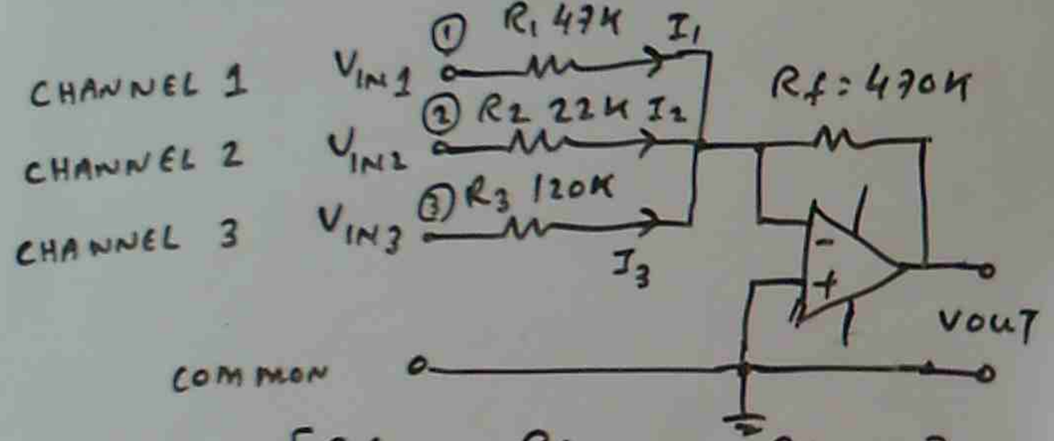
BUFFER
UNITY GAIN
AMPLIFIER

$V_{IN} = V_{(+)} = V_{(-)}$

$R_o = 0$

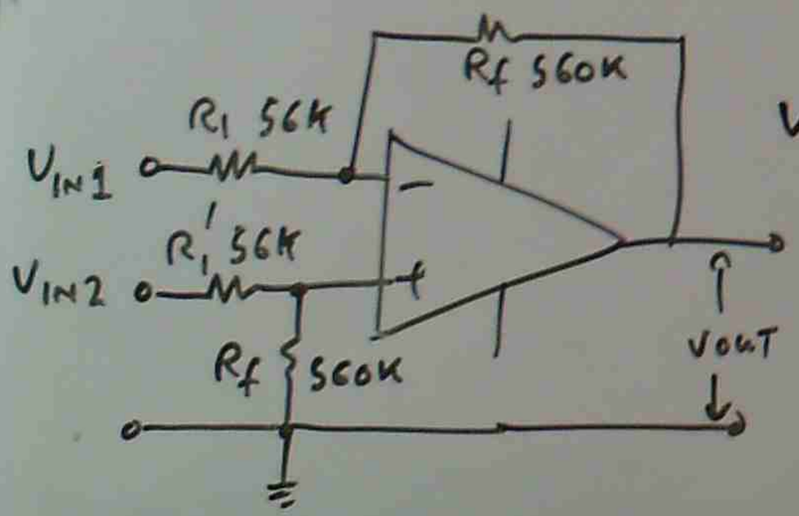
OPERATIONAL AMPLIFIER CIRCUIT (2)

THE IDEAL INVERTING SUMMER AMPLIFIER



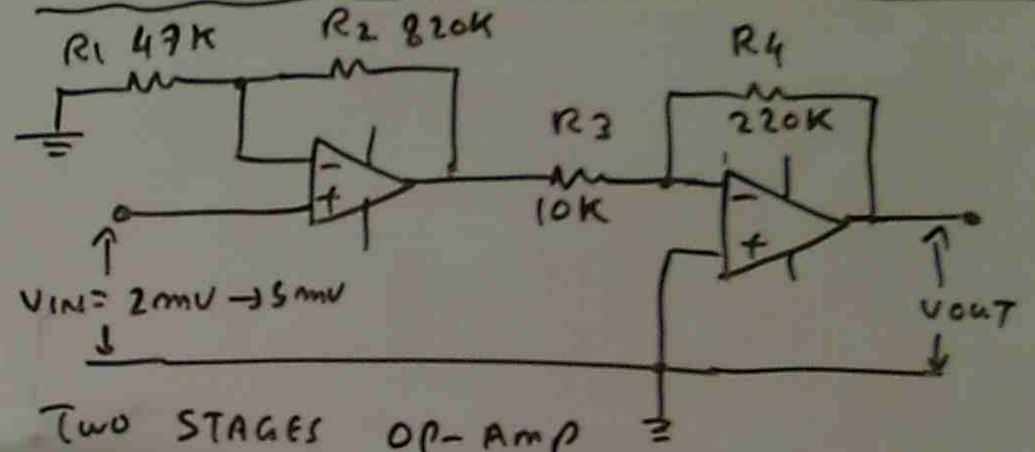
$$V_o = -\left[\frac{Rf}{R_1}V_1 + \frac{Rf}{R_2}V_2 + \frac{Rf}{R_3}V_3\right]$$

THE IDEAL DIFFERENTIAL AMPLIFIER



$$V_o = \frac{Rf}{R_1}\left(V_{IN2} - V_{IN1}\right)$$

CASCADING OPERATIONAL AMPLIFIER CIRCUITS



Two STAGES OP-AMP CIRCUIT

$A V_{207} = A_{U1} \times (-)A_{U2}$

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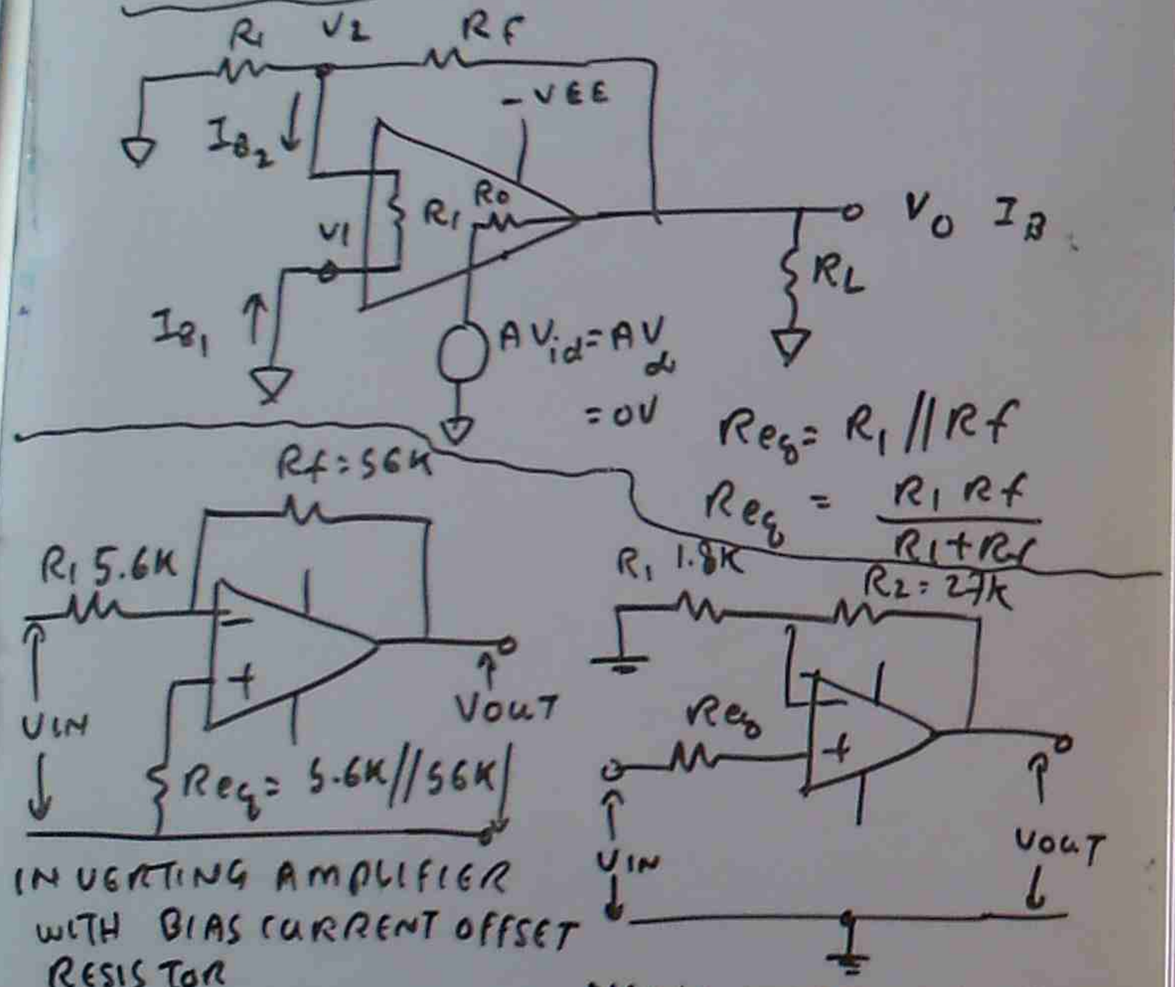
H025

(2) MONOSTABLE CIRCUIT INVERTING

SLIDE (6) ⟶ (28)

Q 17 ⟶ Q 28

(3) OP-AMP CHARACTERISTICS AND BANDWIDTH COMPENSATION



INVERTING AMPLIFIER WITH BIAS CURRENT OFFSET RESISTOR

$Req = R_1 // Rf$

$Req = \frac{R_1 Rf}{R_1 + Rf}$

NON INVERTING AMPLIFIER WITH BIAS CURRENT OFFSET RESISTOR

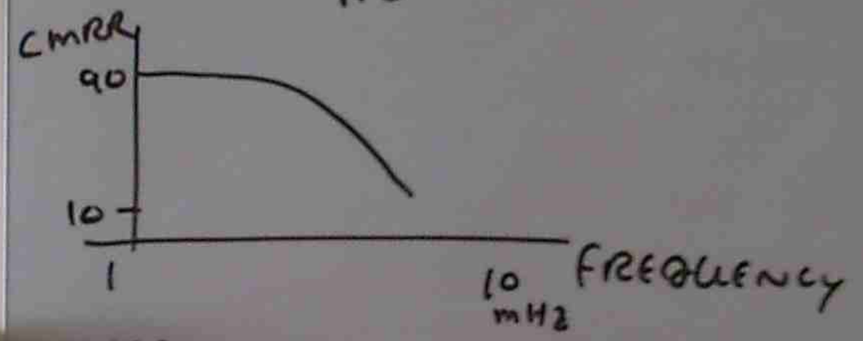
THERMAL DRIFT

THE OFFSETS ARE NOT CONSTANT, VARY WITH

- CHANGE IN TEMPERATURE
- CHANGE IN SUPPLY VOLTAGE
- TIME

COMMON MODE REJECTION RATIO

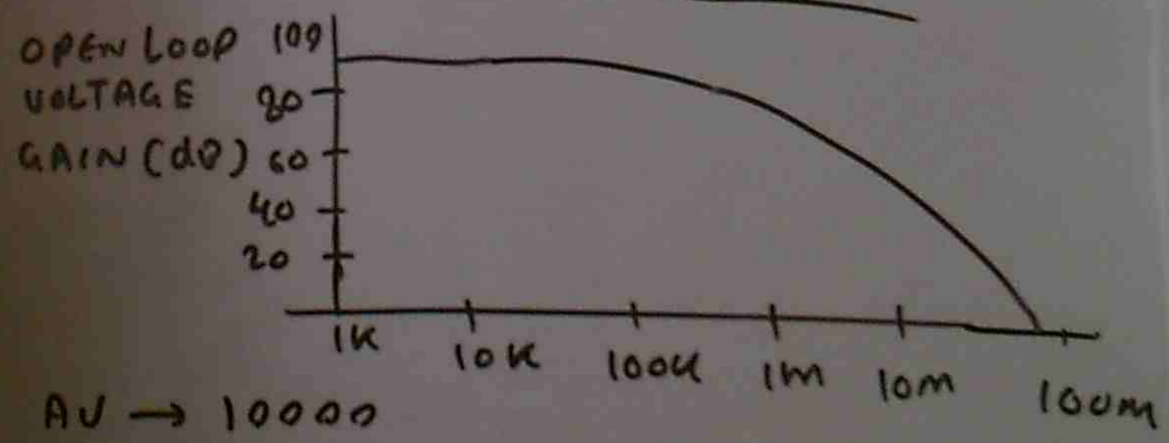
$$CMRR = \frac{Ad}{Ac} \quad (OR) \quad CMRR = 20 \log \frac{Ad}{Ac} \ (dB)$$



NOISE IN OUT PUT VOLTAGE

$$\text{NOISE GAIN} = \frac{Rf}{R_1} + 1$$

OP-AMP CHARACTERISTICS



AV → 10000

PHASE SHIFT PHASE RELATIONSHIP BETWEEN INPUT & OUTPUT VOLTAGES OF OP-AMP

INTERNAL FREQUENCY COMPENSATION

CIRCUITS THAT DO NOT REQUIRE WIDE BANDWIDTHS GENERALLY COMPENSATED OP-AMPS. 741, TL071, TL081, LF411

AN INTERNAL COMPENSATION NETWORK IS USED TO TAILOR THE FREQUENCY RESPONSE FOR A REASONABLE RANGE OF FREQUENCIES AT MODERATE CLOSED LOOP GAINS.

GAIN BANDWIDTH PRODUCT (GBP)

GBP = AV (CLOSED LOOP) x BW = UNITY GAIN BANDWIDTH

SLEW RATE

THE SLEW RATE SPECIFICATION OF AN OP-AMP STATES HOW FAST THE OUTPUT VOLTAGE OF AN OP-AMP CAN CHANGE FOR A STEP CHANGE AT THE INPUT

$$\text{SLEW RATE} = \frac{\text{MAX: CHANGE IN } V_O}{\text{CHANGE IN TIME}}$$

Pb IF 2V P-P SQUARE WAVE AT A FREQUENCY OF 50kHz IS APPLIED TO VOLTAGE FOLLOWER ↑ SLEW RATE 0.5V/μs CALCULATE (a) PERIOD (b) TIME TAKEN FOR OUTPUT TO CHANGE BY 2V

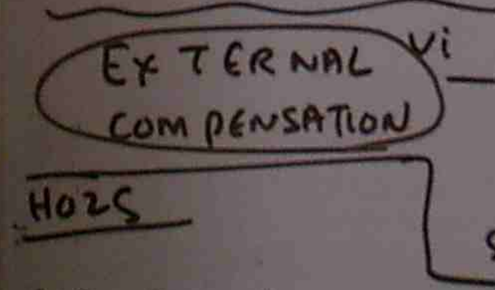
(a) $T = \frac{1}{f} = \frac{1}{50\text{kHz}} = \frac{1}{50\times10^3} = 20\times10^{-6}\text{s} = 20\mu\text{s}$

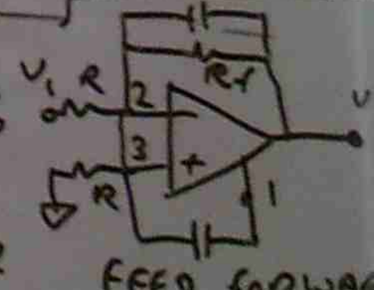
(b) TIME TAKEN TO CHANGE BY 2V $= \frac{\text{VOLTAGE CHANGE}}{\text{SLEW RATE}} = \frac{2\text{V}}{0.5\text{V}/\mu\text{s}} = 4\mu\text{s}$

Pd THE SLEW RATE of 741 IS 0.5 V/μs FIND MAX FREQ: FOR 20V P-P SINE WAVE

$$f_{MAX} = \frac{\text{SLEW RATE}}{2\pi \times V_{O\,MAX}} = \frac{0.5\text{V}}{2\times3.14\times\frac{20}{2}\times1\mu\text{s}} = 7.96\text{ kHz}$$

EXTERNAL COMPENSATION





HO2S

(3) OP-AMP CHARACTERISTICS & BANDWIDTH COMPENSATION
SLIDE (1) ⟶ (19) @ 29 ⟶ 42

OP-AMP DIODE CIRCUITS

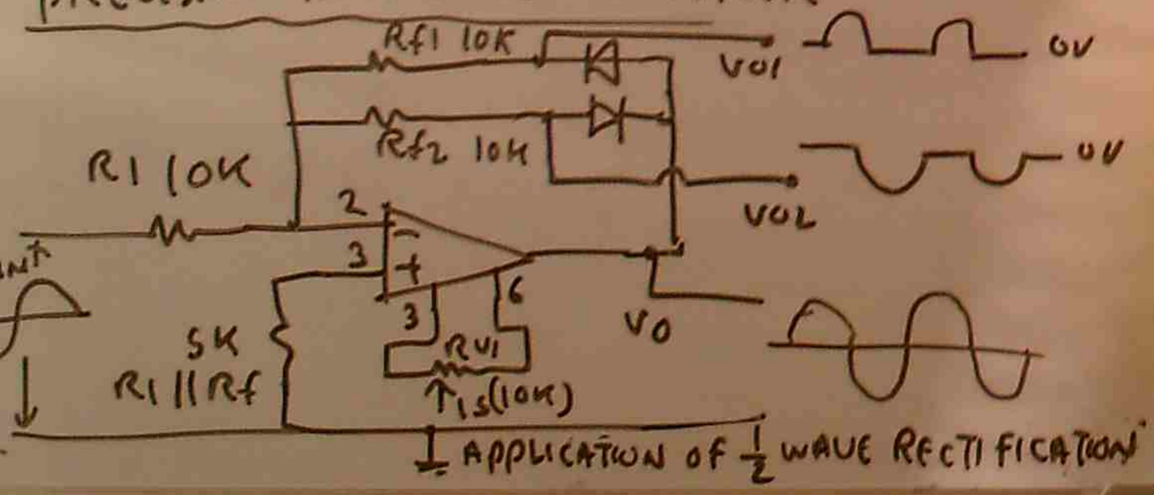
THERE ARE A WIDE RANGE of OPAMP CIRCUITS THAT USE DIODES IN THE FEED BACK PATH. THESE CIRCUITS FALL IN TWO CATEGORIES

- PRECISION RECTIFIERS
- DIODE LIMITERS.

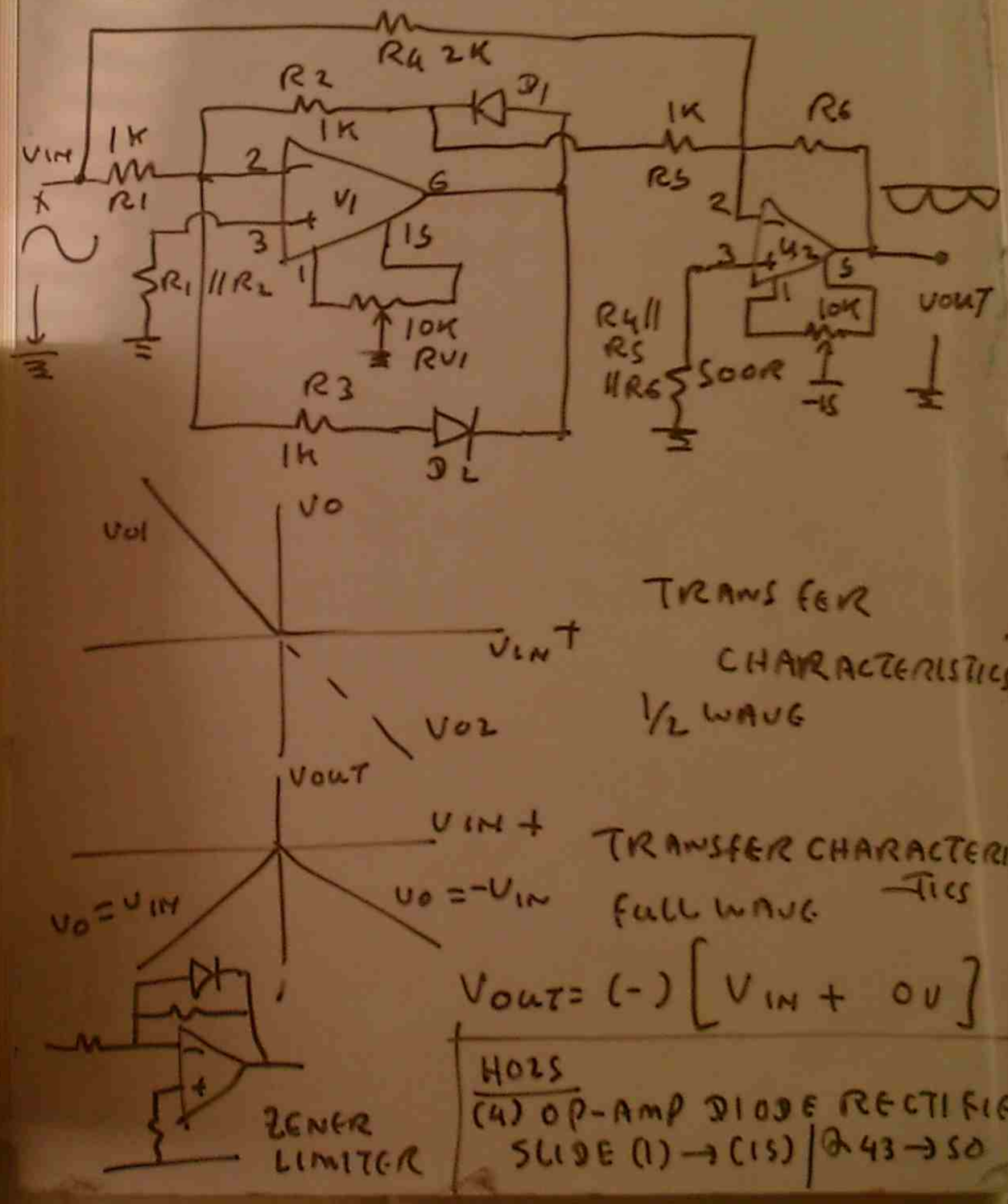
OP-AMP RECTIFIER

PRECISION 1/2 WAVE RECTIFICATION
PRECISION FULL WAVE RECTIFICATION
AVERAGING CIRCUITS
PEAK VALUE CIRCUITS
CLIPPERS

PRECISION HALF WAVE RECTIFIER



PRECISION FULL WAVE RECTIFIER



TRANSFER CHARACTERISTICS
1/2 WAVE

TRANSFER CHARACTERISTICS
FULL WAVE

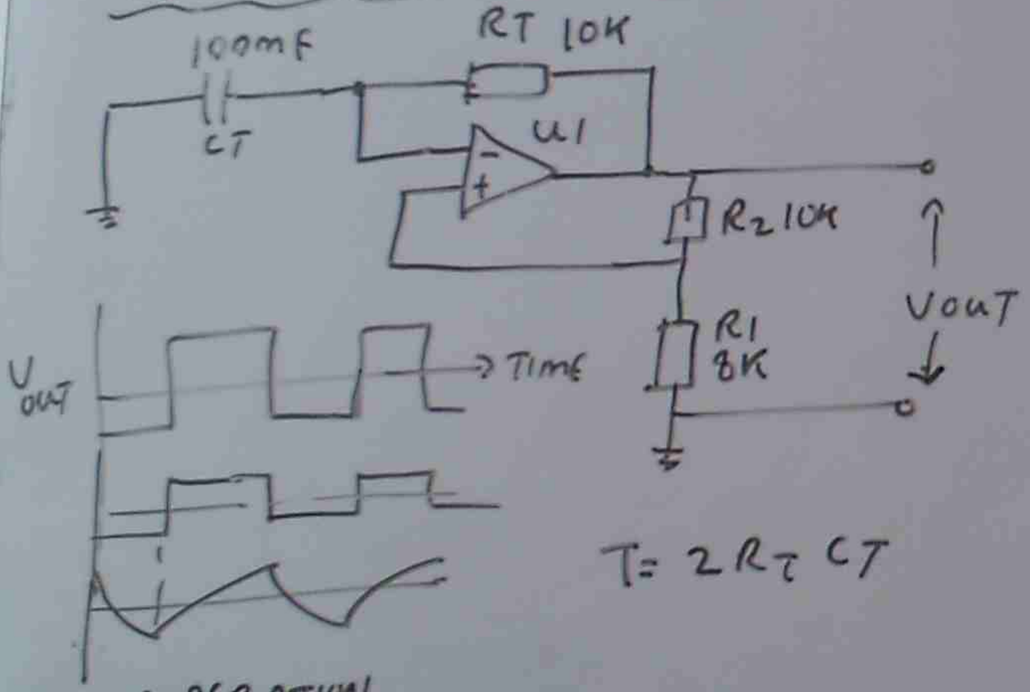
$V_{OUT} = (-)\left[V_{IN} + 0V\right]$

HOLS
(4) OP-AMP DIODE RECTIFIER
SLIDE (1) → (15) | 43 → 50

SINE & SQUARE WAVE OSCILLATOR

OSCILLATORS ARE USED TO PROVIDE TEST SIGNALS, TIMING AND SYNCHRONIZING SIGNALS

OP-AMP ASTABLE



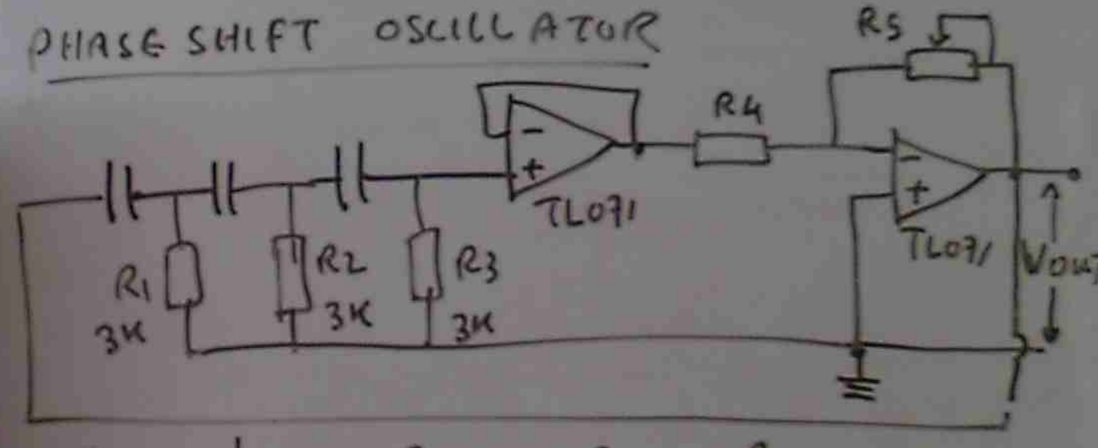
$T = 2R_T C_T$

OPERATION

- THE VOLTAGE ACROSS THE TIMING CAPACITOR WILL CHARGE DOWN TOWARD THE VOLTAGE AT NON INVERTING TERMINAL
- R_T ALLOW CURRENT TO FLOW THROUGH THE CAPACITOR TO V_{OUT}
- THE CAPACITOR WILL START CHARGING POSITIVE DIRECTION UNTIL IT EQUALS TO THE VOLTAGE AT NON INVERTING TERMINAL

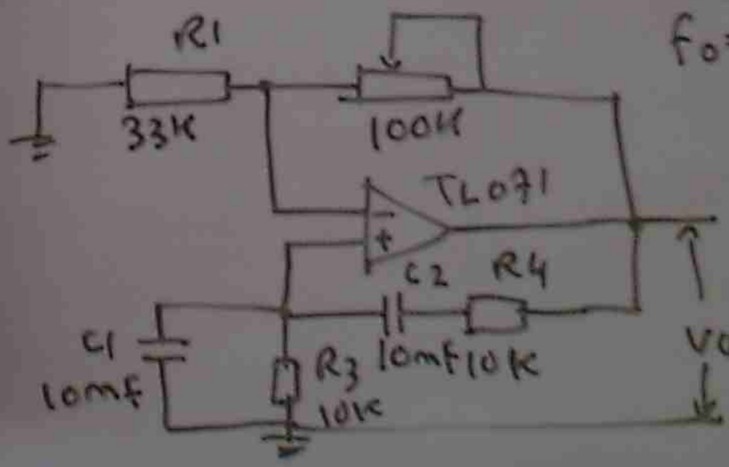
RELATED TOPICS – NON SYMMETRICAL ASTABLE
OP-AMP MONOSTABLE

PHASE SHIFT OSCILLATOR



$f_o = \frac{1}{15.4RC}$ $R = R_1 = R_2 = R_3$ $C = C_1 = C_2 = C_3$ $A_V = 29$

THE WIEN BRIDGE OSCILLATOR



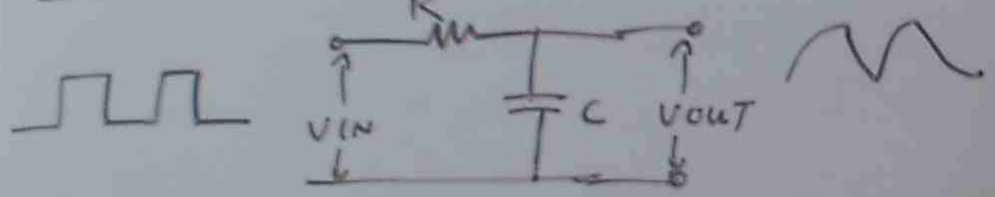
$f_o = \frac{1}{6.28RC}$

$R = R_3 = R_4$

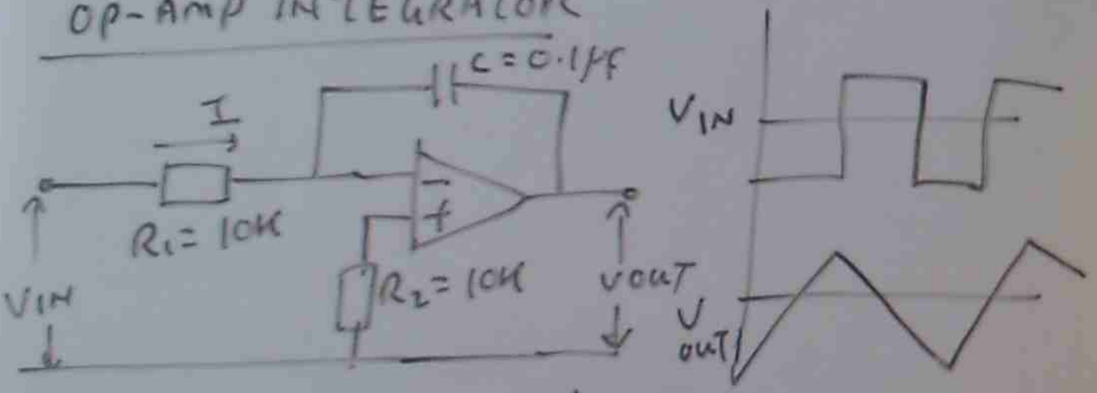
$C = C_1 = C_2$

OP-AMP CIRCUITS

THE INTEGRATOR

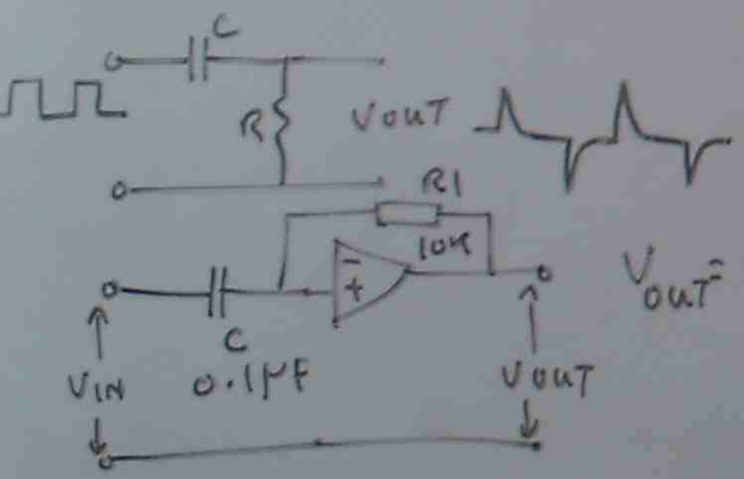


OP-AMP INTEGRATOR



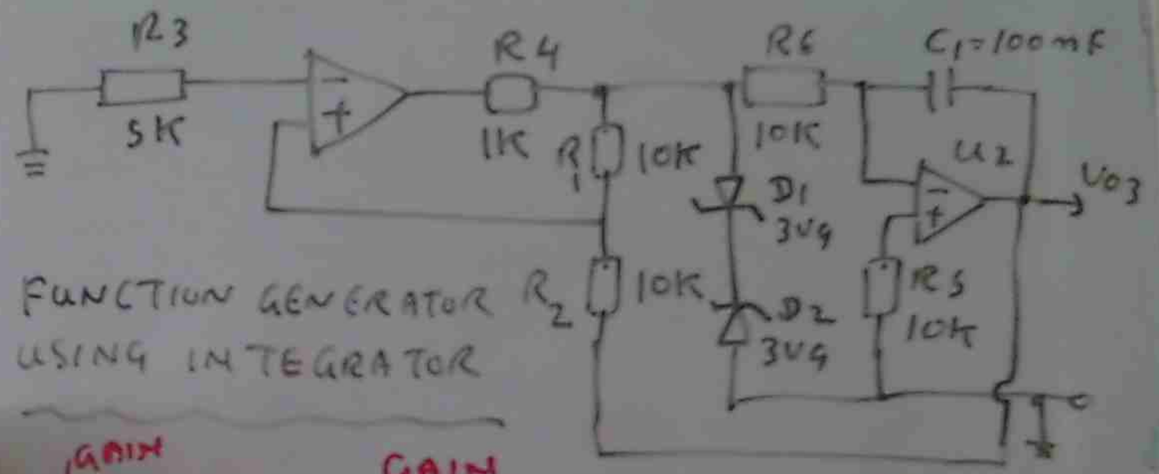
$V_O = (-) V_{IN} \times \frac{1}{R_1 C} \times$ TIME IN SECOND

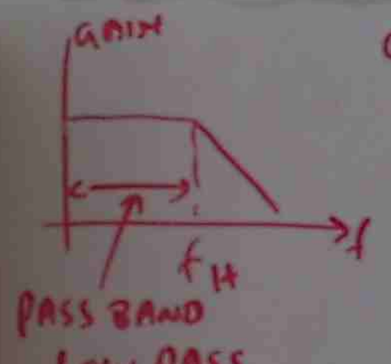
THE DIFFERENTIATOR



$V_{OUT} = (-) R_1 C \times$ RATE OF CHANGE OF V_{IN} (V/SEC)

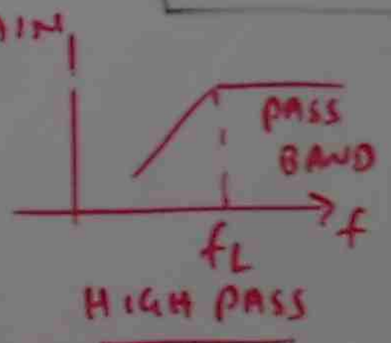
FUNCTION GENERATOR



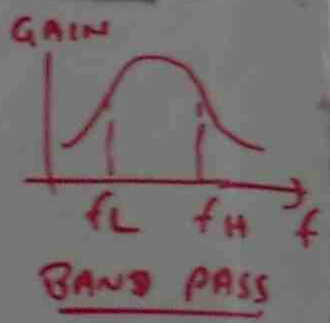


PASS BAND

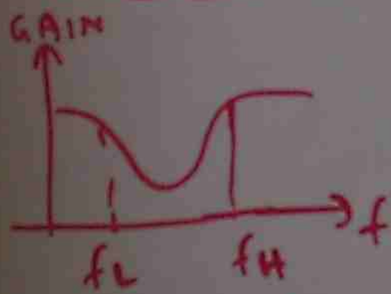
LOW PASS



HIGH PASS



BAND PASS



BAND STOP

XX A FILTER IS DESIGNED TO PASS A SPECIFIED BAND OF FREQUENCIES AND TO REJECT THE OTHERS OUT SIDE THE BAND

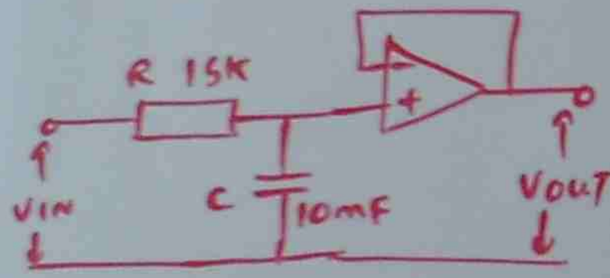
PASSIVE FILTER

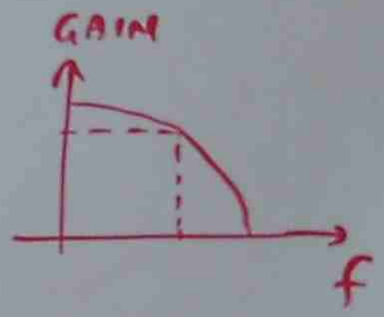
INDUCTOR + CAPACITOR

PASSIVE COMPONENTS + OP-AMP = ACTIVE FILTER

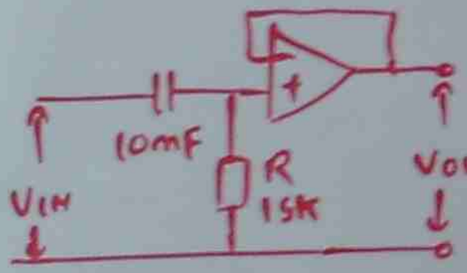
ACTIVE FILTERS USE RC NETWORK TO ATTENUATE THE FREQUENCIES OUTSIDE THE PASS BAND.

SINGLE ORDER ACTIVE FILTERS

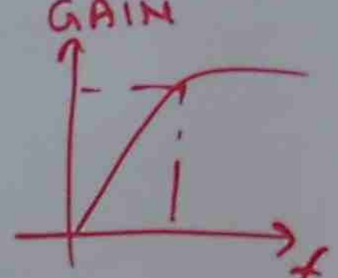




FIRST ORDER FILTER (LOW PASS)

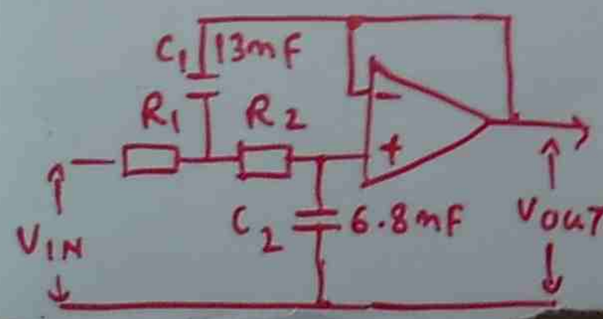


(HIGH PASS)



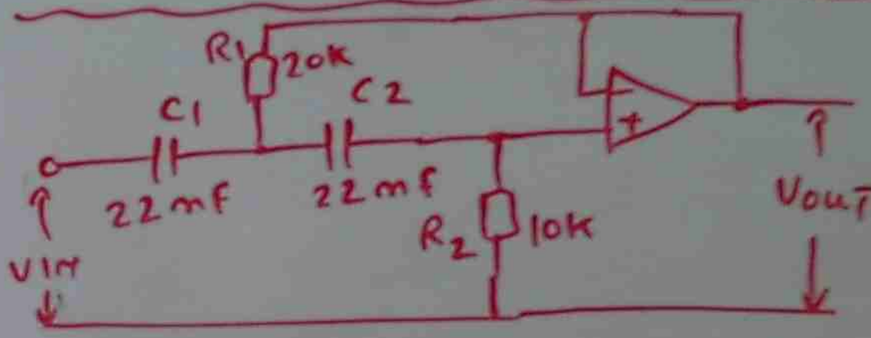
$$f_c = \frac{1}{6.28RC}$$

THE SECOND ORDER LOW PASS BUTTERWORTH FILTER

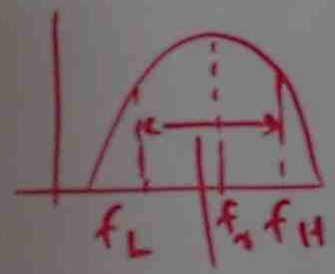


$$f_c = \frac{1}{6.28\sqrt{R_1 R_2 C_1 C_2}}$$

THE SECOND ORDER HIGH PASS BUTTERWORTH FILTER

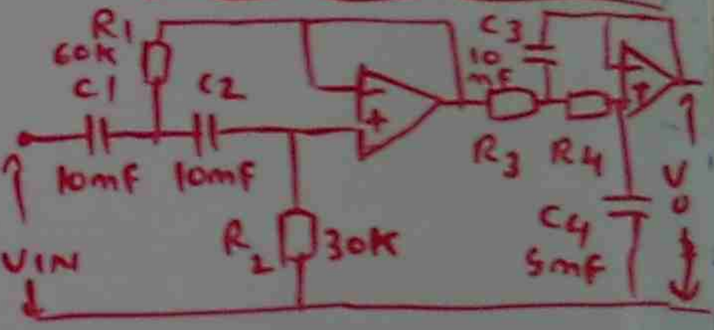


BAND PASS FILTER



$$BW = f_H - f_L$$

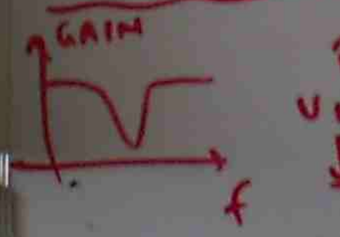
SECOND ORDER BAND PASS FILTER

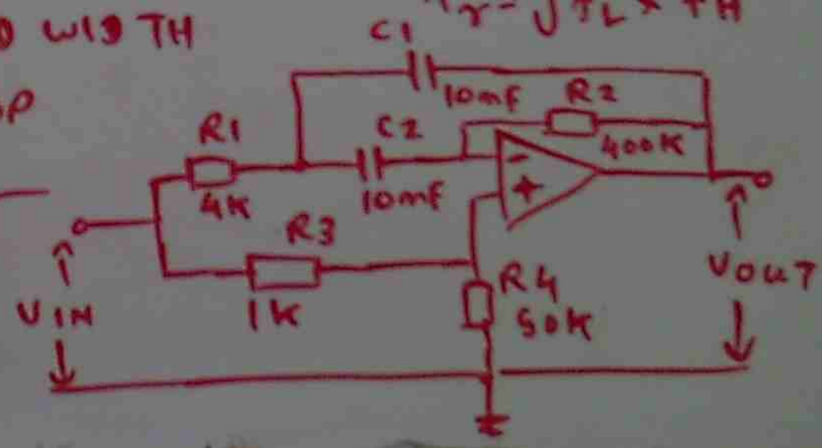


$$Q = \frac{\text{RESONANT FREQUENCY}}{\text{BAND WIDTH}}$$

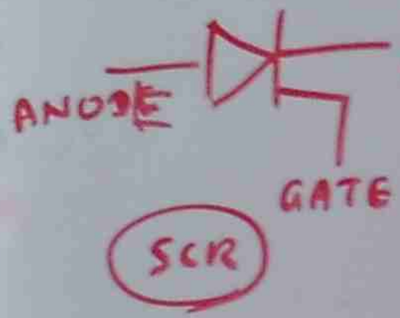
$$f_r = \sqrt{f_L \times f_H}$$

BAND STOP FILTER





SINGLE & THREE PHASE POWER CONTROL EQUIPMENTS



SCRs ARE USED IN 1ϕ AND 3ϕ POWER CONTROL SYSTEMS

VARIABLE FREQUENCY DRIVE

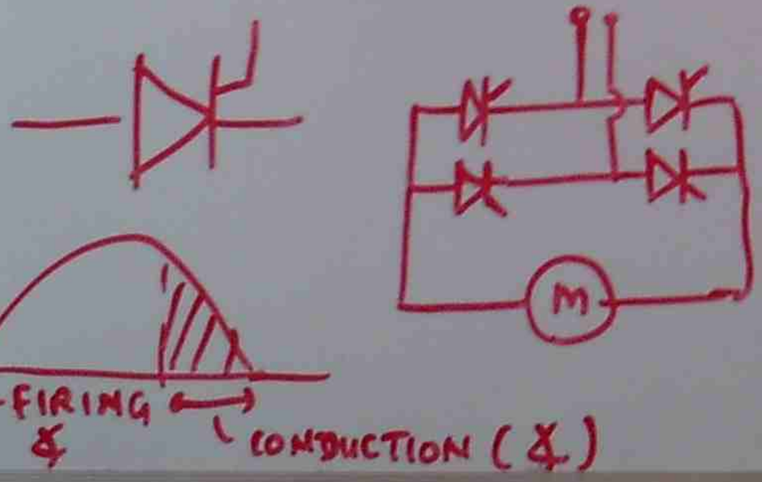
$N_S = \frac{120 f}{P}$

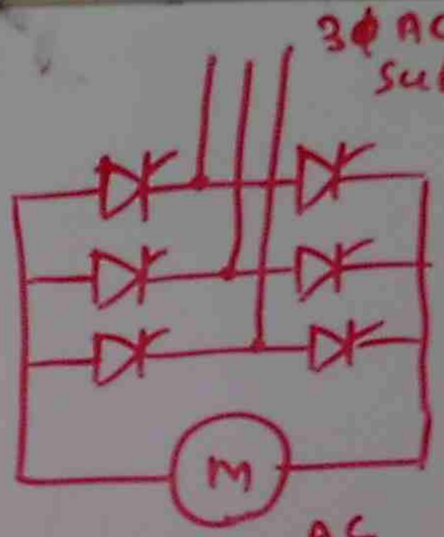
N_S - SYNCHRONOUS SPEED

f = FREQUENCY

P = NO. of POLES

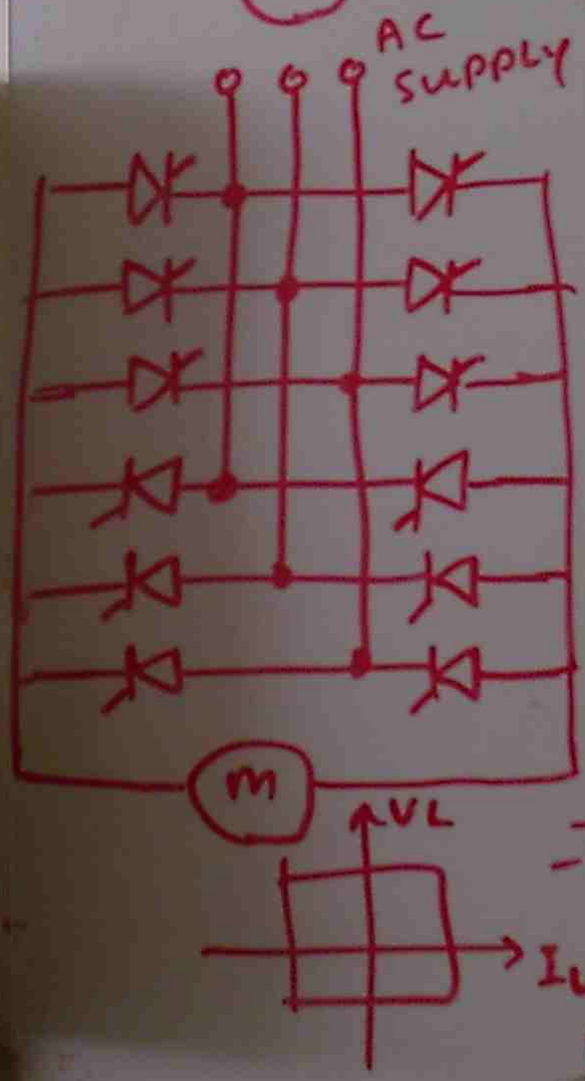
BY CONTROLLING THE FREQUENCY, THE SPEED CAN BE CONTROLLED



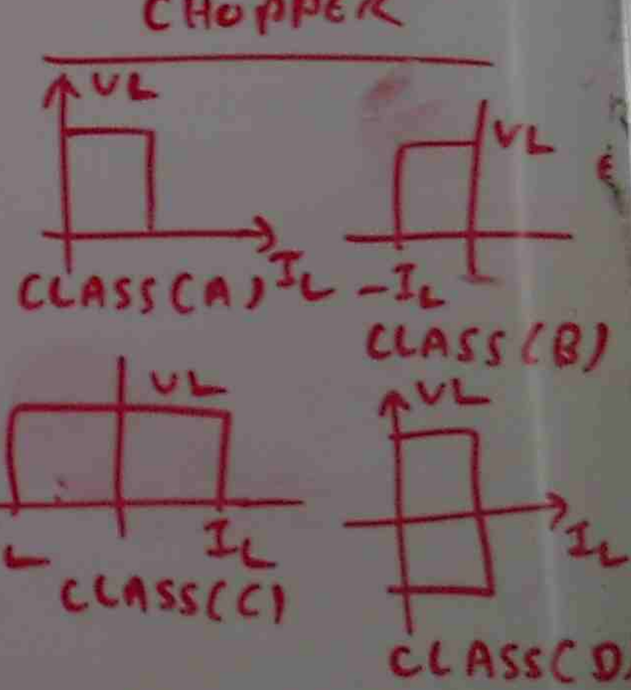


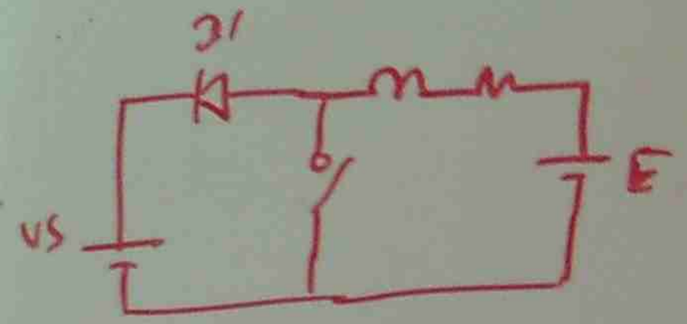
2 REVERSE BRAKING	1 FORWARD DRIVE
3 REVERSE DRIVE	4 FORWARD BRAKING

4 QUADRANTS DRIVE SYSTEM

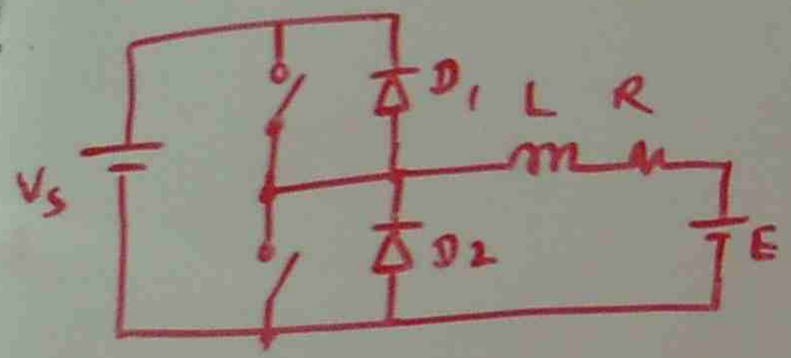


CHOPPER

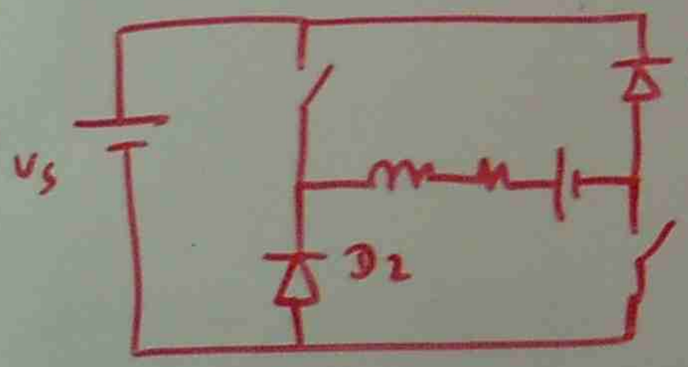




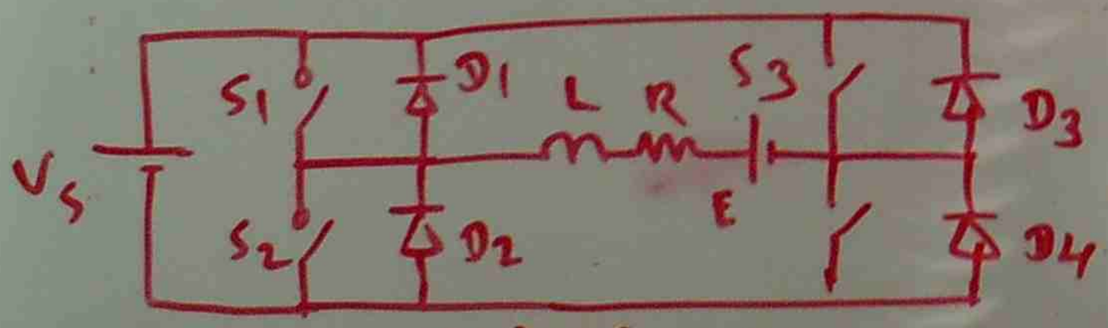
CLASS(B) CHOPPER



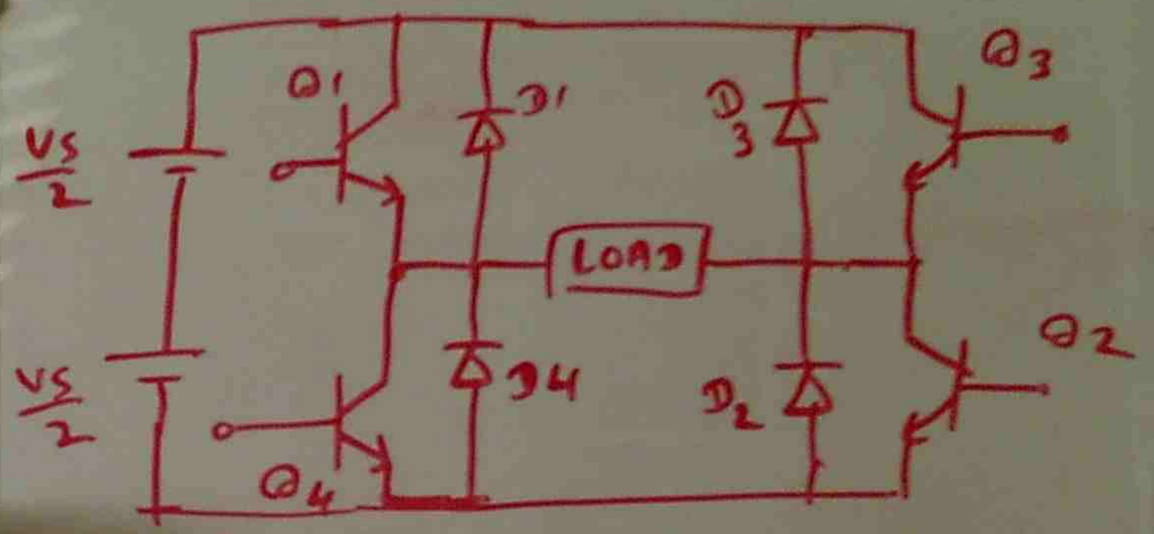
CLASS(C) CHOPPER

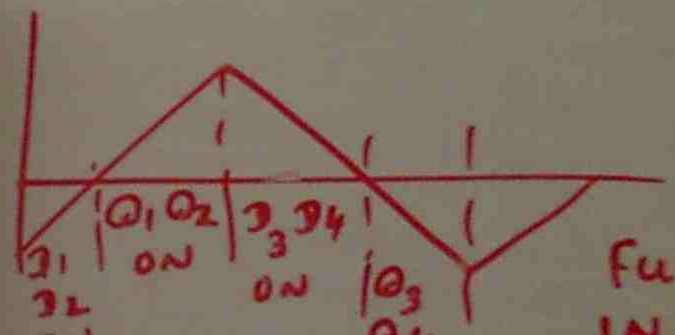


CLASS(D) CHOPPER

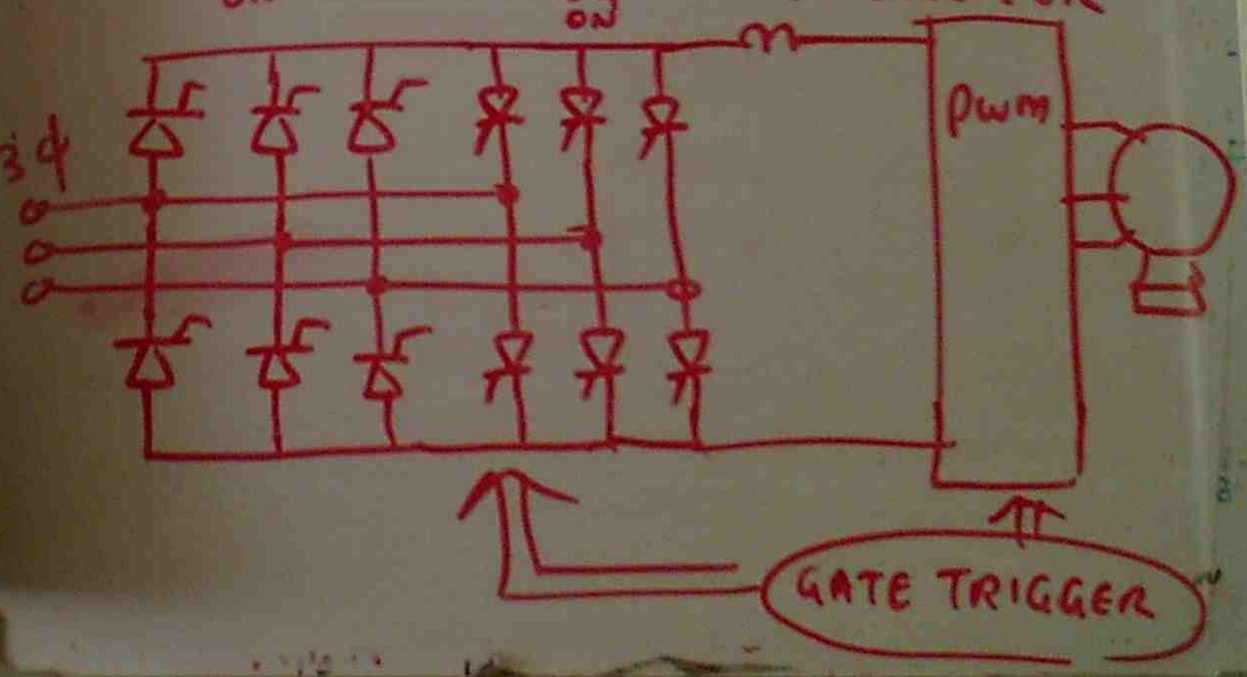


CLASS(E) CHOPPER





1φ FULL BRIDGE INVERTER



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HO 26

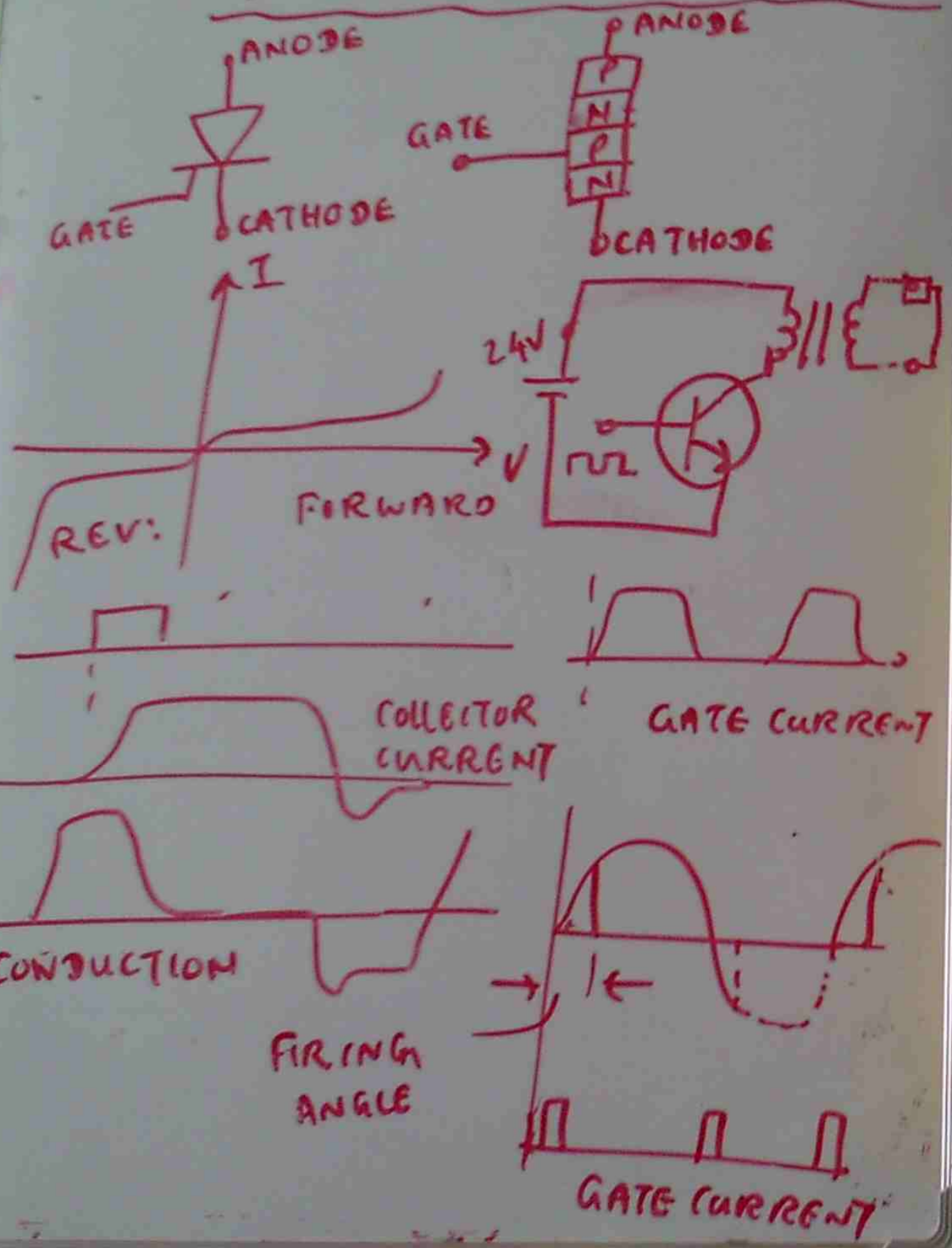
① VARIABLE SPEED DRIVE
SLIDE 1 → 4 , Q1

② CONVERTER
SLIDE 1 → 4 , Q2

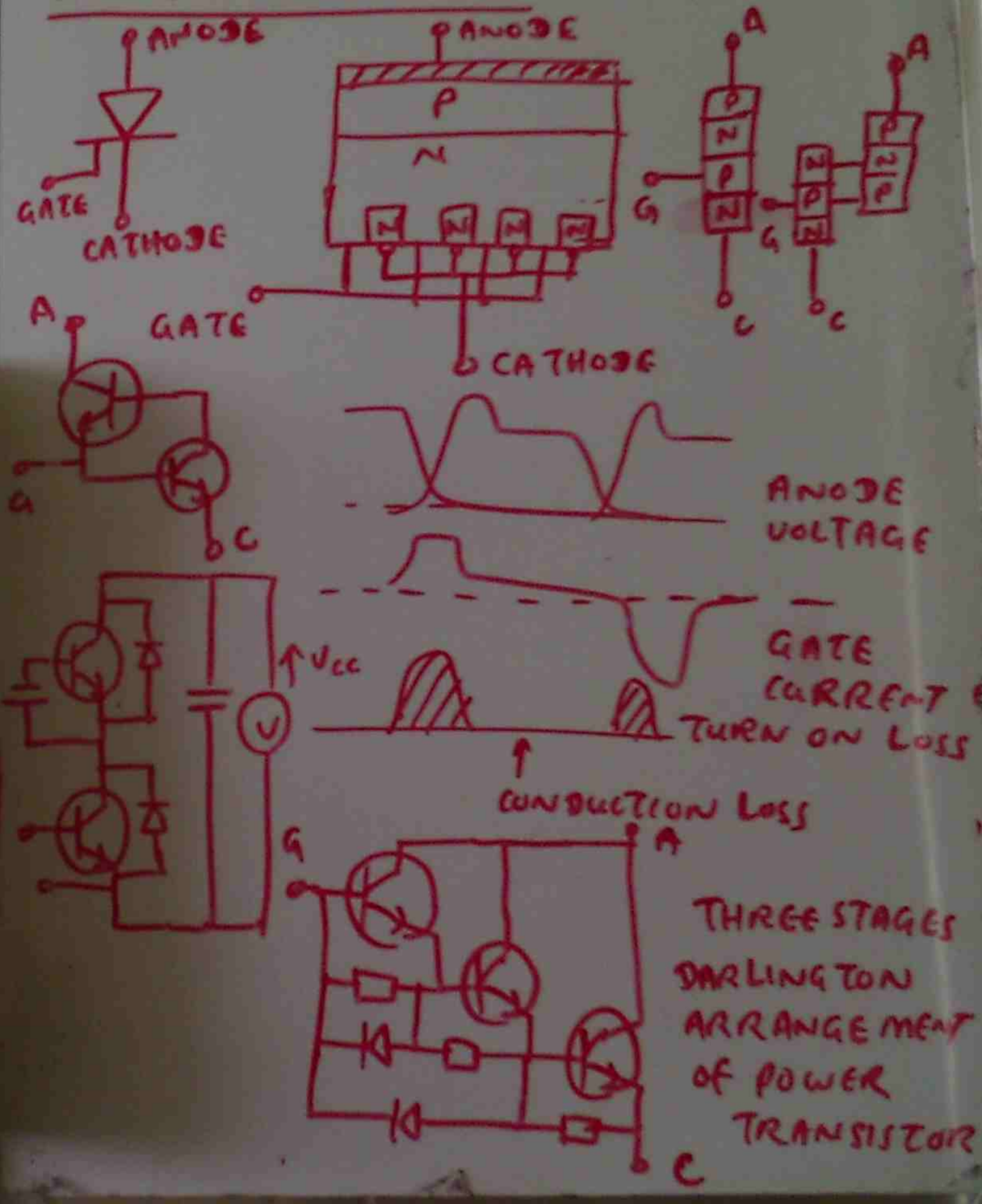
③ CHOPPER CIRCUIT
+ BRIDGE RECTIFIER
+ SCR
SLIDE 1 → 17
Q4 → Q9

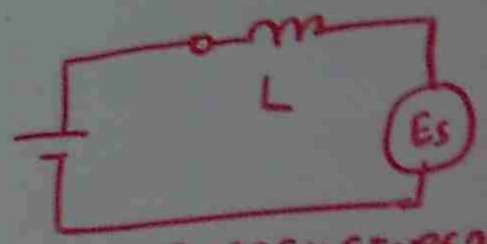
④ 3 PHASE VARIABLE DRIVE SYSTEM
SLIDE 1+2
Q10

SOLID STATE SWITCHING DEVICES

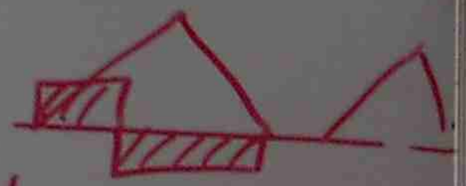


INTER DIGITIZED GATE

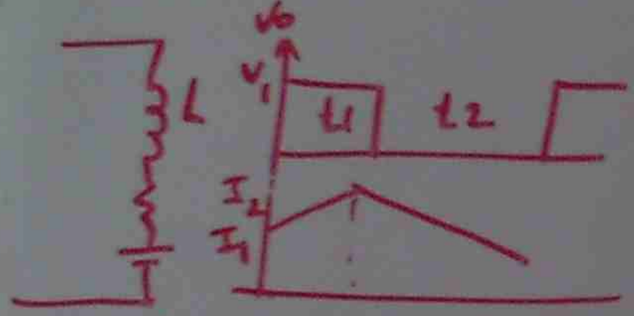




ENERGY STORED IN INDUCTOR

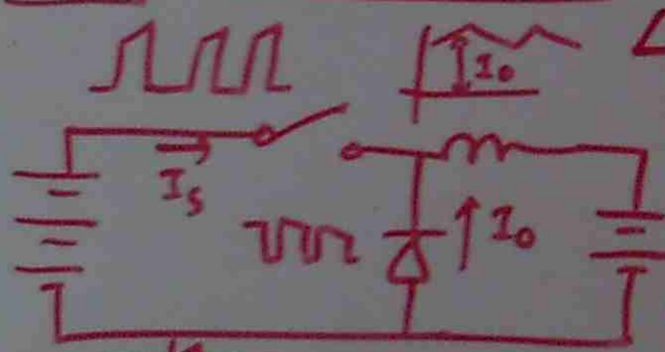


ENERGY STORED IN INDUCTOR

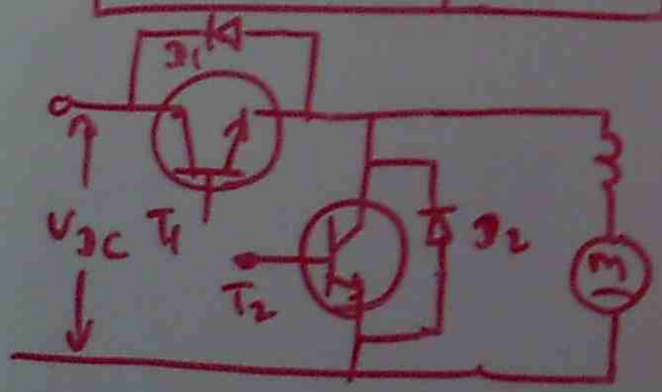


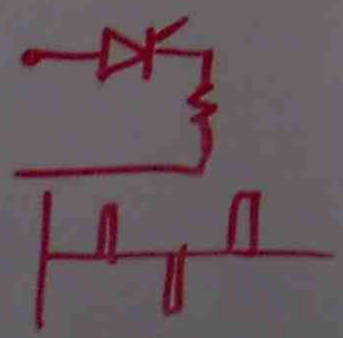
CONTINUOUS CURRENT

$$\Delta I_{RIPPLE} = \frac{V_S}{4fL}$$



CURRENTS IN CHOPPER CIRCUIT

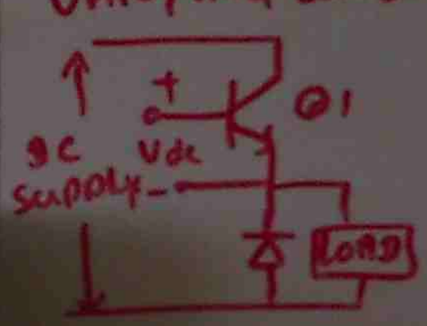


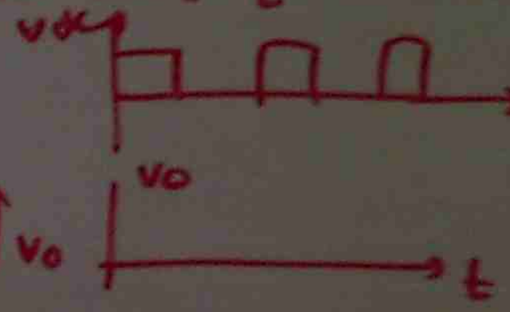


THYRISTOR SWITCH

DC-DC CONVERTER

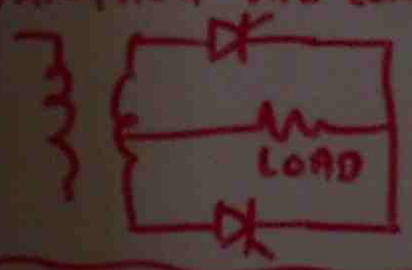
A DC-DC CONVERTER IS ALSO KNOWN AS CHOPPER (OR) SWITCHING REGULATOR THE AVERAGE OUTPUT VOLTAGE IS CONTROLLED BY VARYING CONDITION TIME "t"





AC-DC CONVERTER

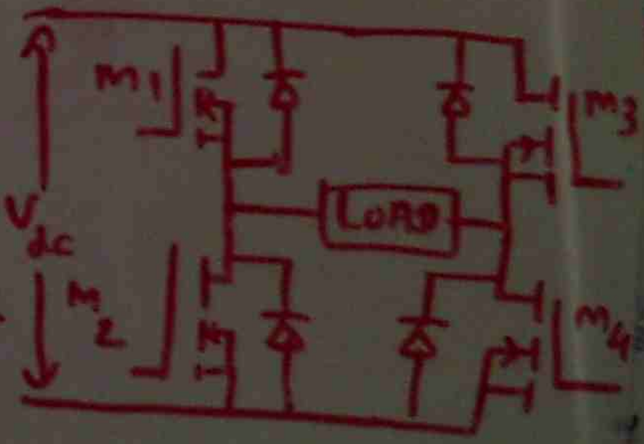
A SINGLE PHASE CONVERTER WITH TWO NATURAL COMMUTATED THYRISTORS. THE AVERAGE VALUE OF OUTPUT VOLTAGE CAN BE CONTROLLED BY VARYING THE CONDUCTION TIME OF THYRISTORS



DC-AC CONVERTER (INVERTER)

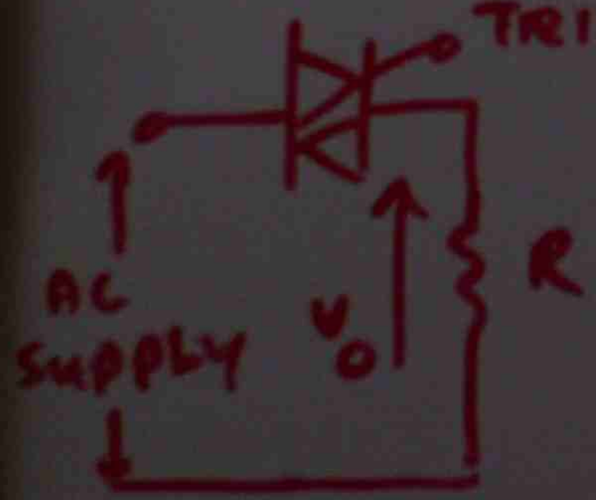
M_1, M_2 CONDUCT FOR ONE HALF PERIOD

M_3, M_4 CONDUCT FOR OTHER HALF

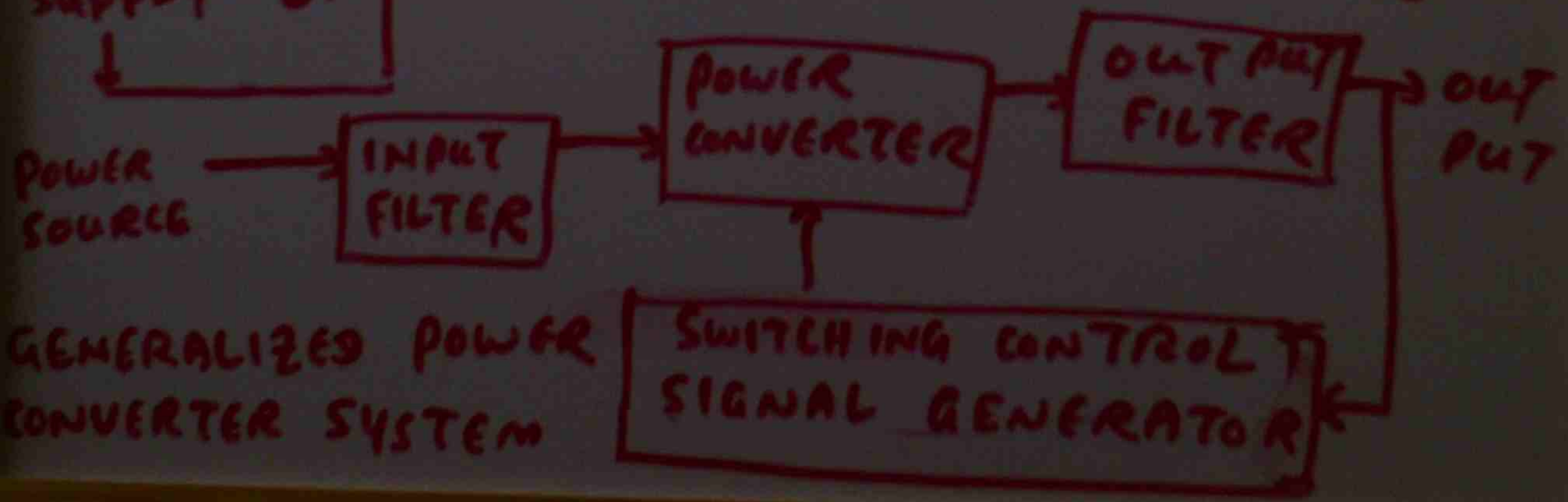


AC-AC CONVERTER

THESE CONVERTERS ARE USED TO OBTAIN A VARIABLE AC OUTPUT VOLTAGE FROM A FIXED AC SOURCE AND A SINGLE PHASE CONVERTER WITH A TRIAC



THE OPERATION OF THE POWER CONVERTERS ARE MAINLY BASED ON SWITCHING of POWER SEMI CONDUCTOR DEVICES



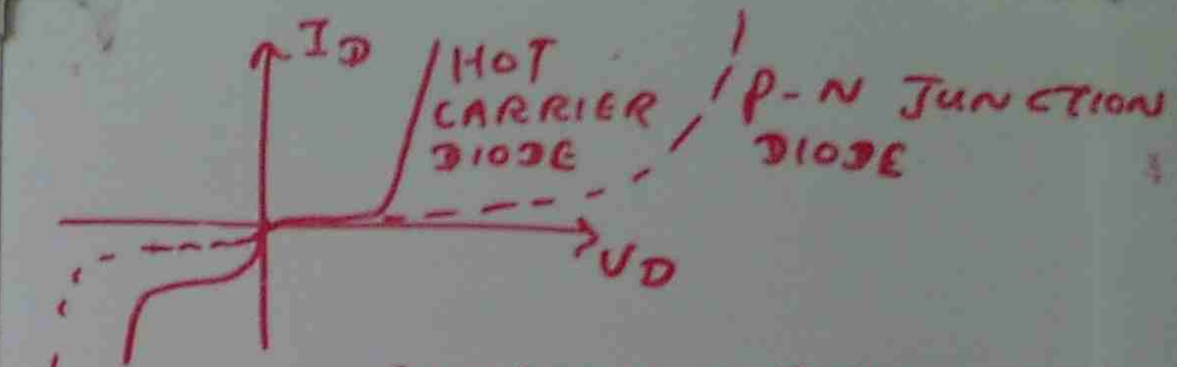
GENERALIZED POWER CONVERTER SYSTEM

POWER DIODES

SCHOTTKY BARRIER (HOT CARRIER) DIODES

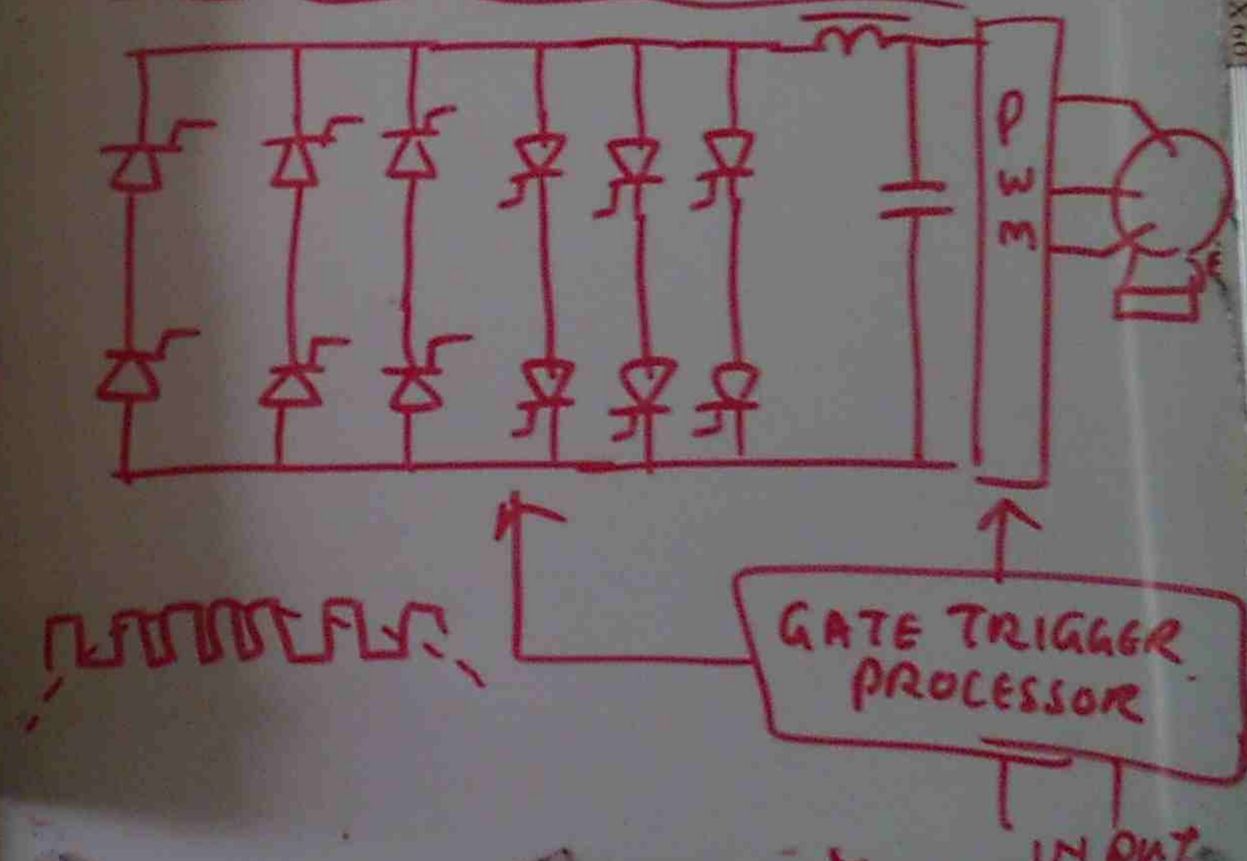


THE ELECTRON IS MAJORITY CARRIER. WHEN THE MATERIALS ARE JOINED TOGETHER, THE "N" TYPE SEMI-CONDUCTOR MATERIAL IMMEDIATELY FLOW IN TO ADJACENT METAL. THE INJECTED CARRIER CARRIES A VERY HIGH ENERGY (HOT CARRIER)



COMPARING THE CHARACTERISTICS OF P-N JUNCTION & HOT CARRIER DIODE

PULSE WIDTH MODULATION



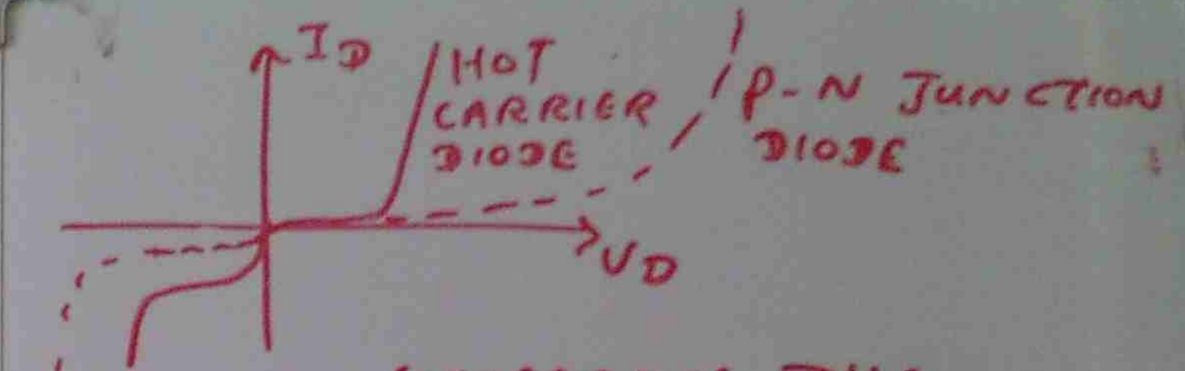
POWER DIODES

SCHOTTKY BARRIER (HOT CARRIER) DIODES



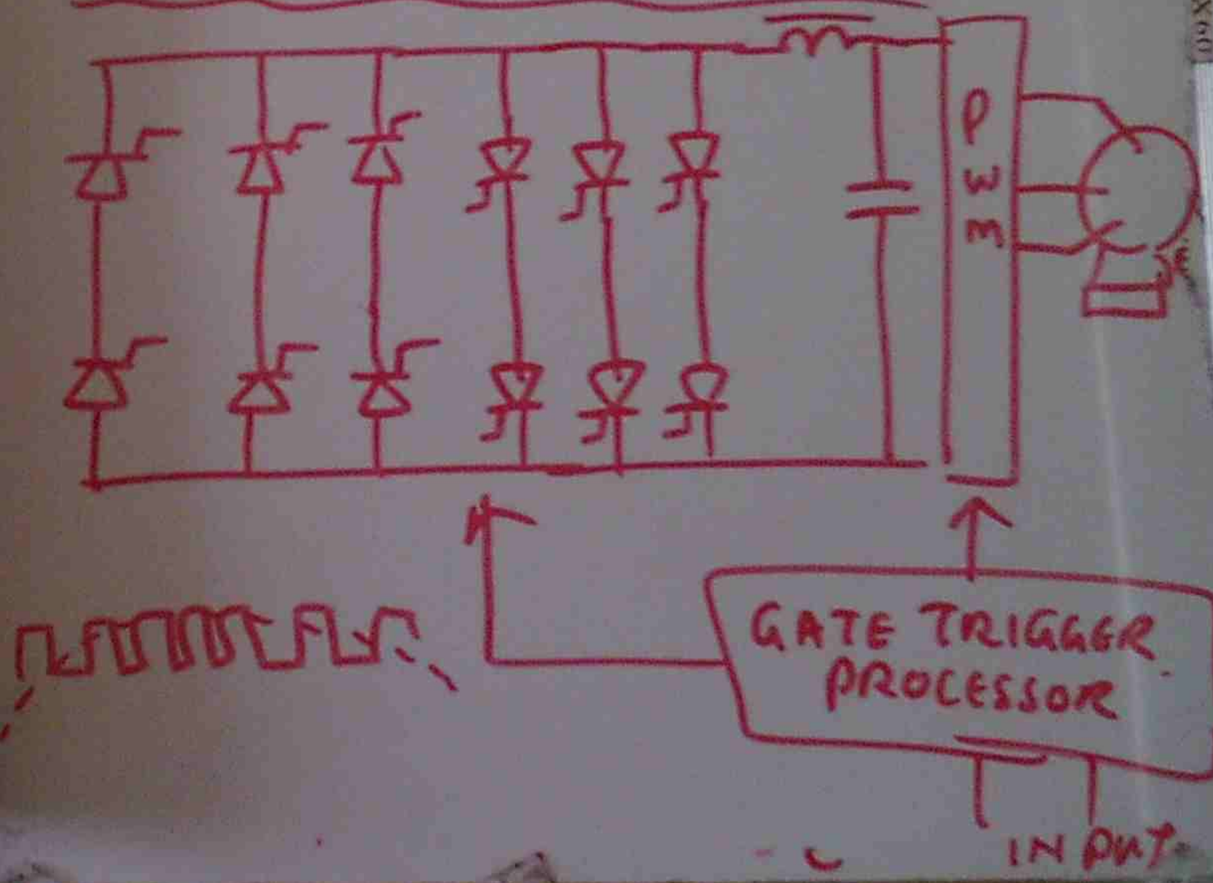
THE ELECTRON IS MAJORITY CARRIER. WHEN THE MATERIALS ARE JOINED TOGETHER, THE "N" TYPE SEMI-CONDUCTOR MATERIAL IMMEDIATELY FLOW IN TO ADJACENT METAL.

THE INJECTED CARRIER CARRIES A VERY HIGH ENERGY (HOT CARRIER)



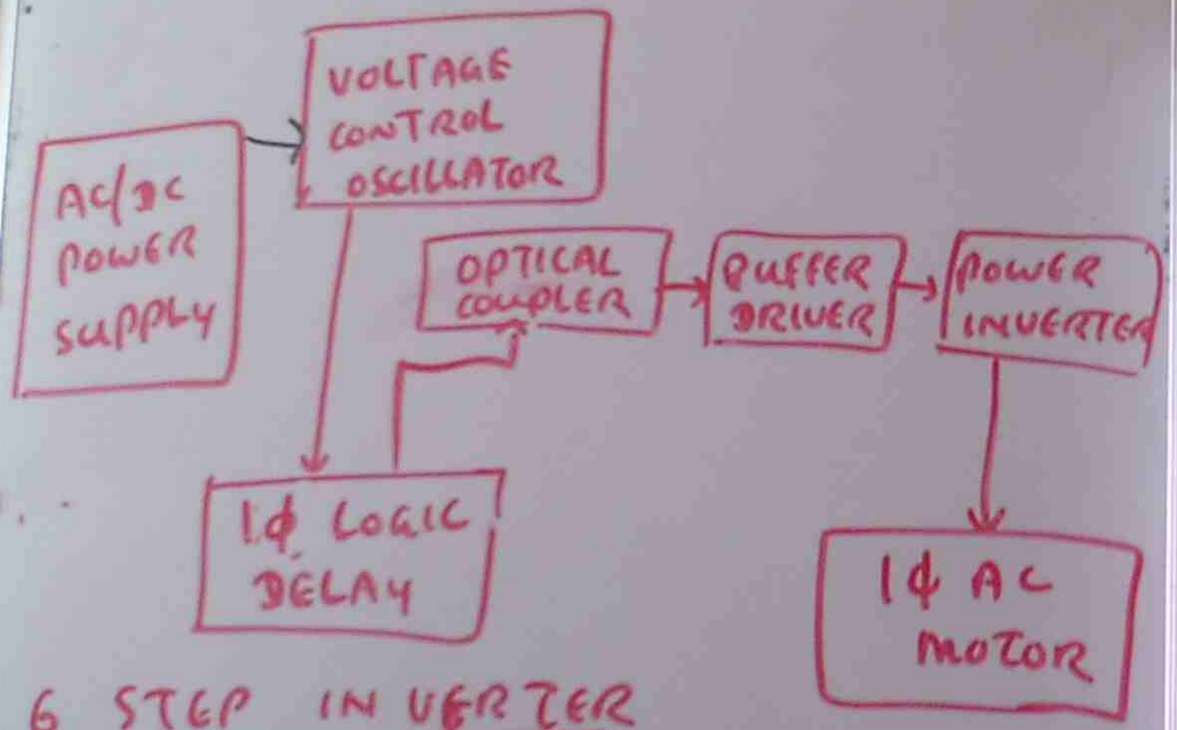
COMPARING THE CHARACTERISTICS OF P-N JUNCTION & HOT CARRIER DIODE

PULSE WIDTH MODULATION

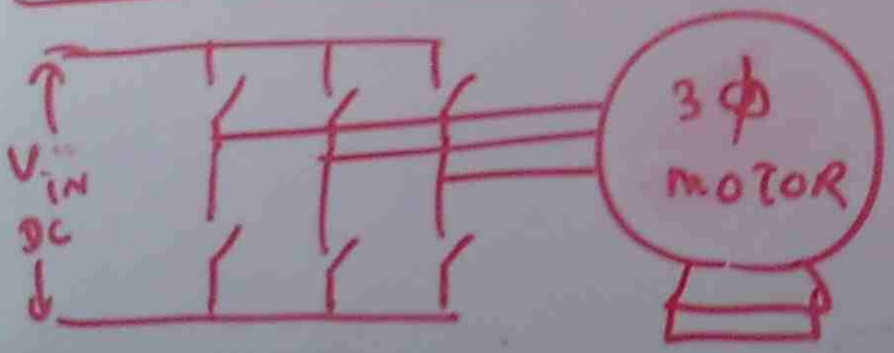


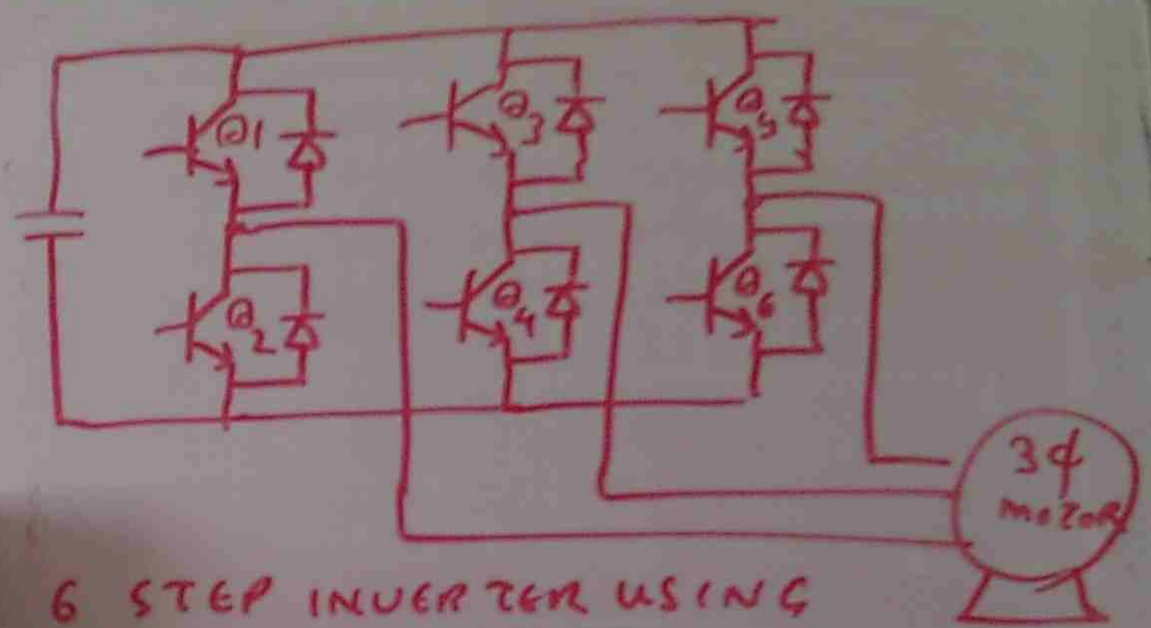
PWM TECHNIQUE

AC MOTOR SPEED CONTROL

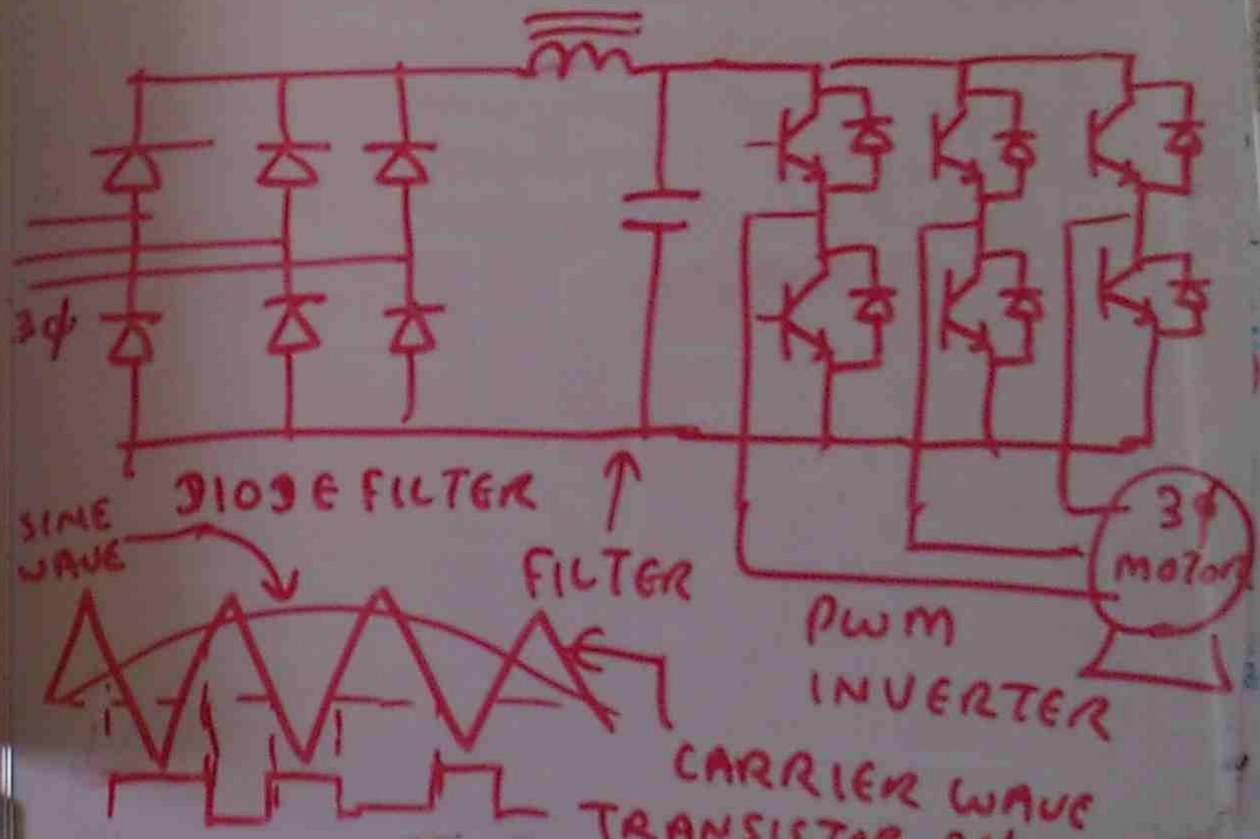


6 STEP INVERTER





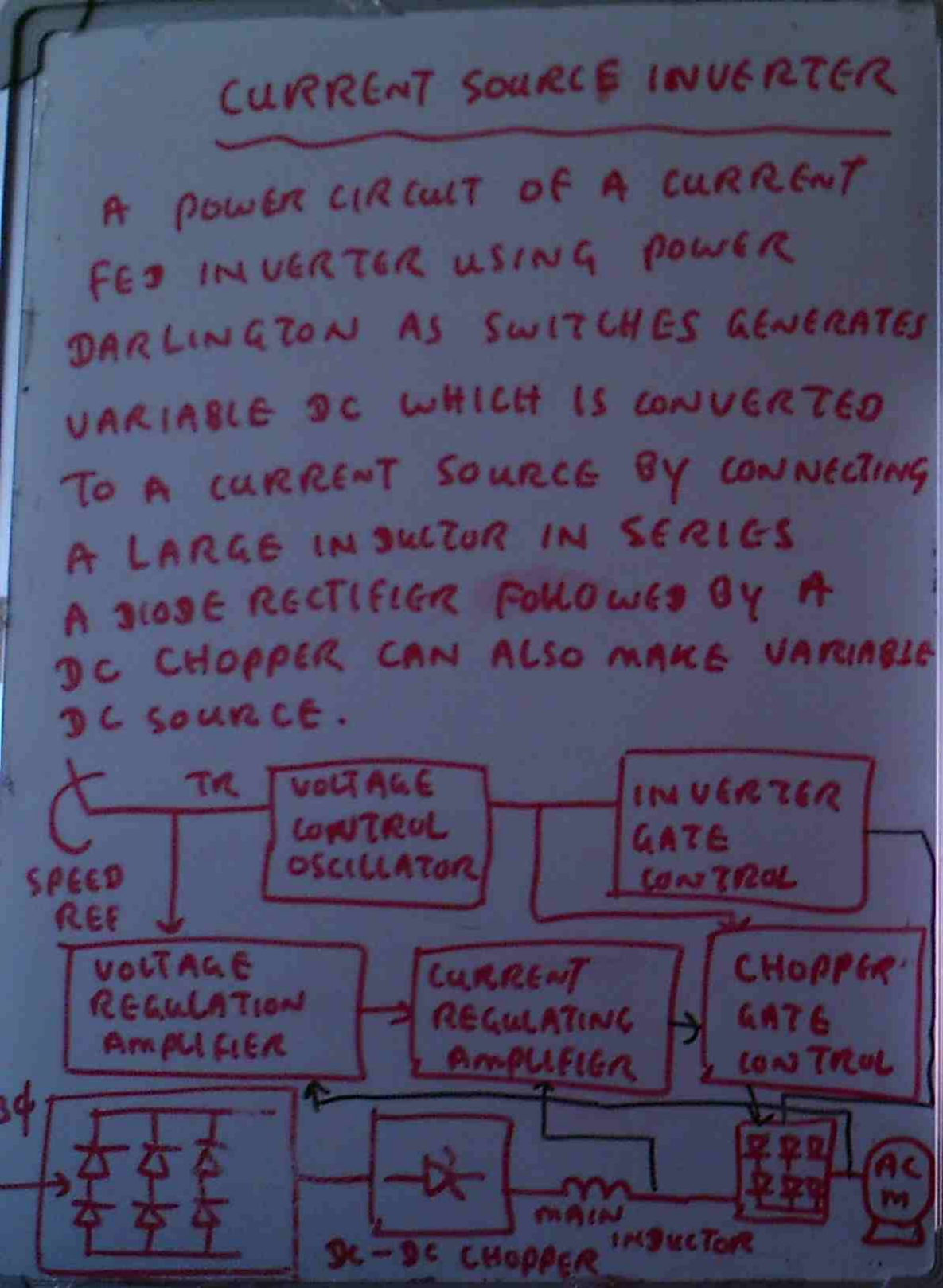
6 STEP INVERTER USING TRANSISTOR AS SWITCH

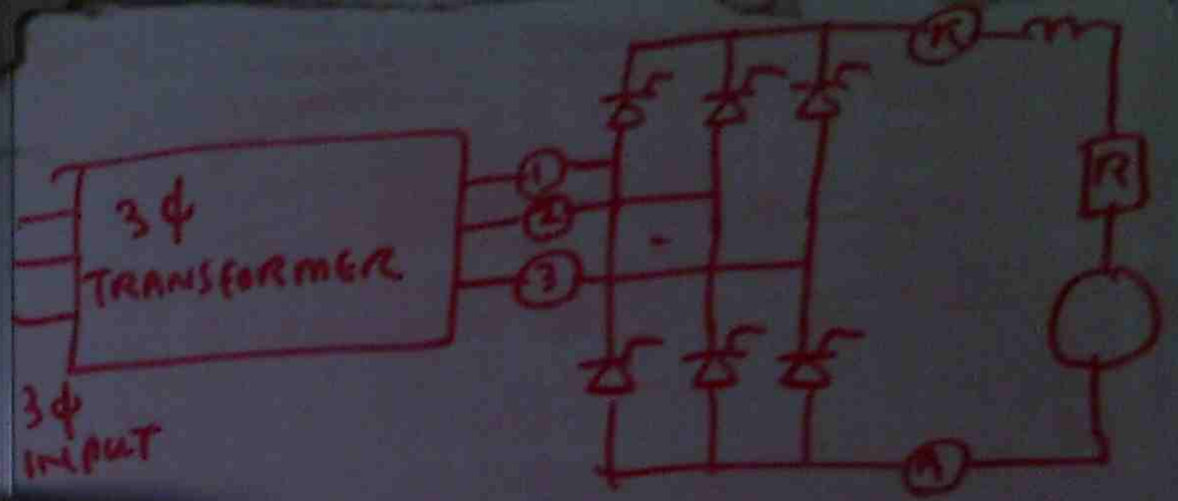


CARRIER WAVE
TRANSISTOR ON

CURRENT SOURCE INVERTER

A POWER CIRCUIT OF A CURRENT FED INVERTER USING POWER DARLINGTON AS SWITCHES GENERATES VARIABLE DC WHICH IS CONVERTED TO A CURRENT SOURCE BY CONNECTING A LARGE INDUCTOR IN SERIES A DIODE RECTIFIER FOLLOWED BY A DC CHOPPER CAN ALSO MAKE VARIABLE DC SOURCE.





$P_i = 1.35\, V_{rms}\, I_d \cos\phi$ KW

$S_i = \sqrt{3}\, V_{rms} \times 0.78\, I_D$

$= 1.35\, V_{rms}\, I_D$

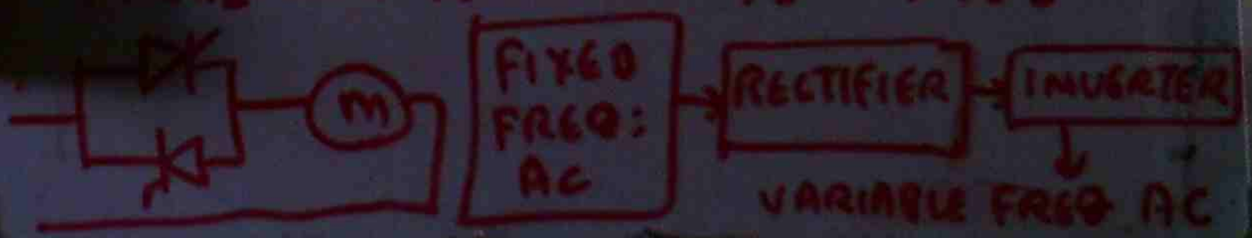
$E_d = 1.35\, E \cos\alpha$

$I_{1rms} = \sqrt{3} \times \frac{\sqrt{2}}{\pi} I_d = 0.78\, I_D$

I_d - DC CURRENT

DELAYED TRIGGERING RECTIFIER MODE

TRIGGERING RANGE $15 \longrightarrow 165°$



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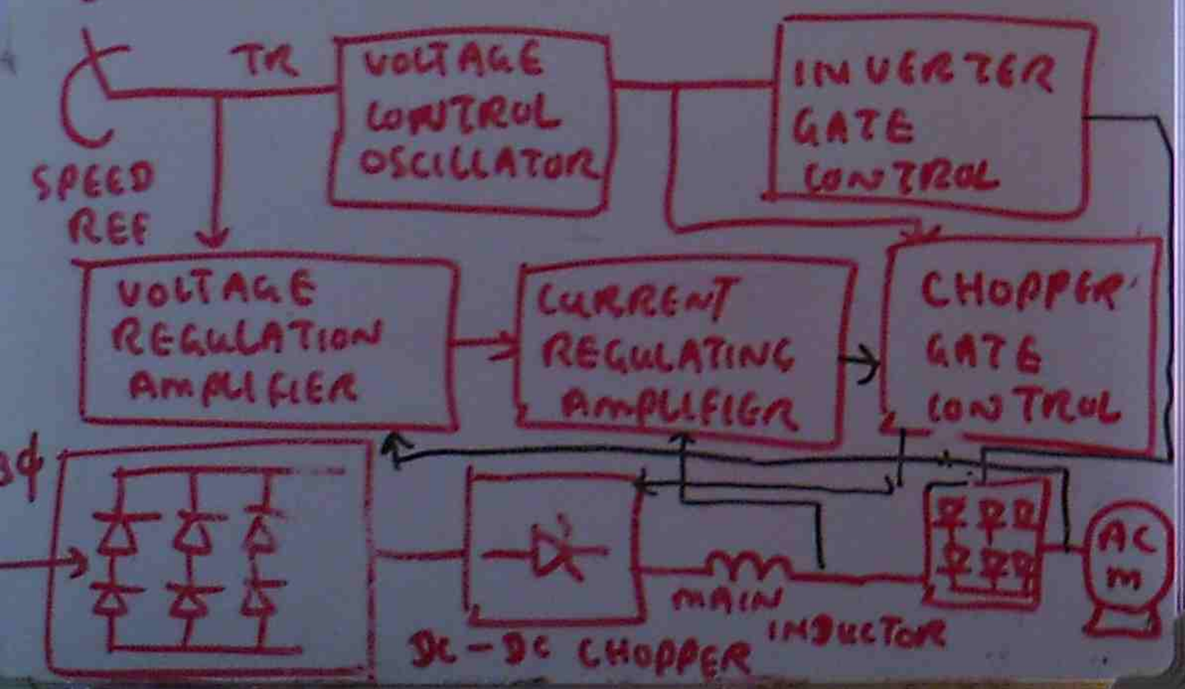

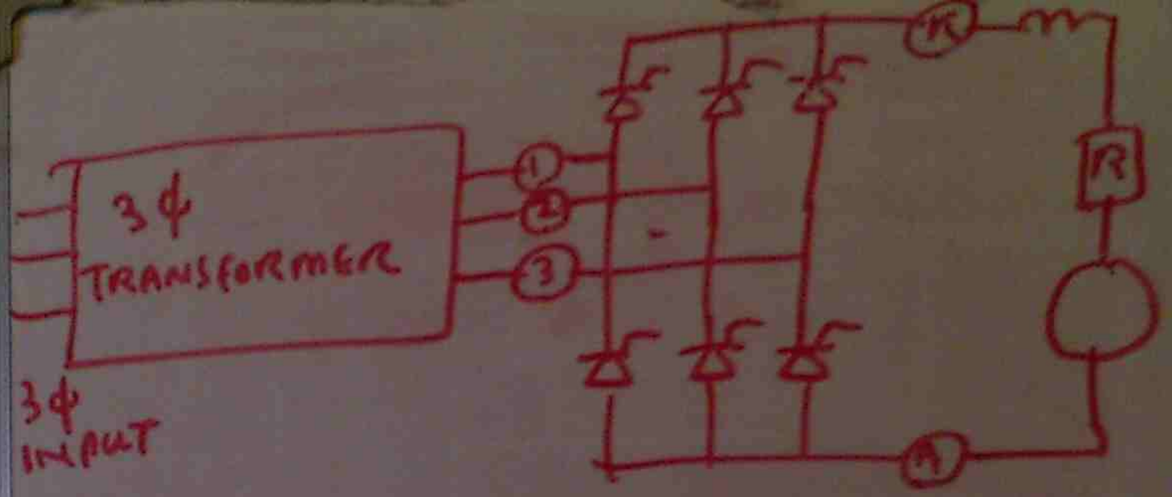

$$P_i = 1.35\, V_{rms}\, I_d \cos\phi \quad \text{KW}$$

$$S_i = \sqrt{3}\, V_{rms} \times 0.78\, I_D$$

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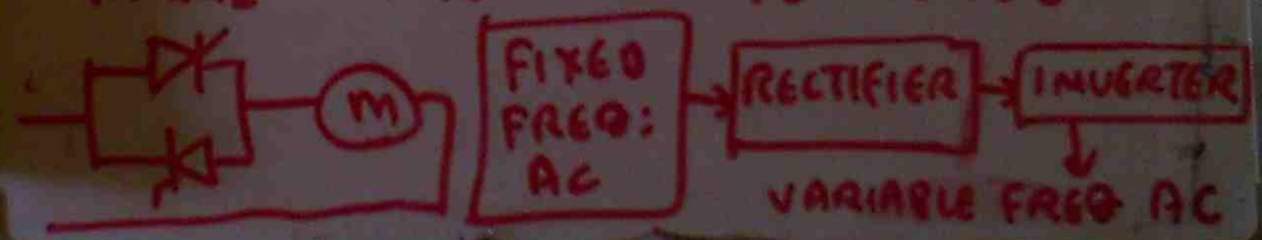


(7) POWER SCR

SLIDE 1 → 8

Q12 + Q13

(8) AC-DC CONVERTER

SLIDE 1 → 9

Q14 + Q15

(9) 3φ THREE PHASE BRIDGE SCR CIRCUIT

SLIDE 1 → 12

Q16 → Q19

(10) VARIABLE VOLTAGE VARIABLE FREQENCY

SLIDE 1

Q20

(11) PULSE WIDTH MODULATOR

SLIDE 1 → 10

Q21 → Q24

(12) CURRENT FED INVERTER

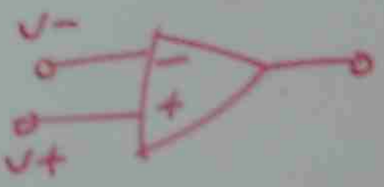
SLIDE 1 → 4

Q25 → Q27

STUDY

VECTOR CONTROL

(1) OPERATIONAL AMPLIFIER



IDEAL op-Amp

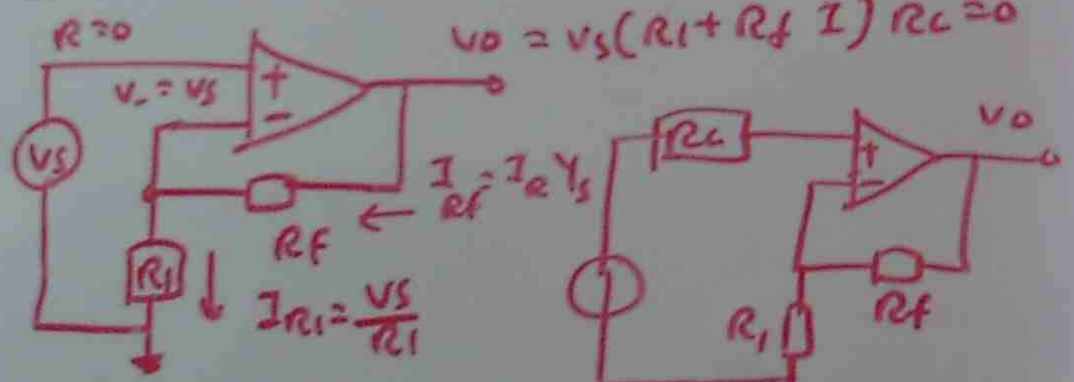
* INFINITE GAIN
* INFINITE INPUT RESISTANCE
* ZERO OUTPUT RESISTANCE

* VERY LARGE VOLTAGE GAIN

NEGATIVE FEED BACK

REDUCING THE EFFECTIVE VOLTAGE GAIN OF A CIRCUIT IN A CONTROLLED MANNER

NON INVERTING OP-AMP



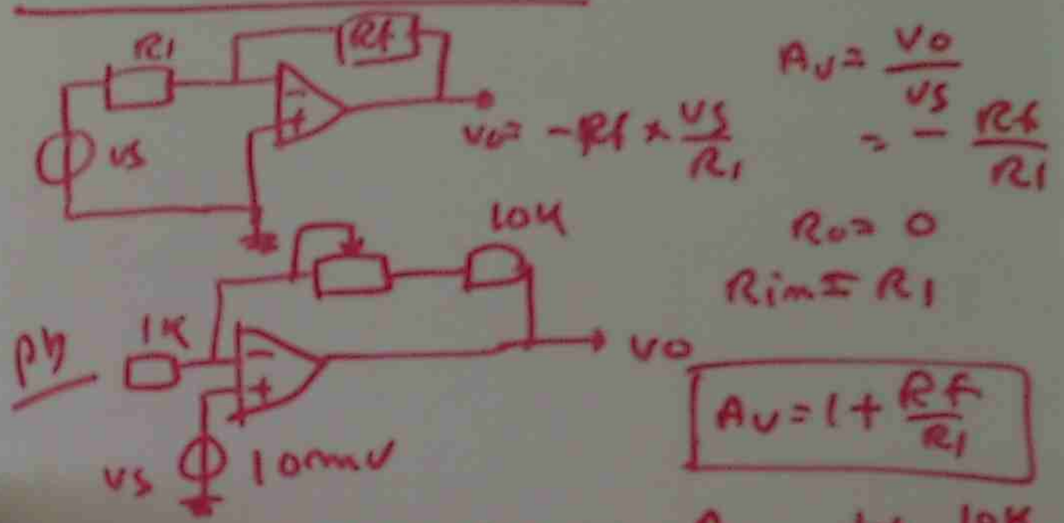
IDEAL CLOSED LOOP VOLTAGE GAIN =

$A_V = \frac{V_0}{V_1} = 1 + \frac{R_f}{R_1}$

INPUT & OUTPUT VOLTAGES ARE IN PHASE

$\frac{V_S}{I_S} = \alpha$, $R_0 = 0$

INVERTING AMPLIFIER



$A_V = \frac{V_0}{V_S} = -\frac{R_f}{R_1}$

$R_0 = 0$

$R_{in} = R_1$

$A_V = 1 + \frac{R_f}{R_1}$

(a) WHAT IS MINIMUM VOLTAGE GAIN → $A_{V_{min}} = 1 + \frac{10K}{1K} = 11$

(b) TO GET VOLTAGE GAIN 61, WHAT IS RESISTANCE OF POTENTIOMETER

$A_V = 1 + \frac{R_f}{R_1}$

$61 = 1 + \frac{R_f}{1}$

$R_f = 60K\Omega$

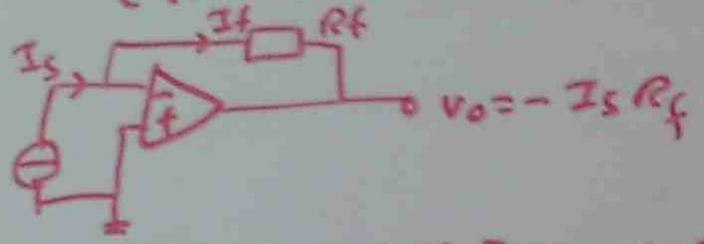
(c) WHAT IS SIGNAL CURRENT DRAWN FROM SOURCE $I_{IN} = \frac{V}{R_{in}} = \frac{V}{\infty} = 0$

(d) IF GAIN IS 30, WHAT IS OUTPUT VOLTAGE $V_0 = \text{GAIN} \times V_{IN} = 30 \times 10mV = 300$

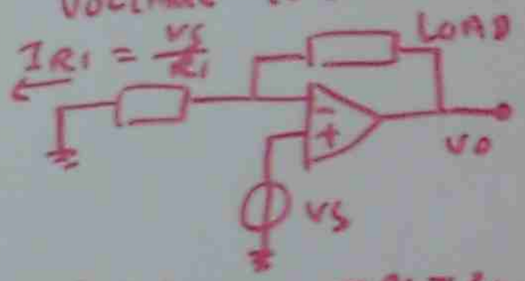
(e) IF THIS AMPLIFIER IS DRIVING ANOTHER WITH R_{in} SAME, WHAT IS OUTPUT VOLTAGE OF FIRST AMPLIFIER – UNCHANGED

(f) IN SIGNAL SOURCE INTERNAL RESISTANCE IS INCR, WHAT IS OUTPUT VOLTAGE – UNCHANGED

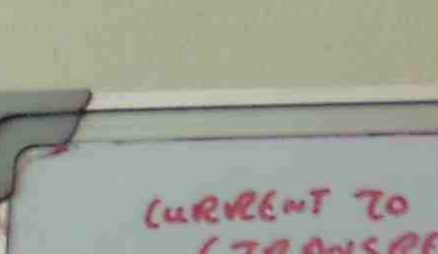
CURRENT TO VOLTAGE CONVERTER (TRANSRESISTANCE)

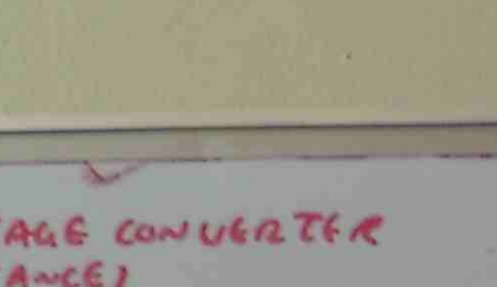


VOLTAGE TO CURRENT CONVERTER (TRANSCONDUCTANCE)

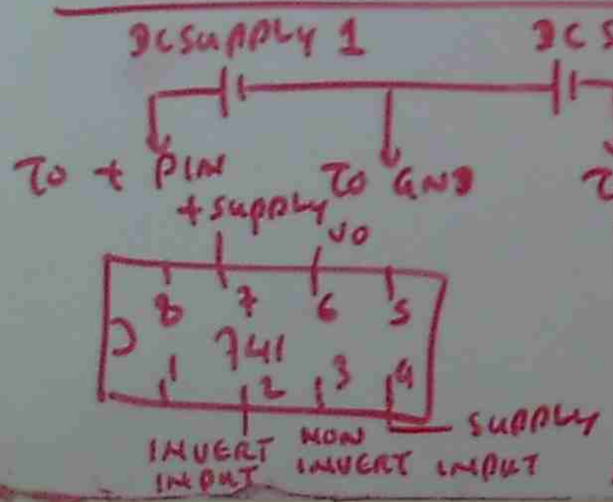


MAXIMUM OUTPUT SWING





POWER SUPPLY FOR OP-AMP



(1) BASIC OP-AMP CKT
SLIDE (1) → (41)
Q1 → Q3

(2) ANALOG AMP CONFIGURATION
SLIDE 1 → 9 Q4 → Q9

(3) INVERTING (NON INVERTING AMPLIFIER

SLIDE (1) → (7) , Q10 → Q12

(2) DC NON IDEALITIES

DC ERRORS → LIGHT LEVELS, TEMPERATURE, PRESSURE (SMALL SIGNAL - SIGNIFICANT)

INPUT OFFSET VOLTAGE (V_{IO})

INPUT OFFSET VOLTAGE IS CAUSED BY SMALL DC IMBALANCES AT THE INPUT STAGE OF AMPLIFIER

EFFECT OF INPUT OFFSET VOLTAGE ON OUTPUT DC VOLTAGE

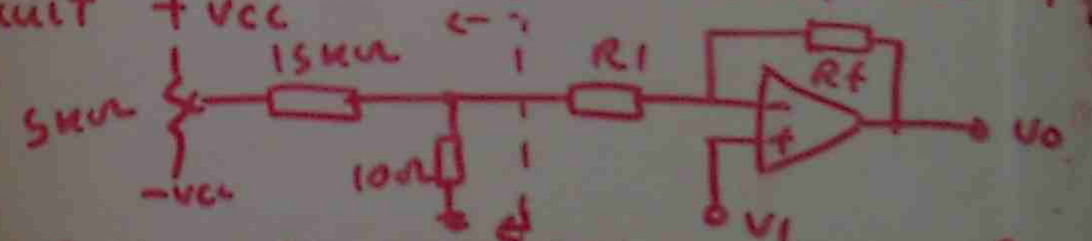
$$V_o = V_{IO}\left(1 + \frac{R_f}{R_1}\right)$$

R_f = FEEDBACK RESISTANCE

R_1 = TOTAL EFFECTIVE RESISTANCE FROM INVERTING INPUT TO GROUND

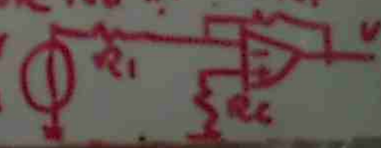
REDUCING THE EFFECT OF INPUT OFFSET VOLTAGE

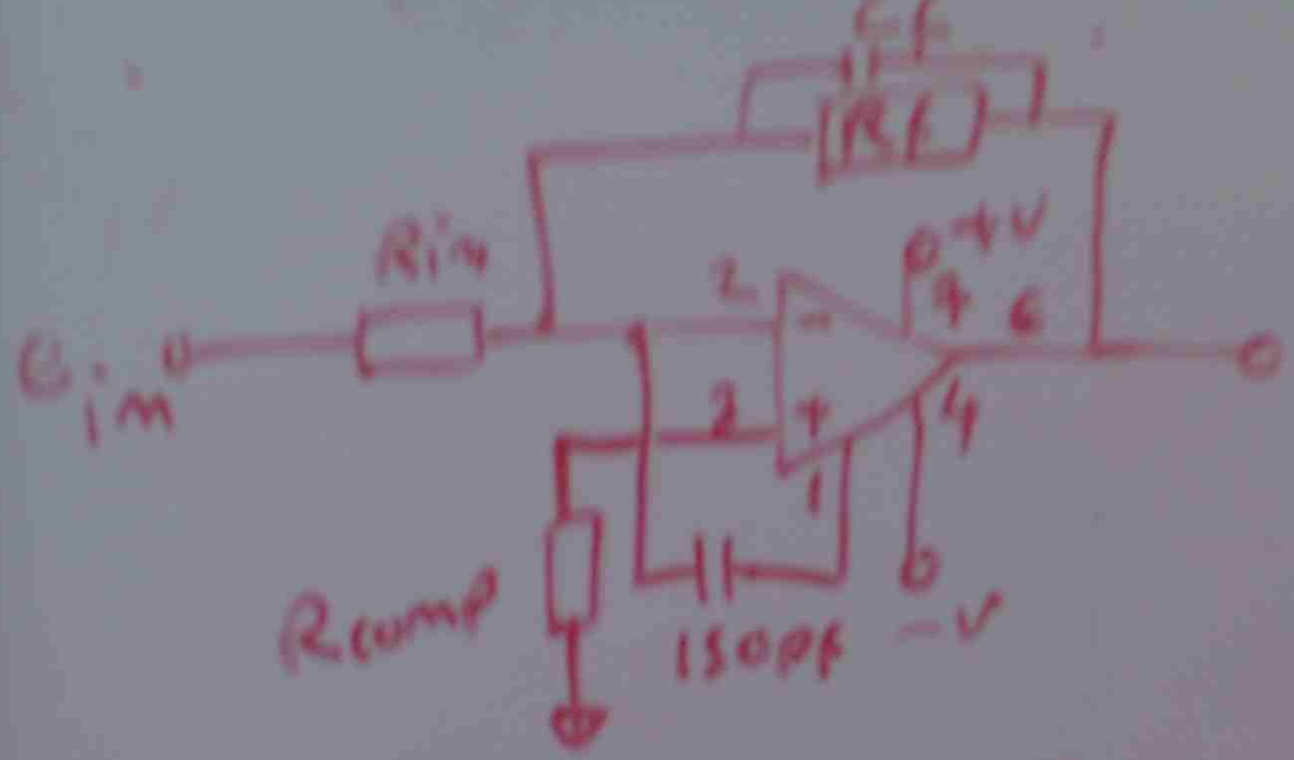
- CHOOSE HIGH QUALITY OP-AMP, WORK WITH AC SIGNAL RATHER THAN DC, USE OFFSET NULLING CIRCUIT



PLACE BIAS COMPENSATION RESISTOR R_C IN SERIES WITH NON INVERTING INPUT

$R_C = R_1 // R_f$





FEED FORWARED COMPENSATION

$C_f = \frac{1}{2\pi f_H R_F}$

P6 NON INVERTING AMPLIFIER VOLTAGE GAIN 20.
INPUT 10mV P-P, 10% → 90% RISE TIME 3.5μS
INPUT INCREASED TO 1V, O/P - 10 → 90% RISE TIME INCREASED TO 12.8 μS

(a) SMALL SIGNAL BAND WIDTH

$BW = \frac{0.35}{3.5\mu S} = 100\,KHz$

(b) O/P: 10% → 90% = (90-10) × 10V = 8V

RISE TIME 12.8μF, $SLEW = \frac{8}{12.8} = 0.625\,V/\mu S$

(c) GBWP: 10 × 100 = 1 MHz

(d) RISE TIME = ?
Av = 5.5, $BW = \frac{1\,MHz}{5.5} = 182\,KHz$

Rise Time $T = \frac{0.35}{182\,KHz} = 1.9\,\mu S$

(7) PHASE MARGIN + CLOSED LOOP
BANDWIDTH

SLIDE 1 → 8
Q 22 → Q 24

(8) COMPENSATION CAPACITOR
CRITICAL DAMPING

SLIDE 1 → 8
Q. 25 → Q28

(9) BANDWIDTH SLEW RATE
INVERTING

SLIDE 1 → 4
Q29

(10) INSTRUMENTATION AMPLIFIER

SLIDE 1 → 6
Q30 → Q31

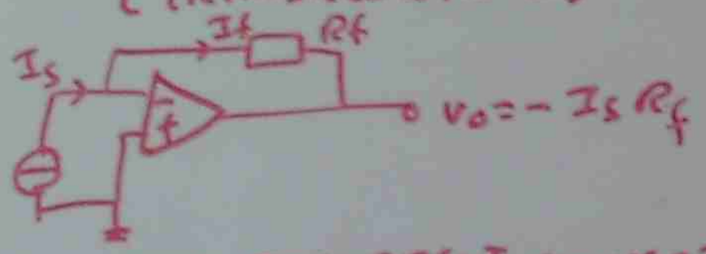
(11) CONSTRUCTION OF ANALOGUE
ELECTRONIC CIRCUIT

SLIDE 2 → 12
Q. 32 → Q36

(12) DIRECT COUPLED AMPLIFIER
DIFFERENTIAL AMPLIFIER

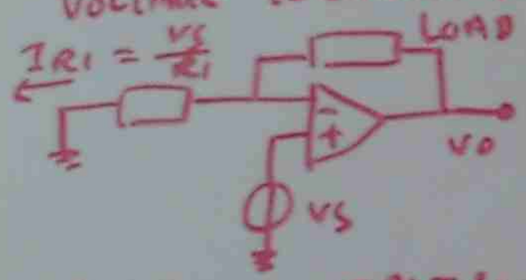
SLIDE 1 → 3
Q37 → Q38

CURRENT TO VOLTAGE CONVERTER (TRANSRESISTANCE)

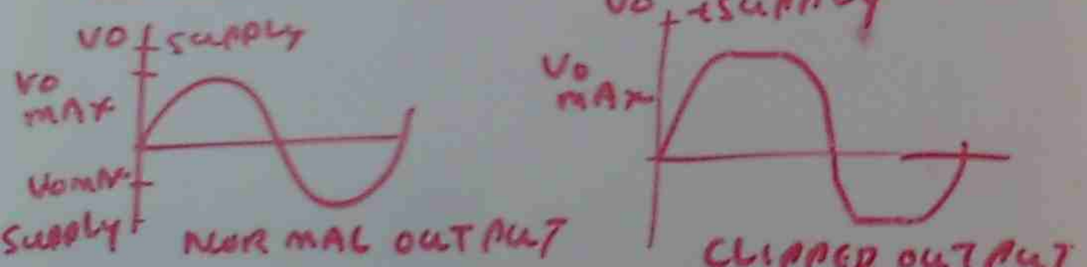


VOLTAGE TO CURRENT CONVERTER (TRANSCONDUCTANCE)

$I_{RI} = \frac{V_S}{R_I}$



MAXIMUM OUTPUT SWING



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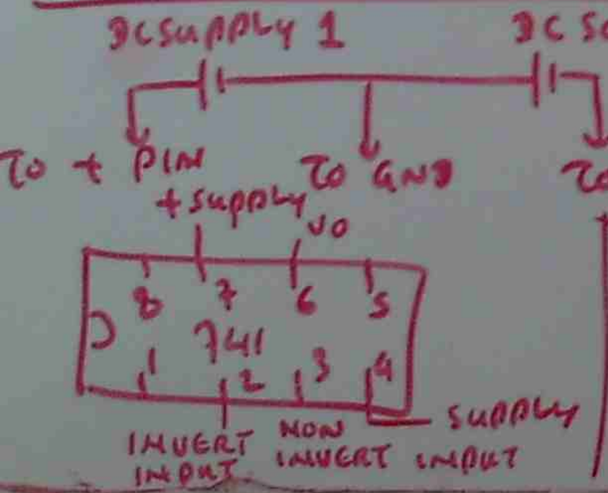

(1) BASIC OP-AM CKT
SLIDE (1) → (4)
Θ1 → Θ3

(2) ANALOG AMP CONFIGURATION
SLIDE 1 → 9 Θ4 → Θ9

(3) INVERTING (NON INVERTING AMPLIFIER

SLIDE (1) → (7), Θ10 → Θ12

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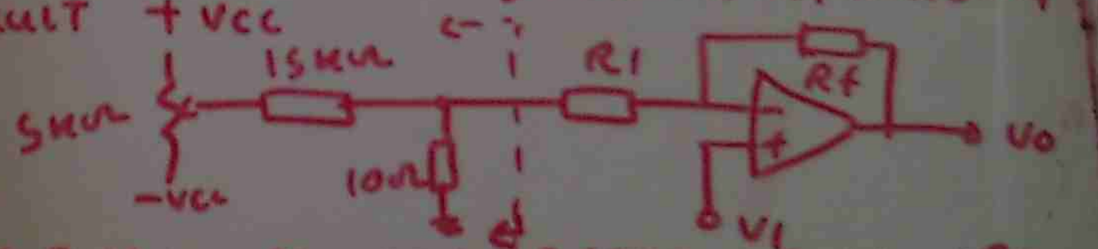

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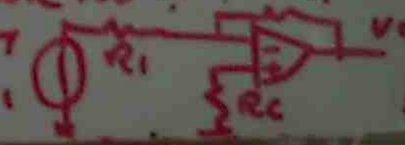

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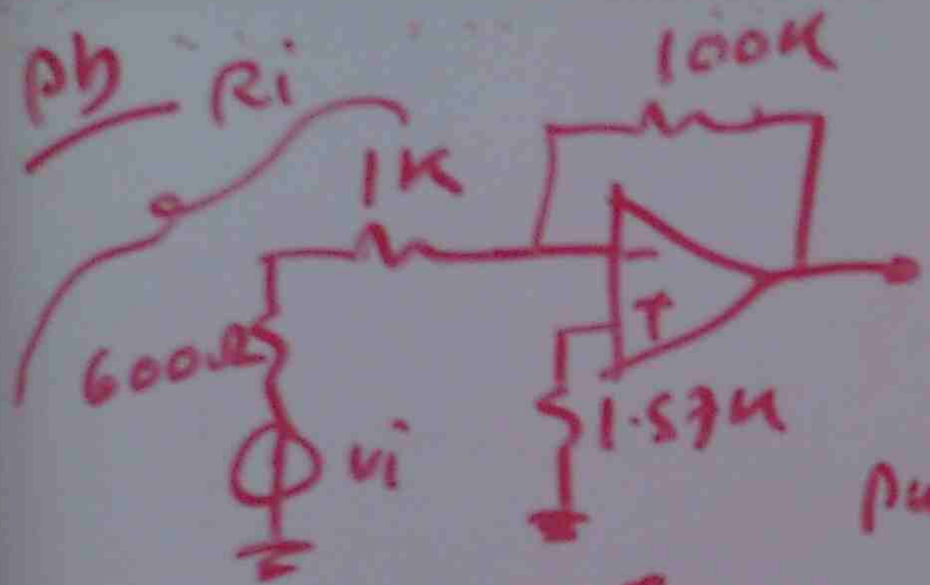
R_f = FEEDBACK RESISTANCE

R_1 = TOTAL EFFECTIVE

Pb



DESIGN BIAS COMPENSATION

$$R_c = R_f \| R_1 = \frac{100\times10^3 \times 1.6\times10^3}{100\times10^3 + 1.6\times10^3}$$

$$= 1.57\times10^3\,\Omega$$

$$= 1.57\,k\Omega$$

PUT 1.57kΩ AT INPUT

OFFSET CURRENT 2mA

$$V_{ODC} = I_{offset} \times R_f = 20\times10^{-9}\times100\times10^3$$

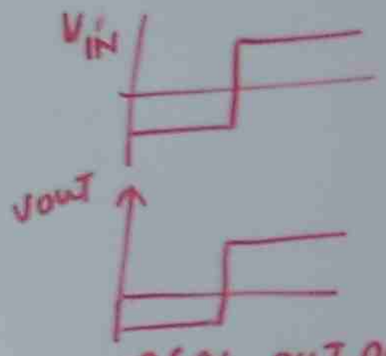
$$= 2\,mV$$

- AC SIGNAL WILL BE LEVEL SHIFT BY OFFSET
- CHANGE IN INPUT OFFSET VOLTAGE = DRIFT IN V_{IO} × CHANGE IN TEMPERATURE
- CHANGE IN INPUT OFFSET CURRENT = DRIFT IN I_{IO} × CHANGE IN TEMPERATURE

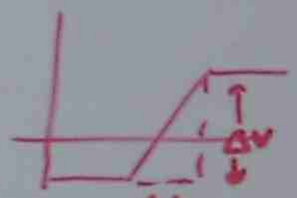
Pb BIAS COMPENSATED OP-AMP, $R_f = 100\,k\Omega$, $R_1 = 1600\,\Omega$ DRIFT $V_{IO} = 30\,\mu V/°C$, DRIFT $I_O = 300\,pA/°C$ NULL AT 20°C, FIND DC OFFSET AT 80°C

$\Delta V_{IO} = 30\times10^{-6}\times(80-20) = 1.8\,mV$ | $\Delta I_O = 300\times10^{-12}(80-20) = 18\,nA$ | $V_O = 1.8\,mV \times \left(1 + \frac{100k}{1.6k}\right)$ | 116 mV

(3) SLEW RATE



SLEW RATE = $\frac{\Delta V}{\Delta t} = \frac{V}{\mu s}$



$$\frac{\text{CHANGE IN OUTPUT VOLTAGE}}{\text{RISE TIME}}$$

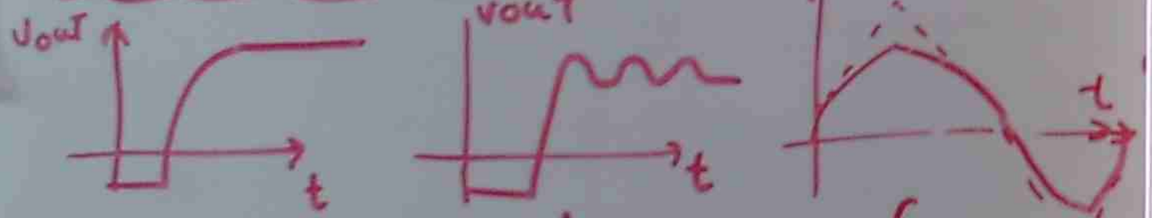
CAUSES OF SLEW RATE

- CAUSED BY SMALL INTERNAL RESISTANCE & EXTERNAL CAPACITANCE

METHODS TO IMPROVE SLEW RATE

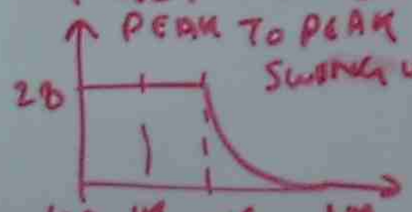
- COMPENSATING CAPACITOR

EFFECTS OF SLEW RATE



SLEW RATE = $2\pi V_{O\text{-AMPLITUDE}} \times f_{MAX}$

FULL POWER BANDWIDTH = $\frac{\text{SLEW RATE}}{2\pi V_{O\text{-MAX-AMPL}}}$



OUTPUT VOLTAGE SWING GRAPH 741 IC

Pb CALCULATE THE FULL POWER BANDWIDTH OF AN OP-AMP WHICH HAS A SLEW RATE 0.8 V/μS AND WORKS WITH ± 15V POWER SUPPLY

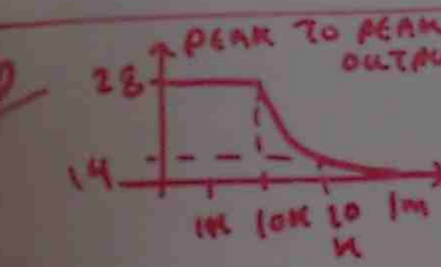
MAXIMUM OUTPUT AMPLITUDE = POWER SUPPLY VOLTAGE − 1

= 15 − 1 = 14V

FULL POWER BANDWIDTH = $\frac{\text{SLEW RATE}}{2\pi V_{O\ MAX\text{-}AMPL}}$

= $\frac{0.8\ V}{10^{-6}\ Sec \times 2 \times 3.1416 \times 14} = 9.1$ KHZ

Pb AN AMPLIFIER WITH THE OUTPUT VOLTAGE SWING GRAPH IS GIVEN. VOLTAGE GAIN OF 10 USING ± 15V DC SUPPLY



(a) WHAT IS THE SLEW RATE of AMPLIFIER

(b) WHAT IS THE MAXIMUM RMS INPUT VOLTAGE AT 1KHZ WITHOUT OUTPUT DISTORTION

(c) WHAT IS THE MAXIMUM RMS INPUT VOLTAGE AT 20KHZ WITHOUT OUTPUT DISTORTION.

(a) FULL POWER BANDWIDTH (FPBW) = 10 KHz

SR = $2\pi\left(\frac{V}{2}\right) \times FPBW = 2 \times 3.1416 \times \frac{28}{2} \times 10$

= 0.89 V/μS

(b) $V_{I\text{-}Rms} = \frac{V}{2\sqrt{2} \times GAIN}$

= $\frac{28}{2 \times 1.4142 \times 10} = 1V$

(c) $V_{I\,Rms} = \frac{14}{2 \times \sqrt{2} \times 10} = 0.5V$

(4) SLEW RATE SLIDE (1)→(3) | Θ13→Θ15
(4) BANDWIDTH - SLEW RATE - NON INVERT SLIDE (1)→(4) | Θ29

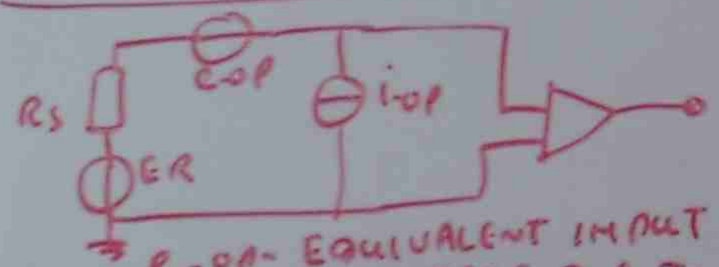
(4) AC NOISE

NOISE IS ANY UNWANTED VOLTAGE (OR) CURRENT AT THE OUTPUT OF THE SYSTEM.

NOISE < EXTERNAL (INTERFERENCE)
INTERNAL (AMPLIFIER)

EXTERNAL - RESISTOR
INTERNAL - RESISTANCE INSIDE AMPLIFIER

NOISE MODEL OF OP-AMP



R_S - SOURCE NOISE RESISTANCE

e_R - THERMAL NOISE VOLTAGE SOURCE

e-op - EQUIVALENT INPUT NOISE VOLTAGE DUE TO OP-AMP

i-op - EQUIVALENT INPUT NOISE CURRENT DUE TO OP-AMP

NOISE POWER DENSITY

- CONSTANT WITH FREQUENCY
- INVERSELY PROPORTIONAL TO FREQUENCY
- LINES AT SPECIFIC FREQUENCIES

$$\text{TOTAL NOISE VOLTAGE OVER A BANDWIDTH} = \sqrt{\left(\frac{\text{NOISE DENSITY}}{\text{VOLT}}\right)^2/\text{Hz} \times \text{B.W}}$$

$$= \text{NOISE DENSITY}\ \text{VOLT}/\sqrt{\text{Hz}} \times \sqrt{\text{BW}}$$

Pb NOISE DENSITY IS $15\ \text{mV}/\sqrt{\text{Hz}}$ FIND NOISE VOLTAGE OVER A BANDWIDTH 30 KHz

TOTAL NOISE VOLTAGE $= 15\ \text{mV}/\sqrt{\text{Hz}} \times \sqrt{30\text{KHz}} = 2.6\ \mu\text{V-rms}$

TOTAL EQUIVALENT INPUT NOISE OF AN AMPLIFIER

$$e_n = \sqrt{e_R^2 + e_{op}^2 + (i_{op}^2 \times R_s^2)}\quad \text{V rms}$$

Pa OP-AMP CKT, THE SOURCE NOISE RESISTANCE = 30 KΩ, THE THERMAL NOISE DUE TO THE SOURCE RESISTANCE = 2.8 μV, THE INTERNAL NOISE CURRENT OF THE OP-AMP = 60 PA AND THE INTERNAL NOISE VOLTAGE OF THE OP-AMP = 4.1 μV.

(a) WHAT IS THE TOTAL EQUIVALENT INPUT NOISE VOLTAGE e_n?

(b) WHAT WILL BE THE NEW VALUE OF e_n IF THE BANDWIDTH IS TRIPLED?

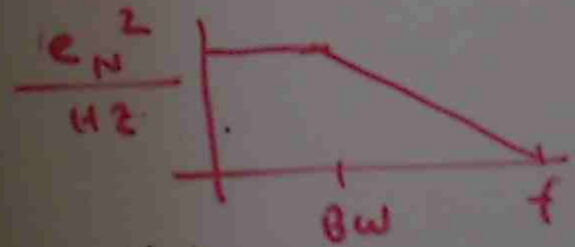
(a) $e_n = \sqrt{(2.8\ \mu\text{V})^2 + (4.1\ \mu\text{V})^2 + (60\ \text{PA} \times 30\text{K}\Omega)^2}$

$= 5.3\ \mu\text{V}$ (rms)

(b) $e_n \propto \sqrt{\text{BW}}$ ∴ NEW $e_n = 5.3 \times \sqrt{3}$

$= 9.2\ \mu\text{V-rms}$

EFFECTIVE NOISE BANDWIDTH



EFFECTIVE NOISE BANDWIDTH $= \frac{\pi}{2} \times$ 3dB BW

NOISE INCREASE FACTOR FOR BANDWIDTH CORRECTION $= \sqrt{\frac{\pi}{2}}$

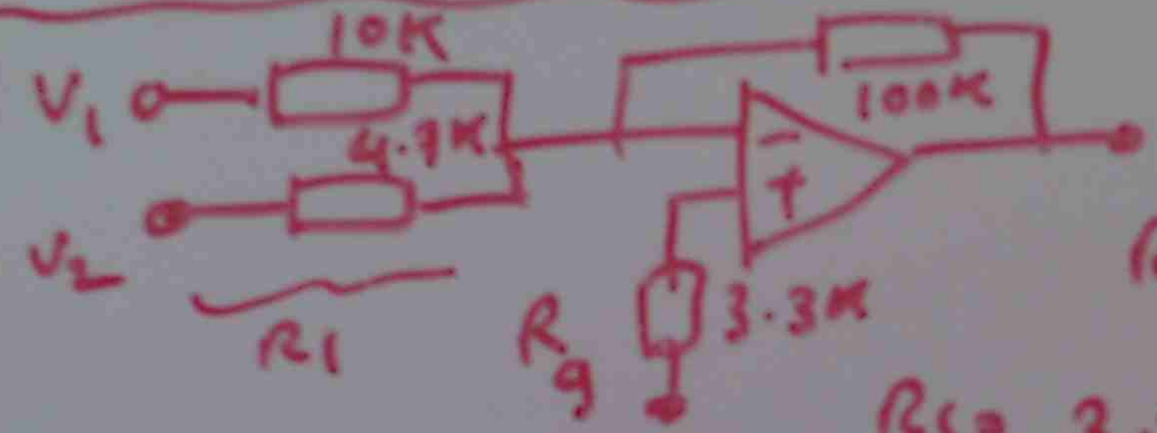
Pa INPUT NOISE 15 nV/Hz. CUT OFF FREQ 20KHz.

(a) EFFECTIVE NOISE BANDWIDTH $= \frac{20\ \text{KHz}}{} \times \frac{\pi}{2} = 31.4\ \text{KHz}$

(b) INPUT NOISE VOLTAGE $= 15 \times \sqrt{31.4} = 266\ \text{nV}$

SOURCE NOISE RESISTANCE

pb

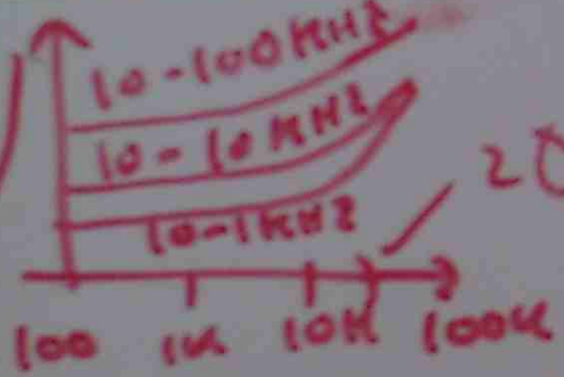


$$R_1 = \frac{10 \times 4.7}{10 + 4.7} = 3.2\,K$$

$$R_S = R_g + \frac{R_1 \times R_f}{R_1 + R_f}$$

$$R_S = 3.3 + \frac{3.2 \times 100}{3.2 + 100} = 6.4\,K\Omega$$

pb



BANDWIDTH = 20KHZ
LIMIT

$$\text{EFFECTIVE BANDWIDTH} = \frac{\text{BW LIMIT} \times \pi}{2}$$

$$= \frac{20 \times 3.14}{2} = 31.4\,KHZ$$

TOTAL NOISE
REFER TO INPUT



$$\text{SIGNAL TO NOISE RATIO (S/N)} = \frac{\text{INPUT SIGNAL}}{e_R}$$

NOISE VOLTAGE $\boxed{e_R = \sqrt{4 \times K T R_S \times B}}$

K = BOLTZMANN'S CONSTANT = 1.38×10^{-23}

pb SOURCE RESISTANCE = 20KΩ

TEMP = 25°C, INPUT NOISE VOLTAGE = $4 \times 10^{-16}\ V^2/Hz$ ← e_{op}

INPUT NOISE CURRENT = $3 \times 10^{-25}\ A^2/Hz$

CALCULATE TOTAL EQUIVALENT NOISE VOLTAGE

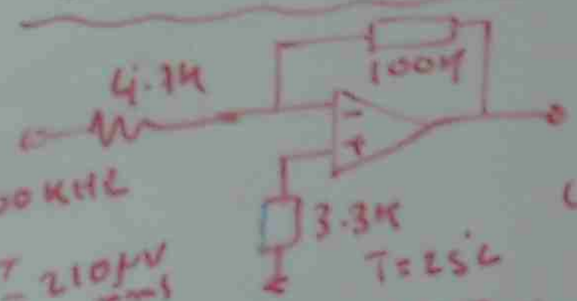
T = °C + 273

R_S = RESISTANCE

B = EFFECTIVE NOISE B.W

$$e_n = \sqrt{e_R^2 + e_{op}^2 + i_{op}^2 \times R_S^2}$$

INPUT AND OUT PUT SNR CALCULATION



BW = 100 KHZ

OUTPUT NOISE = 210 μV rms

CALCULATE OUTPUT SNR, INPUT SNR

CALCULATE
(a) SOURCE NOISE RESISTANCE
(b) OUTPUT SIGNAL 20mV P-P

(b) $\text{OUTPUT SIGNAL}_{MAX} = -\frac{R_f}{R_1} \times V_{IN} = -\frac{100K}{4.7K} \times \frac{20mV_{PK}}{2}$

$\text{OUTPUT SIGNAL RMS} = -\frac{100K}{4.7K} \times \frac{20mV}{2} \times \frac{1}{\sqrt{2}}$

$= 150 mV_{rms}$

OUTPUT NOISE = $210 \mu V_{rms}$

OUTPUT SNR = $\frac{150mV}{210\mu V} = 716.4$

$dB = 10 \log_{10} 716.4 = 57.1 \text{ dB}$

$e_R = \sqrt{4KTR_S B} = \sqrt{4 \times 1.38 \times 10^{-23} \times (25+273) \times \frac{100}{4k}}$

$= 3.24 \mu V$

I/P SNR = $\frac{20}{2 \times \sqrt{2}} \times \frac{1}{3.24} = 2182.4$

$= 66.8 \text{ dB}$

(a) SOURCE NOISE RESISTANCE: ?

$R_1 = 4.7K$

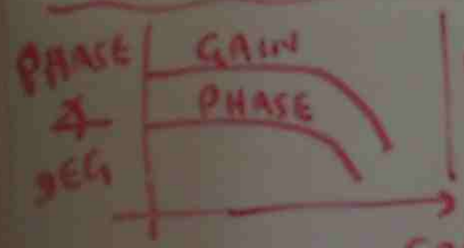
$R_S = \frac{3.3 \times 100}{3.3+100} + 4.7 = 3.1 + 4.7 = 7.8 K\Omega$

(5) NOISE MODEL FOR OP-AMP
SLIDE (1) → (6), Q16 → Q21

(6) METHODS TO IMPROVE NOISE PERFORMANCE
SLIDE (1) → (4) Q17 → Q21

(5) FREQUENCY COMPENSATION

OPEN LOOP FREQUENCY RESPONSE OF OP-AMP



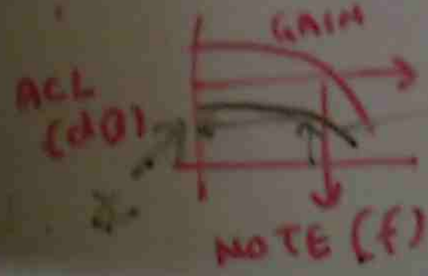
INSTABILITY

PHASE SHIFT BETWEEN INPUT AND OUT PUT SIGNALS

DETERMINING NEGATIVE FEEDBACK NETWORK STABILITY

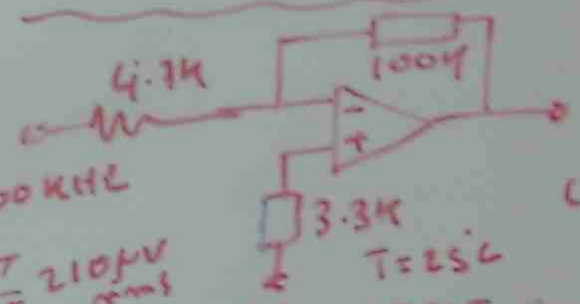
$A_{CL} = 1 + \frac{R_f}{R_1}$

$A_{CL} \text{ dB} = 20 \log A_{CL}$



READ ∠
IF ∠ < -180 UNSTABLE
IF ∠ > -180 STABLE

INPUT AND OUT PUT SNR CALCULATION



BW = 100 KHZ

OUTPUT NOISE = 210 μV rms

T = 25°C

CALCULATE
(a) SOURCE NOISE RESISTANCE
(b) OUT PUT SIGNAL 20mV P-K

CALCULATE OUTPUT SNR, INPUT SNR

(b) OUTPUT SIGNAL = $-\frac{R_f}{R_1} \times V_{IN}$

MAX $= -\frac{100K}{4.7K} \times \frac{20mV_{PK}}{2}$

OUTPUT SIGNAL RMS = $-\frac{100K}{4.7K} \times \frac{20mV}{2} \times \frac{1}{\sqrt{2}}$

$= 150mV$ rms

OUTPUT NOISE = 210 μV rms

OUTPUT SNR = $\frac{150mV}{210\mu V} = 716.4$

$dB = 10 \log_{10} 716.4 = 57.1$ dB

$e_R = \sqrt{4KTR_S B} = \sqrt{4 \times 1.38 \times 10^{-23} \times (25+273) \times 100K}$

$= 3.24 \mu V$

I/P SNR = $\frac{20}{2 \times \sqrt{2}} \times \frac{1}{3.24} = 2182.4$

$= 66.8$ dB

(a) SOURCE NOISE RESISTANCE = ?

$R_1 = 4.7K$

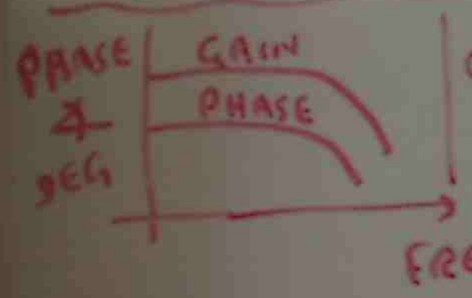
$R_S = \frac{3.3 \times 100}{3.3+100} + 4.7 = 3.1 + 4.7 = 7.8$ KΩ

(5) NOISE MODEL FOR OP-AMP
SLIDE (1) → (6), 216 → 221

(6) METHODS TO IMPROVE NOISE PERFORMANCE
SLIDE (1) → (4) 217 → 221

(5) FREQUENCY COMPENSATION

OPEN LOOP FREQUENCY RESPONSE OF OP-AMP



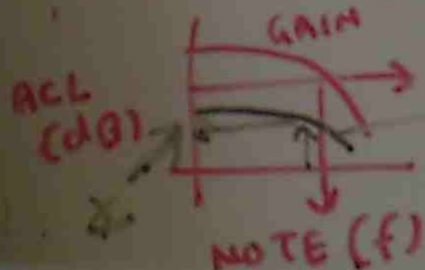
INSTABILITY

PHASE SHIFT BETWEEN INPUT AND OUT PUT SIGNALS

DETERMINING NEGATIVE FEEDBACK NETWORK STABILITY

$A_{CL} = 1 + \frac{R_f}{R_1}$

A_{CL} dB = 20 log A_{CL}



READ ∠

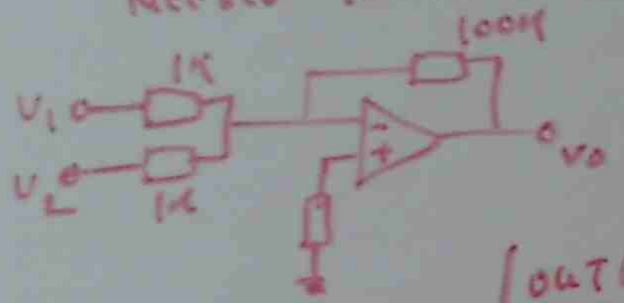
IF ∠ < −180 UNSTABLE

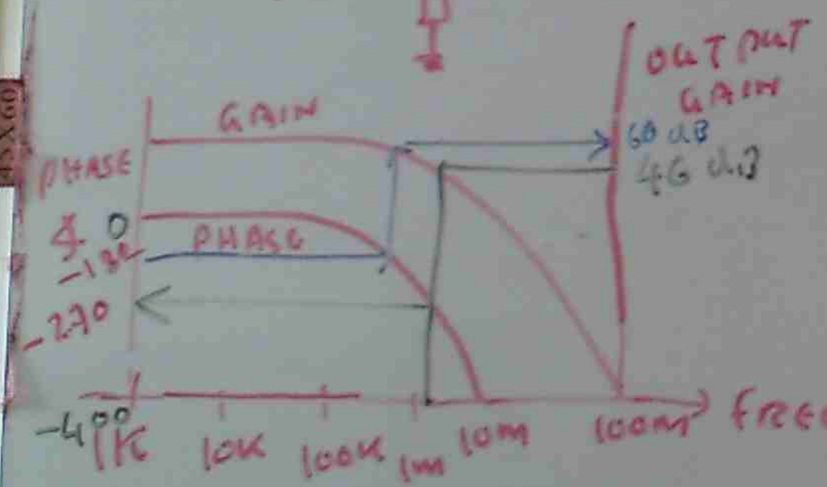
IF ∠ > −180 STABLE

P11 THE OP-AMP IN THE AMPLIFIER CIRCUIT SHOWN BELOW HAS THE GAIN AND PHASE PLOTS SHOWN ON THE SUBSEQUENT GRAPH.

(a) IS THE AMPLIFIER STABLE?

(b) WHAT IS THE MINIMUM ACL NEEDED TO MAKE AMPLIFIER STABLE?





$R_1 = 1K \| 1K = 500\Omega$

$A_{CL} = 1 + \frac{R_f}{R_1} = 1 + \frac{100 \times 10^3}{500} = 200 \rightarrow 20\log 200$

$= 46 dB$

(a) SEE THE GRAPH (BLACK) $\rightarrow -270° < -180$ UNSTABLE

(b) $-180° \rightarrow$ STABLE BLUE LINE

MIN ACL $\rightarrow$ 60dB - STABLE

CLOSED LOOP BANDWIDTH

IF AN AMPLIFIER IS STABLE, IT'S CLOSED LOOP UPPER 3dB CUT OFF FREQUENCY

f_c = THE FREQUENCY WHERE HORIZONTAL ACL LINE CUTS THE OPEN LOOP GAIN GRAPH

PHASE MARGIN

THE NUMBER OF DEGREES THE PHASE PLOT IS ABOVE $-180°$

PHASE MARGIN OF $45°$ $\Rightarrow$ CRITICAL DAMP

$> 45° \Rightarrow$ OVER DAMP

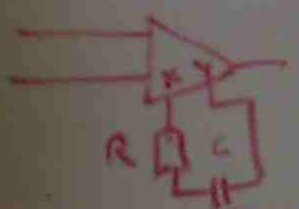
$< 45° \Rightarrow$ UNDER DAMP

FREQUENCY COMPENSATION

THE TECHNIQUE TO CHANGE THE PHASE MARGIN BY ADDING SOME EXTERNAL COMPONENTS TO OP-AMP

INTERNAL & EXTERNAL COMPENSATION

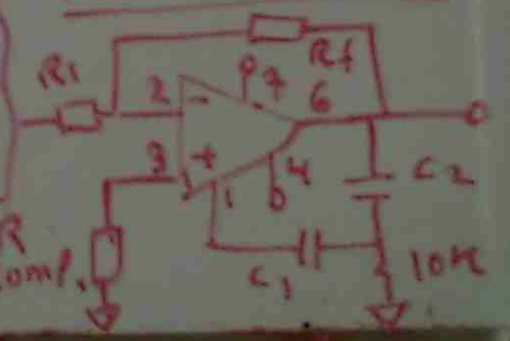
- SINGLE CAPACITOR



$C_c \propto \frac{1}{A_{CL}}$

$C_1 = \frac{R_i \times 30pf}{R_i + R_f}$ $C_2 = 10\,C_1$

- TWO CAPACITORS



PROCESS CONTROL

- SENSOR
- TRANSDUCER
- SIGNAL CONDITIONING
  - ANALOG
  - DIGITAL
- CONTROL PRINCIPLE
- INTERFACE
- DATA TRANSFER
  - COMMUNICATION
  - PNUEMATIC
  - FLUID
  - PRESSURE
  - TEMPERATURE
  - FORCE
  - VELOCITY
  - MASS
- PLC PROGRAM

ANALOG SIGNAL CONDITIONING PROVIDES THE OPERATION NECESSARY TO TRANSFORM A SENSOR OUTPUT INTO A FORM NECESSARY TO INTERFACE WITH OTHER ELEMENTS OF PROCESS CONTROL LOOP

- SIGNAL LEVEL CHANGE
- LINEARIZATION

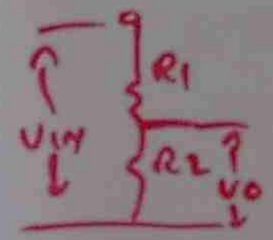
$$V_t = V_0 e^{-kt}$$

$$\log V_t = \log V_0 e^{-kt} = \log V_0 + \log e^{-kt} = \log V_0 - kt$$

CONVERSION, SIGNAL CONDITIONING, SIGNAL TRANSMISSION, DIGITAL INTERFACE

SIGNAL CONDITIONERS

PASSIVE CIRCUITS → POTENTIAL DIVIDER, BRIDGE



$$V_o = V_i \times \frac{R_2}{R_1+R_2}$$



$I_1 R_a = I_2 R_b$

$I_1 R_c = I_2 R_x$

WHEATSTONE BRIDGE $\frac{R_a}{R_c} = \frac{R_b}{R_x} \rightarrow \frac{R_x}{R_b} = \frac{R_c}{R_a} \rightarrow R_x = \frac{R_c R_b}{R_a}$

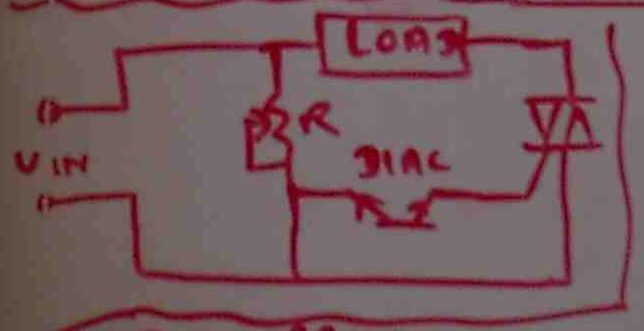


$$\Delta V = V\left[\frac{R_1R_2 - R_3R_4}{(R_1+R_3)(R_2+R_4)}\right]$$

$$V_{th} = V\left[\frac{R_3R_2 - R_1R_4}{(R_1+R_3)(R_2+R_4)}\right]$$

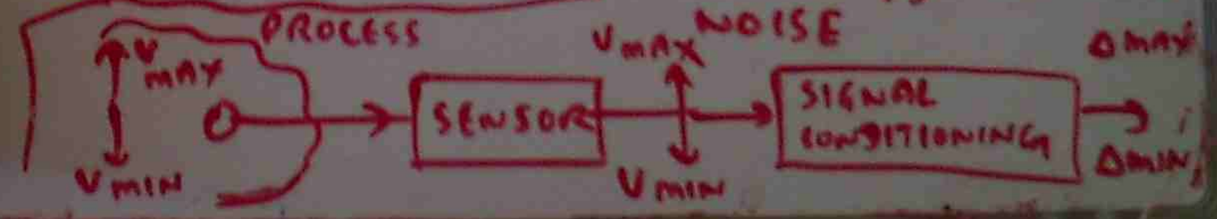
$$R_{in} = \frac{R_1R_3}{R_1+R_3} + \frac{R_2R_4}{R_2+R_4}$$

TRIGGER CONTROL



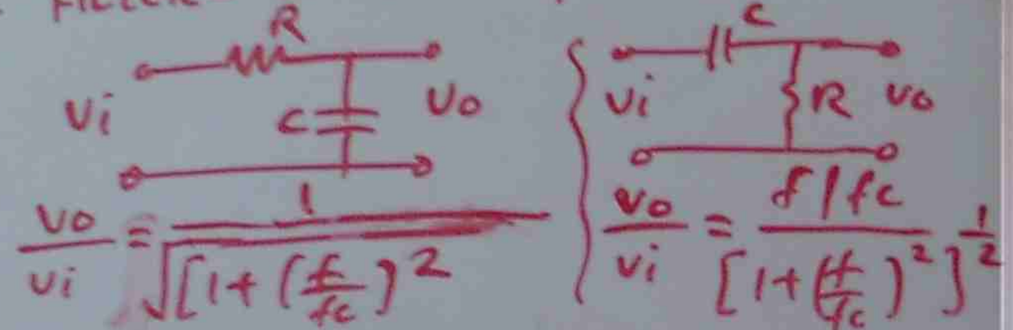
GUIDELINES FOR ANALOG SIGNAL CONDITIONING

PARAMETER, RANGE ACCURACY, LINEARITY NOISE



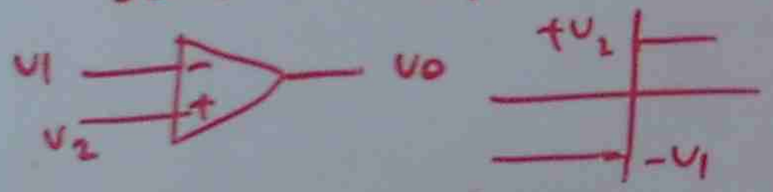
FILTER - TO REMOVE NOISE, SURGE

RC FILTER - LOW PASS / HIGH PASS



OPERATIONAL AMPLIFIER

IC PACKAGES, WIDE FREQUENCY RANGE

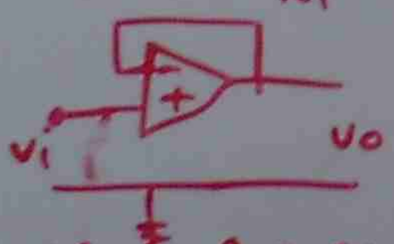


INVERTING OP-AMP



$V_{OUT} = -\frac{R_f}{R_1} \times V_{IN}$

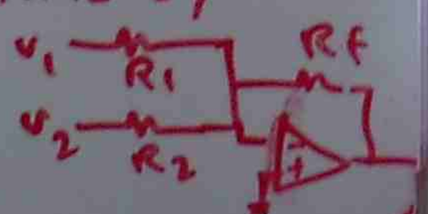
VOLTAGE FOLLOWER

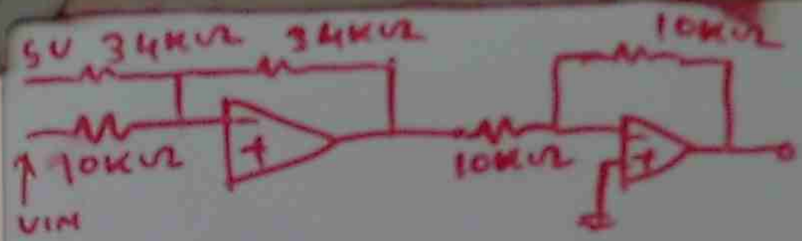


PD DEVELOP AN OP-AMP CIRCUIT THAT CAN PROVIDE AN OUTPUT VOLTAGE THAT IS RELATED TO THE INPUT VOLTAGE BY

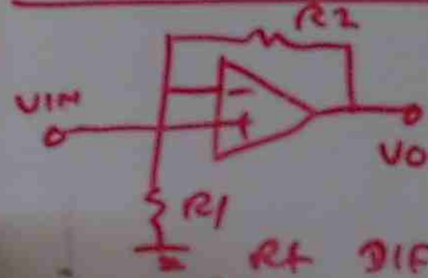
$V_{OUT} = 3.4 V_{IN} + 5$

↕ SUMMING



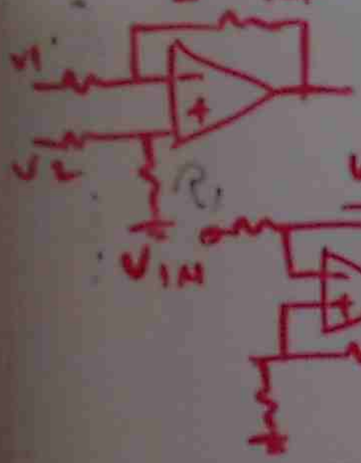


NON INVERTING AMPLIFIER



$V_{OUT} = \left[1 + \frac{R_2}{R_1}\right] V_{IN}$

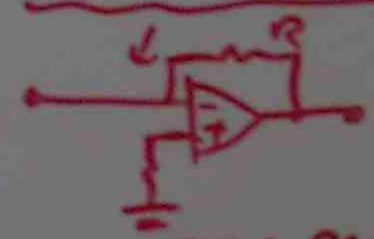
Rf DIFFERENTIAL AMPLIFIER



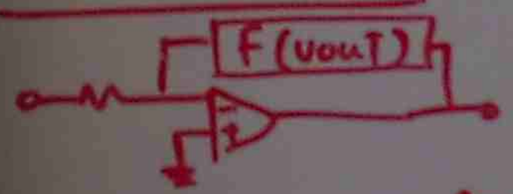
$V_{OUT} = \frac{R_f}{R_1}[V_2 - V_1]$

VOLTAGE TO CURRENT CONVERTER

CURRENT TO VOLTAGE CONVERTER

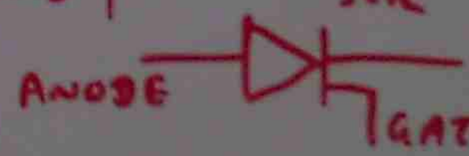


LINEARIZATION



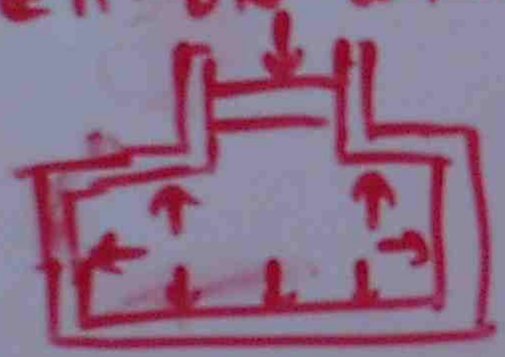
SILICON CONTROL RECTIFIER

SCR



PHYSICAL PRINCIPLES IN PNUEMATIC

PASCAL'S LAW → PRESSURE IS EQUAL TO FORCE PER UNIT AREA (OR) THE FORCE DIVIDED BY THE AREA ON WHICH IT ACTS





$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\text{PRESSURE} = \frac{\text{FORCE}}{\text{AREA}}$$

FORCE = MASS × ACCELERATION

ATMOSPHERIC PRESSURE



$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

T_1, T_2 TEMPERATURE °C + 273

P_1, P_2 - PRESSURE, V_1, V_2 - VOLUME

(1) PROCESS CONTROL TRANSDUCER

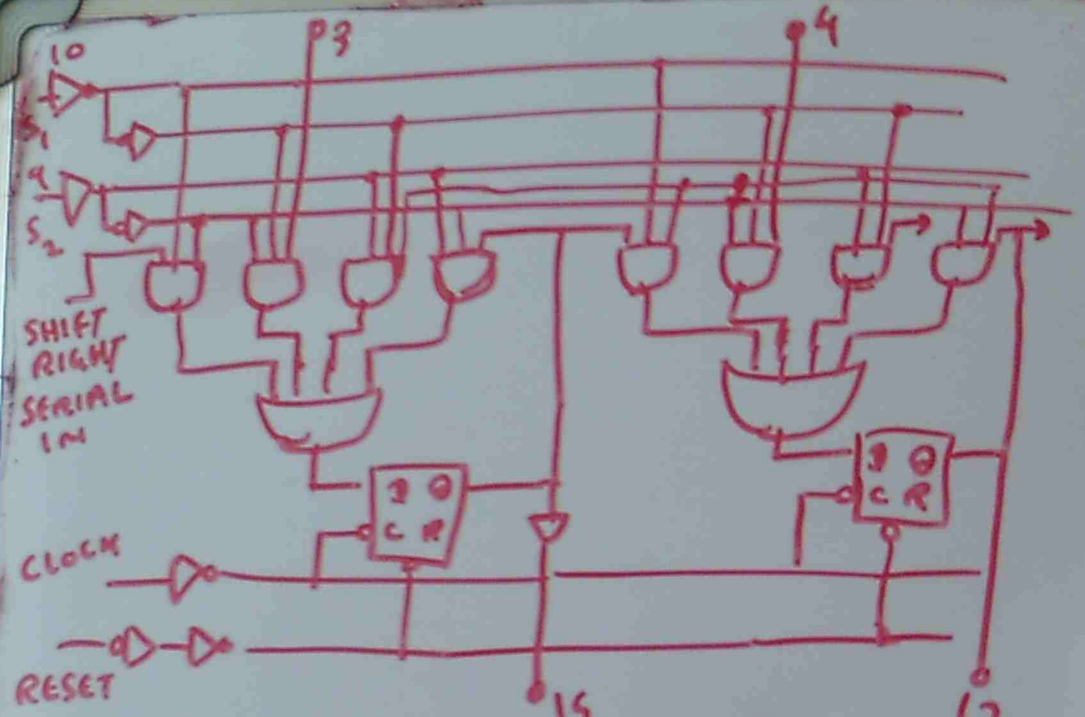
SLIDE (1) → (24), Q1 → Q12

(2) OP-AMP

SLIDE (1) → (19)
Q13 → Q23

(3) PNUEMATIC

SLIDE (1) → (11) & 24 → 33



194 LOGIC DIAGRAM

SERIAL DATA OUT FOR SHIFT LEFT

PARALLEL DATA OUT

PARALLEL IN / PARALLEL OUT — TTL-74LS194A
CMOS 4035

SERIAL IN / PARALLEL OUT - TTL 74LS164
CMOS 4021

PARALLEL IN / SERIAL OUT - TTL 74LS166
(28 BIT STATIC SHIFT REGISTER CMOS MC14562B

COUNTER

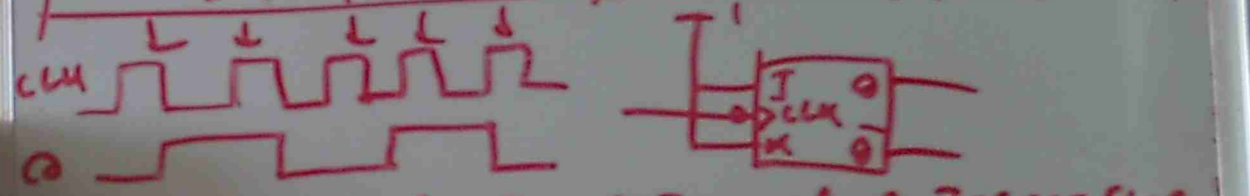
COUNTERS CAN BE USED TO COUNT THE NUMBER OF ITEMS ON A CONVEYOR OR IF USED TO COUNT THE NUMBER OF PULSES FROM A SHAFT.

ENCODER CAN INDICATE THE ROTARY POSITION OF A SHAFT (OR) X-Y POSITION of A MACHIMING BED.

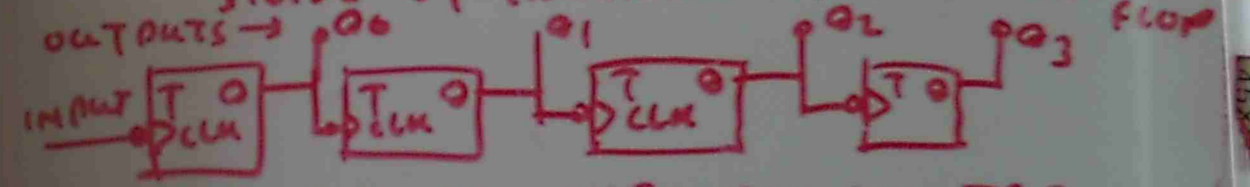
COUNT SEQUENCE

DECIMAL	C	B	A LSB
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1

DECIMAL	C	B	A (LSB)
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1

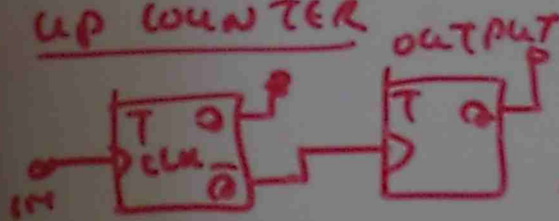


DIVIDE BY TWO ACTION of A TOGGLE FLIP FLOP

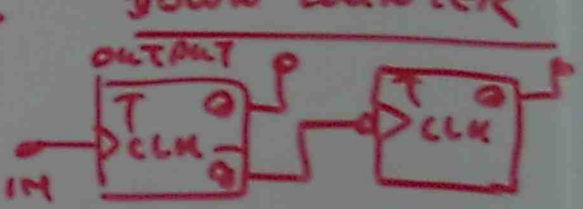


4 BIT ASYNCHRONOUS COUNTER

UP COUNTER



DOWN COUNTER



RIPPLE (OR) ASYNCHRONOUS COUNTER

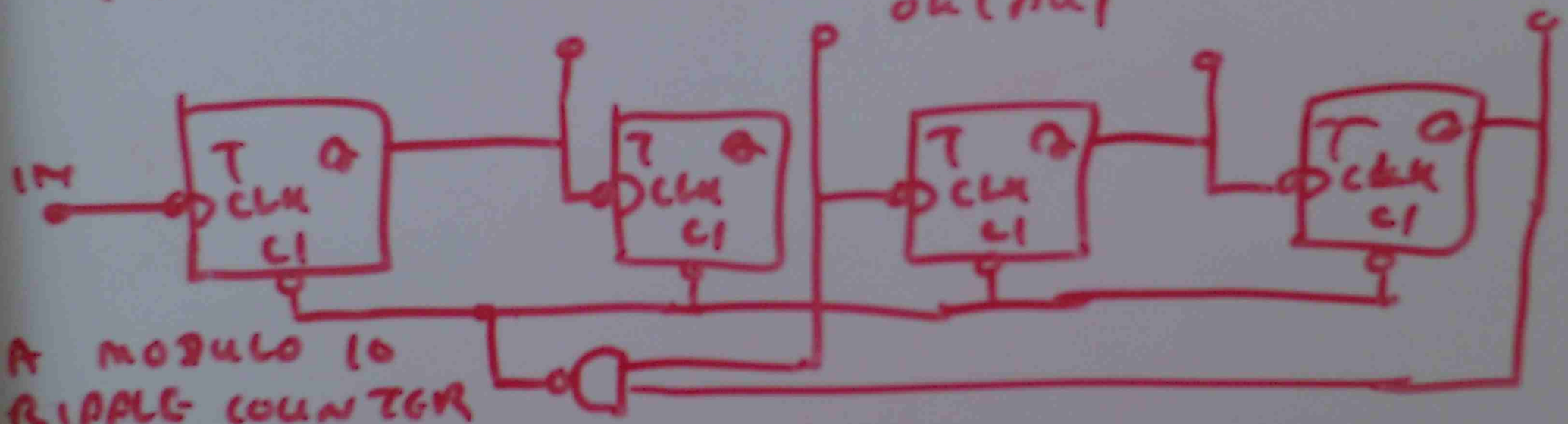
THE RIPPLE IS USED AS EACH FLIP FLOP CHANGES IN RESPONSE TO PREVIOUS FLIPFLOPS OUTPUT (PROPAGATION DELAY of FLIP FLOP

SYNCHRONOUS COUNTER

EXTRA GATING, CLOCK CONNECTED TO ALL FLIPFLOPS

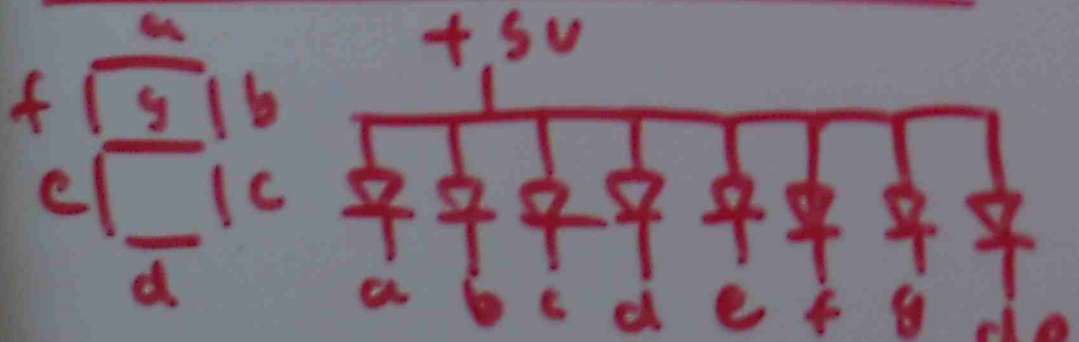
MODULUS OF COUNTER

THE MODULUS OF A COUNTER REFERS TO THE NUMBER OF STATES THE COUNTER CAN OUTPUT.
0 → 15 COUNTER HAS 16 STATES.
4 BIT RIPPLE COUNTER HAS A MODULUS OF 16

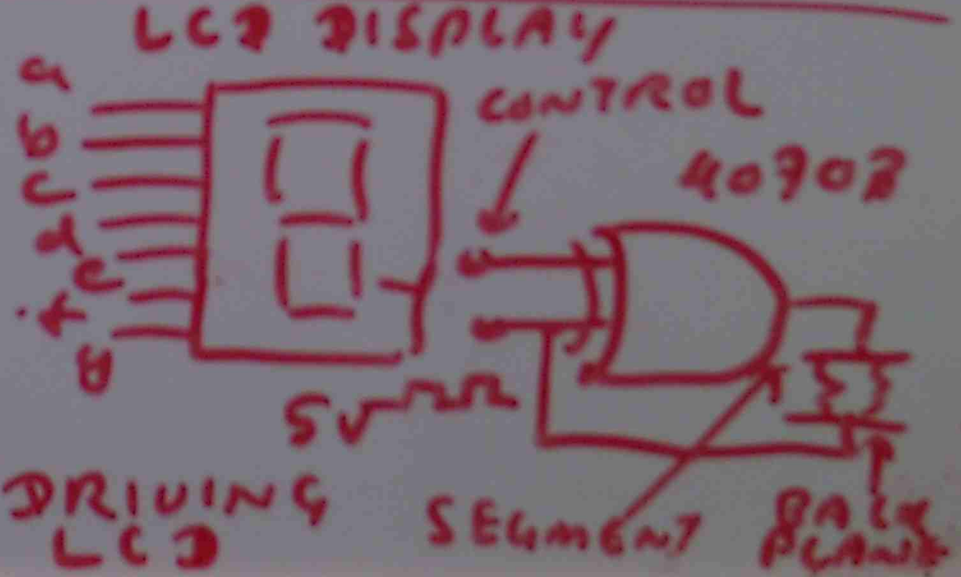


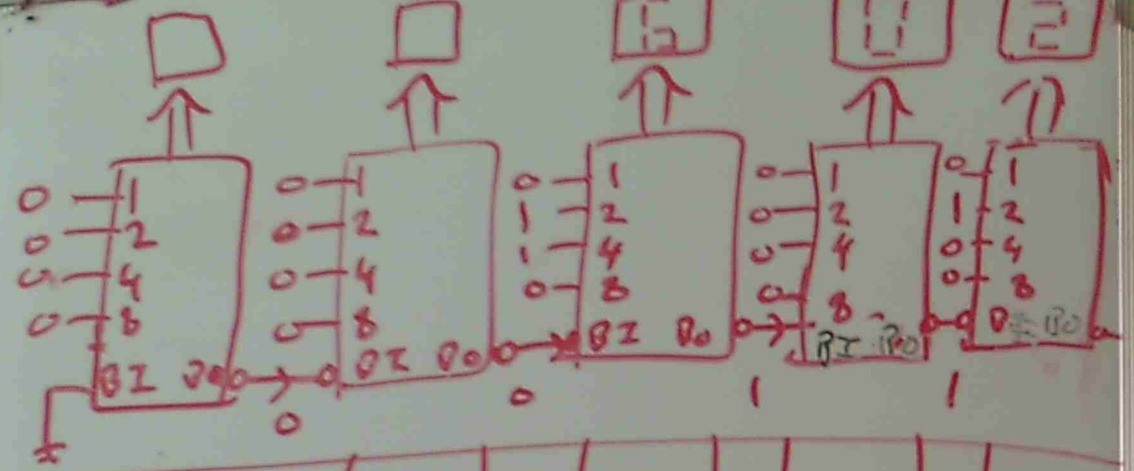
A MODULO 10 RIPPLE COUNTER WITH FEED BACK

7 SEGMENTS DISPLAY



LCD DISPLAY

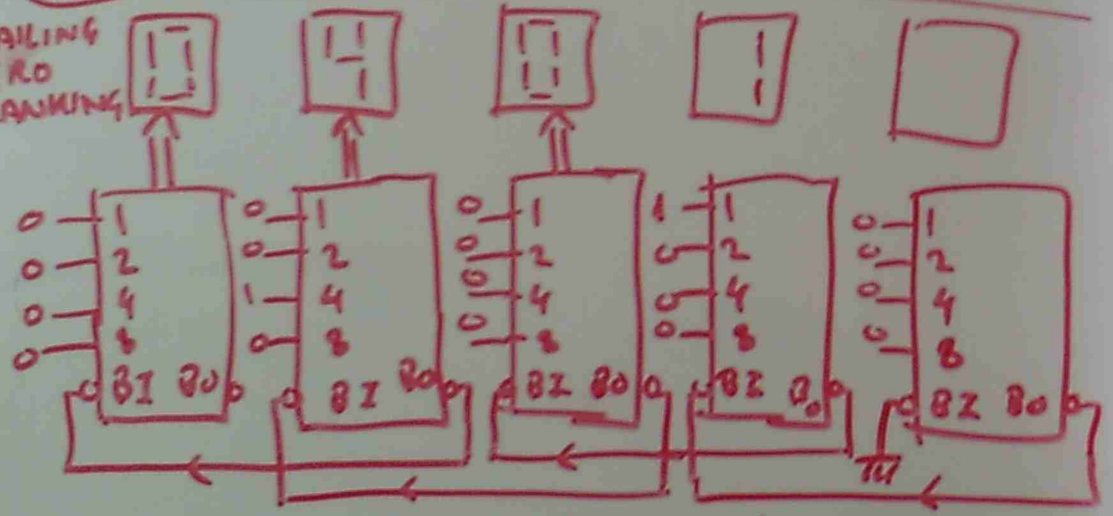




INPUT CODE	000		000		0110		0000		0010
BI	0		0		0		1		1
RO	0		0		1		1		X
DISPLAY	BLANK		BLANK		LIGHT		LIGHT		LIGHT

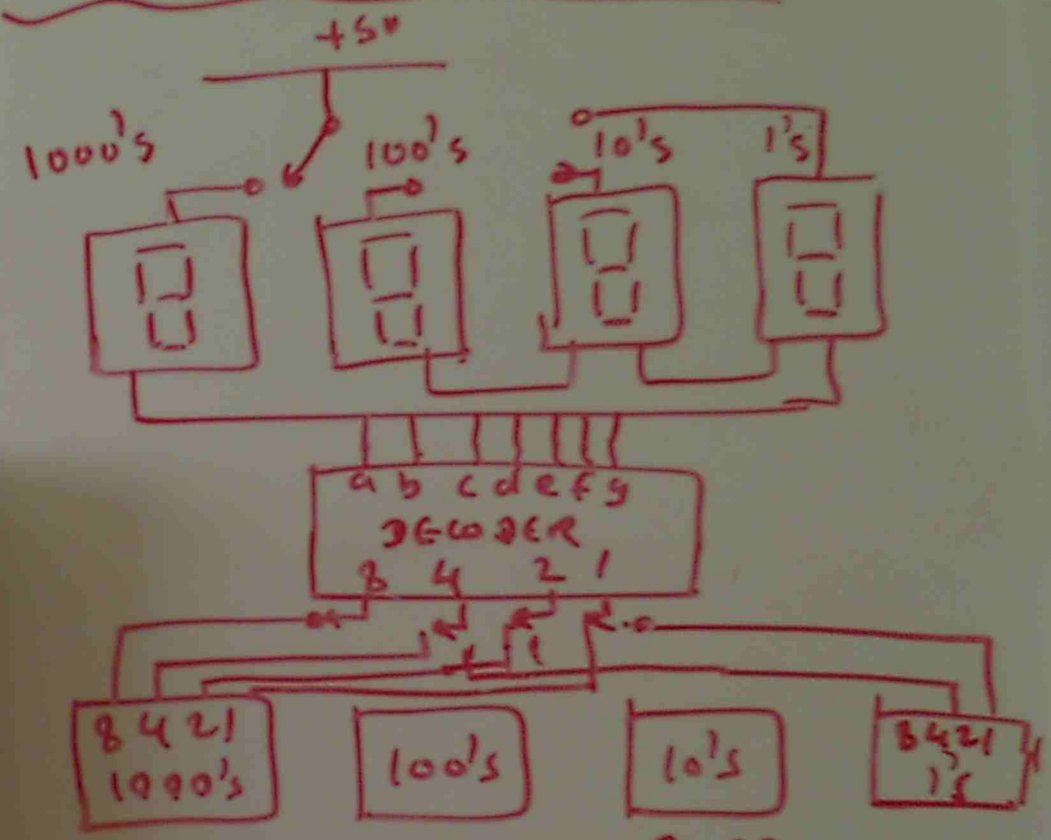
LEADING ZERO BLANKING

TRAILING ZERO BLANKING



INPUT CODE	0000		0100		0000		0000		0022
BI	1		1		1		0		0
RO	X		1		1		1		0
DISPLAY	LIGHT		LIGHT		LIGHT		LIGHT		BLANK

MULTIPLEXED LED DISPLAYS



MULTIPLEXING 7 SEGMENT LED DISPLAYS

THE BASIC PRINCIPLES of DISPLAY MULTIPLEXING IN WHICH SWITCHES ARE USED TO

(a) CONNECT THE SELECTED BINARY VALUE TO THE DECODER

(b) SUPPLY POWER TO THE DISPLAY

- THAT MUST REGISTER THE VALUE

I006- (6) ENCODER + DECODER

SLIDE (1) → SLIDE (22)

Q40 → Q50

H012- (5) NUMBER SYSTEM + DISPLAY + ADC + DAC

SLIDE (1) → SLIDE (33)

Q22 → Q36

DIGITAL CONTROL + DIGITAL PRINCIPLE

ANALOG – A SYSTEM CAPABLE OF PRODUCING AN OUTPUT THAT IS CONTINUOUSLY VARIABLE

DIGITAL – A SYSTEM THAT PRODUCES AN OUTPUT OF TWO STATES ONLY.

INTEGRATED CIRCUIT

CMOS – N/P MOSFET, LOW SPEED OPERATION
TTL – TRANSISTOR TRANSISTOR LOGIC
HIGH SPEED
DTL – DIODE TRANSISTOR LOGIC – COMBINATION OF DIODE & TRANSISTOR
HTL – HIGH THRESHOLD LOGIC – HIGH NOISE IMMUNITY, INDUSTRIAL CONTROL
ECL – EMITTER COUPLED LOGIC – VERY SHORT GATE PROPAGATION DELAY

COMBINATIONAL LOGIC

KNOWN INPUT ⟶ OUT PUT PREDICTABLE

SEQUENTIAL LOGIC

TIME + MEMORY ⟶ SYSTEM

SYNCHRONOUS LOGIC

MASTER CLOCK ⟶ ALL CHANGES ARE EXECUTED IN SYNCHRONISM WITH CLOCK

ASYNCHRONOUS LOGIC EVENTS OCCUR AFTER THE PREVIOUS EVENT IS COMPLETED.

AND

A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

OR

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

NOT

A	Z
0	1
1	0

NAND ≡

A	B	Z
0	0	1
0	1	1
1	0	1
1	1	0

EX-OR

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	0

NOR

A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0

IC – DIGITAL GATE INVERTER – DIL – 4069, TTL 7408

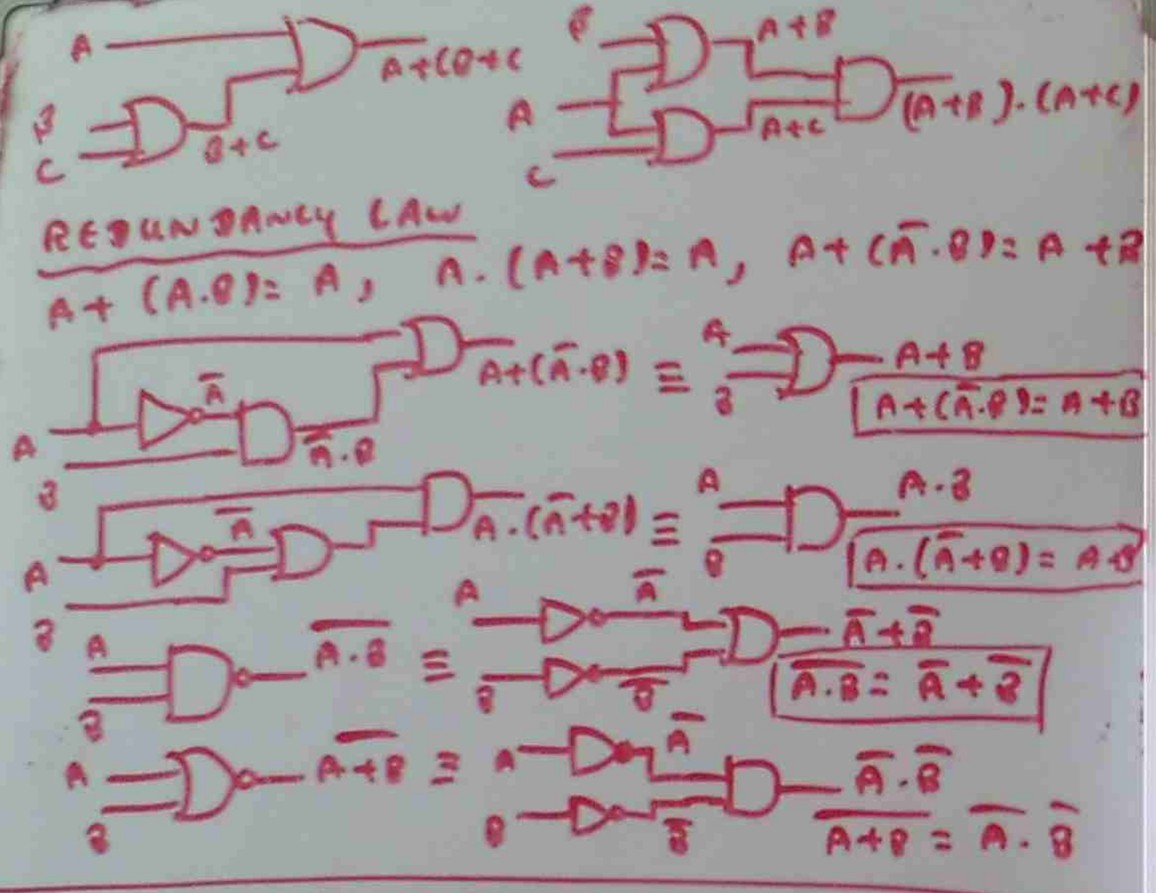
BOOLEAN ALGEBRA

$Z = ABC$ $\quad Z = A+B+C$

$\bar{A}$ $\quad Z = A\bar{B}C$ $\quad Z = \overline{A+B+C}$

$A \cdot B = B \cdot A$
$A+(B+C) = (A+B)+C$

$0 \cdot 0 = 0$	$0+0=0$	$1 \cdot 0 = 0 \cdot 1 = 0$	$A \cdot 0 = 0$	$A \cdot A = A$	$A = 0 \rightarrow \bar{A} = 1$
$1+1=1$	$1 \cdot 1 = 1$	$1+0 = 0+1 = 1$	$A+1 = 1$	$A+\bar{A}=1$	$\bar{\bar{A}} = A$
		$A+0 = A$	$A \cdot 1 = A$	$A \cdot \bar{A} = 0$	$A+B = B+A$



REDUNDANCY LAW

$A+(A.B) = A$, $A.(A+B) = A$, $A+(\bar{A}.B) = A+B$

DE-MORGAN THEOREM

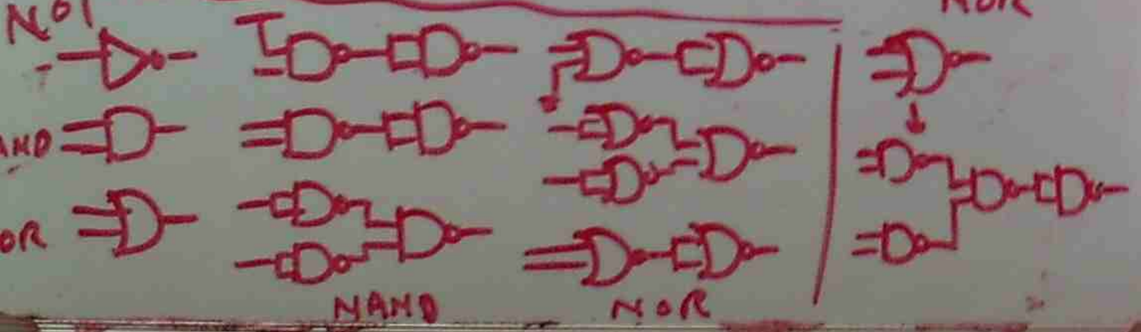
$A+B \xrightarrow{(1)}$ INVERT THE INPUT $\bar{A}+\bar{B}$ ← OUTPUT

(2) INVERT THE OUTPUT $\overline{\bar{A}+\bar{B}}$

(3) CHANGE THE SIGN $\overline{\bar{A}.\bar{B}}$

$\therefore A+B = \overline{\bar{A}.\bar{B}}$

EQUIVALENT LOGIC GATES



IOO6 - (4) DIGITAL CONTROL
SLIDE (1) → (10), Q34 → 37

HO12 - (1) DIGITAL INTRODUCTION
SLIDE (1) → (8), Q1 → Q2

HO12 - (2) LOGIC GATES
SLIDE (1) → (6), Q3 → Q6

HO12 (3) COMBINATIONAL + DE-MORGAN
SLIDE (1) → (12)
Q7 → Q14

HO12 (4) DIGITAL LOGIC SIMPLIFICATION
SLIDE (3) → (12) Q15 → Q21

NUMBER SYSTEM

BINARY - 2 CHARACTERS, 0 & 1
OCTAL - 8 CHARACTERS, 0 TO 7
HEXADECIMAL - 16 CHARACTERS 0 TO 9, A TO F

Ex CONVERT 45_{10} TO BINARY

2	45	1
2	22	0
2	11	1
2	5	1
2	2	0
	1	

$45_{10} = 101101_2$

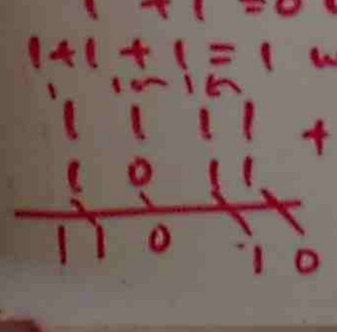
CONVERT 101101_2 TO DECIMAL

$1\times2^5 + 0\times2^4 + 1\times2^3 + 1\times2^2 + 0\times2^1 + 1\times2^0$

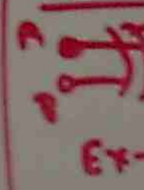
$= 45_{10}$

BINARY ADDITION

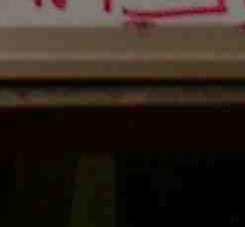
0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 0 WITH A CARRY OF 1
1 + 1 + 1 = 1 WITH A CARRY OF 1

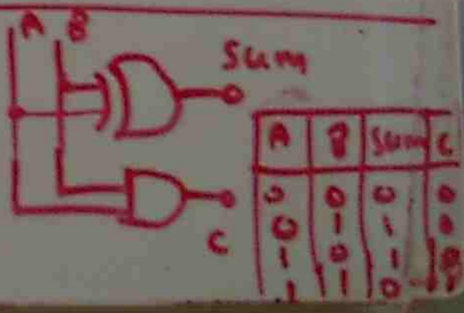


ADDER

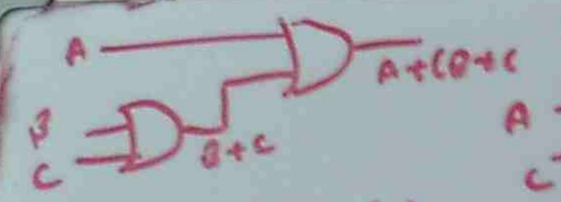


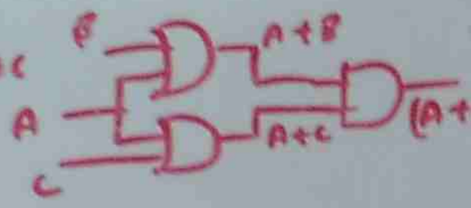
A	B	+
0	0	0
0	1	1
1	0	1
1	1	0





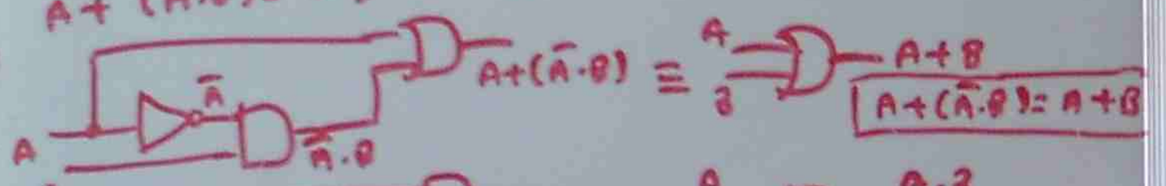
A	B	SUM	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

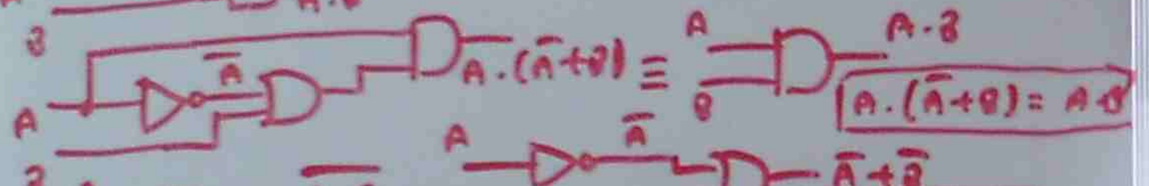


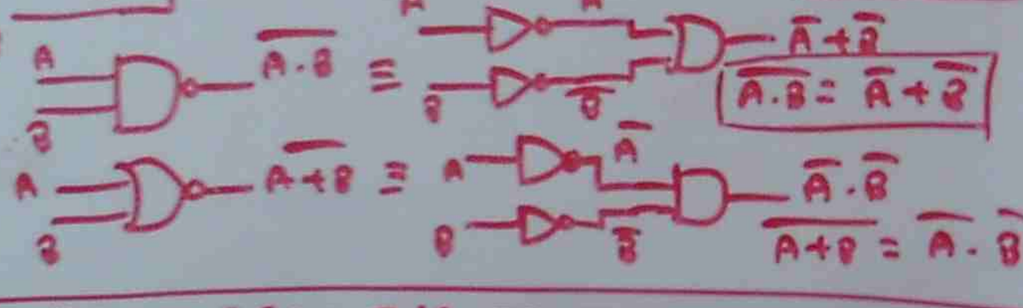


REDUNDANCY LAW

$A+(A.B) = A$, $A.(A+B) = A$, $A+(\bar{A}.B) = A+B$







DE-MORGAN THEOREM

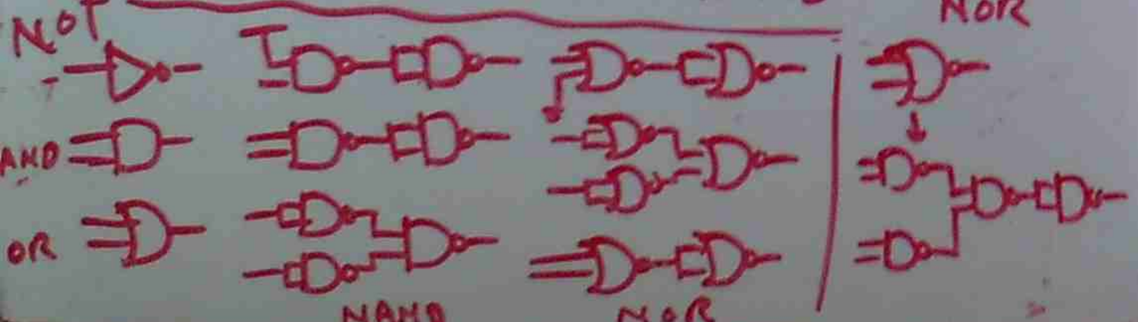
$A+B \xrightarrow{(1)}$ INVERT THE INPUT $\bar{A}+\bar{B}$ ← OUTPUT

(2) INVERT THE OUTPUT $\overline{\bar{A}+\bar{B}}$

(3) CHANGE THE SIGN $\overline{\bar{A}.\bar{B}}$

$\therefore A+B = \overline{\bar{A}.\bar{B}}$

EQUIVALENT LOGIC GATES



IOOG - (4) DIGITAL CONTROL
SLIDE (1) → (10), Q34 → 37

HOI2 - (1) DIGITAL INTRODUCTION
SLIDE (1) → (8), Q1 → Q2

HOI2 - (2) LOGIC GATES
SLIDE (1) → (6), Q3 → Q6

HOI2 (3) COMBINATIONAL + DE-MORGAN
SLIDE (1) → (12) Q7 → Q14

HOI2 (4) DIGITAL LOGIC SIMPLIFICATION
SLIDE (3) → (13) Q15 → Q21

NUMBER SYSTEM

BINARY - 2 CHARACTERS, 0 & 1
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HEXADECIMAL - 16 CHARACTERS 0 TO 9, A TO F

Ex CONVERT 45_{10} TO BINARY

2	45	1
2	22	0
2	11	1
2	5	1
2	2	0
	1	

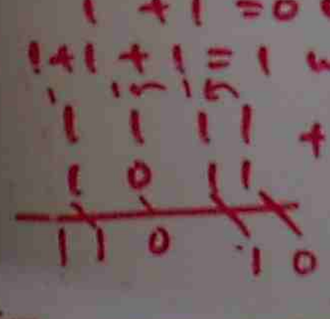
$45_{10} = 101101_2$

CONVERT 101101_2 TO DECIMBAL

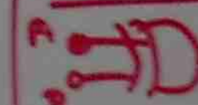
$(1\times2^5 + 0\times2^4 + 1\times2^3 + 1\times2^2 + 0\times2^1 + 1\times2^0$
$= 45_{10}$

BINARY ADDITION

0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 0 WITH A CARRY OF 1
1 + 1 + 1 = 1 WITH A CARRY OF 1

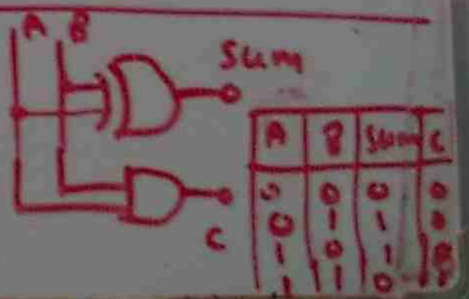


ADDER

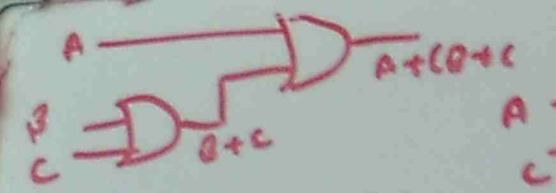


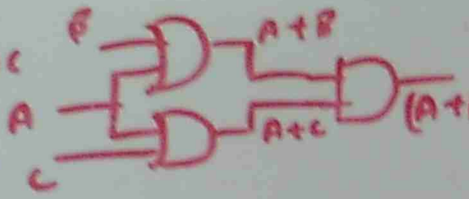
A	B	+
0	0	0
0	1	1
1	0	1
1	1	0





A	B	SUM	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1





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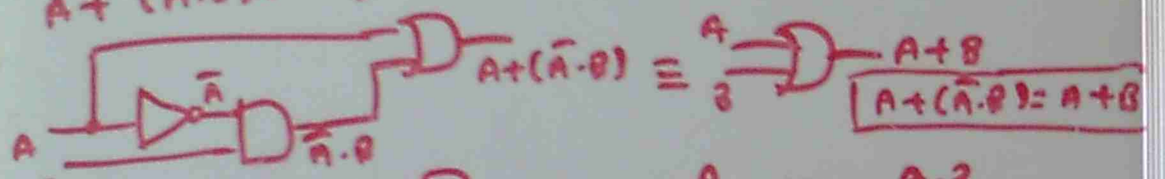

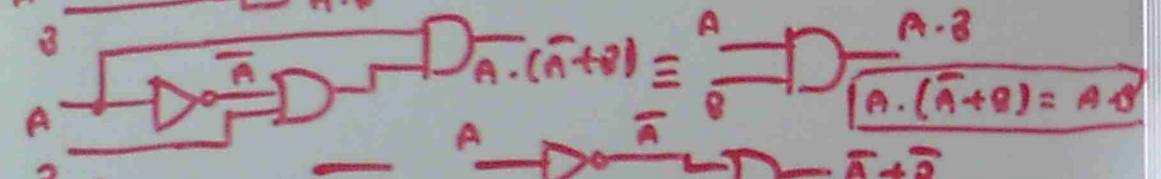

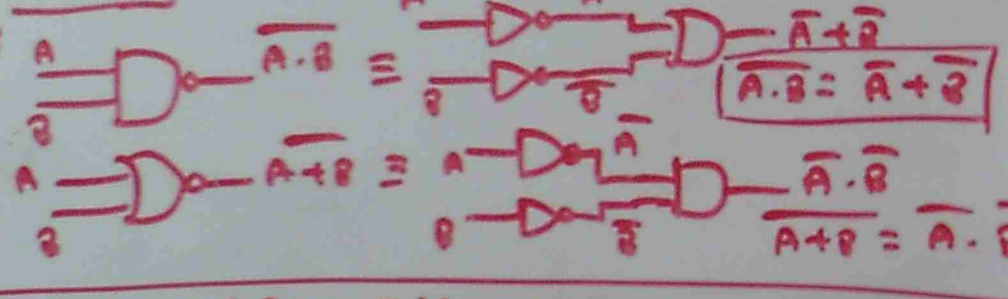

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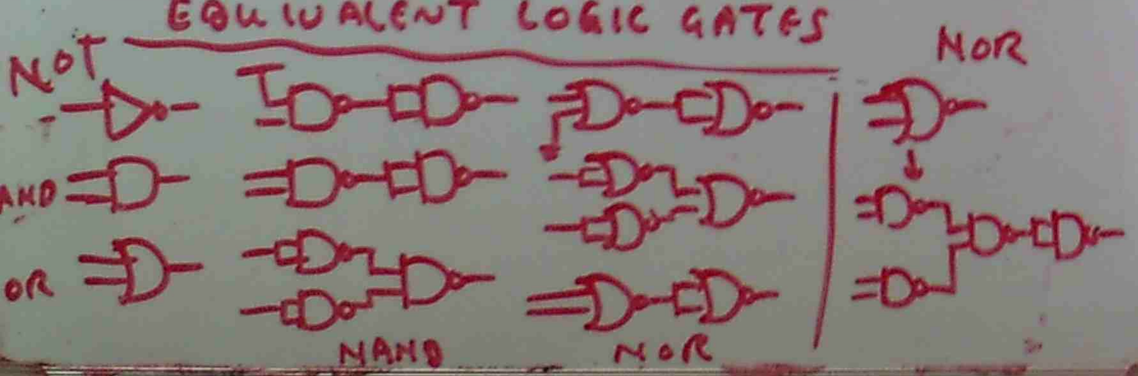
(2) INVERT THE OUTPUT $\overline{\bar{A}+\bar{B}}$

(3) CHANGE THE SIGN $\overline{\bar{A}.\bar{B}}$

$\therefore A+B = \overline{\bar{A}.\bar{B}}$

EQUIVALENT LOGIC GATES



IOOG - (4) DIGITAL CONTROL
SLIDE (1) → (10), Q 34 → 37

HOI2 - (1) DIGITAL INTRODUCTION
SLIDE (1) → (8), Q 1 → Q 2

HOI2 - (2) LOGIC GATES
SLIDE (1) → (6), Q 3 → Q 6

HOI2 (3) COMBINATIONAL + DE-MORGAN
SLIDE (1) → (12) Q 7 → Q 14

HOI2 (4) DIGITAL LOGIC SIMPLIFICATION
SLIDE (3) → (12) Q 15 → Q 21

NUMBER SYSTEM

BINARY - 2 CHARACTERS, 0 & 1
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HEXADECIMAL - 16 CHARACTERS 0 TO 9, A TO F

Pg CONVERT 45_{10} TO BINARY

2	45	1
2	22	0
2	11	1
2	5	1
2	2	0
	1	

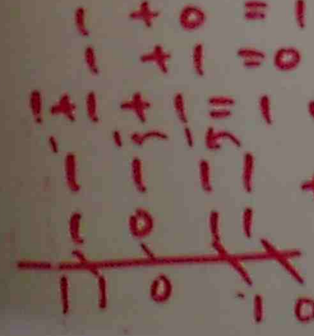
$45_{10} = 101101_2$

CONVERT 101101_2 TO DECIMAL

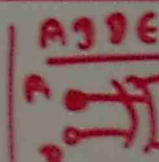
$1\times2^5 + 0\times2^4 + 1\times2^3 + 1\times2^2 + 0\times2^1 + 1\times2^0$
$= 45_{10}$

BINARY ADDITION

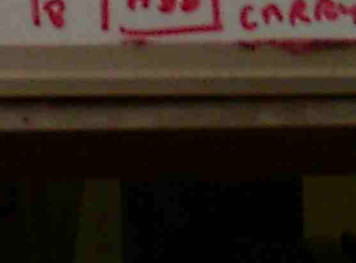
0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 0 WITH A CARRY OF 1
1 + 1 + 1 = 1 WITH A CARRY OF 1

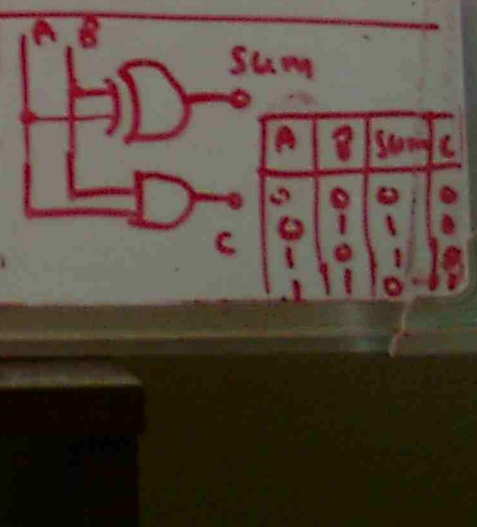


ADDER

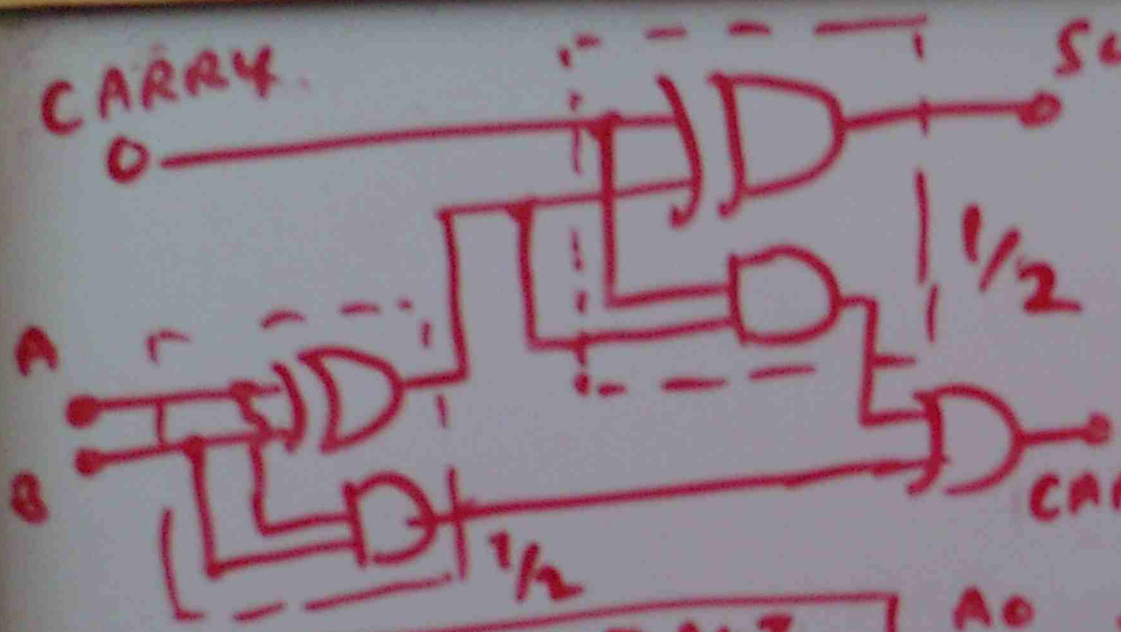


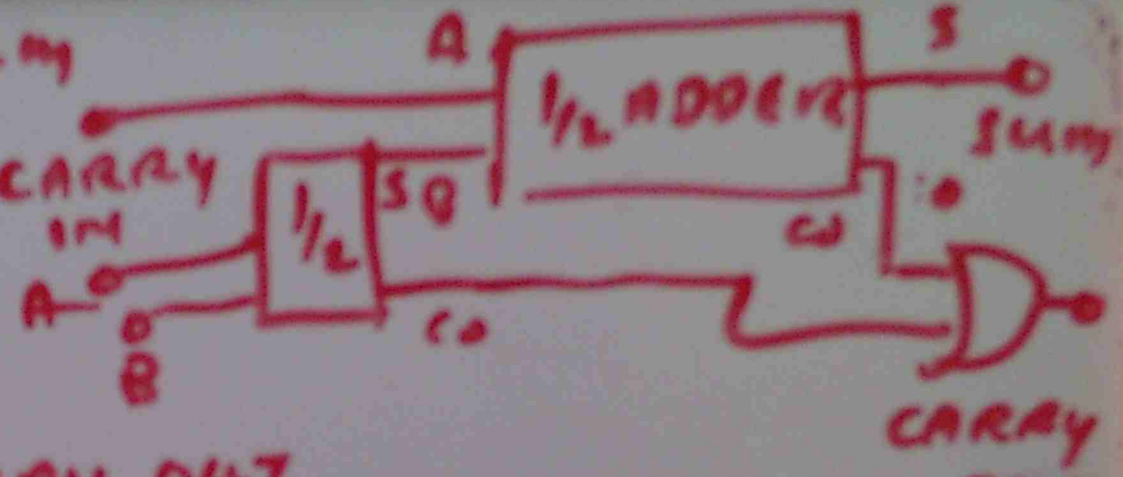
A	B	+
0	0	0
0	1	1
1	0	1
1	1	0



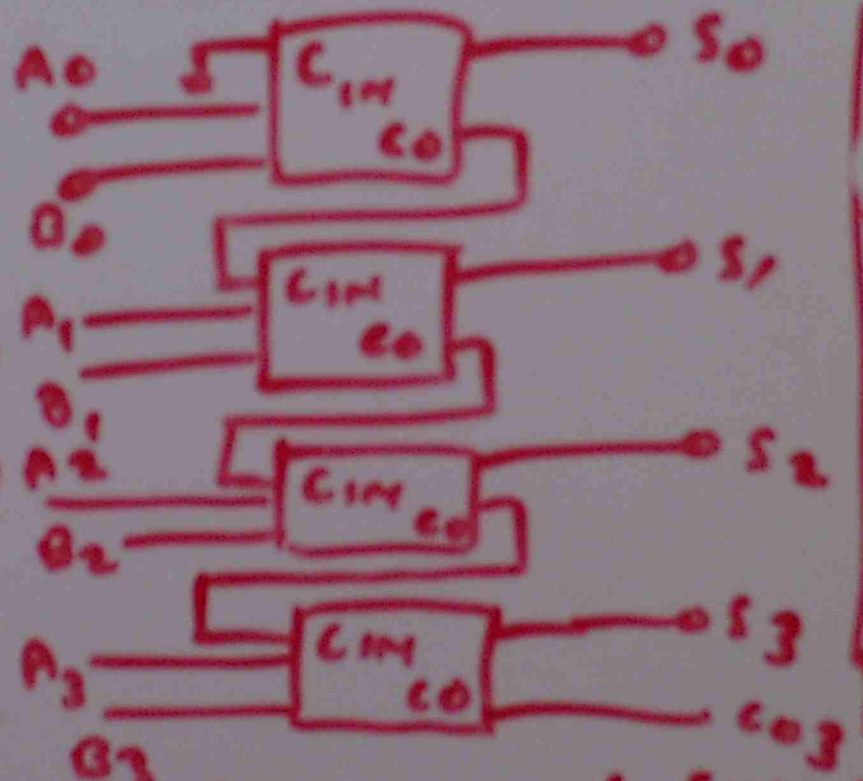


A	B	SUM	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1





INPUT			OUTPUT	
A	B	C_{IN}	SUM	C_{OUT}
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	1	0	0	1
1	1	1	1	1



HEXADECIMAL

0 → 9
11 → A
15 → F
16-F

$4AF3_{16}$

0100 1010 1111 0011

0100 1111 0011

OCTAL

CONVERT 147_8 TO BINARY

$1\times8^2+4\times8+7\times8^0 = 103$

CONVERT 147 TO BINARY

1 — 001
4 — 100
7 = 111 ∴ 001 100 111
1100111_2

CASCADING 4 FULL ADDER TO ADD TWO 4 BIT BINARY NUMBER

BINARY TO OCTAL

001 101 100
1 5 4 $= 154_8$

$100 = 1\times2^2 + 0\times2^1 + 0\times2^0 = 100$

BINARY SUBSTRACTION

MINUEND - THAT WHICH IS SUBSTRACTED FROM
SUBTRAHEND - THAT WHICH IS TAKEN AWAY
DIFFERENCE - THE RESULTANT OF THE SUBSTRACTION
BORROW - IN BINARY SUBTRACTION, IF THE SUBTRAHEND IS LARGER THAN THE MINUEND, A BORROW OF 10 (=2) IS TAKEN FROM NEXT COLUMN

0-1=0, 1-0=1, 1-1=0, 0-1=1 (A BORROW 1)

```
BORROW
(1)  1  1  0  0
     ↓ (0)
     1  1  1  1
     ---------
     0  1  0  1
```

COMPLEMENT SUBSTRACTION

```
 1  1  0  1
 0  1  1  0
 ---------
 1  0  0  1   (1) CHANGE
(2)
 1  1  0  1
 ---------
 0  1  1  0   (3) ADD
(4)
 0  1  1  1   ⊕ ANSWER
```

RE WRITE

CARRY

```
 0  1  1  0
 1  1  0  1
 ---------
 1  0  0  1  0   (1) CHANGE
 0  1  1  0
 ---------
 1  0  0  0   (3) ADD
```

(2) REWRITE

NO CARRY

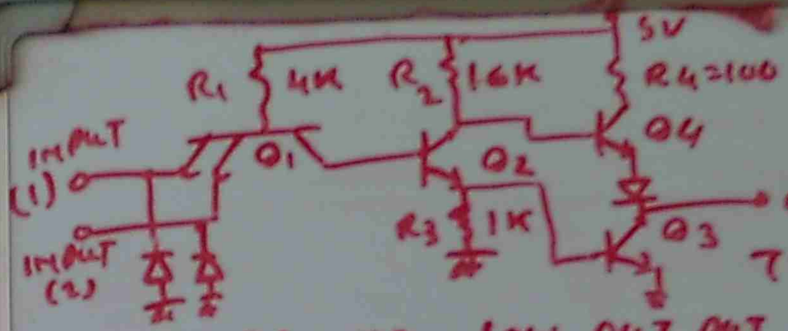
INVERT 1000 → 0111

⊖ ANSWER

LOGIC FAMILY TTL,

V_{MIN} = 2V FOR 1 AT INPUT, V_{MAX} = 0.8V FOR 0 AT INPUT

MAX CURRENT = 40μA
STAGE CHANGE - 1.6 mA
O/P → 1 → 2.4V



TTL NAND GATE

TTL - 35 MHZ, LOW OUTPUT IMPEDANCE

TTL-LS LOGIC - LOW POWER SCHOTTKY

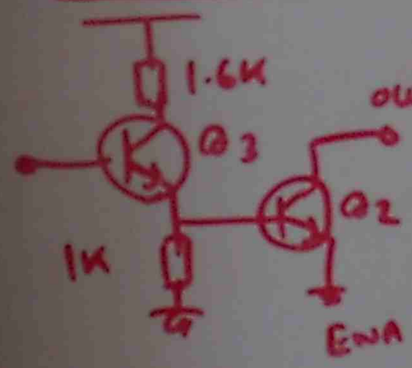


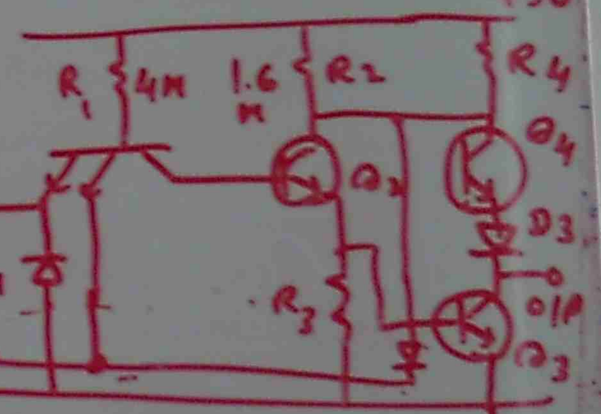
HIGH SPEED SWITCHING DIODE

POWER CONSUMPTION - 20% OF TTL
LESS SWITCHING NOISE
SEE NOTE FOR MORE DETAILED

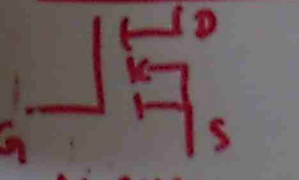
NOISE MARGIN (LOW) = $V_{IL} - V_{OL}$
NOISE MARGIN (HIGH) = $V_{IH} - V_{OH}$

OPEN COLLECTOR LOGIC



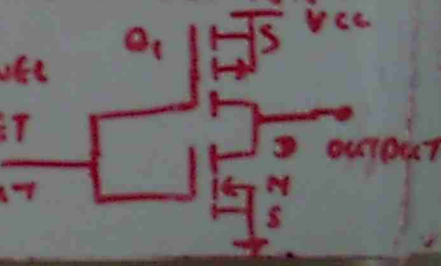


MOS LOGIC FAMILY



N-CHANNEL MOSFET

3 STATES INVERTER



ENCODERS AND DECODERS

BIT - SINGLE BINARY LEVEL 1 (OR) 0
BYTE - A GROUP OF 8 BITS
WORD - A GROUP OF BYTES
SERIAL - A DATA TRANSFER METHOD IN WHICH DATA EACH BIT IS FED SEQUENTIALLY OVER A SINGLE TRANSMISSION LINE
PARALLEL DATA - A DATA TRANSFER METHOD WHERE DATA IS TRANSFERRED OVER A NUMBER OF LINES

BINARY CODED DECIMAL

BINARY VALUES OF THE DECIMAL CHARACTER 0 TO 9 ONLY.

DECIMAL	BCD	DECIMAL	BCD
0	0000	5	0101
1	0001	6	0110
2	0010	7	0111
3	0011	8	1000
4	0100	9	1001

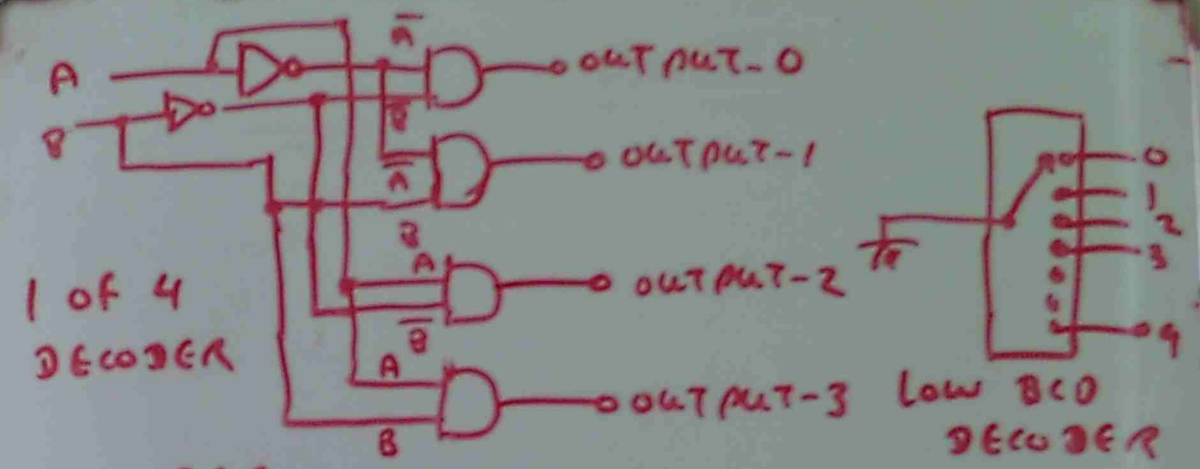
23_{10} → 2 3 → 0010 0011
0010 0011

2594_{10} → 0010 0101 0111 1001

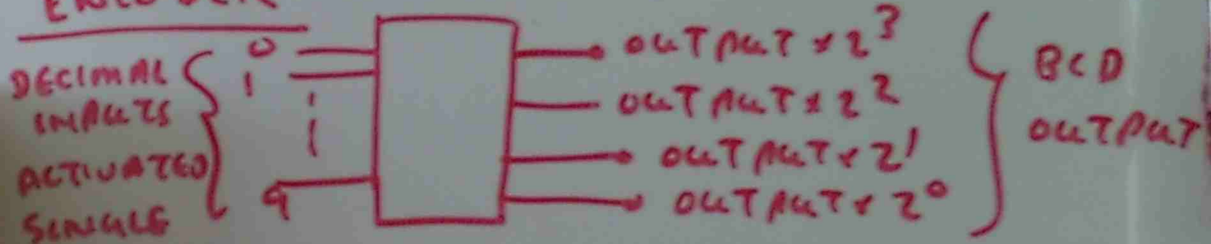
GRAY CODE → ANALOG INPUT → GRAY CODE TABLE

DECODER - A NUMBER OF INPUTS AND OUTPUTS BUT ACTIVATES ONLY ONE OUTPUT FOR A GIVEN INPUT CODE

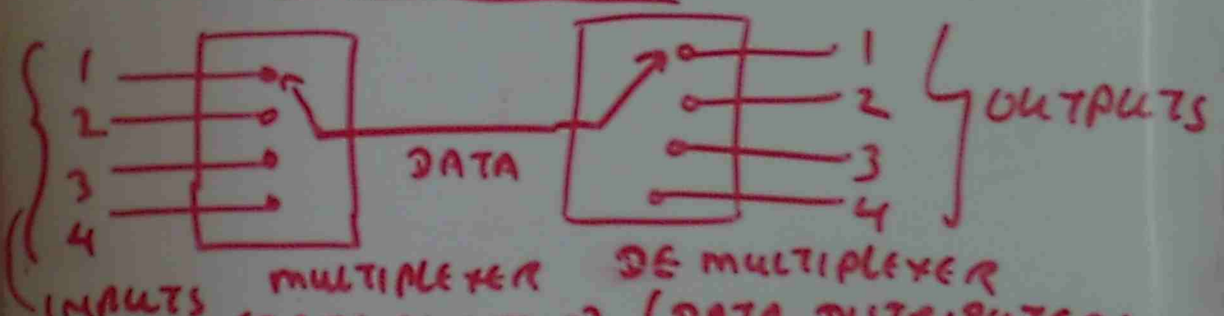
ENCODER → ONLY ONE INPUT AT A TIME IS ACTIVATED TO PRODUCE SPECIFIC CODE AT OUTPUT

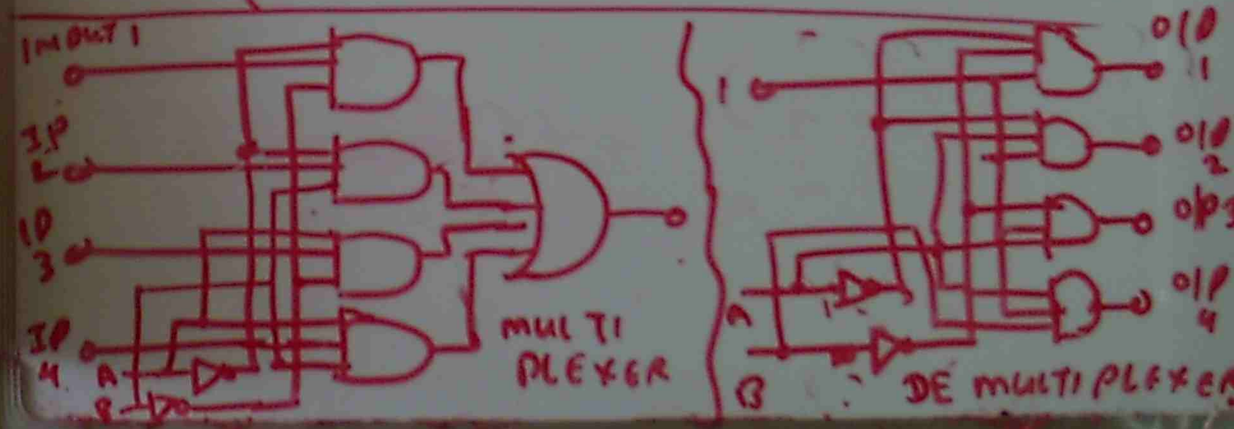


ENCODER



MULTIPLEXERS

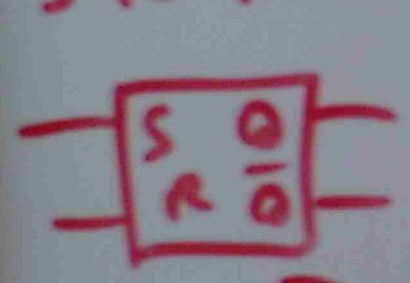




S-R FLIP FLOP- SWITCH DEBOUNCING

THE OUTPUT OF A CIRCUIT CAN BE HELD CONSTANT AFTER THE INPUT CONDITIONS HAVE CHANGED. | MEMORY → SEQUENTIAL DIGITAL SYST.

S R FLIP FLOP - SET | RESET FLIP FLOP

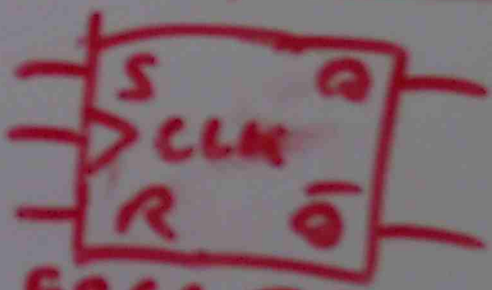


S.R FLIP FLOP NAND GATE

INPUT		OUTPUT		RESULT
S	R	Q	$\bar{Q}$	
X	X	X	X	NO CHANGE
X	✓	X	X	SET
✓	X	1	0	RESET
✓	✓	0	1	INVALID
		UNDEFINED		

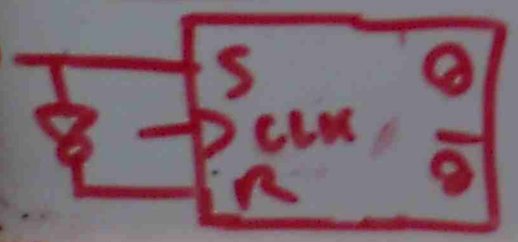


- LEVEL GATED SR LATCH

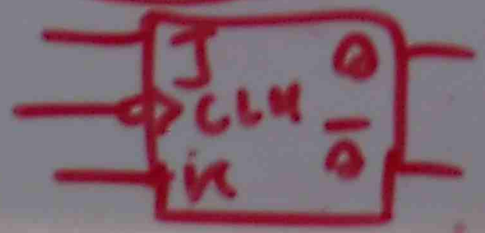


+ EDGE TRIGGER SR FLIP FLOP

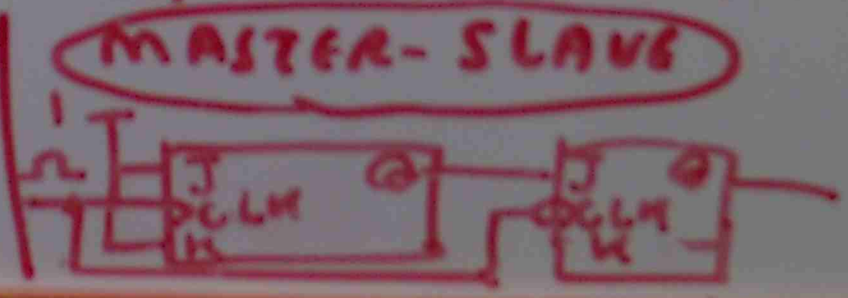
D - FLIP FLOP



J-K



MASTER-SLAVE



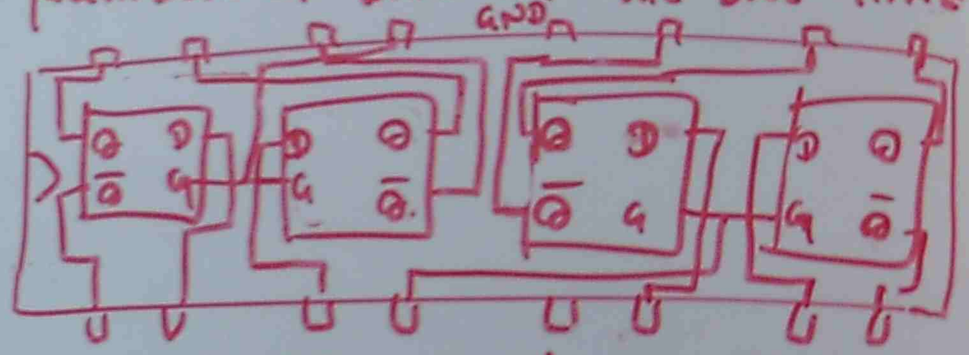
SHIFT REGISTERS AND DATA LATCHES

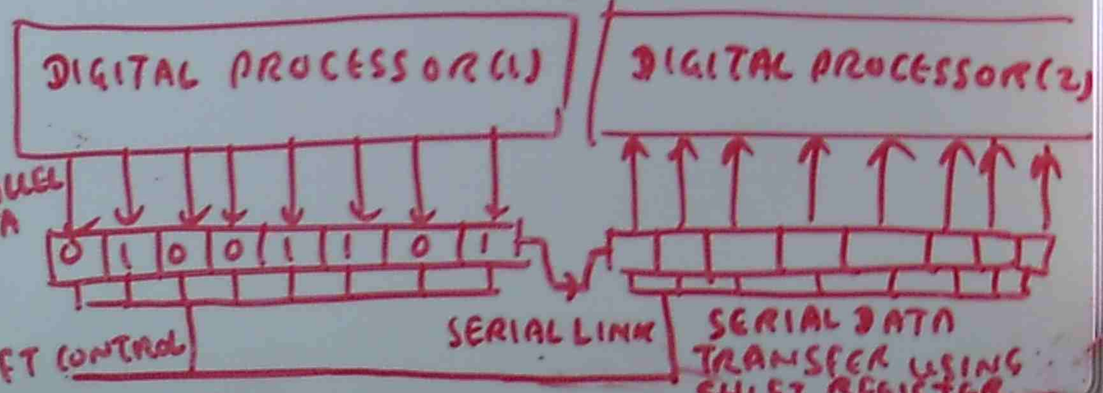
FLIP FLOPS ARE USED IN A VARIETY OF APPLICATIONS INCLUDING THE LATCH AND SHIFT REGISTER FUNCTIONS.

LATCHES

A FLIP FLOP (EITHER D (OR) J-K) IS A STORAGE DEVICE CAPABLE OF STORING ONE BIT OF INFORMATION.

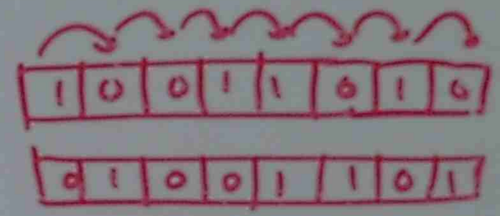
LATCH CONTAINS THE NUMBER OF INTER-CONNECTED FLIP FLOPS CAPABLE OF STORING A NUMBER OF BITS AT THE ONE TIME





SHIFT REGISTER

MANY DIGITAL APPLICATIONS REQUIRE THAT BINARY DATA BE SHIFTED EITHER TO THE RIGHT (OR) LEFT

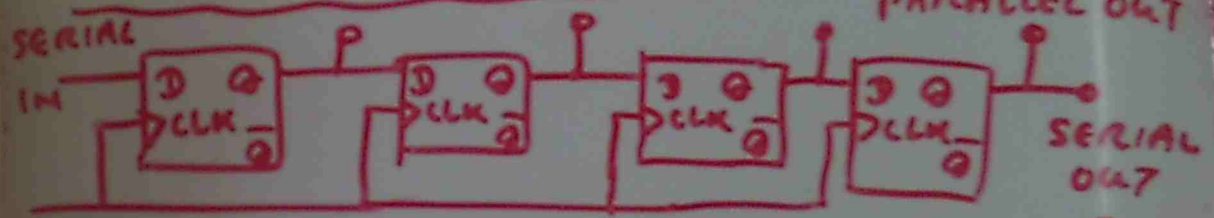


$77_{10} = \frac{154_{10}}{2}$

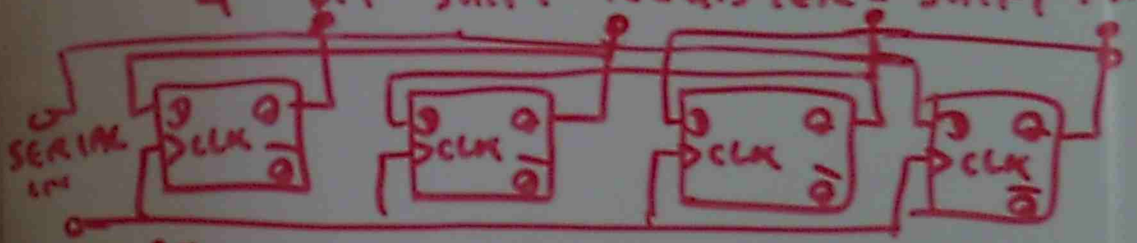
DIVIDER

RIGHT DIVIDER { LEFT — MULTIPLIER

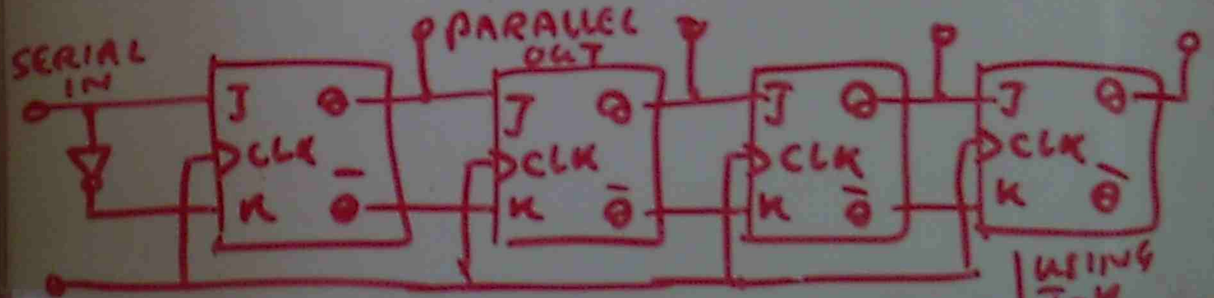
SHIFT REGISTER CONSTRUCTION



4 BIT SHIFT REGISTER - SHIFT RIGHT



4 BIT SHIFT REGISTER - SHIFT LEFT



A SHIFT RIGHT SHIFT REGISTER USING J-K FLIPFLOPS

DIGITAL SIGNAL PROCESSING

ELECTRICAL NOISE INTERFERENCE & DRIFT IN AMPLIFIER GAIN CAN BE INCLUDED IN ANALOGUE SIGNAL. DIGITALLY ENCODED IS NOT SUSPECTIBLE TO THE PROBLEM ASSOCIATED WITH ANALOG PROCESSING. DIGITAL COMPUTER REQUIRES INFORMATION ENCODED IN DIGITAL FORMAT BEFORE IT CAN BE USED.

NUMBER SYSTEM

$N_{10} = a_m 2^m + a_{m-1} 2^{m-1} + \cdots + a_2 2^2 + a_1 2^1 + a_0 2^0$

pb FIND THE BINARY EQUIVALENT OF 25

$$\begin{array}{r|rl} 2 & 25 & 1 \\ 2 & 12 & 0 \\ 2 & 6 & 0 \\ 2 & 3 & 1 \\ & 1 & \end{array} \qquad 11001_2$$

pb FIND BINARY EQUIVALENT OF 33_8

$33_8 = 3$ AND 3

$$\begin{array}{r|rl} 2 & 3 & 1 \\ 2 & 1 & \\ & 0 & \end{array} \qquad \therefore 011\ 011_2 \text{ OR } 11011_2$$

pb FIND DECIMAL EQUIVALENT OF 47H, 30DH

$47H = 4 \times 16^1 + 7 \times 16^0 = 71_{10}$

$30DH = 3 \times 16^2 + 0 \times 16^1 + (13) \times 16^0 = 781_{10}$

$D \Rightarrow 13$

pb FIND HEX DECIMAL EQUIVALENT OF 29_{10}

$$\begin{array}{r|rl} 16 & 29 & 13 \\ & 1 & \end{array} = 1\,(13) \to D = 1DH$$

FRACTIONAL BINARY NUMBERS

$N_{10} = b_1 2^{-1} + b_2 2^{-2} + \cdots - b_m 2^{-m}$

pb FIND BASE 10 EQUIVALENT OF THE BINARY NUMBER 0.110102

$N_{10} = 1 \times 2^{-1} + 1 \times 2^{-2} + 0 \times 2^{-3} + 1 \times 2^{-4} + 0 \times 2^{-5}$

$= \frac{1}{2} + \frac{1}{4} + \frac{1}{16} = 0.8125_2$

pb FIND THE BINARY, OCTAL AND HEX EQUIVALENT 0.3125_{10}

$0.3125_{10} \Rightarrow$
$2 \times 0.3125 = 0.6250 \rightarrow b_1 = 0$
$2 \times 0.625 = 1.250 \rightarrow b_2 = 1$
$2 \times 0.25 = 0.5 \rightarrow b_3 = 0$
$2 \times 0.5 = 1.0 \rightarrow b_4 = 1$

$\therefore 0.3125_{10} = 0101_2$

$0101 \rightarrow 0.010100$ PUT (0) $= 010, 100$

OCTAL CONVERSION

$0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 \Rightarrow 2$

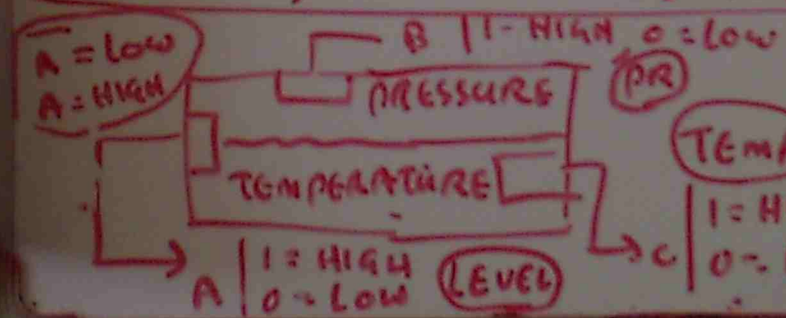
$1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0 \Rightarrow 4 = 24_8$

HEX DECIMAL CONVERSION

$0.0101 \rightarrow 0101\ 0000$ PUT =

$0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$ (6 0 H), $0 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$

(1) $D = \bar{A} \cdot B$, (2) $D = A \cdot C$ (3) $D = A\bar{C}B \rightarrow D = \bar{A}B + AC + A\bar{C}B$



ALARM
1. LOW LEVEL HIGH PR
2. HIGH LEVEL HIGH TEMP
3. HIGH LEVEL HIGH PR. HIGH TEMP

DIGITAL SIGNAL PROCESSING

ELECTRICAL NOISE INTERFERENCE & DRIFT IN AMPLIFIER GAIN CAN BE INCLUDED IN ANALOGUE SIGNAL. DIGITALLY ENCODED IS NOT SUSPECTIBLE TO THE PROBLEM ASSOCIATED WITH ANALOG PROCESSING. DIGITAL COMPUTER REQUIRES INFORMATION ENCODED IN DIGITAL FORMAT BEFORE IT CAN BE USED.

NUMBER SYSTEM

$N_{10} = a_m 2^m + a_{m-1} 2^{m-1} + \dots + a_2 2^2 + a_1 2^1 + a_0 2^0$

Pb FIND THE BINARY EQUIVALENT OF 25

2 | 25	1
2 | 12	0
2 | 6	0
2 | 3	1
1	

11001_2

Pb FIND BINARY EQUIVALENT of 33_8

33_8 = 3 AND 3

2 | 3	1
2 | 1	
0	

$\therefore 011\ 011_2$ OR 11011_2

Pb FIND DECIMAL EQUIVALENT of 47H, 30DH

$47H = 4 \times 16^1 + 7 \times 16^0 = 71_{10}$

$30DH = 3 \times 16^2 + 0 \times 16^1 + (13) \times 16^0 = 781_{10}$

D ⇒ 13

Pb FIND HEXDECIMAL EQUIVALENT OF 29_{10}

16 | 29	13 = D
1	

$29_{10} = 1(13)_{16} = 1DH$

FRACTIONAL BINARY NUMBERS

$N_{10} = b_1 2^{-1} + b_2 2^{-2} + \dots - b_m 2^{-m}$

Pb FIND BASE 10 EQUIVALENT OF THE BINARY NUMBER 0.110102

$N_{10} = 1 \times 2^{-1} + 1 \times 2^{-2} + 0 \times 2^{-3} + 1 \times 2^{-4} + 0 \times 2^{-5}$

$= \frac{1}{2} + \frac{1}{4} + \frac{1}{16} = 0.8125_2$

Pb FIND THE BINARY, OCTAL AND HEX EQUIVALENT 0.3125_{10}

$0.3125_{10} \Rightarrow$ $2 \times 0.3125 = 0.6250 \rightarrow b_1 = 0$

$2 \times 0.625 = 1.250 \rightarrow b_2 = 1$

$2 \times 0.25 = 0.5 \rightarrow b_3 = 0$

$2 \times 0.5 = 1.0 \rightarrow b_4 = 1$

$\therefore 0.3125_{10} = 0101_2$

$-0101 \rightarrow 0.010100$

OCTAL CONVERSION

PUT (0) = 010, 100

$0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$; $1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$

2 ; $4 = 24_8$

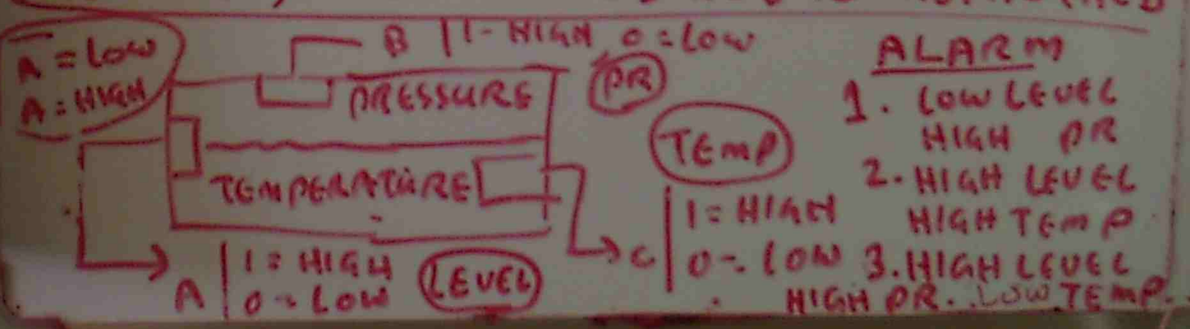
HEXADECIMAL CONVERSION

$0.0101 \rightarrow 0101\ 0000$ PUT =

$0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$, $0 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$

5 0H

(1) $D = \bar{A} \cdot B$, (2) $D = A \cdot C$ (3) $D = A\bar{C}B \rightarrow D = \bar{A}B + AC + A\bar{C}B$

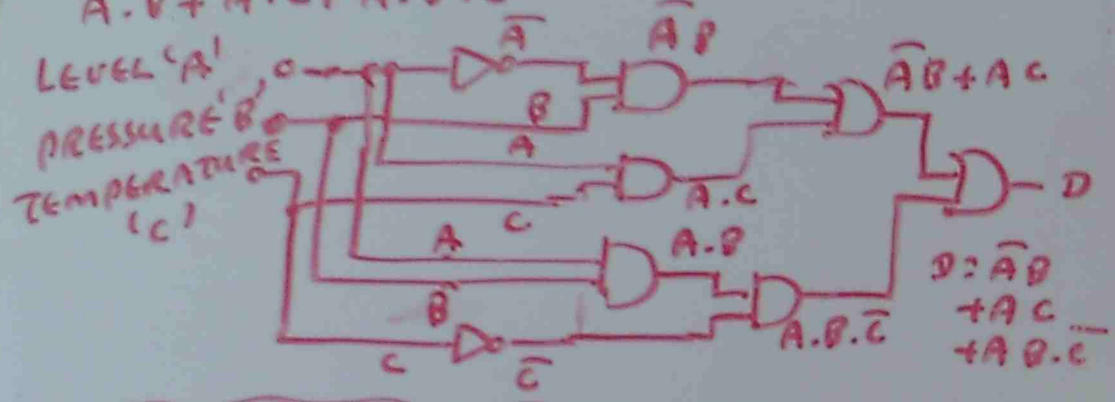


ALARM

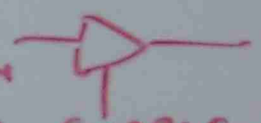
1. LOW LEVEL HIGH PR
2. HIGH LEVEL HIGH TEMP
3. HIGH LEVEL HIGH PR. LOW TEMP.

DEVELOP LOGIC GATE

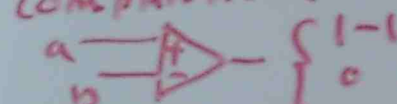
$\bar{A}.B + A.C + A.B.\bar{C}$



TRI STATE BUFFER



COMPARATOR



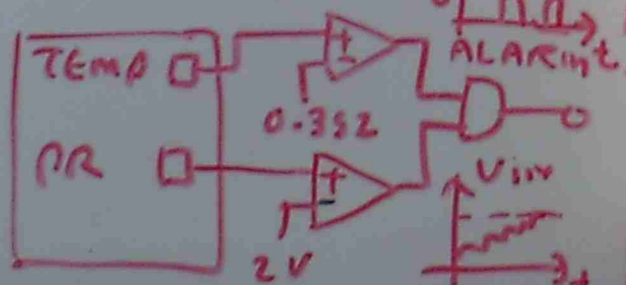
Pb/ A PROCESS CONTROL SYSTEM SPECIFIES THAT TEMPERATURE SHOULD NEVER EXCEED 160°C IF THE PRESSURE ALSO EXCEEDS 10 Pa. DESIGN AN ALARM SYSTEM TO DETECT THIS CONDITION USING TEMPERATURE AND PRESSURE TRANSDUCERS WITH TRANSFER FUNCTIONS OF 2.2 mV/°C AND 0.2V/Pa RESPECTIVELY.

TEMP → VOLT

$160 \times 2.2 \times 10^{-3} = 0.352V$

PRESSURE → VOLT

$0.2 \times 10 = 2V$



$V_{IN} = V_{REF} - \frac{R}{Rf} V_O$

HYSTERESIS COMPARATOR

DIGITAL TO ANALOG CONVERTER (DAC)

$V_{out} = V_R [b_1 2^{-1} + b_2 2^{-2} + --- b_m 2^{-n}]$

V_{out} = ANALOG OUTPUT VOLTAGE

V_R = REFERENCE VOLTAGE

$b_1\ b_2 \ldots b_m$ = n BIT BINARY WORD

$V_{out} = \frac{N}{2^n} V_{REF}$

Pb/ WHAT IS THE OUTPUT VOLTAGE OF A 10 BIT DAC WITH 10V REFERENCE IF INPUT IS (a) 001 0110 101 (b) 20FH

(a) 001 01 10 101 = 10 BIT

$V_{out} = V_{REF} [2^{-1} + \ldots 2^{-10}]$

$= 10 [0\times2^{-1} + 0\times2^{-2} + 1\times2^{-3} + 0\times2^{-4} + 1\times2^{-5} + 1\times2^{-6} + 0\times2^{-7} + 1\times2^{-8} + 0\times2^{-9} + 1\times2^{-10}]$

$= 10 \times 0.176\,7528 = 1.762\,528V$

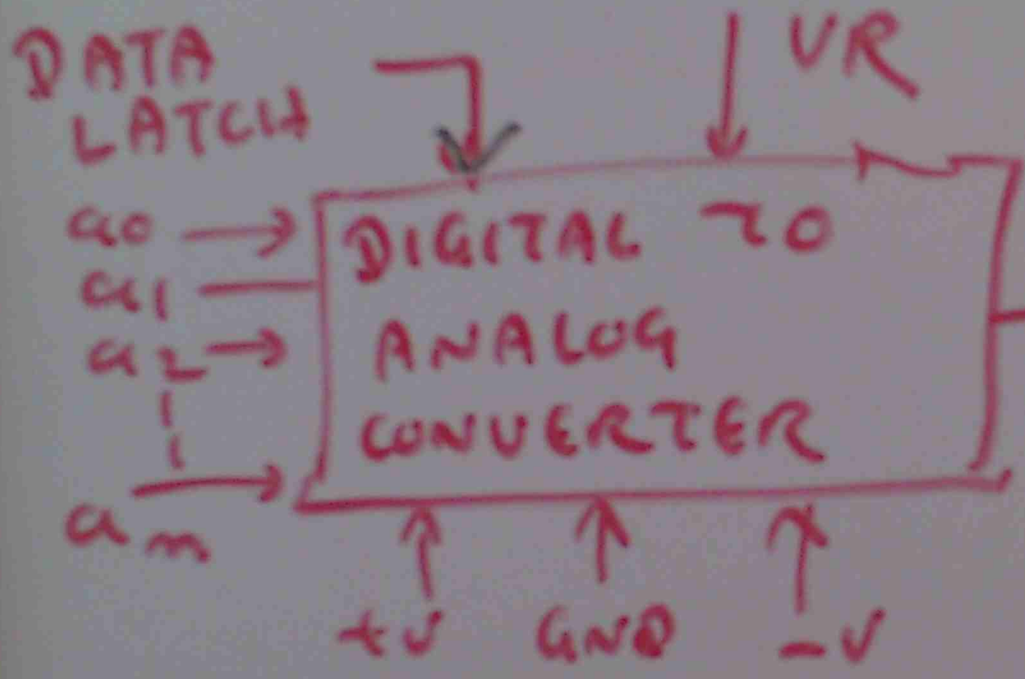
(b) $20FH = 2\times16^2 + 0\times16^1 + 15\times16^0 = 527_{10}$

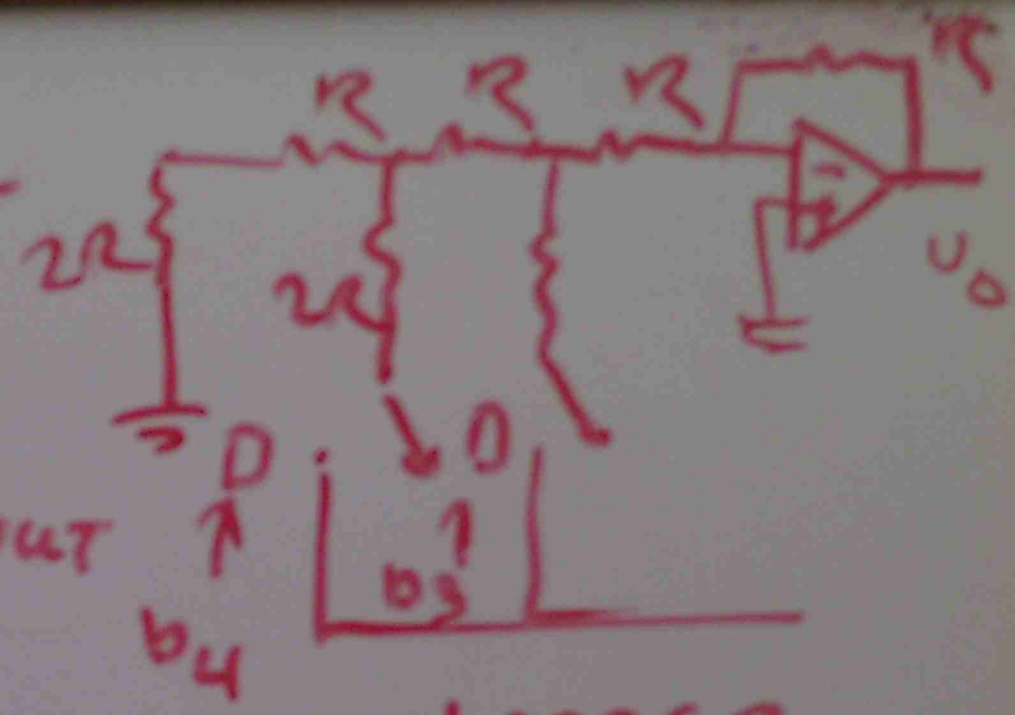
$V_{out} = \frac{N}{2^n} V_{REF} = \frac{527}{2^{10}} \times 10 = 5.1464V$

For 6.5V output $\rightarrow 6.5 = \frac{N}{2^{10}} \times 10 \Rightarrow N = 665.6$

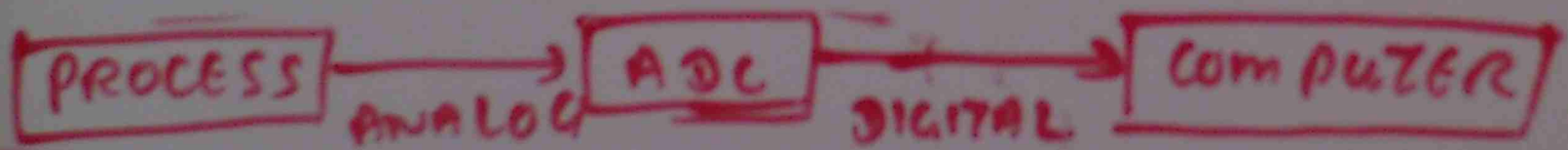
$\Delta V_{out} = V_N \times 2^{-n}$

DAC CHARACTERISTICS





ANALOG TO DIGITAL WANDERTER (ADC)



$\Delta V = V_R \bar{2}^m$

$V_{IN} = V_R [b_1 \bar{2}^1 + b_2 \bar{2}^2 + \dots]$

Pb TEMPERATURE IS MEASURED BY A SENSOR WITH OUT PUT 0.02 V/°C. DETERMINE ADC REF & WORD SIZE TO MEASURE 0 → 100°C WITH 0.1°C RESOLUTION

V_R = MAX TEMP × V/°C = 100 × 0.02 = 2V, ΔV = RESOLUTION × V/°C

$0.002 = 2 \times \bar{2}^m \rightarrow m = 10 \rightarrow V = V_R \times \bar{2}^n = 0.1 \times 0.02 = 0.002$

$= 10 \times \bar{2}^{10} = 0.00195V$

$INT(N) = \frac{1}{V_R} [V_{IN} + \frac{V_R}{2}] \times 2^m$ | $V_{REF} = 10V$, 8BIT

$\Delta V_{IN} = V_{REF} / 2^m = 10/2^8 = 0.039V/STEP$

Pb FIND THE DIGITAL WORD THAT RESULTS FROM A 3.127V INPUT TO A 5 BIT ADC WITH A 5V REFERENCE

$$V_{IN} = V_R \left[a_1 \bar{2}^1 + a_2 \bar{2}^2 + a_3 \bar{2}^3 + a_4 \bar{2}^4 + a_5 \bar{2}^5 \right]$$

$$3.127 = 5 \left[a_1 \bar{2}^1 + a_2 \bar{2}^2 + a_3 \bar{2}^3 + a_4 \bar{2}^4 + a_5 \bar{2}^5 \right]$$

$$\therefore a_1 \bar{2}^1 + a_2 \bar{2}^2 + a_3 \bar{2}^3 + a_4 \bar{2}^4 + a_5 \bar{2}^5 = \frac{3.127}{5} = 0.6254V$$

DIGITAL

$0.6254 \times 2 = 1.2508 \longrightarrow a_1 = 1$
$0.2508 \times 2 = 0.5016 \longrightarrow a_2 = 0$
$0.5016 \times 2 = 1.0032 \longrightarrow a_3 = 1$
$0.0032 \times 2 = 0.0064 \longrightarrow a_4 = 0$
$0.0064 \times 2 = 0.0128 \longrightarrow a_5 = 0$

OUTPUT = 10100_2

Pb THE INPUT TO A 10 BIT ADC WITH A 2.5V REFERENCE IS 1.45V. WHAT IS THE HEX OUTPUT. SUPPOSE THE OUTPUT WAS FOUND TO BE 1B4H. WHAT IS THE OUTPUT VOLTAGE?

(a) INTEGER PART OF ACTUAL OUTPUT (N) $= \frac{V_{IN}}{V_R} \times 2^n$

$= \frac{1.45}{2.5} \times 2^{10} = 593$

16 | 593 → 1
16 | 37 → 5
2

251_H

(b) $1B4H = 1 \times 16^2 + 11 \times 16^1 + 4 \times 16^0 = 436V$

$INT(N) = \frac{V_{IN}}{V_R} \times 2^n$

$436 = \frac{V_{IN}}{2.5} \times 2^{10} \longrightarrow \left\{ V_{IN} = \frac{436 \times 2.5}{2^{10}} = 1.06445 \text{ V} \right.$

BIPOLAR OPERATION

A BIPOLAR ADC IS ONE WHICH ACCEPTS INPUT BIPOLAR VOLTAGE FOR CONVERSION INTO AN APPROPRIATE DIGITAL OUTPUT.

$$INT(N) = \frac{1}{V_R} \left[V_{IN} + \frac{V_R}{2} \right] \times 2^n$$

Pb REFERENCE VOLTAGE = 10V, 8BIT

$$\Delta V_{IN} = \frac{V_{REF}}{2^n} \rightarrow \frac{10}{2^8} = 0.039V$$

(for −5V) ZERO STEP = −5V ⇒ 00000000_2 (8 BIT)

1 STEP → 0.039 V

$(-5) - (-0.039) = -4.961 \rightsquigarrow 00000001_2$

$-4.961 - (-0.039) = -4.822 \rightsquigarrow 00000011_2$

$-4.822 - (-0.039) = -4.783 \rightsquigarrow 00000111_2$

↓

INCREASE → DECIMAL IS REPRESENTED

$-0.039 \Rightarrow 00000001$

$+0.039 \Rightarrow 10000000$ → OPPOSITE 01111111_2

Pb WHAT IS THE HEX AND BINARY OUTPUT OF A BIPOLAR 12 BIT ADC WITH A 5V REFERENCE FOR INPUTS OF −0.35V AND +1.5V? WHAT INPUT VOLTAGE WOULD CAUSE OUTPUT 72H

$$INT(N) = \frac{1}{V_R} \left[V_{IN} + \frac{V_R}{2} \right] 2^n$$

$$= \frac{1}{5} \left[-0.35 + \frac{5}{2} \right] \times 2^8 = 84V$$

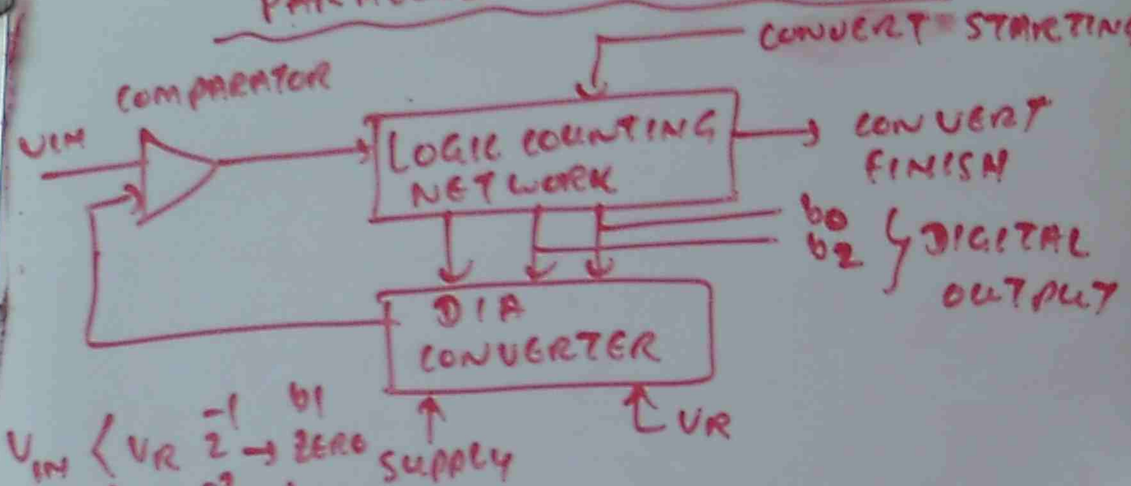
$84_{10} \rightarrow$ HEX: 16 | 84 → 4 ; 5 → $= 54_H$

$84_{10} \rightarrow$ BINARY: $1010100 \rightarrow 01010100_2$

2 | 84 0
2 | 42 0
2 | 21 1
2 | 10 0
2 | 5 1
2 | 2 0
1

$72H \rightarrow 7 \times 16^1 + 2 \times 16^0 = 114$ | $114 = \frac{1}{5} \left[V_{IN} + \frac{5}{2} \right] \times 2^8$ | $V_{IN} = -0.278V$

PARALLEL FEEDBACK ADC



$V_{IN} < V_R\,\bar{2}^{-1} \rightarrow b_1$ ZERO

$V_{IN} > V_R\,\bar{2}^{2} \rightarrow b_2$ 1

Ph FIND THE SUCCESSIVE APPROXIMATION ADC OUTPUT FOR A 4 BIT CONVERTER TO A 3.217V INPUT IF THE REF IS 5V.

(1) I/P = 3.217V → SET n=1, VREF = 5V

$V_F = V_{REF} \times \bar{2}^{n} = 5 \times \bar{2}^{1} = 2.5V$

$V_{IN} > V_{REF} \rightarrow b_1 = 1$

(2) I/P = 3.217V SET n = 2

$V_F = V_{REF} \times \bar{2}^{n} + \frac{V_{REF}}{2} = 5 \times \bar{2}^{2} + \frac{5}{2} = 3.75V$

V_{IN} 3.217 < V_F 3.75 → $b_2 = 0$

(3) I/P = 3.217V SET n = 3

$V_F = V_{REF} \times \bar{2}^{n} + \frac{V_{REF}}{2} = 5 \times \bar{2}^{3} + \frac{5}{2} = 3.125$

V_{IN} 3.217 > V_F 3.125 → $b_3 = 1$

ZIP 3.217 SET n = 4

REF = 5V

$V_F = V_{REF} \times \bar{2}^{n} + \frac{V_{REF}}{2} = 5 \times \bar{2}^{4} + \frac{5}{2} = 3.437V$

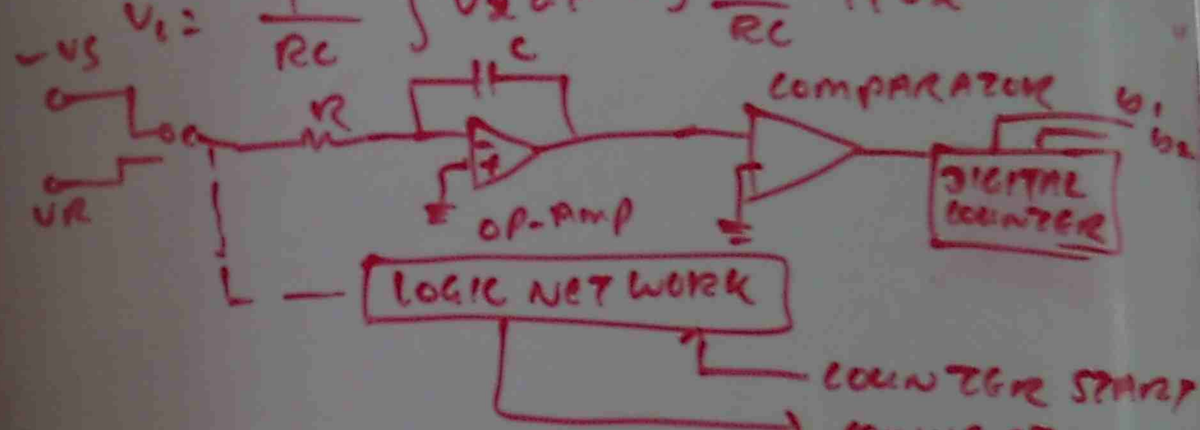
3.217 < V_F 3.437 $b_4 = 0$

$b_1\ b_2\ b_3\ b_4 = 1010_2$

RAMP A/D

COMPARE INPUT VOLTAGE TO A LINEARILY INCREASING RAMP VOLTAGE

DUAL SLOPE RAMP A/D



$V_1 = \frac{1}{RC} \int V_x\,dt \rightarrow \frac{1}{RC} T_1 V_x$

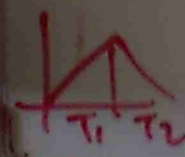
Ph DUAL SLOPE ADC

R = 100 KΩ C = 0.01 μF

V_{REF} = 10V, CONVERSION TIME = 10ms

FIND CONVERSION TIME FOR 6.8 V INPUT

$I_{V_1} = \frac{1}{RC} T_1 V_x = \frac{10ms \times 6.8}{100K\Omega \times 0.01\mu F} = 6.8V$



$t_x = \frac{T_1 V}{V_R} = \frac{10ms \times 6.8}{10V} = 6.8ms$

Ph A TEMPERATURE MEASUREMENT USE A SENSOR THAT OUTPUT 6.5 mV/°C MUST MEASURE TO 100°C A 6 BIT ADC WITH A 10V REF IS USED (a) DEVELOP A CIRCUIT TO INTERFACE WITH THE SENSOR AND ADC. (b) FIND TEMPERATURE RESOLUTION.

mV/°C × Δt = SENSOR OUTPUT

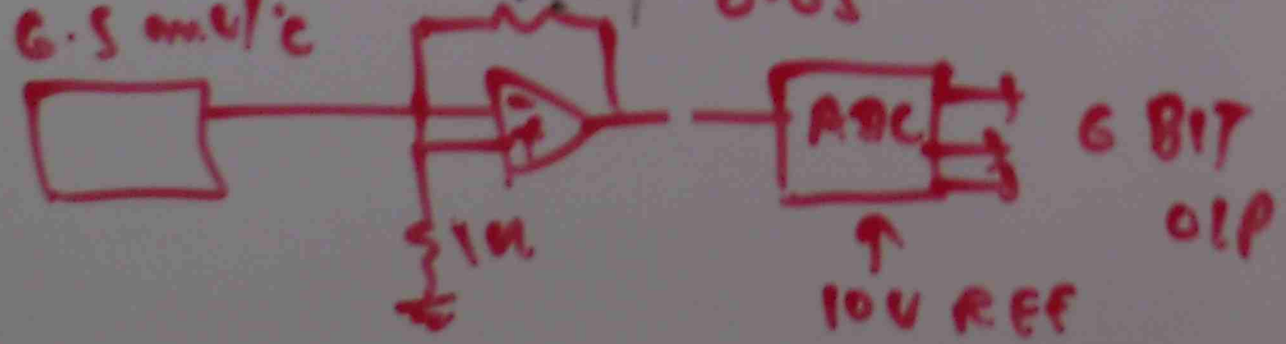
6.5 mV/°C × 100°C = 0.65V

$V_{OUT} = V_R(a_1 2^{-1} + a_2 2^{-2} + \dots a_6 2^{-6})$

$= 10(\frac{1}{2} + \frac{1}{2^2} + \dots \frac{1}{26})$

$= 9.84375V$

$GAIN = \frac{V_{OUT}}{V_{IN}} = \frac{9.84375}{0.65} = 15.14$



Temp resolution

$\frac{\Delta V}{V/°C} =$

$\Delta V = V_R \times 2^{-n}$

$= 10 \times 2^{-6} = 0.15625$ V

$\Delta V = \frac{\Delta V}{GAIN} = \frac{0.1526}{15.14}$

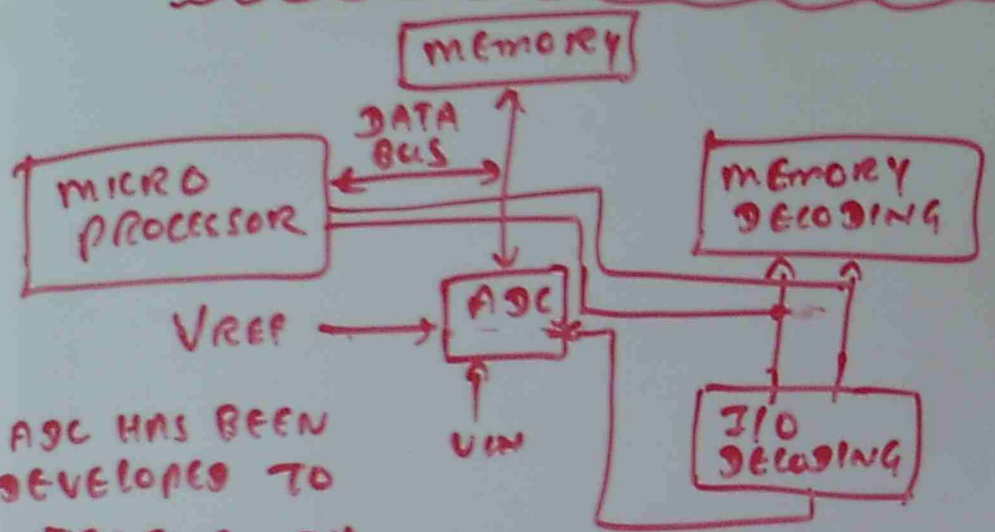
$= 0.01012$

$\Delta T = \frac{\Delta V_T}{V/°C} = \frac{0.01012}{6.5 \times 10^{-3}}$

$= 1.56°C$

SAMPLE & HOLD
MICROPROCESSOR
COMPATIBLE ADC

MICRO PROCESSOR COMPATIBLE ADC

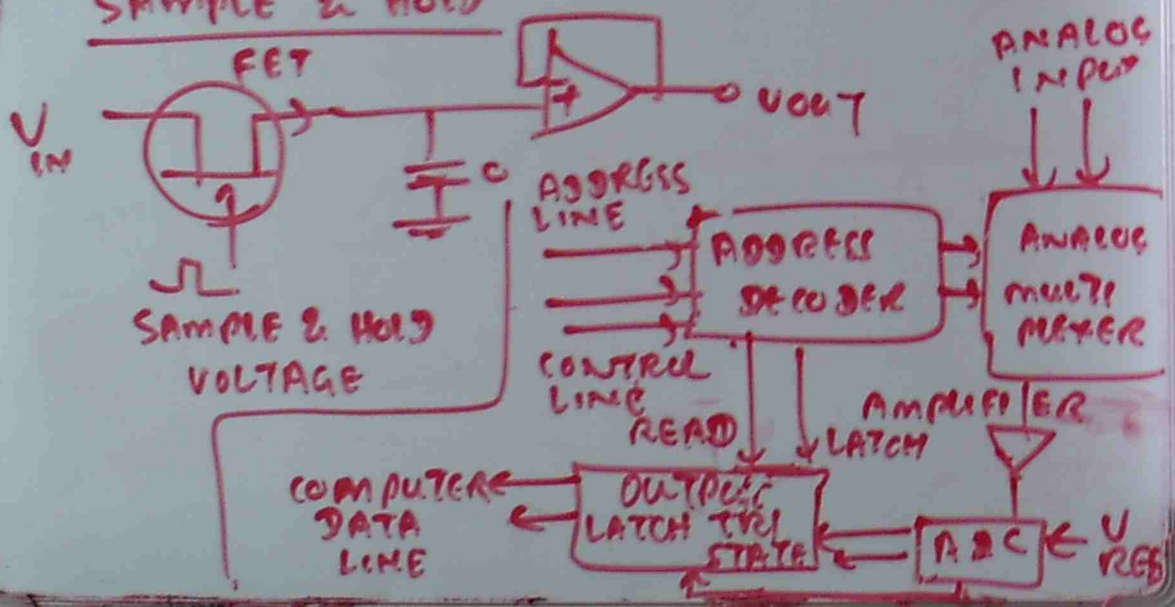


ADC HAS BEEN DEVELOPED TO INTERFACE WITH MICRO PROCESSOR
ADC - TRISTATE. DATA FROM ADC IS PLACED ON DATA BUS WHEN APPROPRIATE COMMAND IS ISSUES.

DATA INPUT BOARD

DATA INPUT BOARD, ADDRESSING, BUS INTERFACE

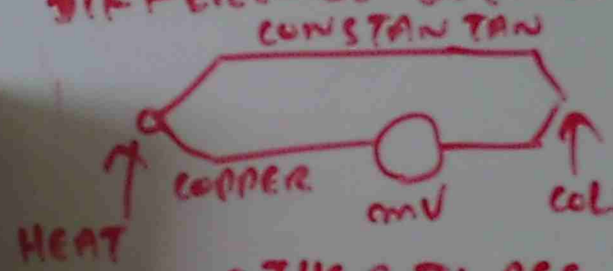
SAMPLE & HOLD



THERMOCOUPLE

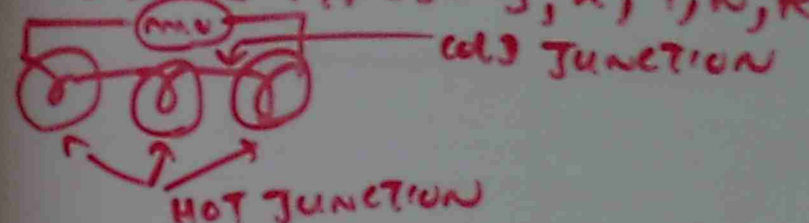
OPERATION

WHEN TWO DISSIMILAR METALS ARE JOINED AT ONE END (THE HOT JUNCTION) AND OTHER END JOINED (THE COLD JUNCTION) A VOLTAGE WILL BE DEVELOPED BETWEEN TWO JUNCTIONS IF THERE IS A TEMPERATURE DIFFERENCE BETWEEN TWO JUNCTIONS



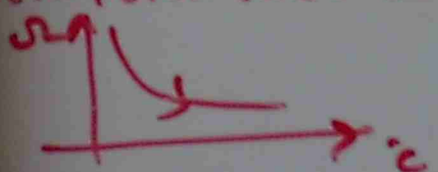
- CHROMEL - TYPE K
- IRON (+)
- CONSTANTAN (-) TYPE J

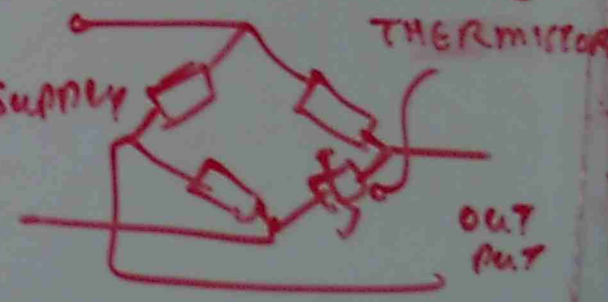
OTHER TYPES - J, K, T, N, R, S, E



THERMISTOR

TEMPERATURE DEPENDENT RESISTORS

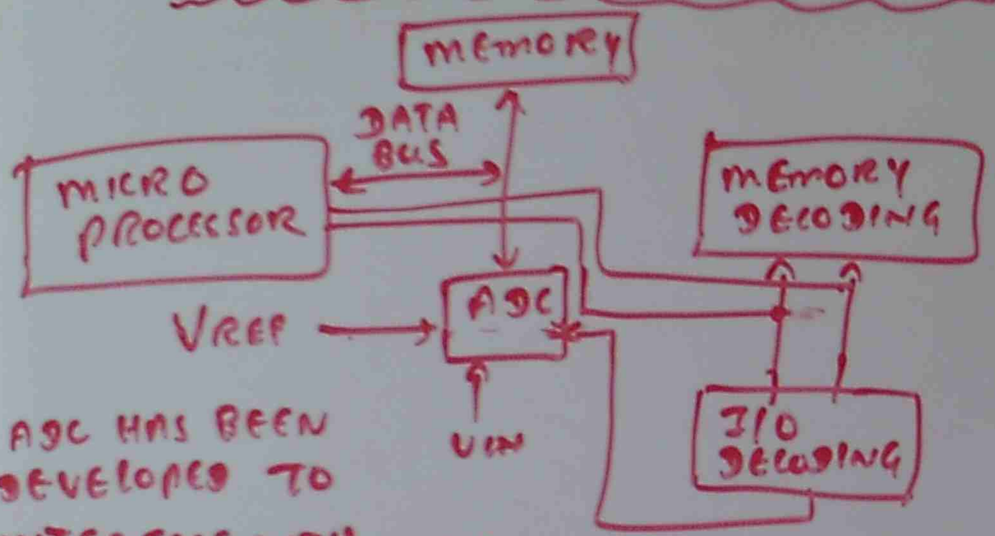




RTD RESISTANCE TEMPERATURE DETECTOR



MICRO PROCESSOR COMPATIBLE ADC



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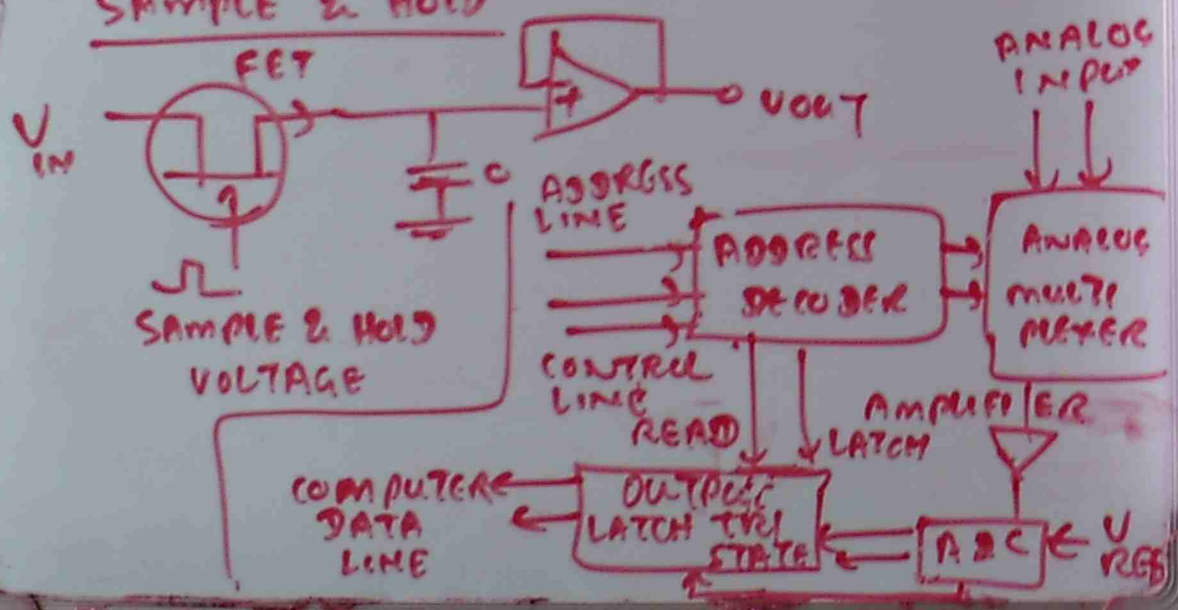
DATA INPUT BOARD

DATA INPUT BOARD, ADDRESSING, BUS INTERFACE

SAMPLE & HOLD



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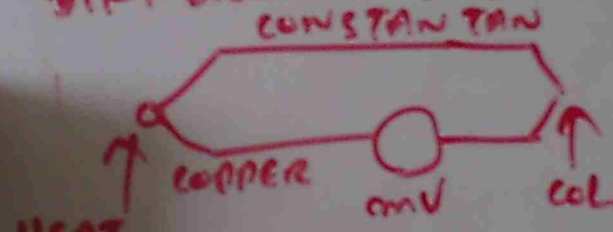

- CHROMEL - TYPE K
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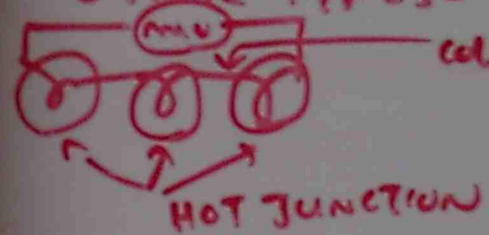
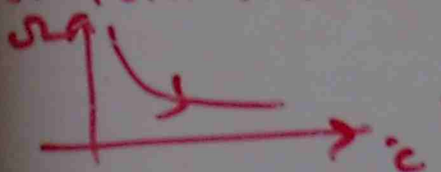
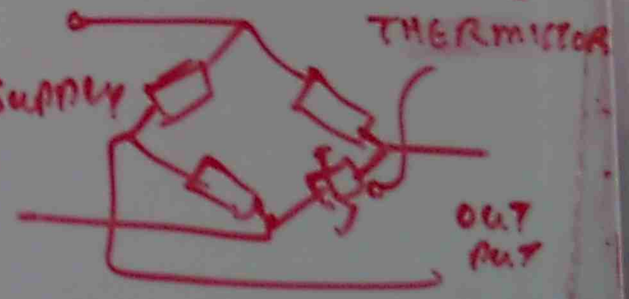


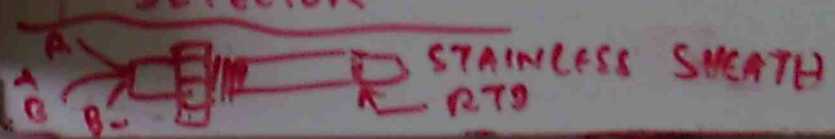
THERMISTOR

TEMPERATURE DEPENDENT RESISTORS

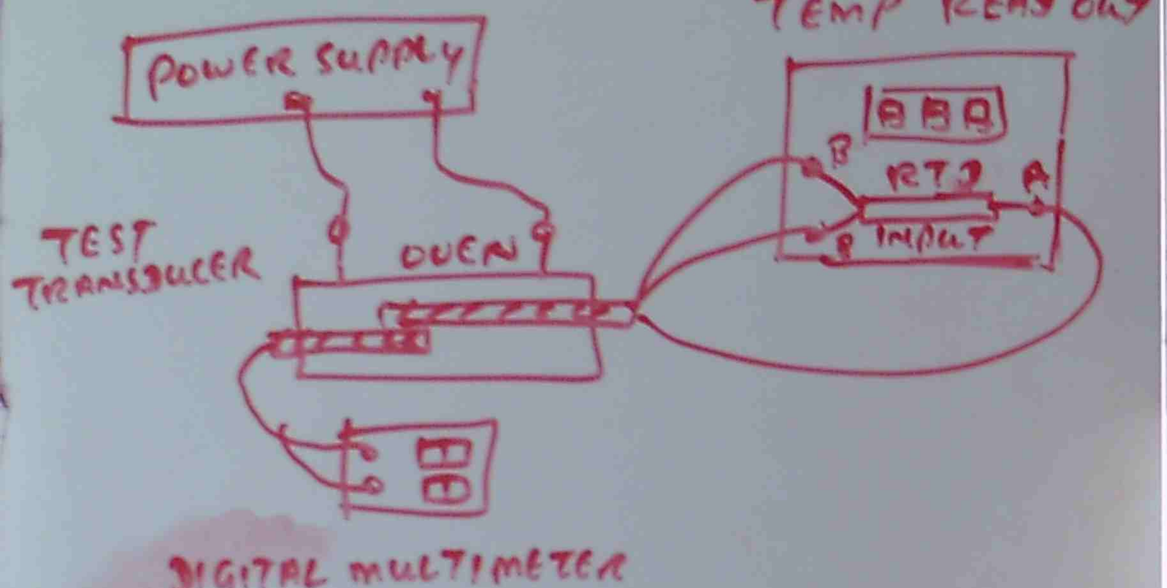




RTD RESISTANCE TEMPERATURE DETECTOR

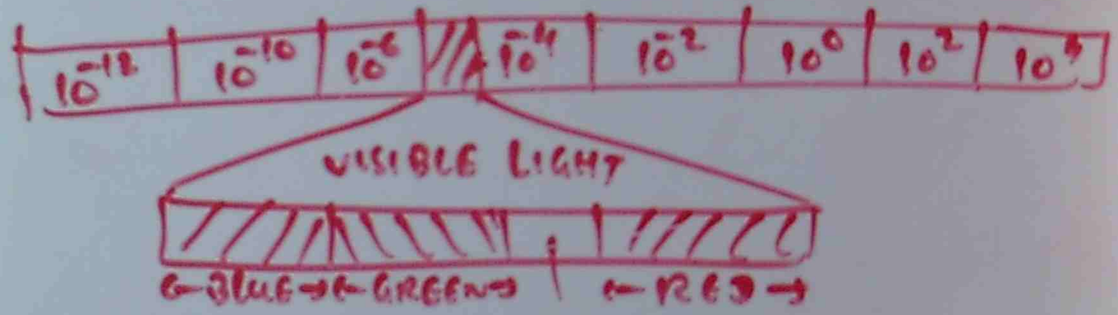


TEMPERATURE MEASUREMENT

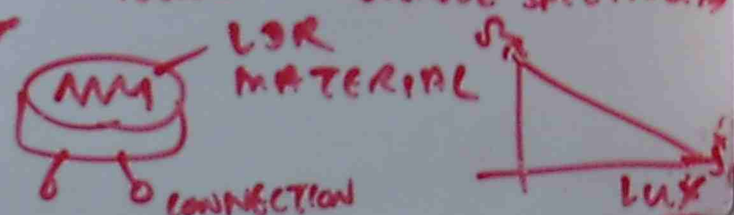


LIGHT

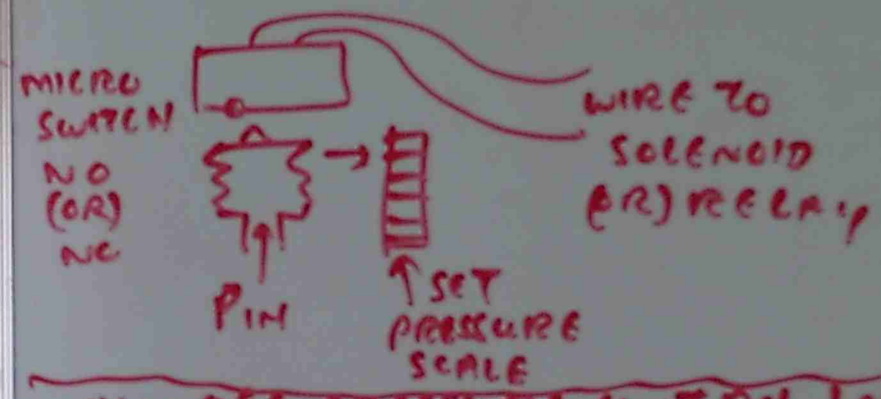
GAMMA RAYS | X-RAYS | UV | INFRA RED | MICRO WAVES | TV WAVE | SHORT WAVE | LONG WAVE



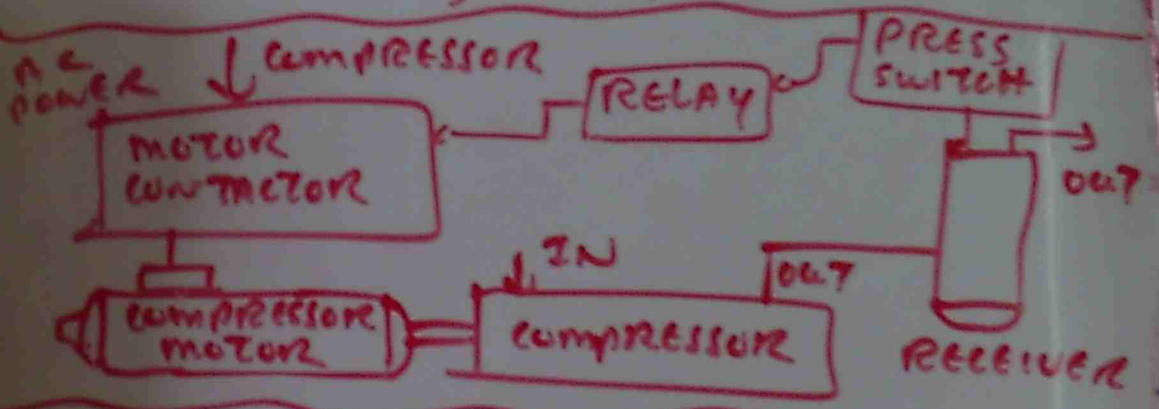
LDR - LIGHT DEPENDENT RESISTOR



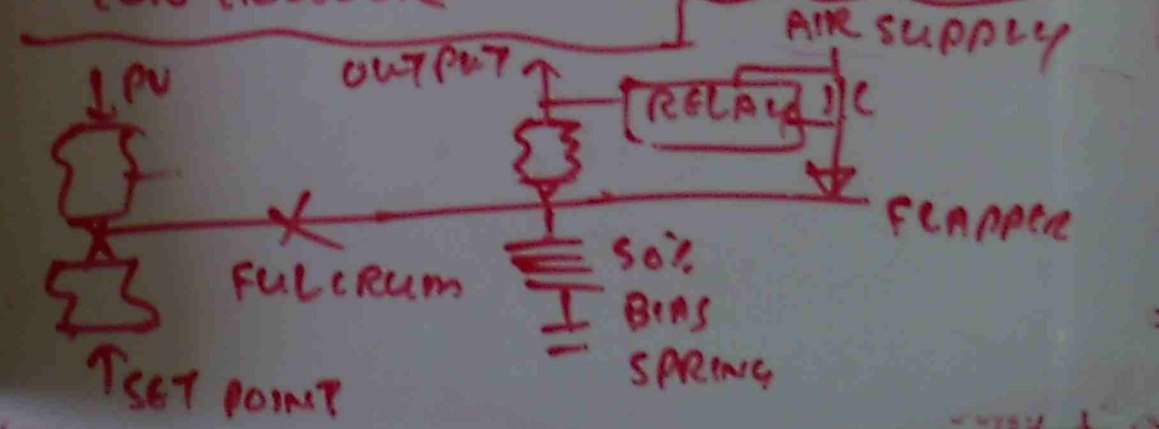
BELLOW OPERATED ON-OFF CONTROLLER



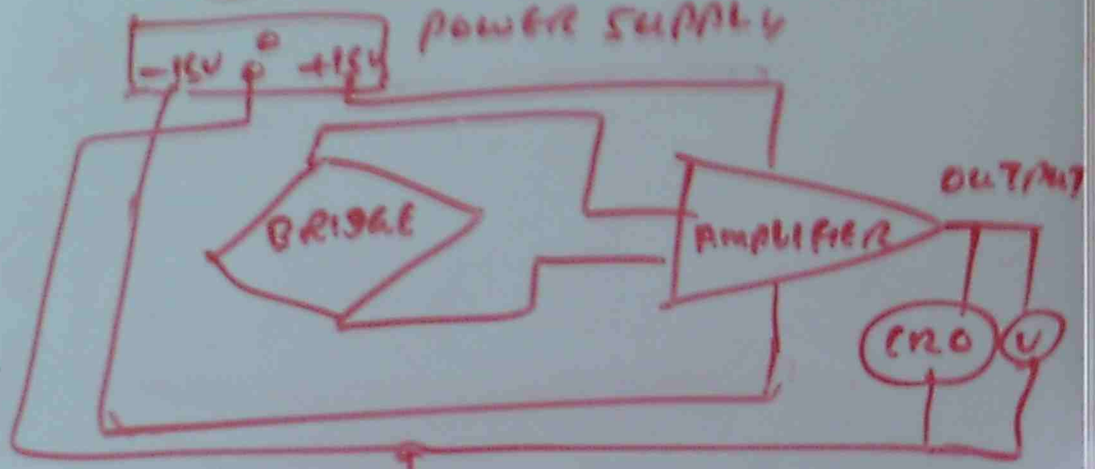
ON-OFF PRESSURE CONTROL LOOP SHOWING PRESSURE SWITCH, RELAY COMPRESSOR

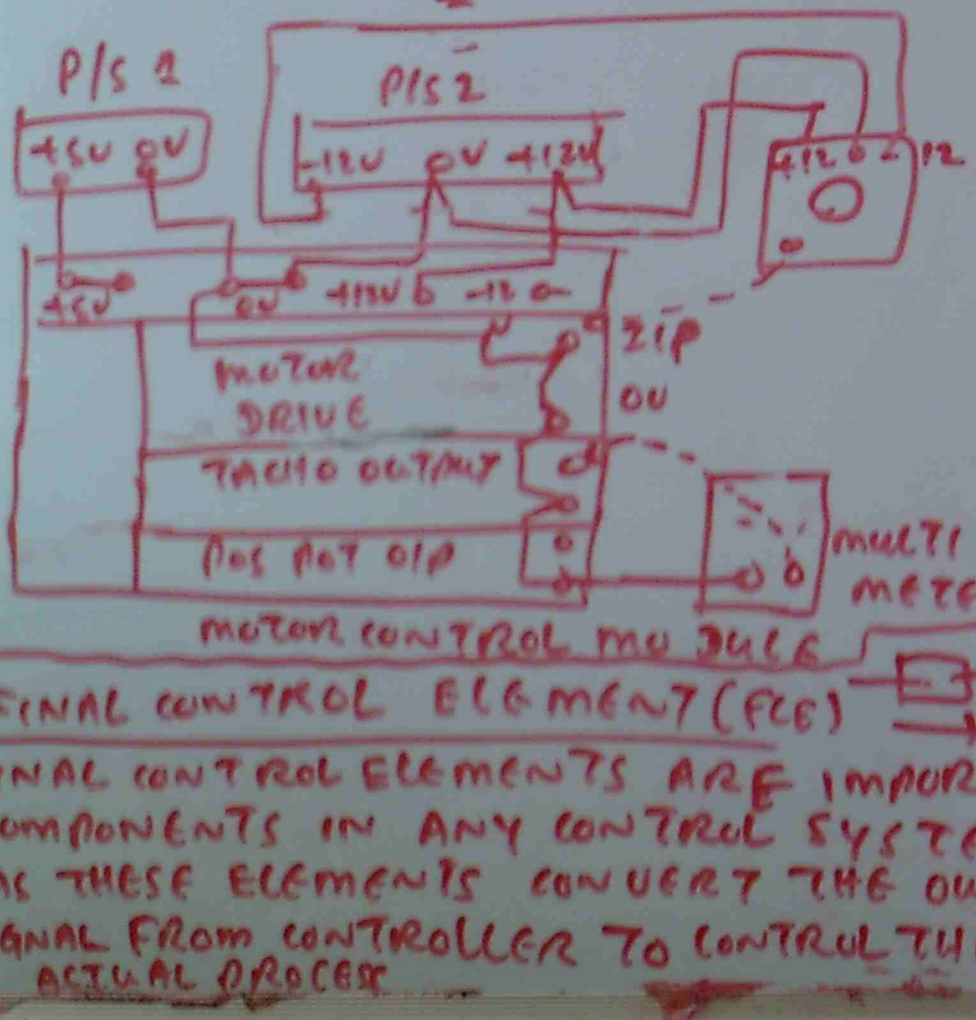


PNUEMATIC FORCE BALANCE PROPORTIONAL CONTROLLER



FORCE MEASUREMENT

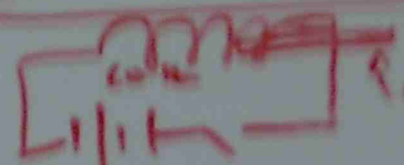




FINAL CONTROL ELEMENT (FCE)

FINAL CONTROL ELEMENTS ARE IMPORTANT COMPONENTS IN ANY CONTROL SYSTEM AS THESE ELEMENTS CONVERT THE OUTPUT SIGNAL FROM CONTROLLER TO CONTROL THE ACTUAL PROCESS

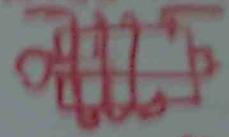
ELECTROMAGNETIC DEVICES



SOLENOID

RELAYS & CONTACTORS

REED RELAY

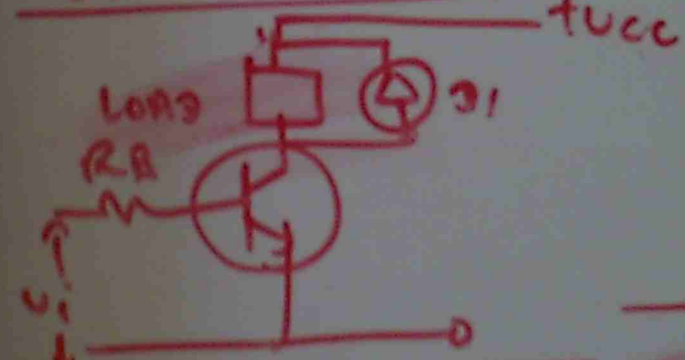


RELAY SELECTION

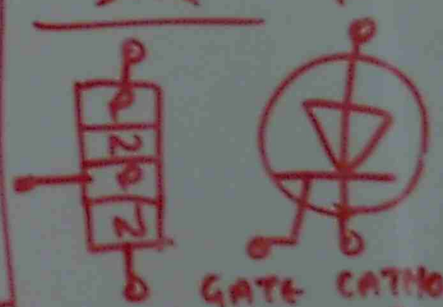
COIL TYPE, PICK UP VOLTAGE, OPERATING/RELEASE TIME, TEMPERATURE RANGE OF USE, CONTACT ARRANGEMENT, CONTACT CURRENT RATING



BJT TRANSISTOR

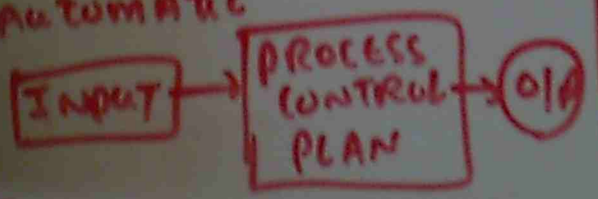


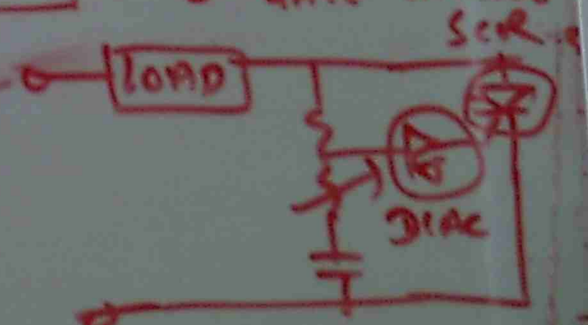
SCR



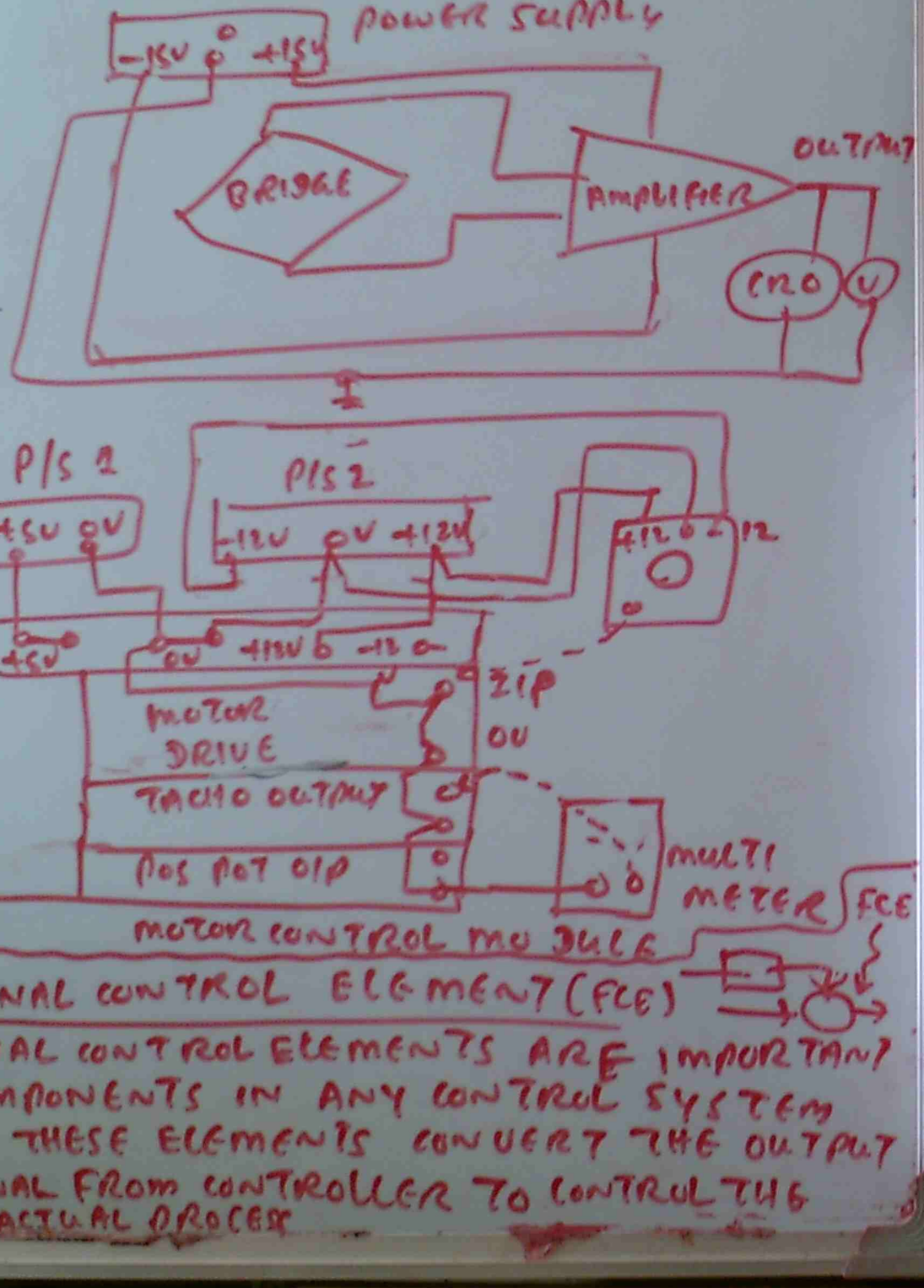
CONTROL SYSTEM

AUTOMATIC





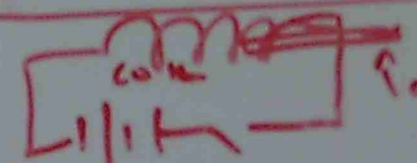
FORCE MEASUREMENT



FINAL CONTROL ELEMENT (FCE)

FINAL CONTROL ELEMENTS ARE IMPORTANT COMPONENTS IN ANY CONTROL SYSTEM AS THESE ELEMENTS CONVERT THE OUTPUT SIGNAL FROM CONTROLLER TO CONTROL THE ACTUAL PROCESS

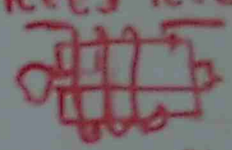
ELECTROMAGNETIC DEVICES



SOLENOID

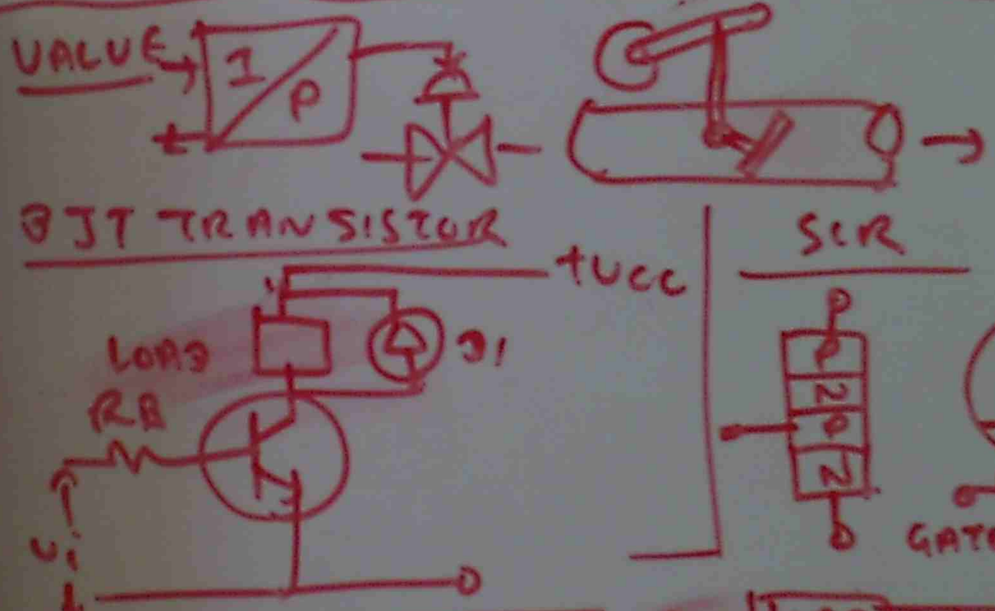
RELAYS & CONTACTORS

REED RELAY



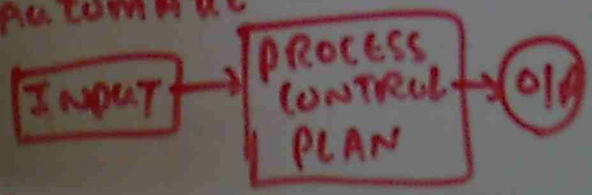
RELAY SELECTION

COIL TYPE, PICK UP VOLTAGE, OPERATING RELEASE TIME, TEMPERATURE RANGE OF USE CONTACT ARRANGEMENT, CONTACT CURRENT RATING



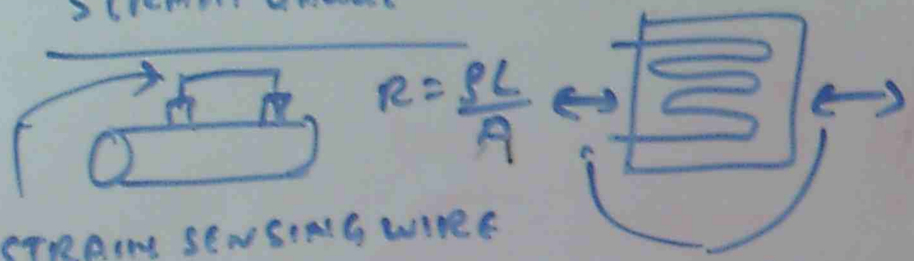
CONTROL SYSTEM

AUTOMATIC

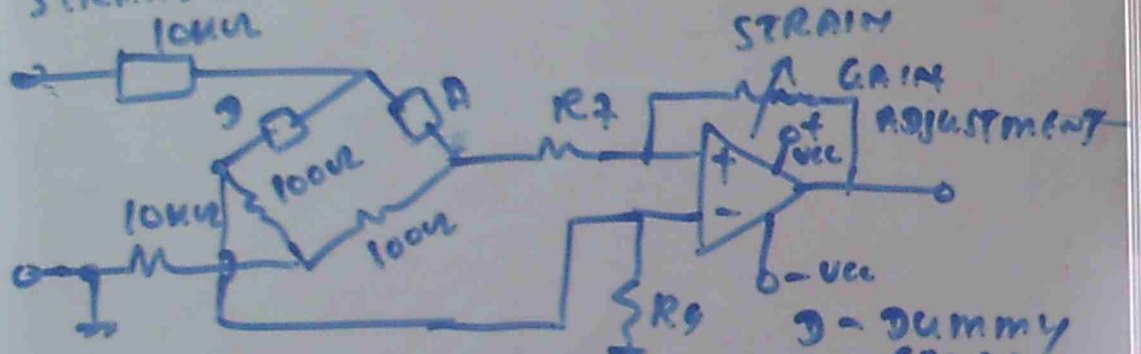


STRAIN GAUGE

$R = \frac{\rho L}{A}$



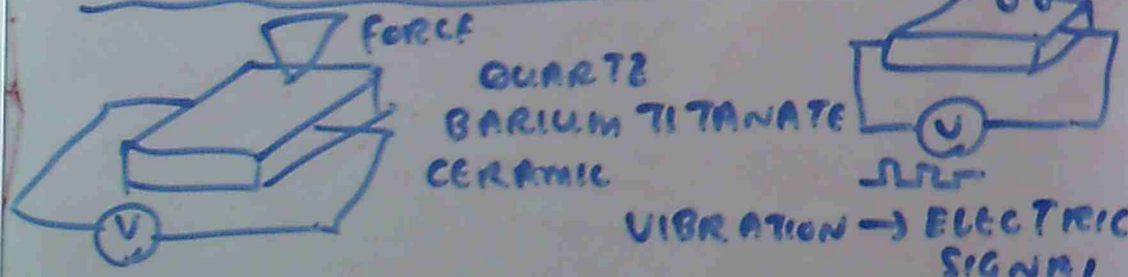
STRAIN SENSING WIRE



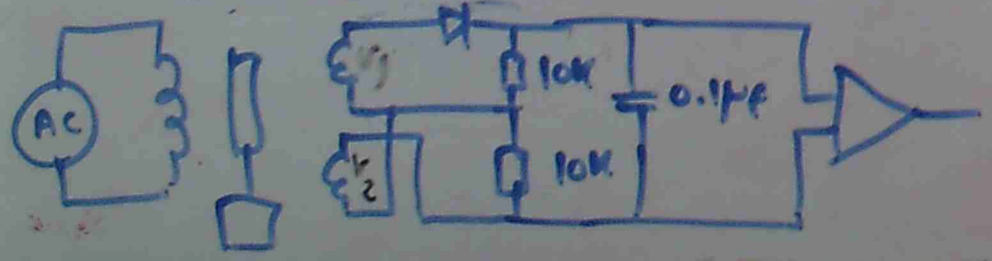
STRAIN GAUGE CIRCUIT

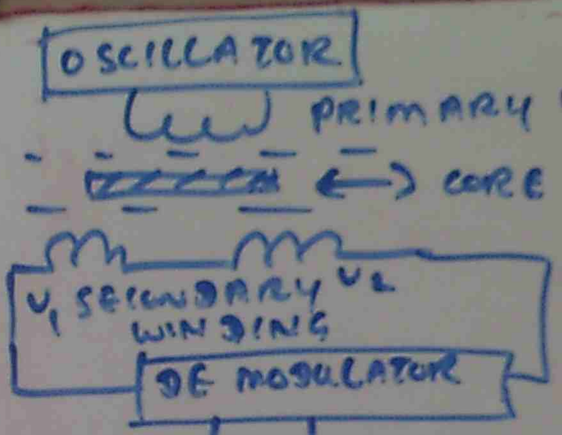
D - DUMMY GAUGE
A - ACTIVE GAUGE

PIEZO ELECTRIC EFFECT



LINEAR VARIABLE DIFFERENTIAL TRANSFORMER

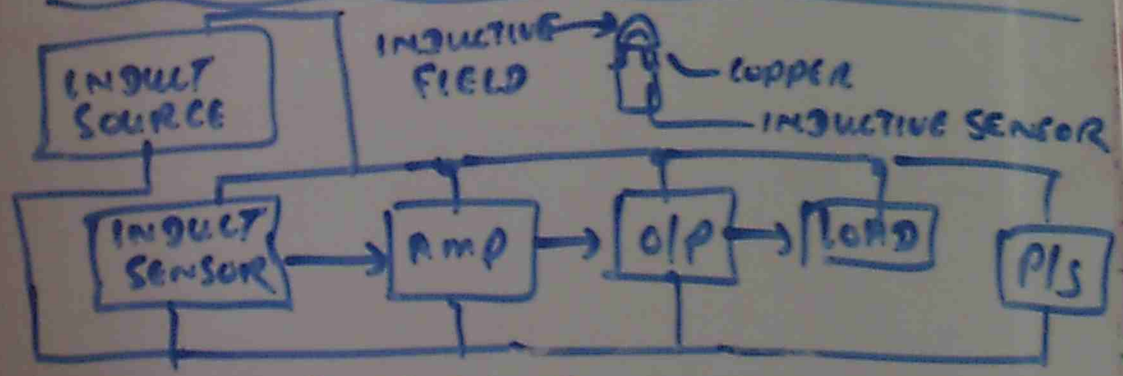




CORE MOVEMENT PRODUCES V_1 & V_2 IN SECONDARY WINDING DEPENDING ON THE POSITION OF CORE

OUTPUT VOLTAGE = $V_1 \sim V_2$

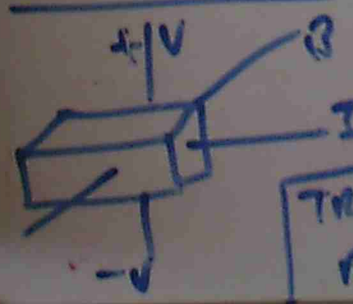
ELECTRONIC FIELD PROXIMITY SENSOR



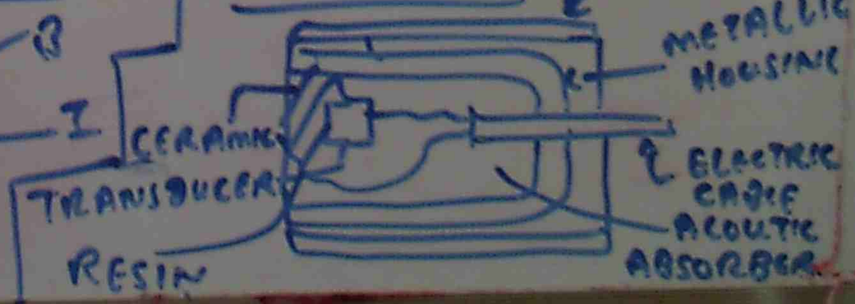
CAPACITANCE PROXIMITY DETECTOR

$C = \frac{AK}{d}$

HALL EFFECT



ULTRASONIC



SOUND

$\lambda = \frac{c}{f}$ λ = WAVE LENGTH (m)

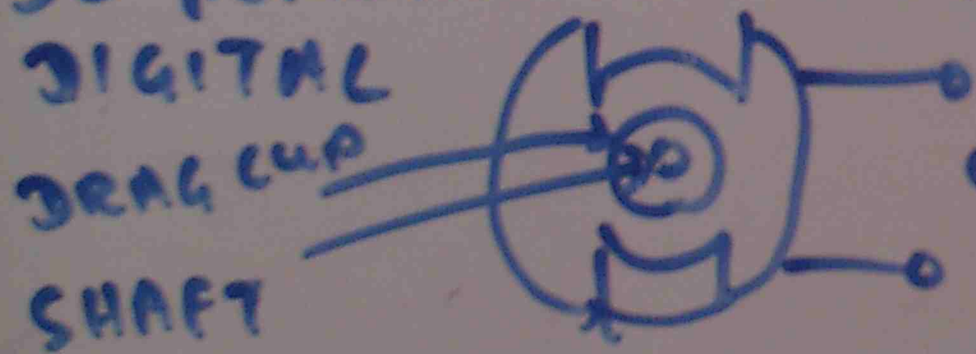
c = LIGHT SPEED

f = FREQUENCY HZ

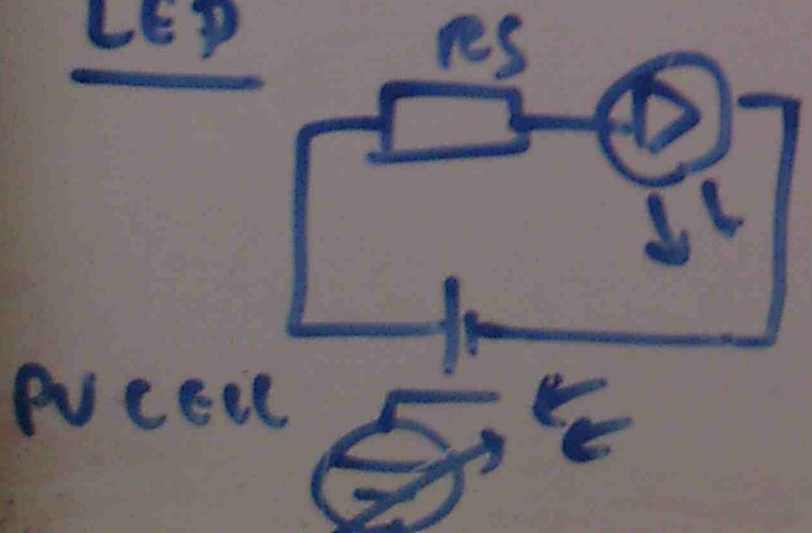
$dB = 20 \log_{10} \frac{P}{P_0}$ $dB = 10 \log_{10} \frac{I_1}{I_2}$

ANALOG TACHO METER

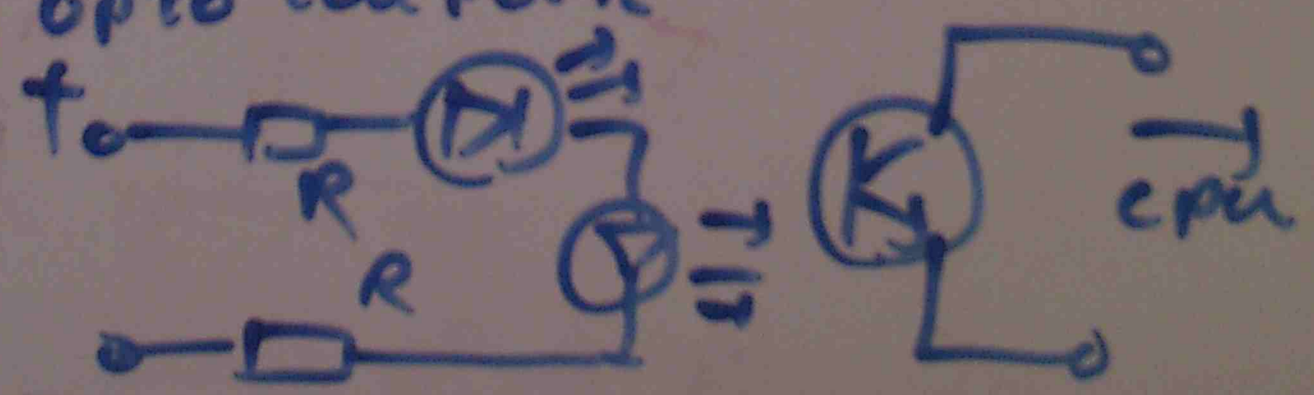
DC PERMANENT MAGNET / AC PERMANENT MAGNET



LED



OPTO COUPLER



PIEZO ELECTRIC EFFECT

SOURCE

(15) TYPES OF TRANSDUCERS

SLIDE (1) ⟶ (14)

@ 138 ⟶ @ 144

(16) SPEED MEASUREMENT

SLIDE (1) ⟶ (16)

@ 150 ⟶ @ 159

PROPORTIONAL MODE

- PROVIDE A CORRECTION THAT IS PROPORTIONAL TO THE SIZE (MAGNITUDE) OF ERROR
- STABILISE THE PROCESS

INTEGRAL MODE

- PROVIDE A CORRECTION THAT IS PROPORTIONAL TO THE TIME DURATION OF ERROR
- RETURN (RESET)

DERIVATIVE MODE

- PROVIDE A CORRECTION THAT IS PROPORTIONAL TO THE RATE OF CHANGE OF ERROR
- COMPENSATE FOR TIME LAG IN CONTROL LOOP



(6) DECODER + ENCODER
SLICE (1) → (22) @ 40 → @ 50

(9) DIGITAL SIGNAL PROCESSING
SLICE (1) → (20) | @ 51 → 63

(7) DIGITAL SIGNAL PROCESSING

SLIDE (1) → (20)
Q S1 → Q G3

(8) DACT FLIP FLOPT SENSOR

SLIDE (1) → (16)
Q G4 → Q 74

(4) ANALOG TO DIGITAL CONVERSION

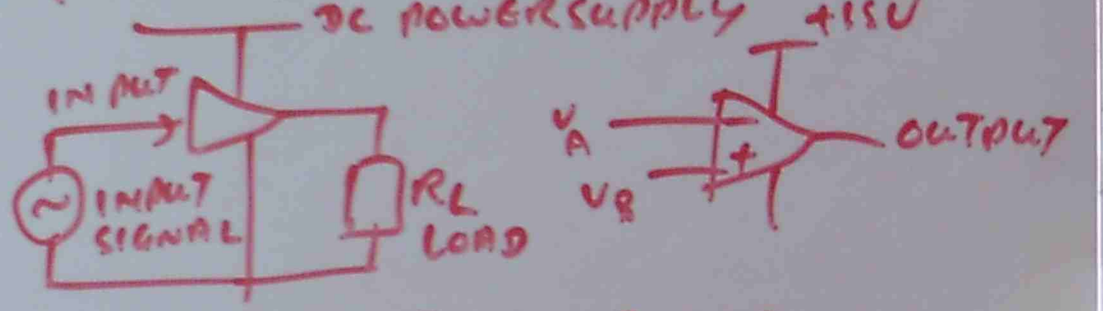
SLIDE (1) → 23
Q 35 → Q 83

(10) TEMPERATURE CONTROL

SLIDE 1 → 3 | Q 89

OPERATIONAL AMPLIFIER

- USED IN CLOSED LOOP OPERATION INVERTING, NON INVERTING, VOLTAGE FOLLOWER, INTEGRATOR, DIFFERENTIATOR



INDUSTRIAL TRANSDUCER

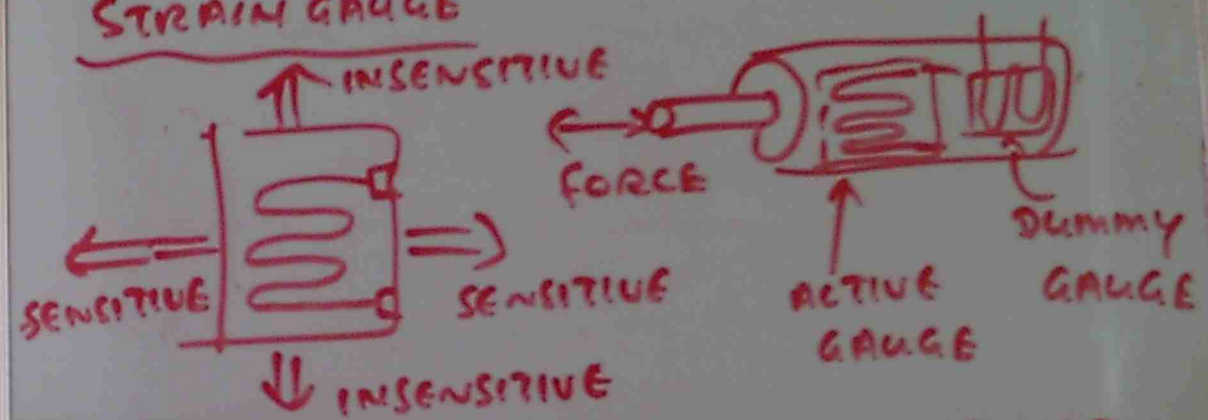
RADIANT (LIGHT, VISIBLE, INFRARED)
MECHANICAL (DISPLACEMENT, VELOCITY ACCELERATION, FORCE, PRESSURE)
THERMAL - TEMPERATURE, CONDUCTION HEAT FLOW
ELECTRICAL - VOLTAGE, CURRENT, RESISTANCE DIELECTRIC CONSTANT
MAGNETIC - MAGNETIC FLUX, FIELD STRENGTH
CHEMICAL - COMPOSITION, PH, ACIDITY

CHARACTERISTICS

RANGE, SPAN, LINEARITY, SENSITIVITY, RESOLUTION

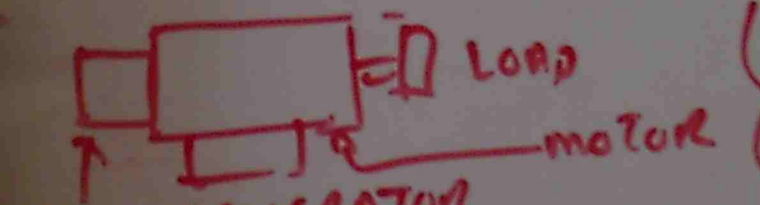
FORCE MEASUREMENT

STRAIN GAUGE



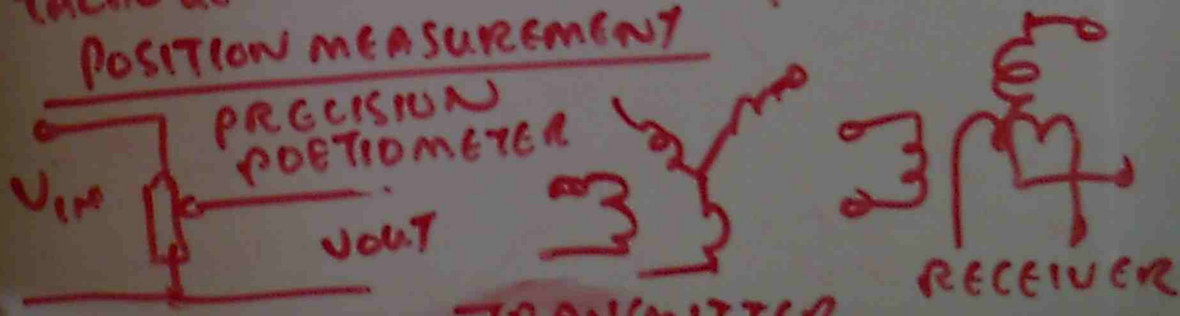
THE STRAIN, LOAD, TORQUE, ACCELERATION AND VIBRATION ON AN OBJECT CAN BE DETERMINED BY MEASURING THE DISPLACEMENT OF PRE-DETERMINED POINT
STRAIN GAUGE SENSES - TRANSVERSE / LONGITUDINAL STRAINS

SPEED MEASUREMENT

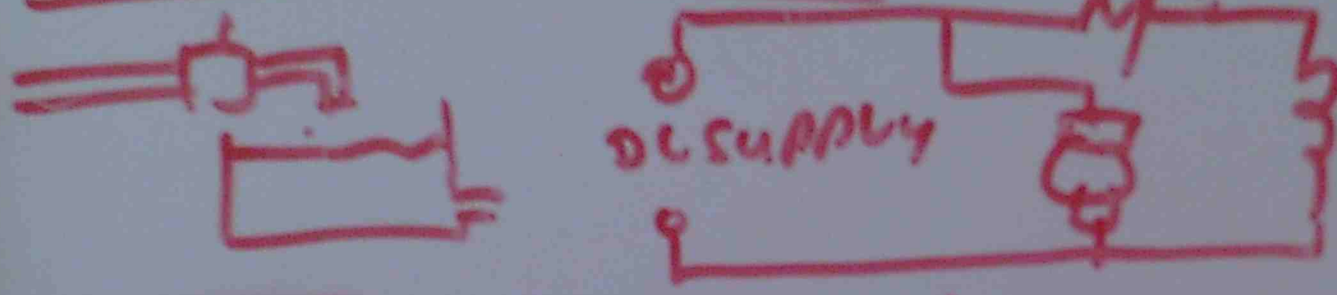


ENCODER
ANALOG → DIGITAL

POSITION MEASUREMENT

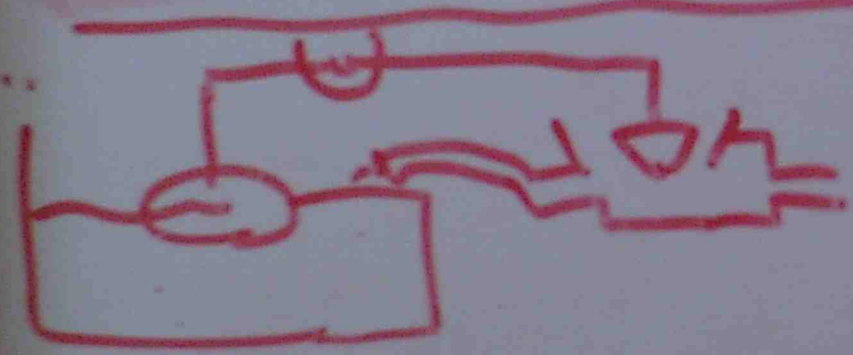


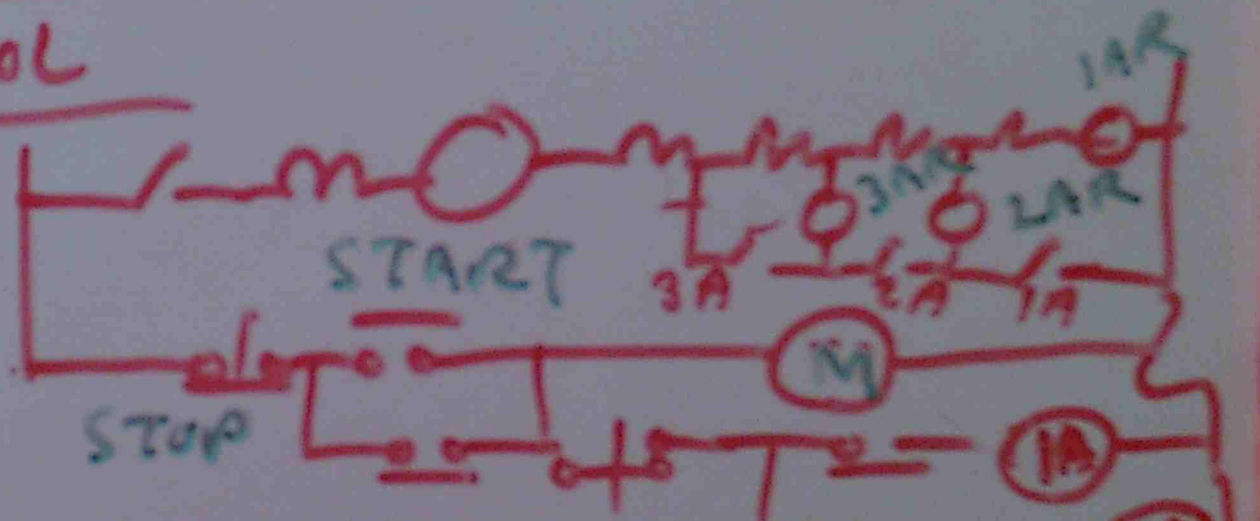
OPEN LOOP CONTROL



TIME LIMIT STARTER

CLOSED LOOP CONTROL





CONTROL LOOP

SENSING DEVICE, FEED BACK, CONTROLLER

\+ FEED BACK → REIN FORCE OUTPUT
INSTABILITY, INPHASE, GAIN INCREASE

— FEED BACK → 180° OUT OF PHASE,
DECREASE GAIN, STABILITY

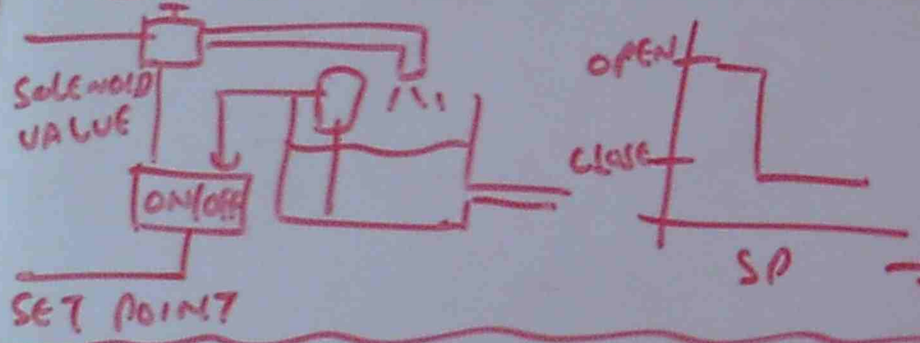
- CONTROL - ON/OFF
PROPORTIONAL | PROPORTIONAL + INTEGRAL
PROPORTIONAL + INTEGRAL + DERIVATIVE

PROPORTIONAL CONTROL - USED FOR STABILITY

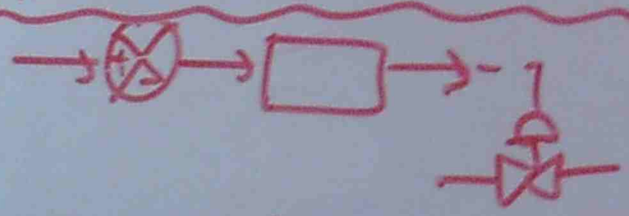
INTEGRAL CONTROL - USED TO ELIMINATE OFFSET DUE TO PROPORTIONAL ACTION

DERIVATIVE CONTROL - GIVES ANTIPATORY ACTION TO OVERCOME TIMELAG

ON/OFF CONTROL - LEVEL CONTROL



PROPORTIONAL CONTROL (P)



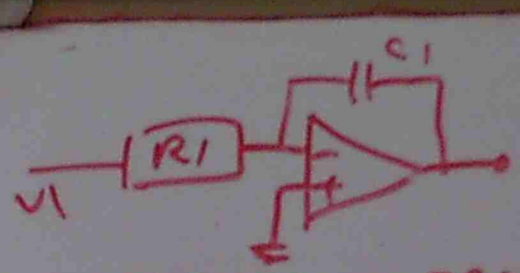
GAIN = CHANGE IN O/P / CHANGE IN I/P

OUTPUT = ERROR × CONTROLLER GAIN

PROPORTIONAL + INTEGRAL CONTROL

INTEGRAL - RESET

TOTAL CHANGE IN OUTPUT = CHANGE DUE TO PROPORTIONAL + CHANGE DUE TO INTEGRAL PROPORTION



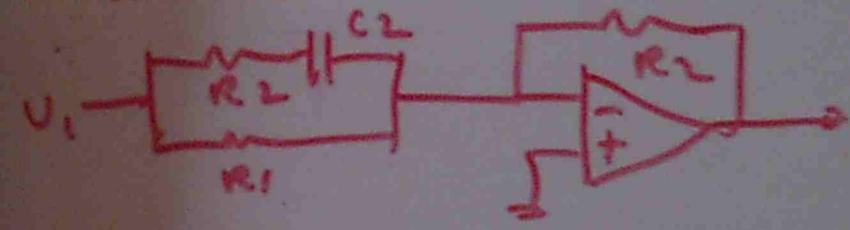
INTEGRAL CONTROL



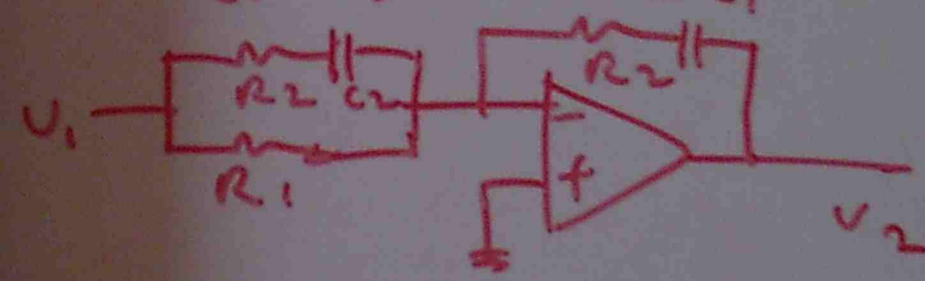
PROPORTIONAL + INTEGRAL CONTROL

DERIVATIVE CONTROL

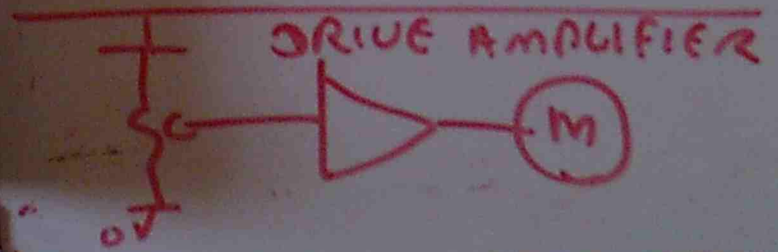
PROVIDE CORRECTION PROPORTIONAL TO THE RATE OF CHANGE OF ERROR



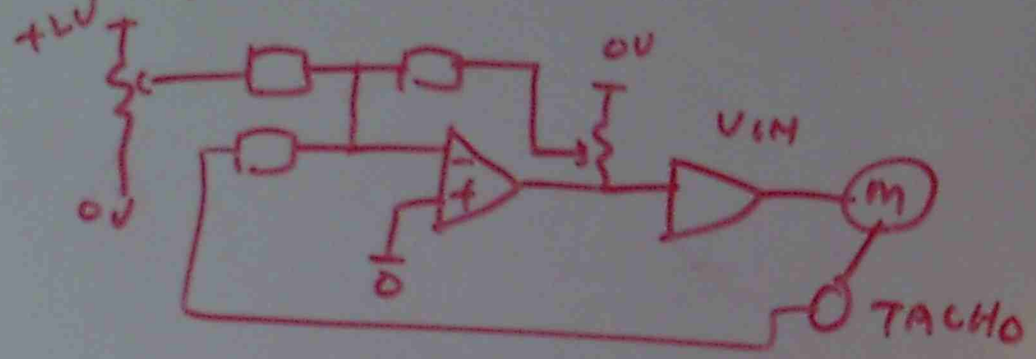
PROPORTIONAL + INTEGRAL + DERIVATIVE (PID) CONTROL



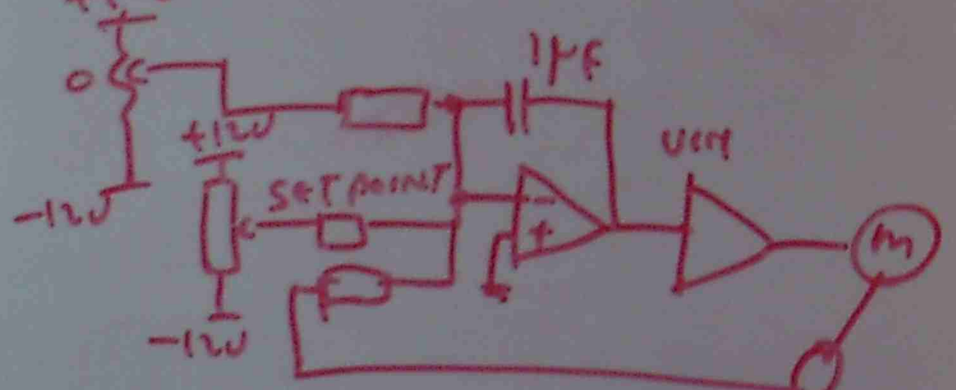
OPEN LOOP SPEED CONTROL



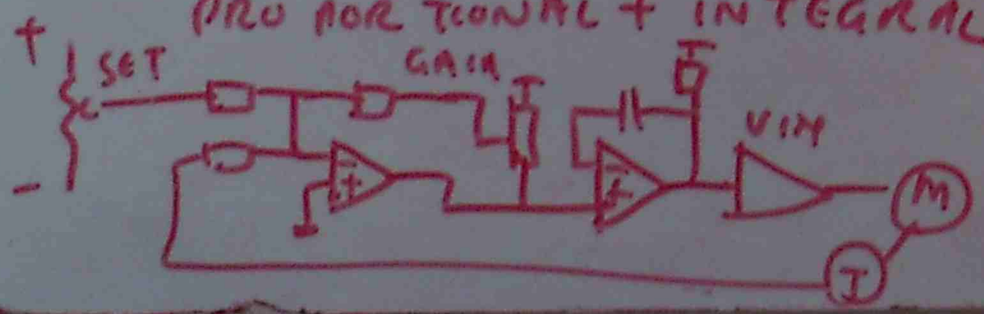
CLOSED LOOP SPEED CONTROL
- PROPORTIONAL CONTROL



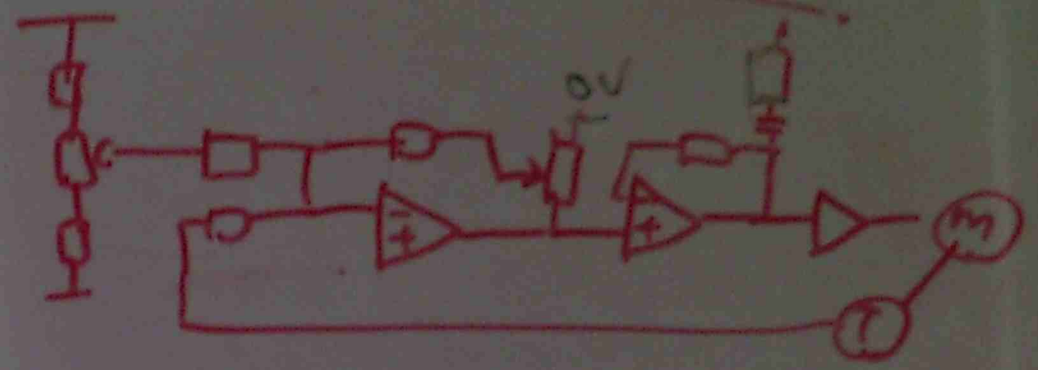
CLOSED LOOP SPEED CONTROL
INTEGRAL CONTROL



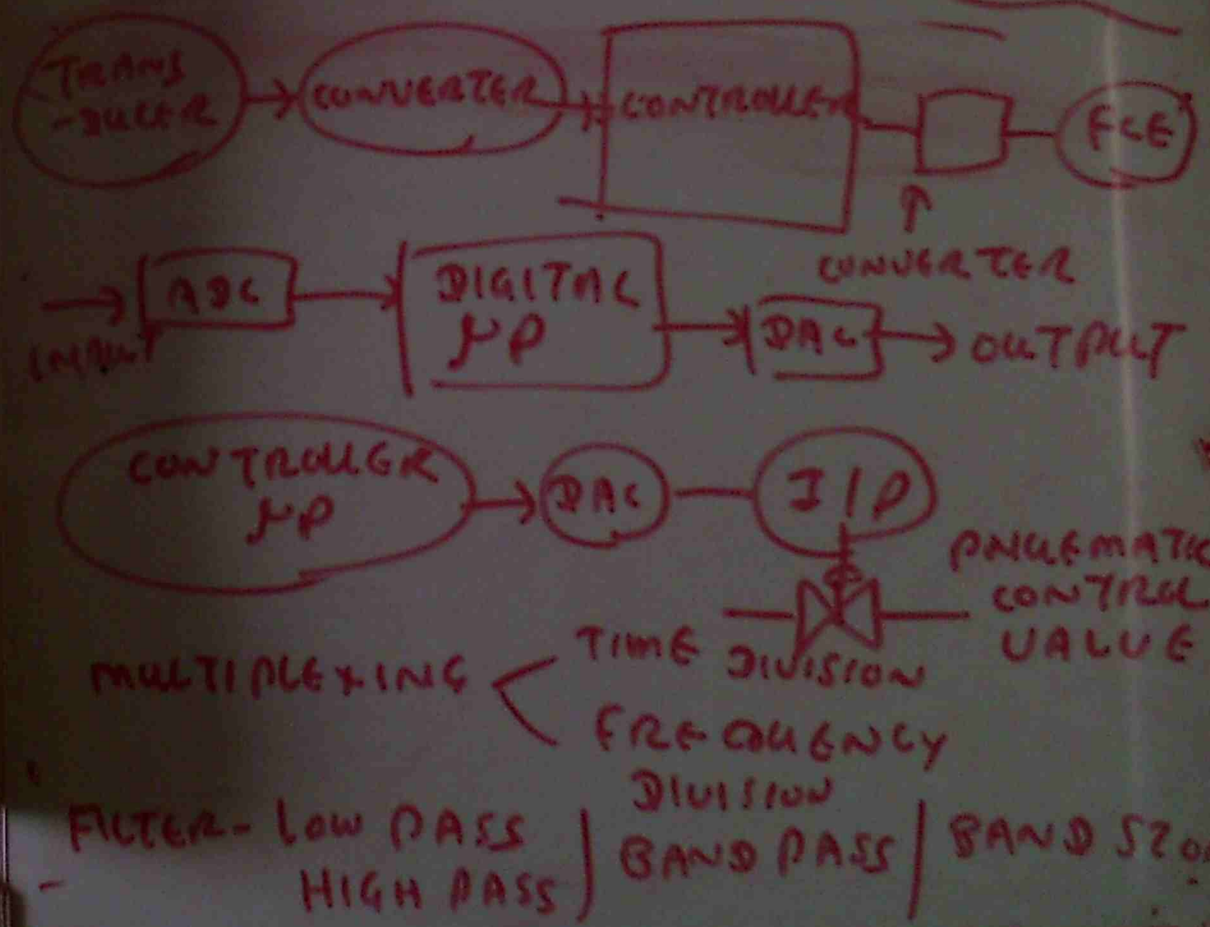
CLOSED LOOP SPEED CONTROL
PROPORTIONAL + INTEGRAL



PROPORTIONAL + DERIVATIVE

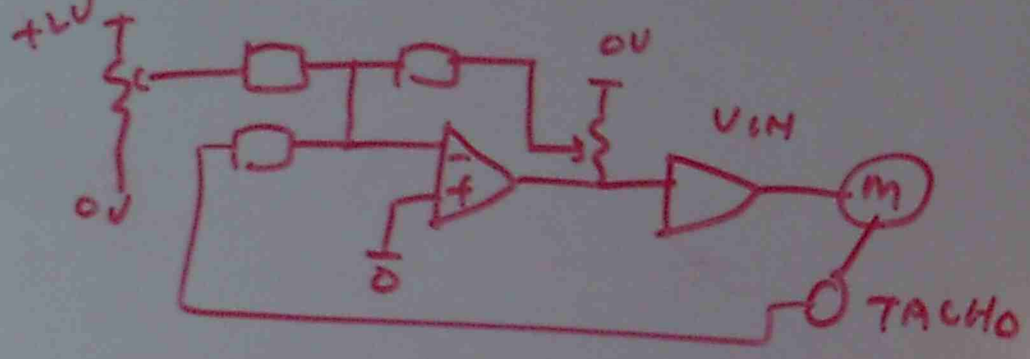


CONTROL LOOP CONDITIONING



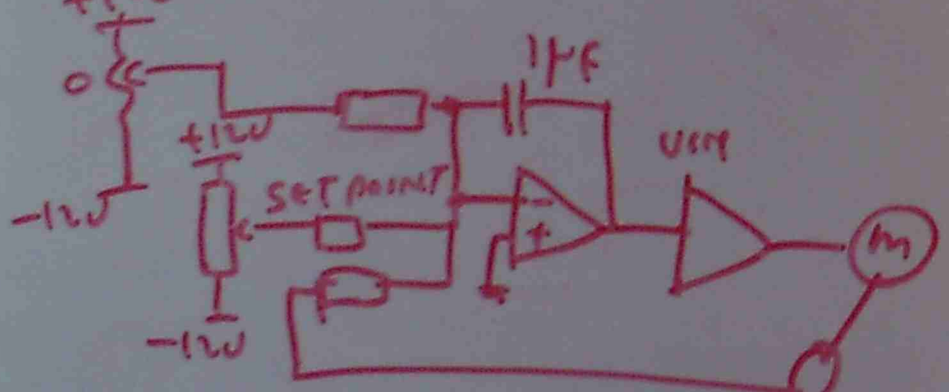
CLOSED LOOP SPEED CONTROL

PROPORTIONAL CONTROL



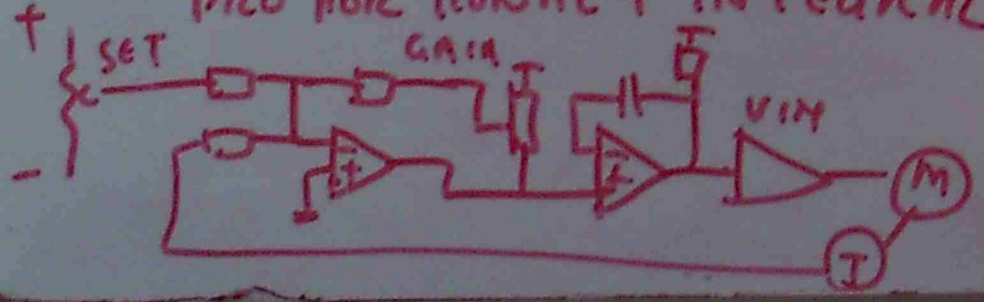
CLOSED LOOP SPEED CONTROL

INTEGRAL CONTROL

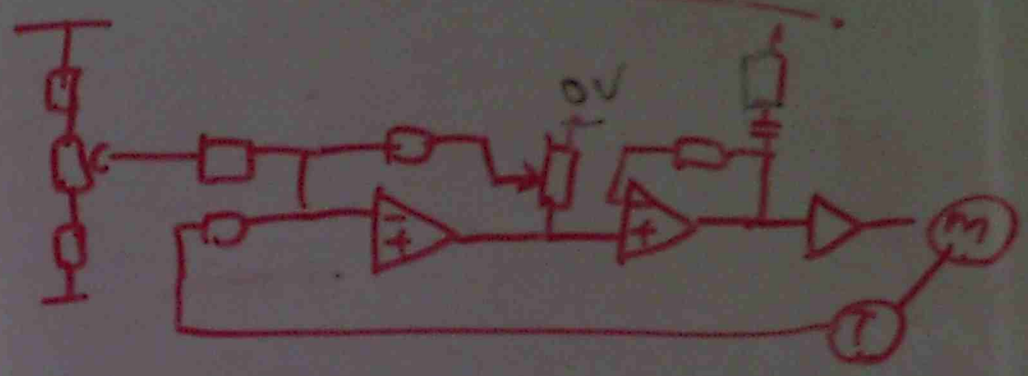


CLOSED LOOP SPEED CONTROL

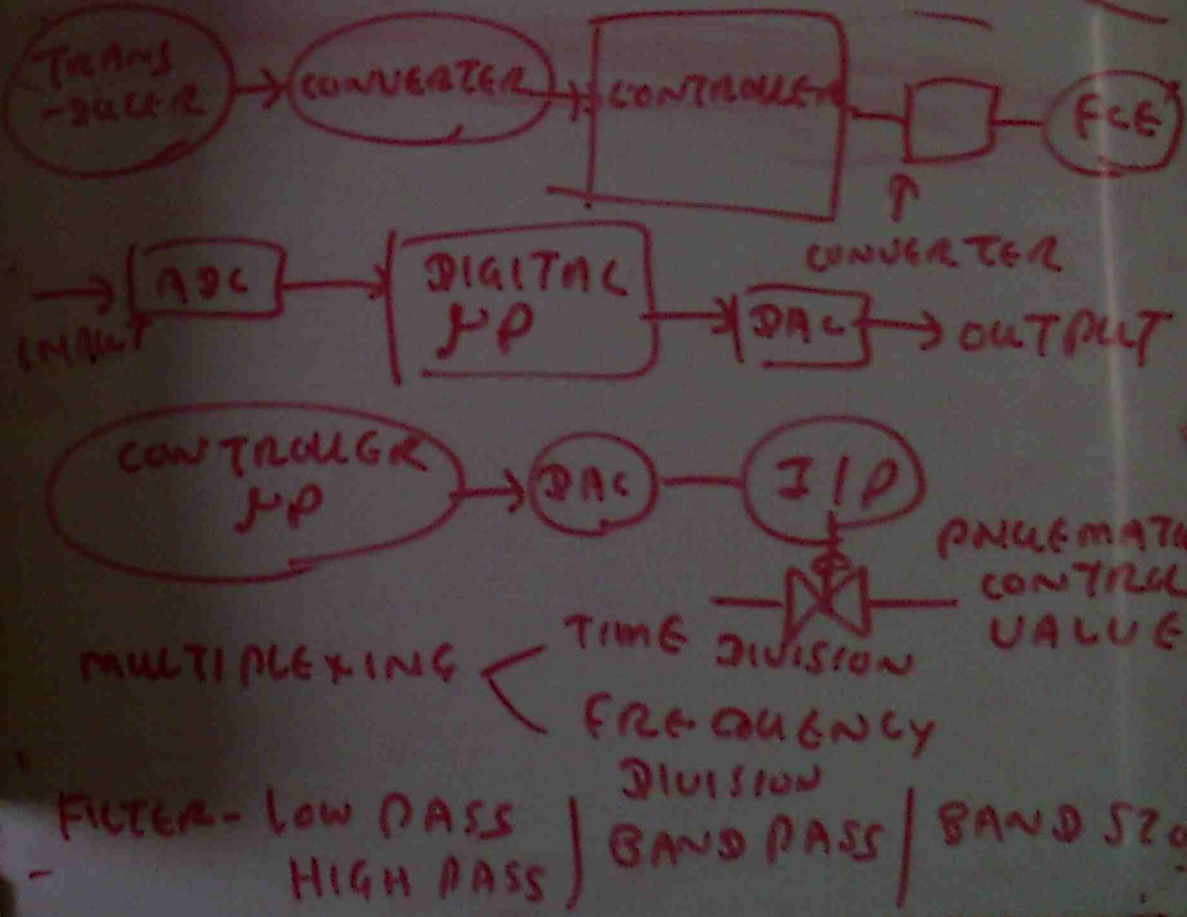
PROPORTIONAL + INTEGRAL



PROPORTIONAL + DERIVATIVE



CONTROL LOOP CONDITIONING



(11) INDUSTRIAL TRANSDUCER

SLIDE (1) → (20)

Q 90 → Q 100

(12) CONTROL SYSTEM EVALUATION

SLIDE (1) → SLIDE (14)

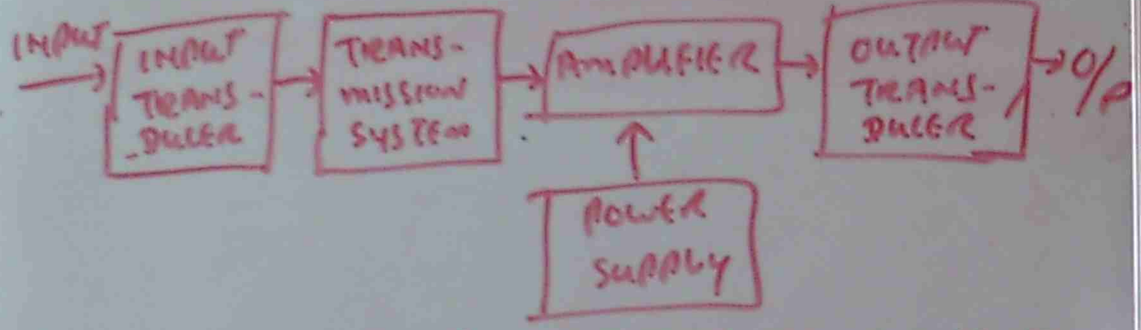
Q 101 → Q 112

(13) PROPORTIONAL CONTROL

SLIDE (1) → (15)

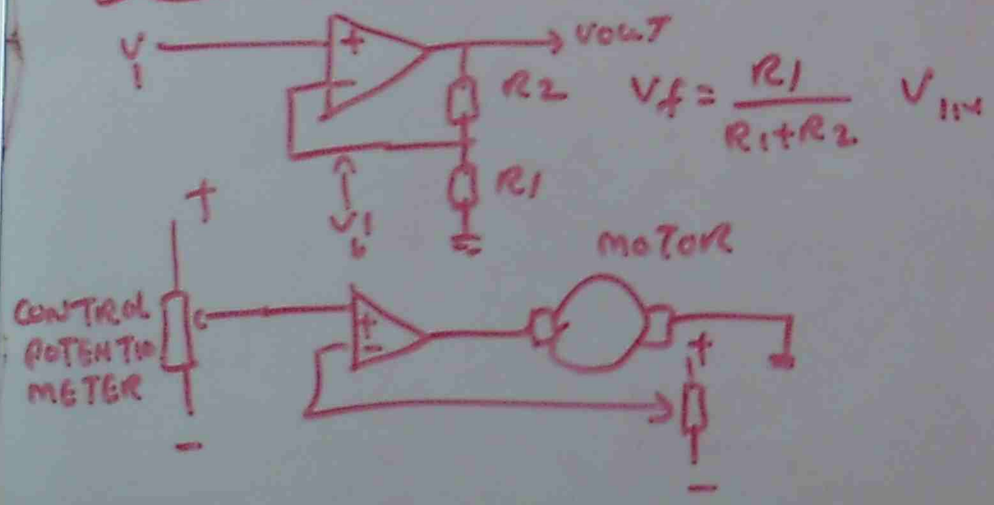
Q 113 → Q 120

INFORMATION TRANSFER SYSTEM



- THE PURPOSE OF INPUT TRANSDUCER IS TO CONVERT THE INFORMATION FROM THE SOURCE INTO AN ELECTRICAL SIGNAL
- TRANSMISSION MEDIUM CONEYS THE THE SIGNAL TO THE AMPLIFIER

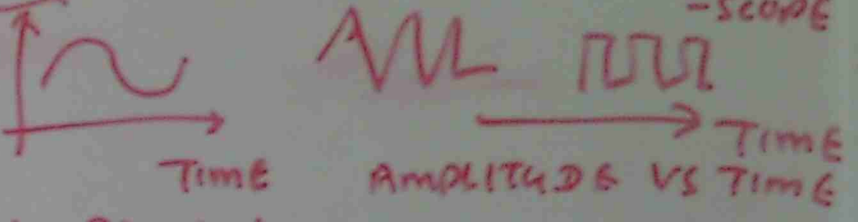
NEGATIVE FEED BACK AMPLIFIER



$V_f = \frac{R1}{R1+R2} V_{in}$

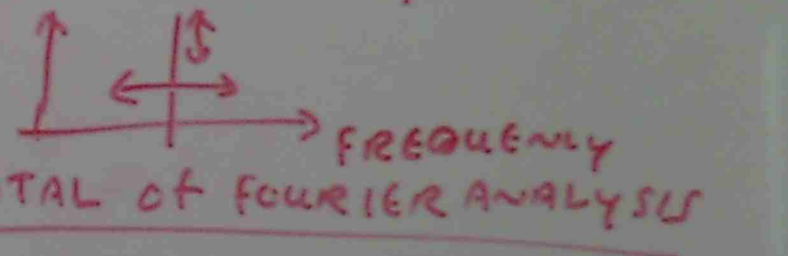
TIME AND FREQUENCY DOMAIN

TIME DOMAIN - VIEW THE SIGNAL IN OSCILLO-SCOPE

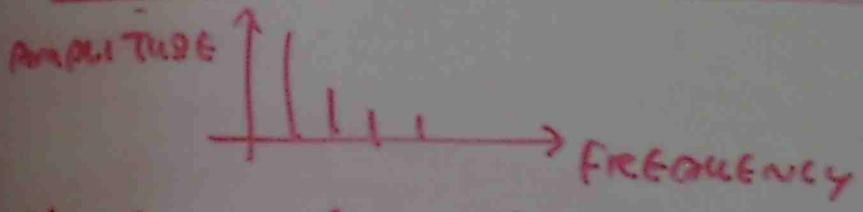


FREQUENCY DOMAIN VIEW THE SIGNAL IN FREQUENCY ANALYZER

AMPLITUDE VS FREQUENCY



FUNDAMENTAL of FOURIER ANALYSIS



Pb A WAVEFORM HAS A PERIOD $T = 40ms$
CALCULATE THE FREQUENCY OF THE FUNDAMENTAL, THE SECOND, THIRD AND FOURTH HARMONICS

$$\text{FUNDAMENTAL FREQUENCY} = \frac{1}{T} = \frac{1}{40\times10^{-3}} = 25\,Hz$$

SECOND HARMONIC = 2x 25 Hz = 50 Hz
THIRD HARMONIC = 3x 25 Hz = 75 Hz
FOURTH HARMONIC = 4x 25 Hz = 100 Hz



GOOD TRANSMISSION ⟷ POWER SPECTRUM

NON LINEARITY → HARMONIC
→ NOISE
→ INTERMODULATED DISTORTION

Pg 1 KHz SINE WAVE AND 10 KHz SINEWAVE ARE ADDED TOGETHER. FIND ALL POSSIBLE OUTPUTS

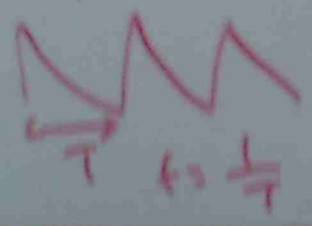
1KHz, 10KHz → ORIGINAL FREQUENCIES
2KHz, 3KHz, 4KHz (HARMONICS OF 1KHz)
20KHz, 30KHz, 40KHz (HARMONICS OF 10KHz)
9KHz, 11KHz (2nd ORDER INTERMODULATION)
8KHz, 12KHz, 19KHz, 21KHz (3rd ORDER INTERMODULATION)

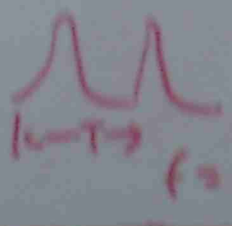
f_1 f_2 ← FUNDAMENTAL
$f_1 \pm f_2$ ← 2nd ORDER
$f_1 \pm (f_1 \pm f_2)$ (OR) $f_2 \pm (f_1 \pm f_2)$ 3rd ORDER

$2f_1, 3f_1, f_1, 3f_2, f_2$ HARMONICS

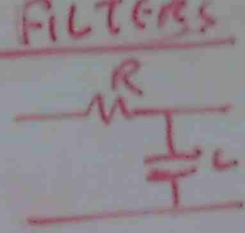


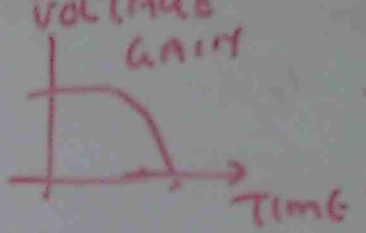
$$V(t) = \frac{A}{\pi} + \frac{A}{2}\sin 2\pi f_0 t + \sum_{n=2}^{\infty} \frac{A(1+(-1)^n)}{\pi(1-n^2)} \cos 2\pi n f_0 t$$

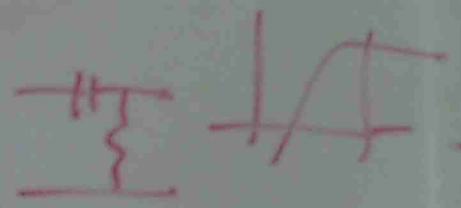




FILTERS







LOW PASS



HIGH PASS



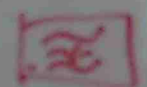


BAND PASS

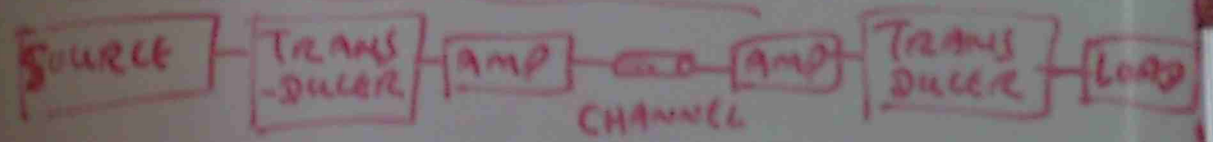




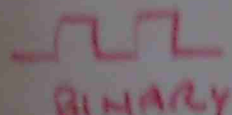
BAND STOP



COMMUNICATION SYSTEM

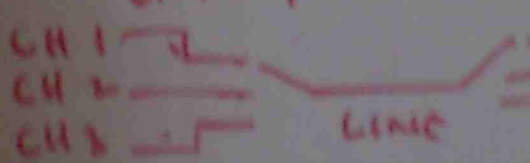


ANALOG SIGNAL — CODEC → DIGITAL SIGNAL



→ MODEM → ANALOG

BINARY



TIME DIVISION MULTIPLEXING

SAMPLING

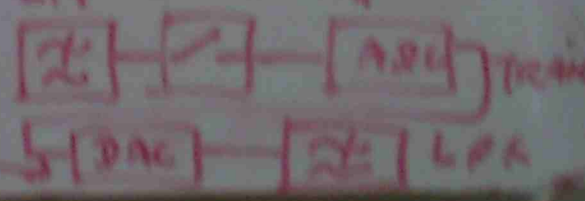


LPF
LOW PASS FILTER

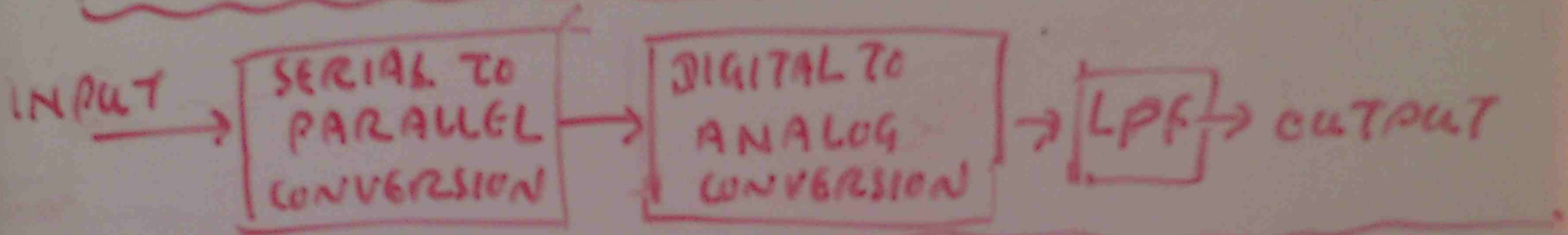
REMOVING

PCM ENCODING

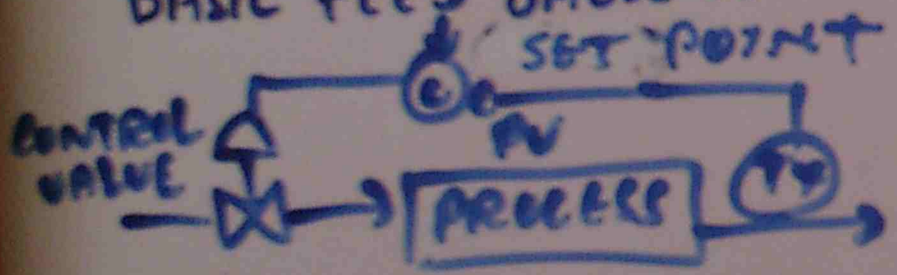
LPF SAMPLING



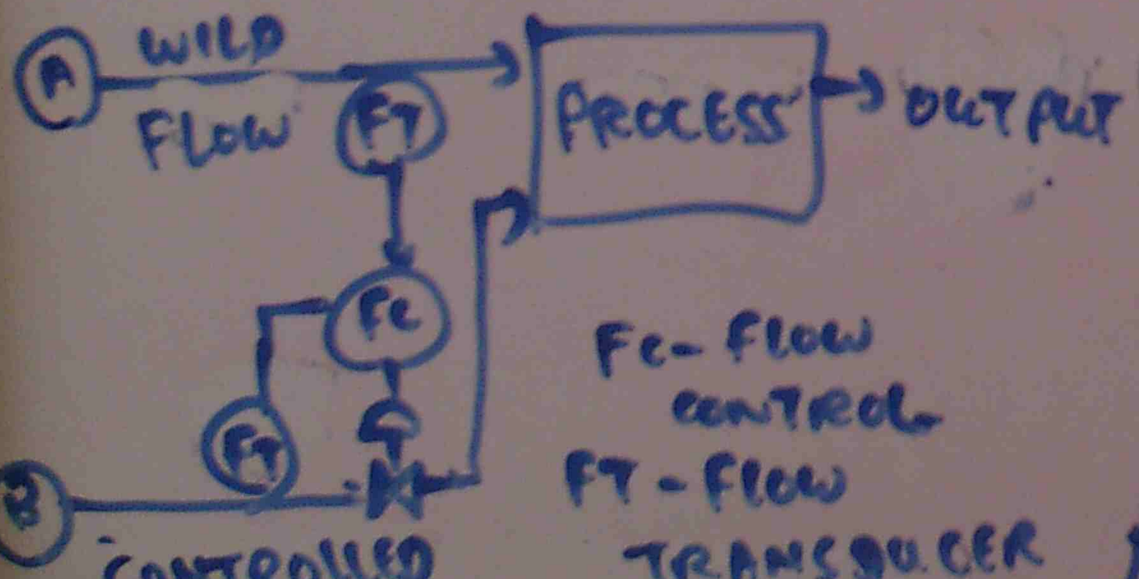
PCM DECODING PROCESS – NOISE IMMUNITY



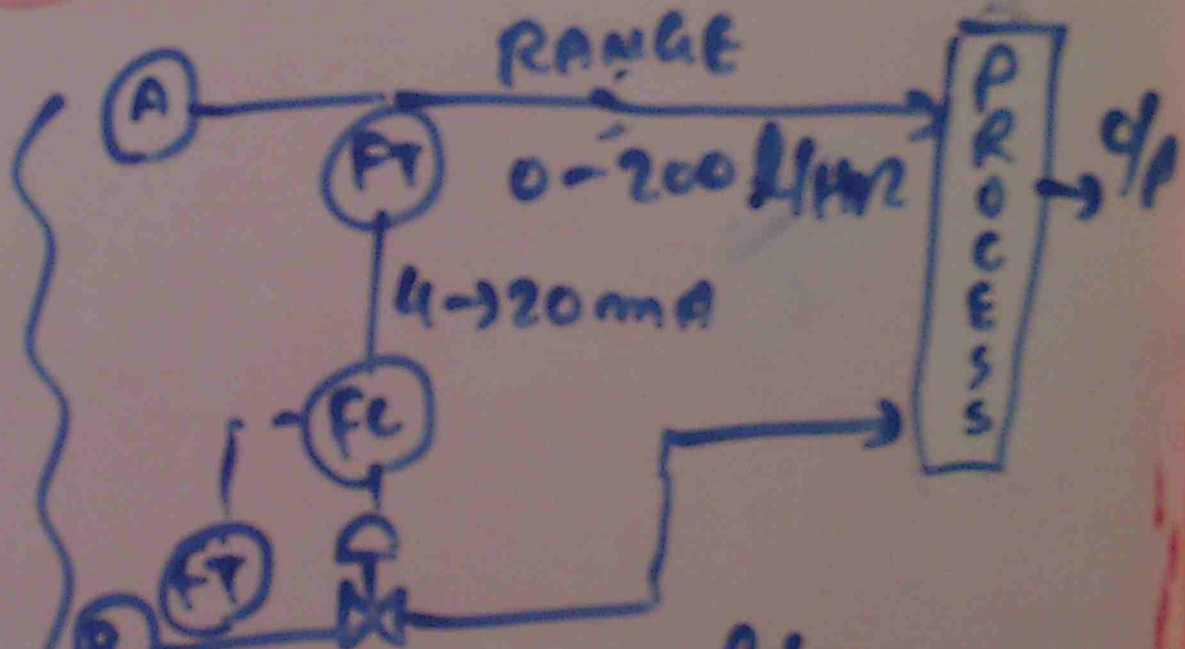
BASIC FEED BACK CONTROL



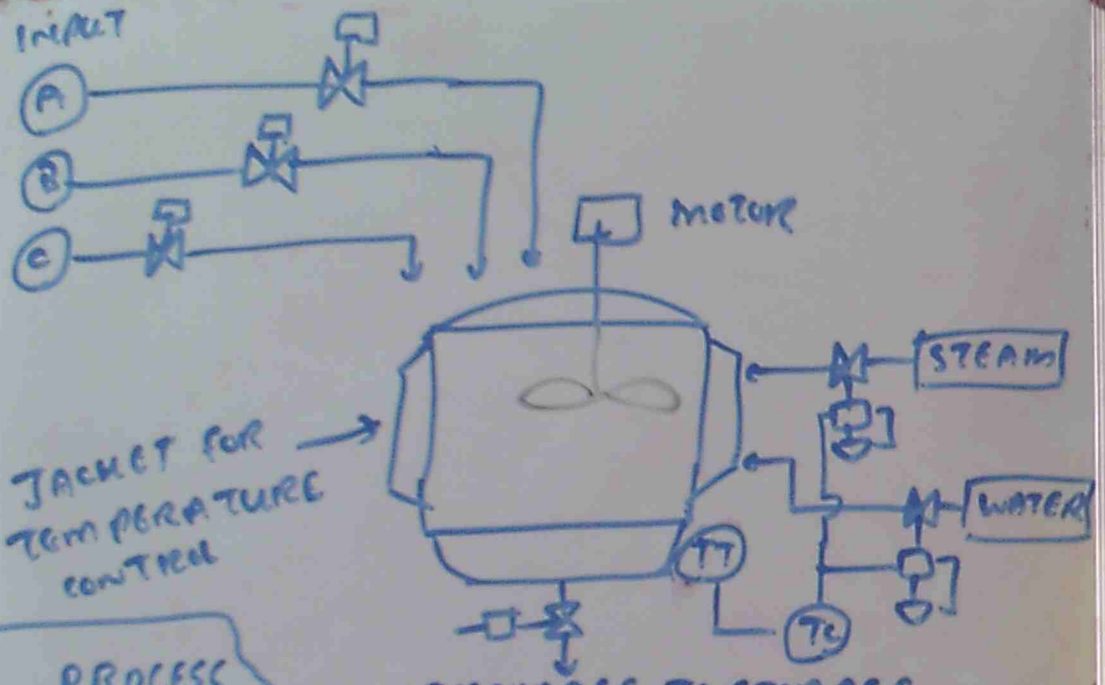
RATIO CONTROL LOOP



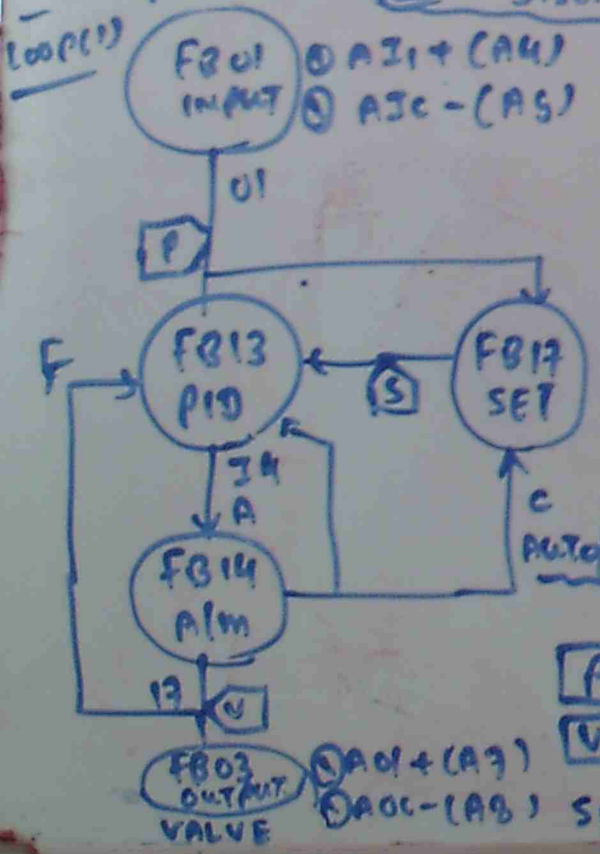
Fc - FLOW CONTROL
FT - FLOW TRANSDUCER



RATIO 1:1, FLOW (A) INCREASE 20 l/HR
A - $\frac{20}{200} * \frac{1}{10}$ - SIGNAL 10% INCREASE
$\therefore$ (B) → $\frac{1}{10} \times 500 = 50$ l/HR



PROCESS



INPUT
+A4, -A5
OUTPUT
+A7, -A8

LOOP(1)
TRACKING SET POINT
LOOP(2)
REMOTE SET POINT

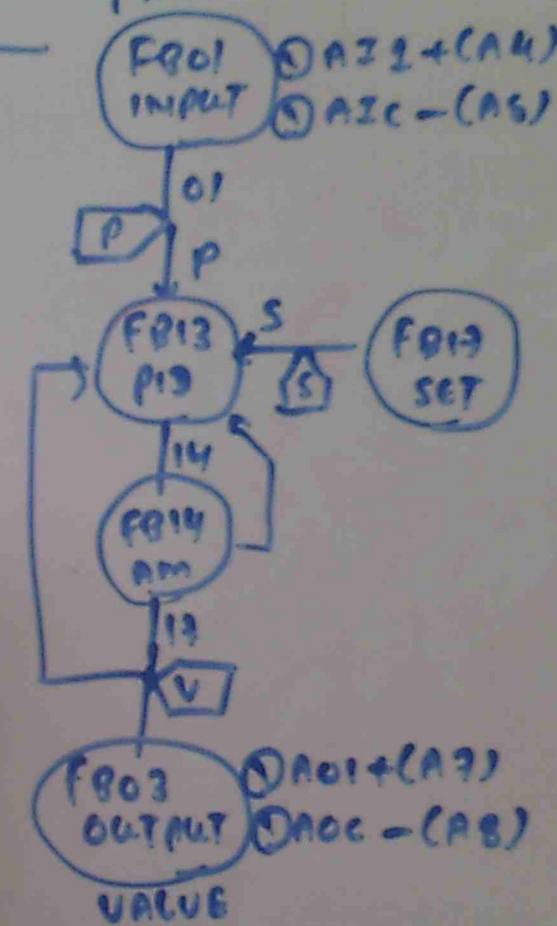
CONTROLLER FUNCTION BLOCK

FB13
AUTO/MANUAL FUNCTION BLOCK

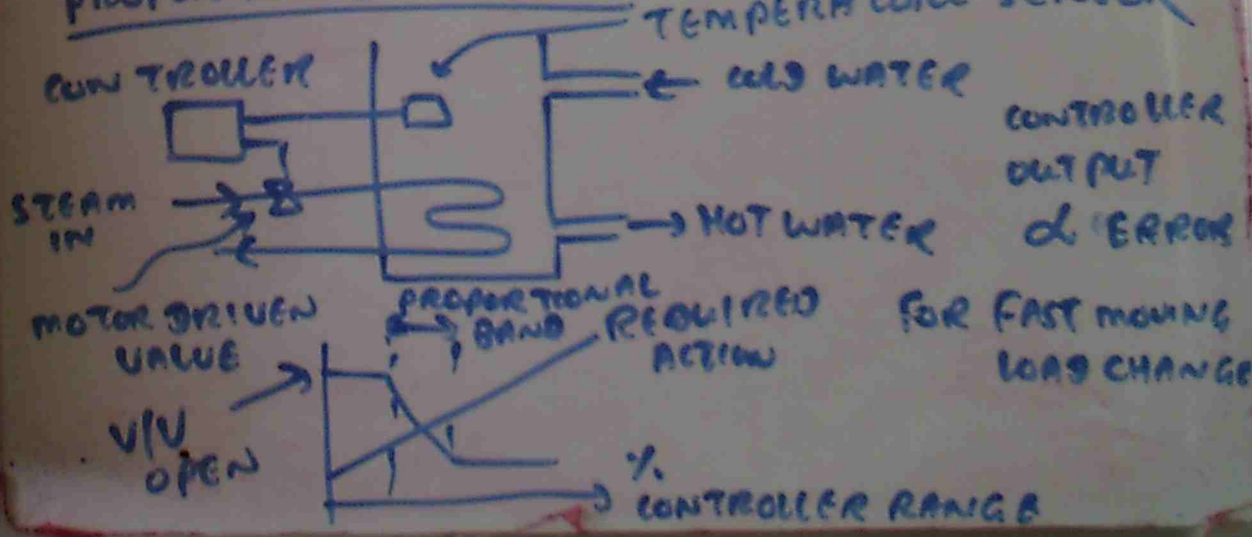
FB14
P PROCESS VARIABLE
V OUTPUT SIGNAL TO VALVE
SET FUNCTION BLOCK - FB17

LOOP(2)

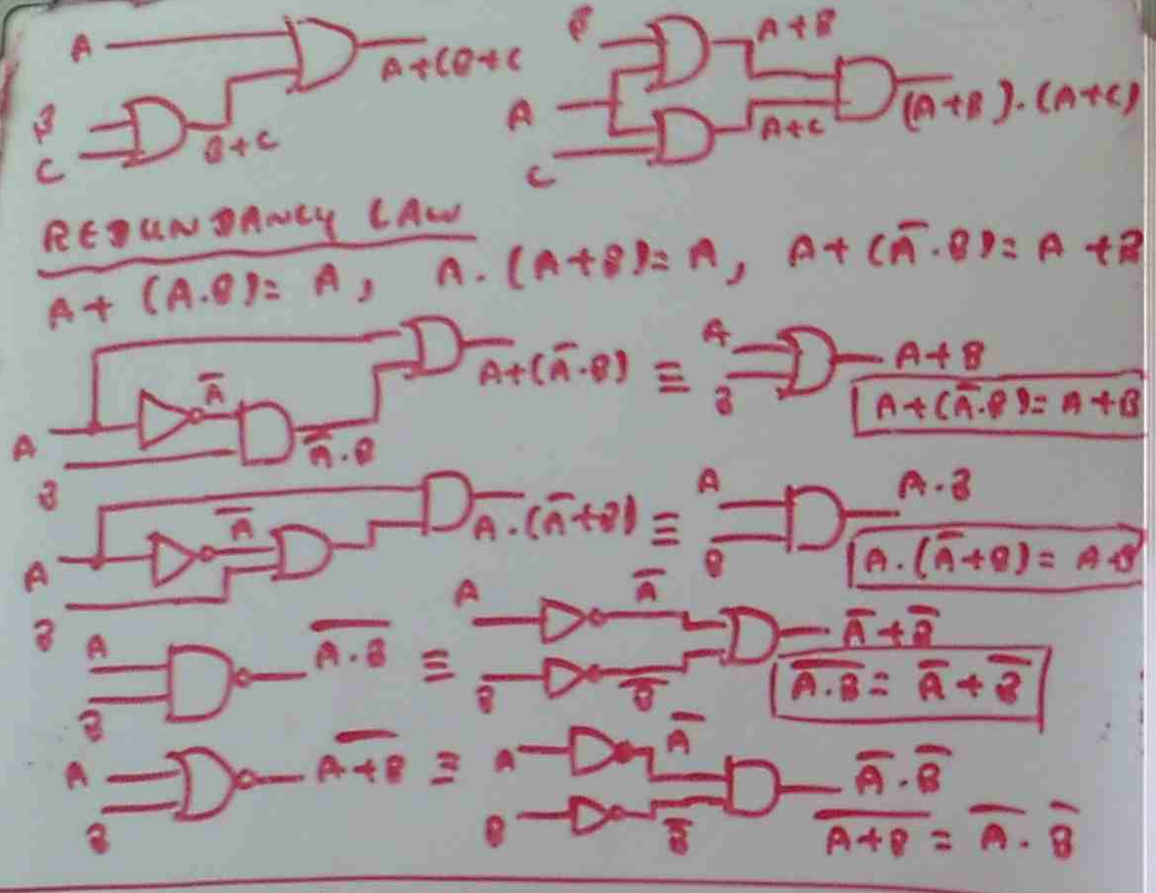
PROCESS



PROPORTIONAL CONTROL



CONTROLLER OUTPUT
∝ ERROR
FOR FAST MOVING LOAD CHANGE



REDUNDANCY LAW

$A+(A.B) = A$, $A.(A+B) = A$, $A+(\bar{A}.B) = A+B$

DE-MORGAN THEOREM

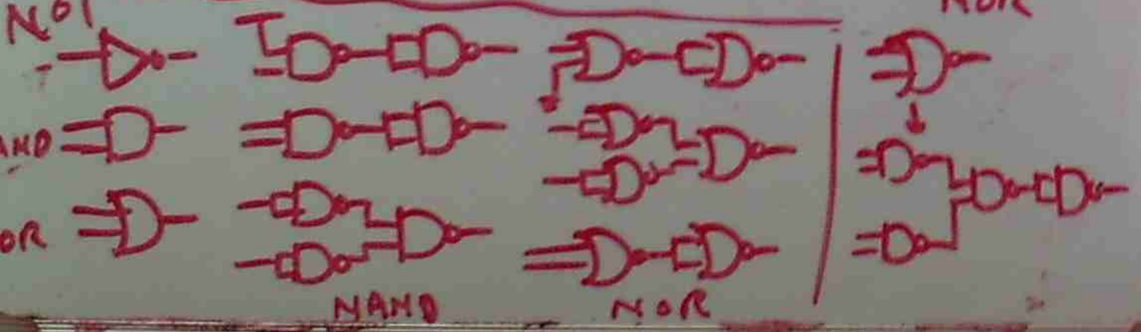
$A+B \xrightarrow{(1)}$ INVERT THE INPUT $\bar{A}+\bar{B}$ ← OUTPUT

(2) INVERT THE OUTPUT $\overline{\bar{A}+\bar{B}}$

(3) CHANGE THE SIGN $\overline{\bar{A}.\bar{B}}$

$\therefore A+B = \overline{\bar{A}.\bar{B}}$

EQUIVALENT LOGIC GATES



IOO6 - (4) DIGITAL CONTROL
SLIDE (1) → (10), Q34 → 37

HO12 - (1) DIGITAL INTRODUCTION
SLIDE (1) → (8), Q1 → Q2

HO12 - (2) LOGIC GATES
SLIDE (1) → (6), Q3 → Q6

HO12 (3) COMBINATIONAL + DE-MORGAN
SLIDE (1) → (12)
Q7 → Q14

HO12 (4) DIGITAL LOGIC SIMPLIFICATION
SLIDE (3) → (12) Q15 → Q21

NUMBER SYSTEM

BINARY - 2 CHARACTERS, 0 & 1
OCTAL - 8 CHARACTERS, 0 TO 7
HEXADECIMAL - 16 CHARACTERS 0 TO 9, A TO F

Ex CONVERT 45_{10} TO BINARY

2	45	1
2	22	0
2	11	1
2	5	1
2	2	0
	1	

$45_{10} = 101101_2$

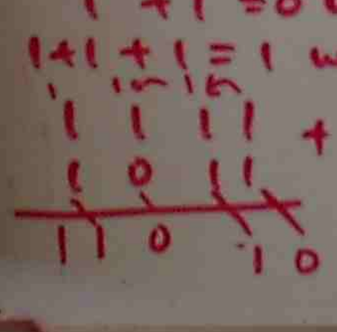
CONVERT 101101_2 TO DECIMAL

$1\times2^5 + 0\times2^4 + 1\times2^3 + 1\times2^2 + 0\times2^1 + 1\times2^0$

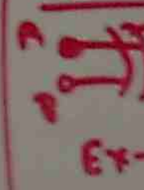
$= 45_{10}$

BINARY ADDITION

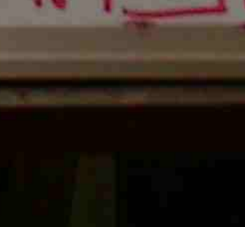
0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 0 WITH A CARRY OF 1
1 + 1 + 1 = 1 WITH A CARRY OF 1

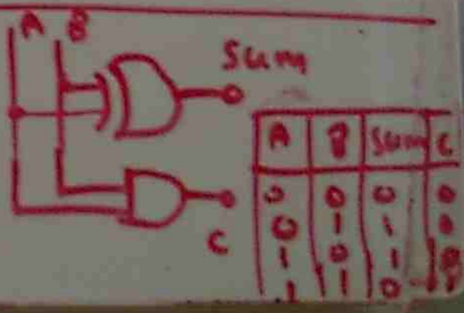


ADDER



A	B	+
0	0	0
0	1	1
1	0	1
1	1	0





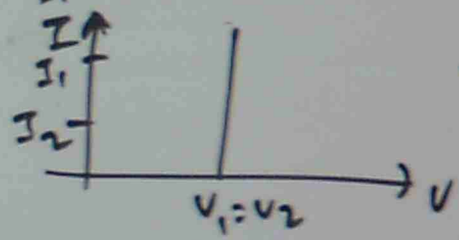
A	B	SUM	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

P.V CELL

A P.V CELL IS AN UNUSUAL POWER SOURCE
IT IS A CONSTANT CURRENT SOURCE

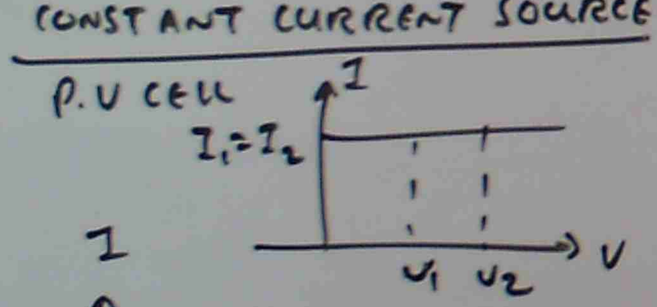
CONSTANT VOLTAGE SOURCE

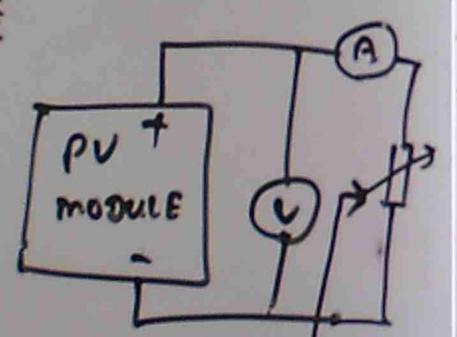
BATTERY, SUPPLY VARYING CURRENT AT A RELATIVELY CONSTANT VOLTAGE

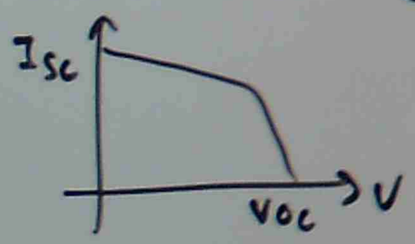


I.V CURVE FOR CONSTANT VOLTAGE SOURCE

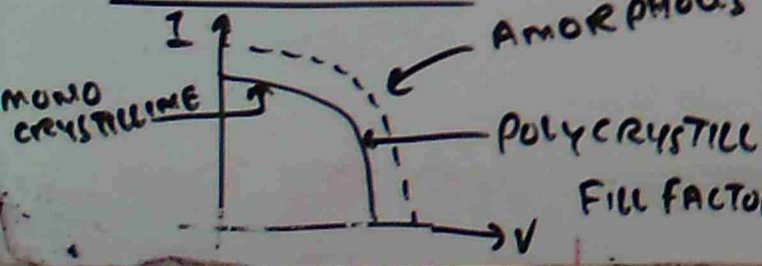
CONSTANT CURRENT SOURCE

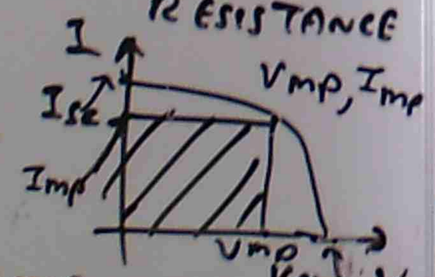






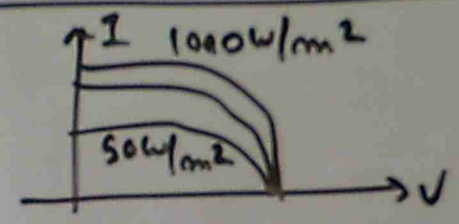
CELL P.V CURVE

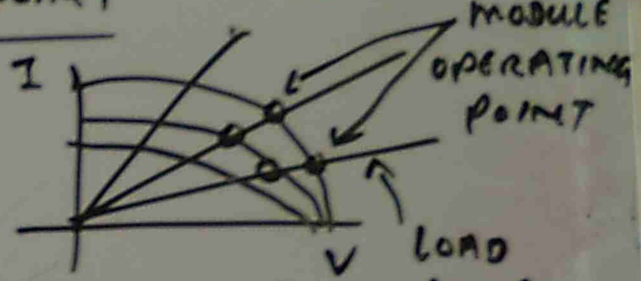




$$\text{FILL FACTOR} = \frac{P_{mp}}{V_{oc} \times I_{sc}} = \frac{V_{mp} \times I_{mp}}{V_{oc}\, I_{sc}}$$

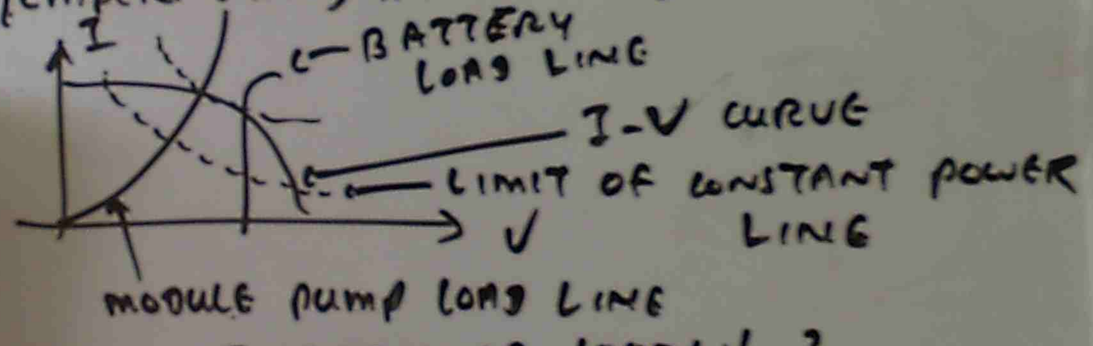
MODULE OPERATING POINT





THE P.V MODULE OPERATES AT IT'S MPP REGARDLESS OF TEMPERATURE, IRRADIANCE (OR) LOAD

BASED ON 'R'



MAXIMUM IRRADIANCE 1000 W/m²

MODULE TEMPERATURE RISE

$$T_{cell} = T_a + K \times G$$

T_{cell} - CELL TEMPERATURE FOR THE MODULE (°C)
T_a - AMBIENT AIR TEMPERATURE (°C)
K - CELL TEMPERATURE COEFFICIENT
G - IRRADIANCE (W/m^2)

NORMAL OPERATURE CELL TEMPERATURE (NOCT)

IRRADIANCE (G) = 800 W/m² $K = \frac{NOCT - 20}{800}$
WIND SPEED 1 m/s
AMBIENT TEMPERATURE - 20°C $T_{cell} = T_A + \left(\frac{NOCT-20}{800} \times G\right)$

MANUAL CALCULATION of IRRADIATION DATA

$$\frac{\bar{H}}{\bar{H}_a} = \left\{ a + b \times \frac{\bar{n}}{\bar{N}} \right\}$$

a, b - LOCATION CONSTANT

$\bar{n}$ = MONTHLY AVERAGE DAILY SUNSHINE HOUR (TABLE)

$\bar{H}$ = MONTHLY AVERAGE DAILY IRRADIATION ON HORIZONTAL PLANE (mJ/m^2)

$\bar{H}_a$ = EXTRATERRESTRIAL IRRADIATION ON HORIZONTAL PLANE (mJ/m^2)

$$H_a = \frac{24 \times 3600 \times G_{sc}}{\pi \times 10^6} \left[1 + 0.033 \cos\left\{ \frac{360\,n}{365} \right\} \right] \times \left[\cos\phi \cos\delta \sin w_s + \frac{2\pi w_s}{360} \sin\phi \sin\delta \right]$$

$\bar{N}$ = MONTHLY AVERAGE MAXIMUM POSSIBLE DAILY SUNSHINE HOUR

$$\bar{N} = \frac{2}{15} \cos^{-1}(-\tan\phi \tan\delta)$$

$w_s = \cos^{-1}(-\tan\phi \tan\delta)$ for $\Omega z = 0$

w_s = SUN SET HOUR ANGLE

ϕ = LATITUDE ANGLE (LOCATION)

δ = DECLINATION ANGLE

G_{sc} - SOLAR CONSTANT 1367 W/m^2

Q.b CALCULATE MONTHLY DAILY TOTAL IRRADIATION ON HORIZONTAL SURFACE FOR JANUARY IN BRISBANE

$n = 17$ (DAY NO.) $\delta = -20.9°$

$a = 0.42$, $b = 0.22$ $\bar{n} = 7.5$ $\bar{N} = ?$

$$w = \cos^{-1}(-\tan\phi \tan\delta) = \cos^{-1}\left(-\tan(-27.5) \tan(-20.9)\right)$$

$$= 101.47°$$

$$\bar{H_a} = \frac{24 \times 3600 \times G_{sc}}{\pi \times 10^6} \left[1 + 0.33 \cos\left(\frac{360\,n}{365}\right) \right] \left[\cos\phi \cos\delta \sin w + \frac{2\pi w_s}{360} \sin\phi \sin\delta \right]$$

$$= \frac{24 \times 3600 \times 1367}{\pi \times 10^6} \left[1 + 0.33 \cos\left(\frac{360 \times 17}{365}\right) \right] \times \cos(-27.5) \cos(-20.9) \sin 101.4 + 2\pi \times \frac{101.47}{360} \left\{ \sin(-27.5) \sin(-20.9) \right\}$$

$$= 42.81\ mJ/m^2$$

$$\bar{N} = \frac{2}{15} \cos^{-1}(-\tan\phi \tan\delta) = \frac{2}{15} \cos^{-1}\left(-\tan(-27.5) \tan(-20.9)\right)$$

$$= 13.3$$

$$\frac{\bar{H}}{\bar{H_a}} = a + b \frac{\bar{n}}{\bar{N}}$$

$$\frac{\bar{H}}{42.81} = 0.42 + 0.22 \times \frac{7.5}{13.3} \Rightarrow \bar{H} = 23.3\ mJ/m^2$$

STANDARD SILICON SOLAR CELL TECHNOLOGY

- REDUCTION OF SAND TO METALLURGICAL GRADE SILICON
- PURIFICATION OF METALLURGICAL GRADE SILICON TO SEMICONDUCTOR GRADE SILICON.
- CONVERSION OF SEMI CONDUCTOR GRADE SILICON TO SINGLE CRYSTAL SILICON WAFERS
- PROCESSING OF SINGLE CRYSTAL SILICON WAFERS IN TO SOLAR CELLS
- SOLAR CELL ENCAPSULATION INTO WEATHER PROOF SOLAR CELL MODULE

$SiO_2 + 2C \longrightarrow Si + 2CO$

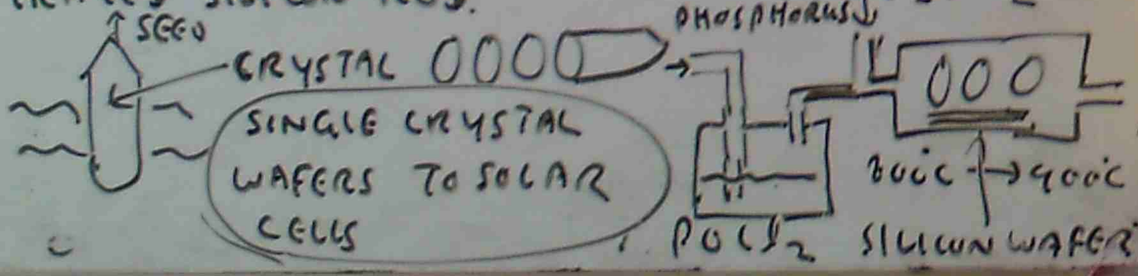
SAND IS REDUCED IN LARGE FURNACE BY CARBON.

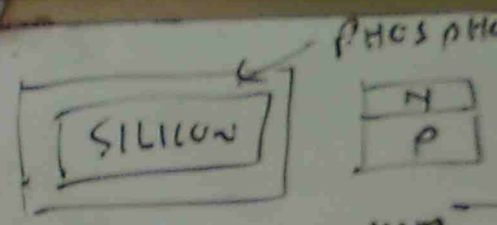
METALLURGICAL GRADE SILICON → SEMI CONDUCTOR GRADE SILICON

$Si + 3HCl = SiHCl_3 + H_2$ → GAS EMITTED

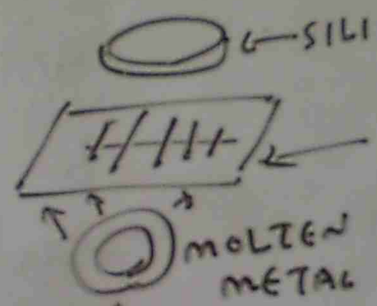
$SiHCl_3 + H_2 \Rightarrow Si + 3HCl$

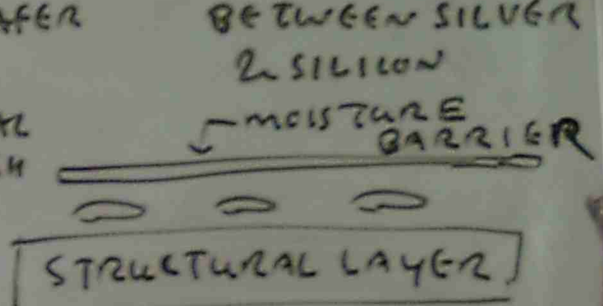
- SILICON IS DEPOSITED IN A FINE GRAINED POLY CRYSTALLINE FORM ONTO AN ELECTRICALLY HEATED SILICON ROD.

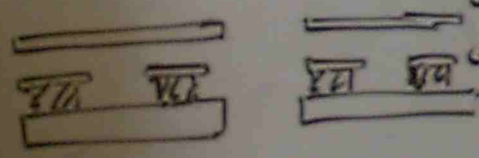


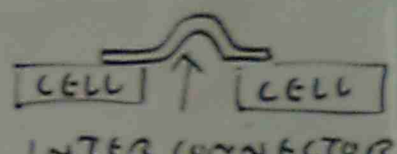


CONTACT SILVER (GOOD CONDUCTION)
PALLADIUM TO PREVENT THE REACTION BETWEEN SILVER & SILICON









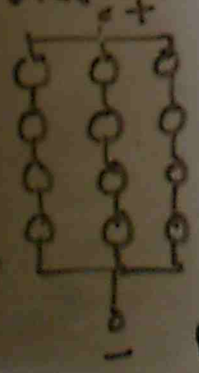
CELL OPERATING TEMPERATURE $T_{cell} = T_{AMBIENT}(^{\circ}C) + 0.3 \times \text{INTENSITY}\ (mW/m^2)$

MODULE DEGRADATION

EXCESSIVE MECHANICAL STRESS — BREAKAGE OF CELL

CORROSION, DISCOLOURING, DIRT

BREAKAGE INTER CONNECTOR



MAXIMUM POWER OUTPUT RELATED TO SERIES RESISTANCE

$$P_m = P_{mp}\left(1 - \frac{I_{sc}}{V_{oc}} * R_s\right)$$

EFFECT OF SHUNT RESISTANCE ON FILL FACTOR

$$FF_{sh} = FF_0\left[1 - \left(\frac{V_{oc} + 0.7}{V_{oc}} * \frac{FF_0}{V_{sh}}\right)\right]$$

$$I = I_L - I_0 \left\{ e^{\frac{V+IRS}{nKT/q}} - 1 \right\} - \frac{(V+IRS)}{R_{SH}}$$

n = NO. OF ELECTRON q = ELECTRON CHARGE

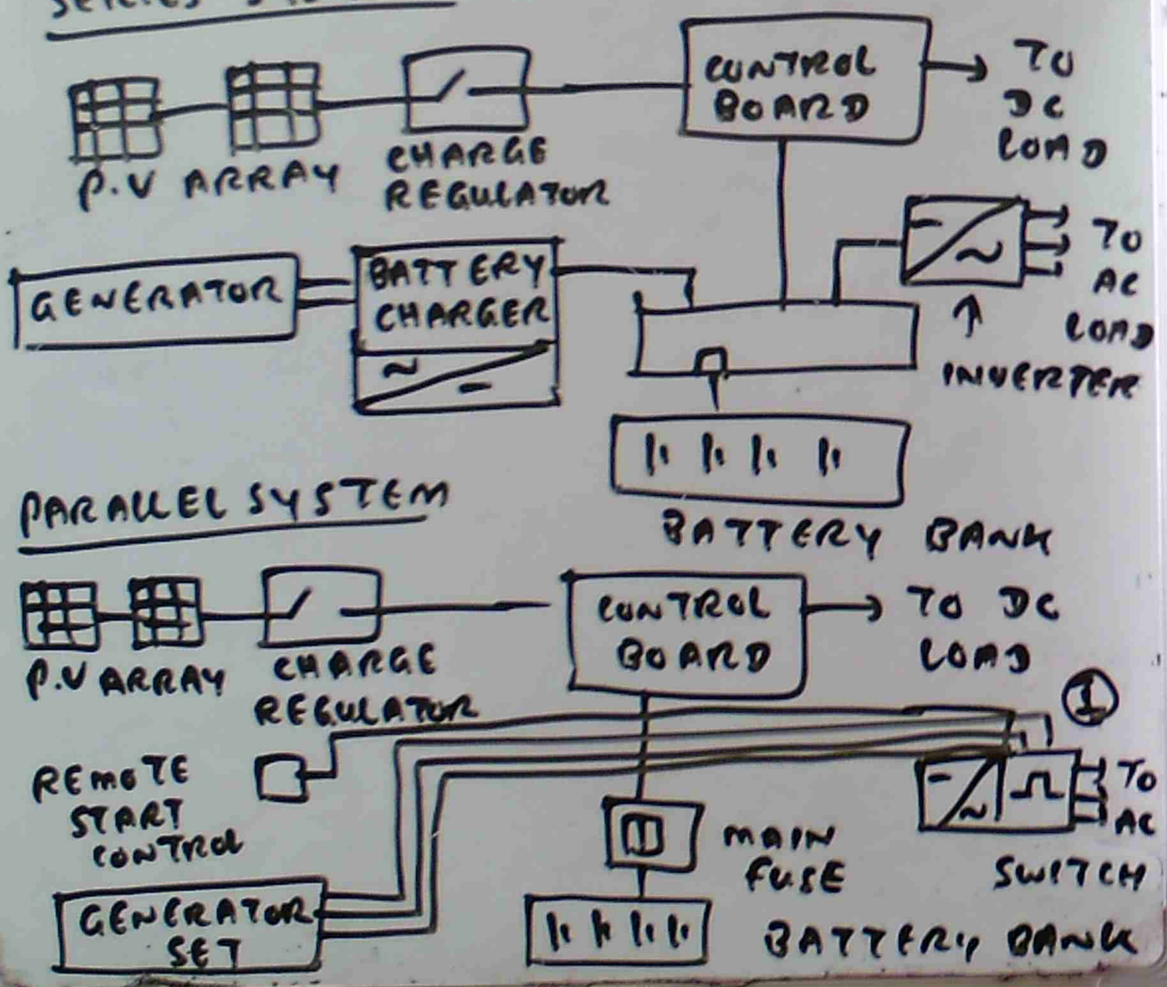
I_0 = DARK CURRENT K = PLANK CONSTANT

T = ABSOLUTE TEMPERATURE

I_L = LIGHT GENERATED CURRENT

P.V SYSTEMS

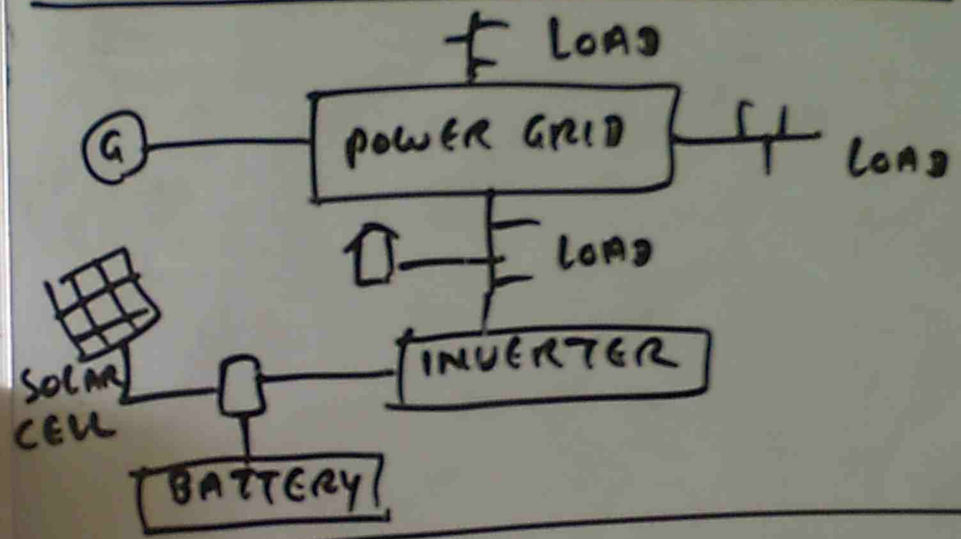
SERIES SYSTEM



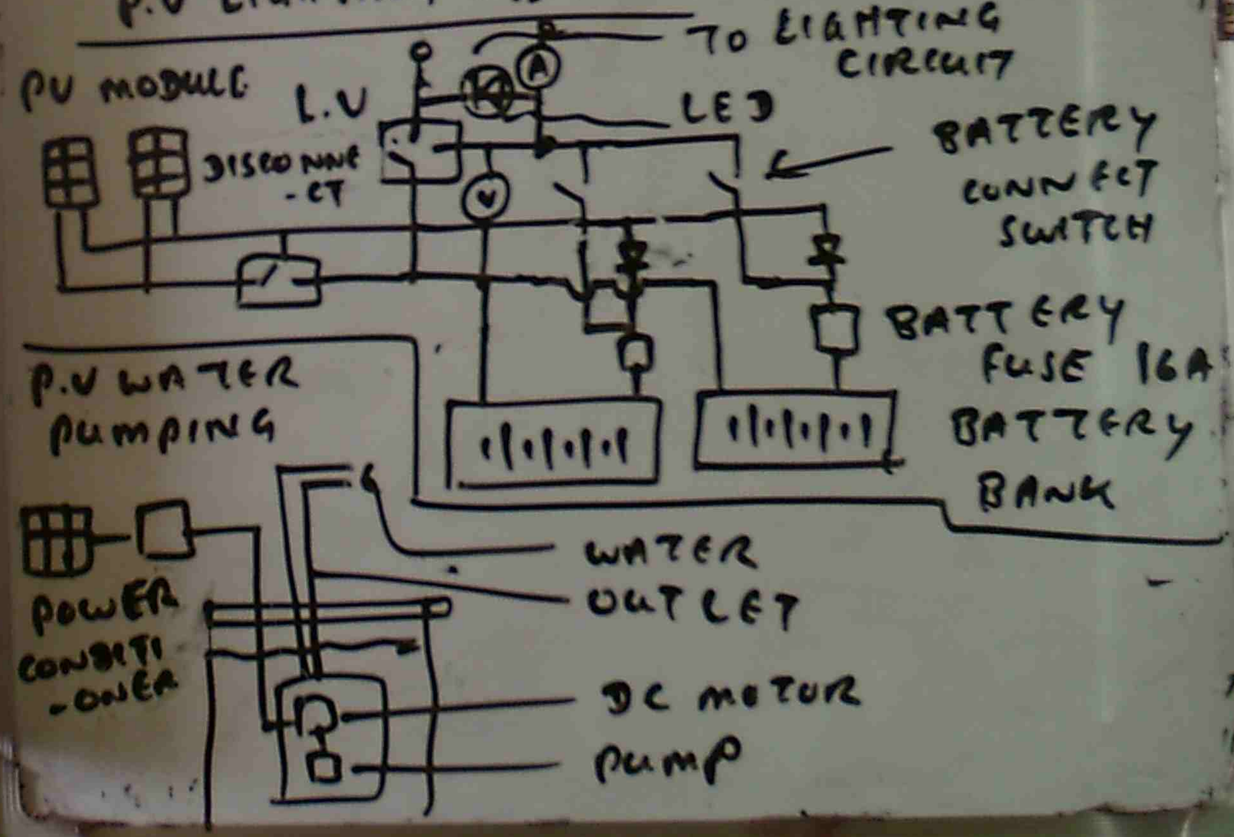
PARALLEL SYSTEM

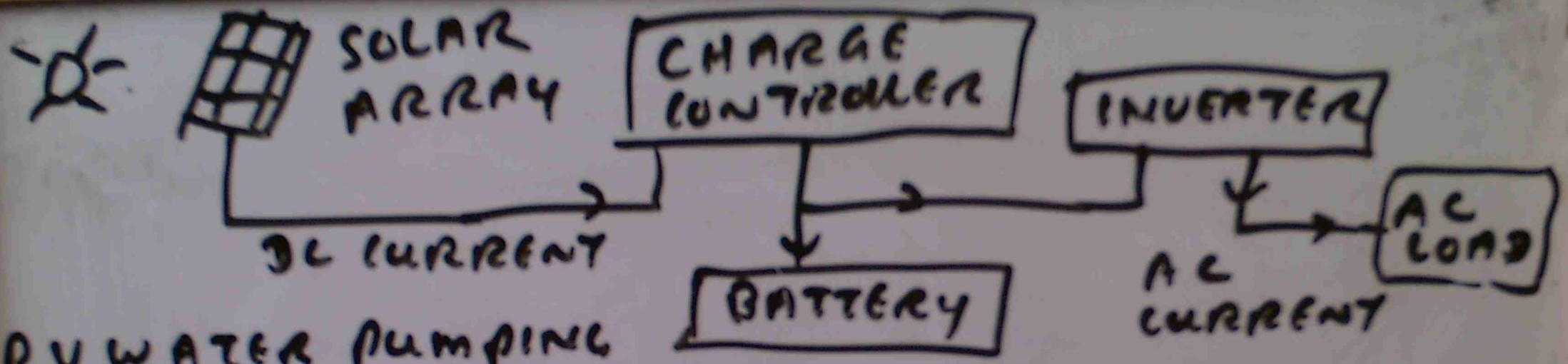
(I) - INTERACTIVE INVERTER.

GRID INTERACTIVE P.V SYSTEM



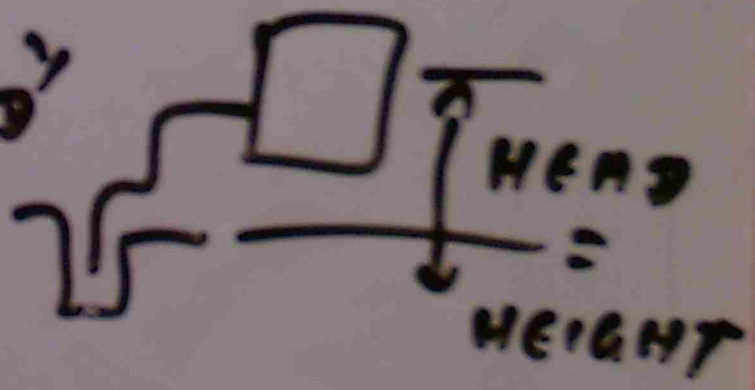
P.V LIGHTING SYSTEM





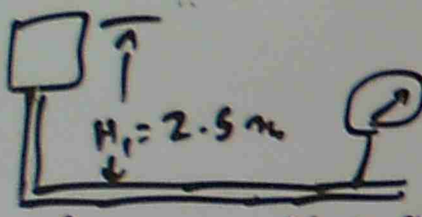
PV WATER PUMPING SYSTEM DESIGN

1. DETERMINE THE VOLUME OF WATER TO BE PUMPED
2. DETERMINE WATER "HEAD"
3. DETERMINE PUMPING RATE



4. MEASURE NUMBER OF SUNLIGHT HOURS
5. SELECT PUMP TYPE BASED ON TORQUE SPEED CHARACTERISTICS OF PUMP
6. SELECT APPROPRIATE SOLAR PANEL

PU



CALCULATE P_2

TOTAL HEAD AT POINT (1) = TOTAL HEAD AT POINT (2)

$$H_1 + \frac{V_1^2}{2g} + \frac{P_1}{\rho g} = H_2 + \frac{V_2^2}{2g} + \frac{P_2}{\rho g} + f$$

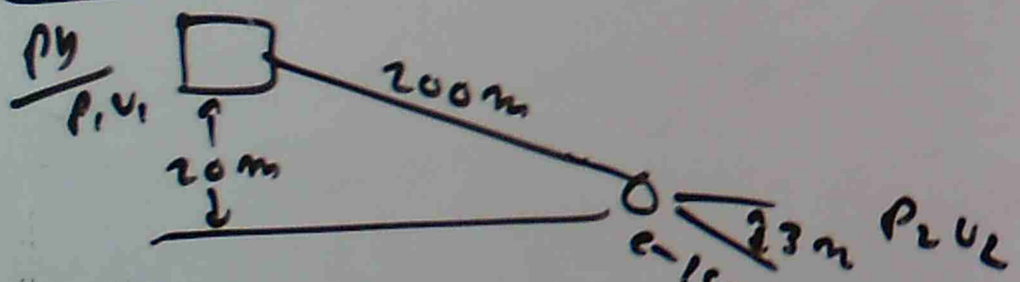
$$2.5 + \frac{0^2}{2\times 9.81} + \frac{0}{1\times 9.81} = 0 + \frac{0.5^2}{2\times 9.81} + \frac{P_2}{1\times 9.81} + 0.3$$

$$2.5 = 0.127 + 0.3 + \frac{P_2}{9.81}$$

$$\frac{P_2}{9.81} = 2.1873 \longrightarrow P_2 = 9.81 \times 2.1873$$

$$= 21.45 kPa$$

PU



THE PUMP SHOWN IN FIGURE IS LIFTING THE WATER FROM A DAM AT A RATE OF 3600 LITRE / HR TO A STORAGE TANK AT 200m AWAY. SELECT THE PIPE SIZE & DETERMINE TOTAL HEAD AGAINST WHICH THE PUMP MUST OPERATE

FLOW $3600 L/HR = \frac{3600L}{3600S} = 1 L/s$

$$\frac{\pi D^2}{4} \times V_1 = 1 L/s$$

$$H_1 + \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \text{FRICTION LOSS} + H_2 + \frac{P_2}{\rho g} + \frac{V_2^2}{2g}$$

$$\text{TOTAL HEAD} = \frac{215}{100} \times 1 + 23 + 0 + \frac{0.6^2}{2\times 9.81}$$

$$= 25.22m$$

NOTES

⑥ SOLAR MODULE ENERGY OUTPUT

SLIDE 1 → 4 , Q 16 → 18

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⑦ SOLAR GEOMETRY

SLIDE 1+2 Q 19

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⑧ ALTITUDE AND AZIMATH ANGLE

SLIDE 1 → 4 Q 20 → Q 22

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⑨ FREE ELECTRON + ENERGY FROM SUN

SLIDE 1 → 8 Q 23 → Q 27

(11) LIGHT FALL ON SOLAR CELL

SLIDE 1 → 5 @ 28

(12) PRODUCTION & CURRENT EQUATION - SOLAR CELL

SLIDE 1 → 12, @ 29 → @ 33

(13) SOLAR RADIATION & SHADING ASSESSMENT

SLIDE 1 → 3, @ 34 → @ 36

(14) IRRADIATION CALCULATION

SLIDE 1 → 7, @ 37 → @ 38

(15) EXCITING OF FREE ELECTRON BY LIGHT

SLIDE 1 → 7, @ 34 → @ 42

(16) SOLAR IRRADIATION

SLIDE 1 → 10 | @ 43 → @ 48

(17) BATTERY CHARGER SYSTEM

Q 49

(18) CONFIGURATION OF SOLAR SYSTEM

SLIDE 1 → 8 Q 50 → Q51

(19) P.V WATER PUMPING

SLIDE 1 → 20 Q 52 → Q60

(20) ARRAY EFFICIENCY & SYSTEM DESIGN

SLIDE 1 → 20 , Q 56 → Q60

(21) SOLAR WATER PUMP CALCULATION

SLIDE 1 → 11 , Q61 → Q65

py A PARTICULAR MODULE HAS NOCT OF 49°C. WHAT IS CELL TEMPERATURE COEFFICIENT WHAT WILL BE IT'S CELL TEMPERATURE IF THE AMBIENT TEMPERATURE IS 35°C & IRRADIANCE 65 W/m²)

(i) $K = \frac{NOCT - 20}{800} = \frac{49-20}{800} = 0.313$

(ii) $T_{cell} = T_a + \left(\frac{NOCT - 20}{800} \times G\right)$

$= 35 + \frac{49-20}{800} \times 65 = 58.8°C$

TEST - MECHANICAL / ELECTRICAL / THERMAL

MAXIMUM POWER (PEAK POWER) P_{mp}

CURRENT AT MAXIMUM POWER = I_{mp}

SHORT CIRCUIT CURRENT = I_{sc}

OPEN CIRCUIT VOLTAGE = V_{oc}

TEMPERATURE COEFFICIENT OF SHORT CIRCUIT CURRENT (α)

TEMPERATURE COEFFICIENT OF OPEN CIRCUIT VOLTAGE (β)

TEMPERATURE COEFFICIENT OF MAXIMUM POWER (γ)

I_{scT} - SHORT CIRCUIT CURRENT AT TEMPERATURE T_c

V_{OCT} - OPEN CIRCUIT VOLTAGE AT TEMPERATURE T_c

P_{mpT} - MAXIMUM POWER AT TEMPERATURE(T_c)

P_{mpSTC} - MAXIMUM POWER AT STC

STC - STANDARD TEST CONDITION

$I_{scT} = I_{sc-STC}(1 + \alpha(T_{cell} - T_{STC}))$

$V_{OCT} = V_{OC-STC}(1 - \beta(T_{cell} - T_{STC}))$

$P_{mpT} = P_{mp\,STC}(1 - \gamma(T_{cell} - T_{STC}))$

POWER CONVERSION EFFICIENCY

$P_{PV} = G \times A$

P_{PV} = TOTAL POWER IN LIGHT INCIDENT

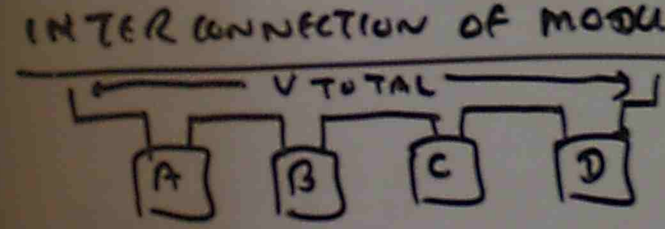
G - IRRADIANCE

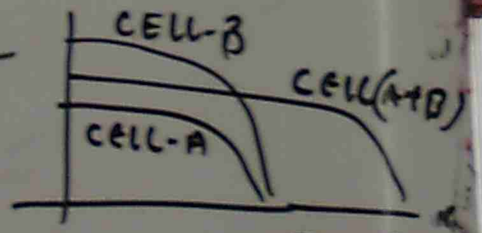
A - SURFACE AREA

$\text{POWER CONVERSION EFFICIENCY} = \frac{P_{mp}}{P_{PV}} = \frac{V_{mp} \times I_{mp}}{G \times A}$

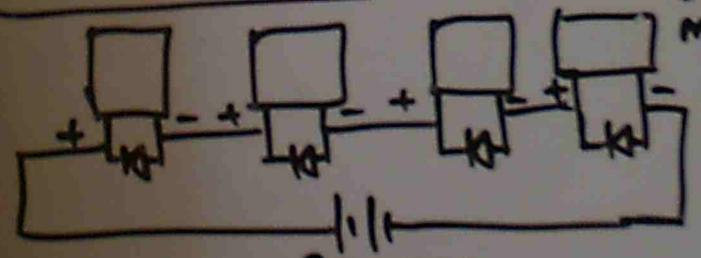
$\eta = \frac{V_{OC} I_{SC} \times FF}{G \times A}$

INTERCONNECTION OF MODULE



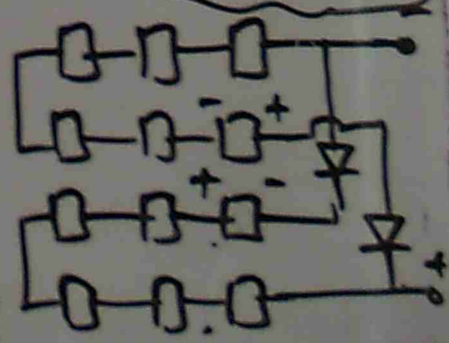


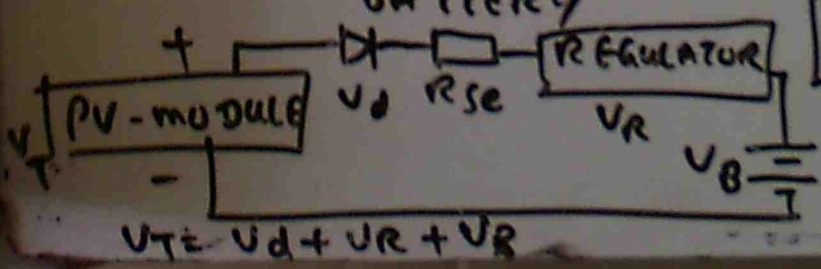
MISMATCH LOSSES



SOLAR MODULE

SERIES PARALLEL





MODULE POWER DE-RATING WITH TEMPERATURE

$$P_T = P_{STC}\left(1 - \gamma\,(T_{cell} - T_{STC})\right) \times \frac{G}{G_{STC}}$$

Pb FIND THE OUTPUT OF A MODULE OPERATING AT MAXIMUM POWER POINT GIVING THE FOLLOWING THAT

TYPICAL MAXIMUM POWER AT STC = 77W

NOCT = 49°C. POWER OUT PUT COEFFICIENT $\gamma = -0.38\%$

AMBIENT TEMPERATURE = 35°C, IRRADIANCE 865 W/m²

$$T_{cell} = T_A + \frac{NOCT - 20}{800} \times G = 35 + \frac{49 - 20}{800} \times 865 = 66.36°C$$

$$P_T = P_{STC} \times \left(1 - \gamma\,(T_{cell} - T_{STC}) \times \frac{G}{G_{STC}}\right)$$

$$= 77\left(1 - \frac{0.38}{100}(66.36 - 25) \times \frac{865}{1000}\right) = 56.1\,W$$

$E_{MODULE} = P_{STC} \times P_{SH} \times f_{derate}$

P_{STC} = POWER (STANDARD TEST CONDITION), P_{SH} - PEAK SUN HR POWER

f_{derate} = DERATING FACTOR.

$$E_{MODULE} = V_{MODULE} \times \frac{I}{TU} \times f_{man} \times f_{dirt} \times H_{DAILY} \,\Big|\, \frac{I_{TU}}{O/P\ CURRENT}$$

V_{MODULE} = DEPEND ON THE CHARGING VOLTAGE, VOLTAGE DROP BETWEEN THE MODULE & BATTERY

I_{TV} - CURRENT READ FROM I-V CURVE

$T_{cell\,(eff)} = T_{A\,DAY} + k(80\,H_{DAILY} + 150)$

$T_{cell(eff)}$ = AVERAGE DAILY EFFECTIVE TEMPERATURE (°C)

$T_{A\,DAY}$ = DAY TIME AVERAGE AMBIENT TEMPERATURE, THE MONTH OF INTEREST

K = TEMPERATURE COEFFICIENT OF THE MODULE (0.3 °C/W-m²)

H_{DAILY} = IRRADIATION ON THE TILTED PLANE Kwh/m²

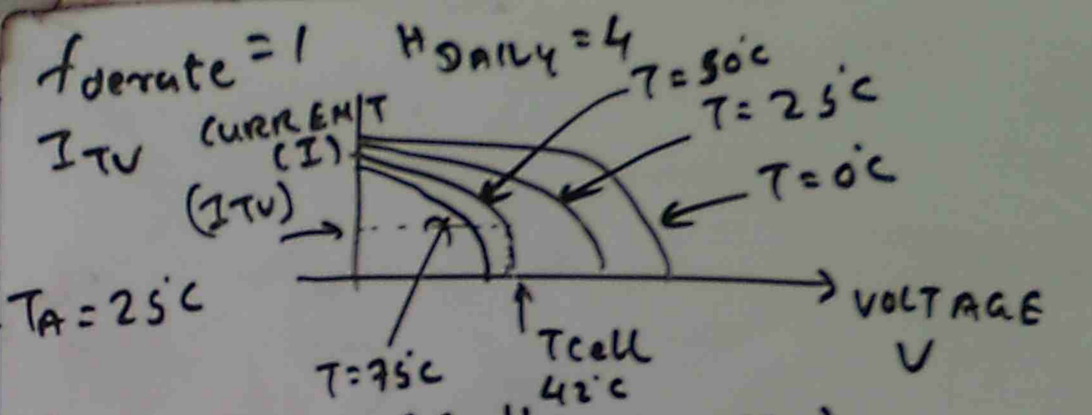
PD CALCULATE DAILY ENERGY OUTPUT OF 77W LEAD ACID BATTERY CHARGING, AMBIENT TEMPERATURE, $f_{derate} = 1$, $V_{MODULE} = 14V$ IRRADIATION = 4 Wh/m², MAXIMUM MODULE POWER RATING = 72W, NOLT = 49°C

$H_{DAILY} = 4$

$E_{MODULE} = V_{MODULE} \times I_{TV} \times f_{man} \times f_{derate} \times H_{DAILY}$

$f_{man} = \frac{\text{MODULE POWER}}{\text{ENERGY OUTPUT}} = \frac{72}{77} = 0.94$

$f_{derate} = 1$ $H_{DAILY} = 4$



$T_{cell} = T_A + k(80\,H_{DAILY} + 150)$

$= 25 + 0.03(80 \times 4 + 150) = 42°C$

FROM GRAPH → Tcell 42°C → $I_{TV} = 4.8$ AMP

$E_{MODULE} = V_{MODULE} \times I_{TV} \times f_{man} \times f_{derate} \times H_{DAILY}$

$= 14 \times 4.8 \times 0.94 \times 1 \times 4$

$= 253$ W-hr

MODULE CHARACTERISTICS

- IV CURVE, FILL FACTOR, OPERATING POINT MPP, CELL TEMPERATURE COEFFICIENT NOCT, VOLTAGE, POWER COEFFICIENT
- P.V. CELL EQUIVALENT CIRCUIT
- I V CURVE, FAMILY FOR P.V MODULE
- P.V MODULE RATING
- OPERATING POINT
- P.V ARRAY CONFIGURATION
- POWER AT MPP.

MODULE DAILY ENERGY OUTPUT ACCURATE METHOD

Pb/ A CALCULATE THE DAILY ENERGY OUTPUT OF A 100W POLYCRYSTALLINE MODULE OPERATING UNDER THE FOLLOWING CONDITIONS.
MAXIMUM POWER POINT TRACKING REGULATOR (MPPT), AMBIENT DAY TIME TEMPERATURE 25°C IRRADIATION 5.5 KWh/m², ENVIRONMENT WITH ANNUAL MAINTENANCE ONLY. THE MANUFACTURER WHO TESTS THE MODULES TO INTERNATIONAL STANDARDS GUARANTEES THE MAXIMUM MODULE POWER RATING TO BE 95W AND NOCT IS 49°C. $\gamma = 0.5\%$

$$MPPT \rightarrow E_{MODULE} = P_{STC}\left[1 - r(T_{cell} - T_{ref}) \times f_{man} \times f_{dirt} \times H_{DAILY}\right]$$

$P_{STC} = 95W$, $f_{man} = 1$, $f_{dirt} = 95\% = 0.95$

$H_{DAILY} = 5.5$

$T_{cell} = T_A + K\,(80\,H_{DAILY} + 150)$

$K = \frac{NOCT - 20}{800} = \frac{49 - 20}{800} = 0.036$

$T_{cell} = 25 + 0.036\,(80 \times 5.5 + 150) = 43^{\circ}C$

$E_{MODULE} = P_{STC}\left[1 - r(T_{cell} - T_{ref}) f_{man} f_{dirt}\right.$

$= 95\left[1 - \frac{0.5}{100}(43 - 35) \times 1 \times 0.95 \times 5.5\right. = 435\,W\text{-}h_{DAILY}$

THE CHARACTERISTICS of SUN LIGHT

$$E = hf = \frac{hc}{\lambda}$$

E = ENERGY
f = FREQUENCY
h = PLANK'S CONSTANT 6.63×10^{-34}
c = VELOCITY OF LIGHT 3×10^{8} m/s
λ = WAVE LENGTH

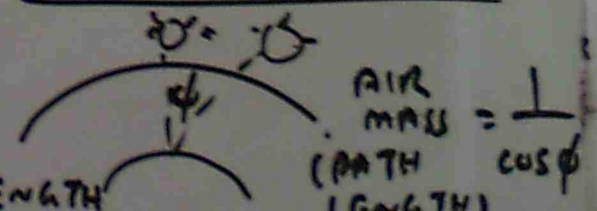
ENERGY DENSITY of BLACK BODY

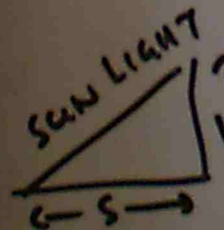
$$\varphi(f)\,df = \frac{8\pi h f^3\,df}{e^{3} \times \left[e^{hf/KT} - 1\right]}$$

$\varphi(f)$ - ENERGY PER UNIT AREA & UNIT WAVE LENGTH
K = BOLTZAMAN'S CONSTANT, f = FREQUENCY
h = PLANK CONSTANT, df = CHANGE IN FREQ:
$\varphi(f)\,df$ = CHANGE IN ENERGY PER UNIT AREA AND WAVE LENGTH DUE TO CHANGE OF FREQUENCY



SOLAR RADIATION ON EARTH'S SURFACE





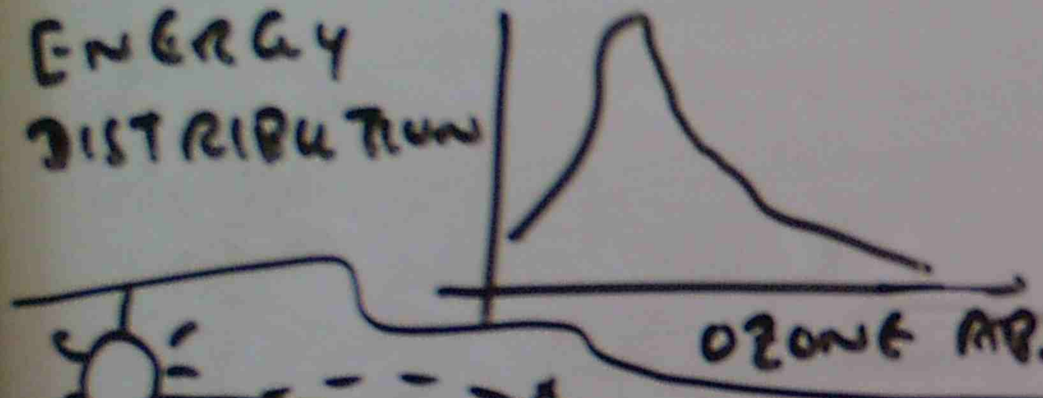
S = SHADOW LENGTH
h = HEIGHT OF VERTICAL

$$Am = \sqrt{1 + \left(\frac{S}{h}\right)^2}$$

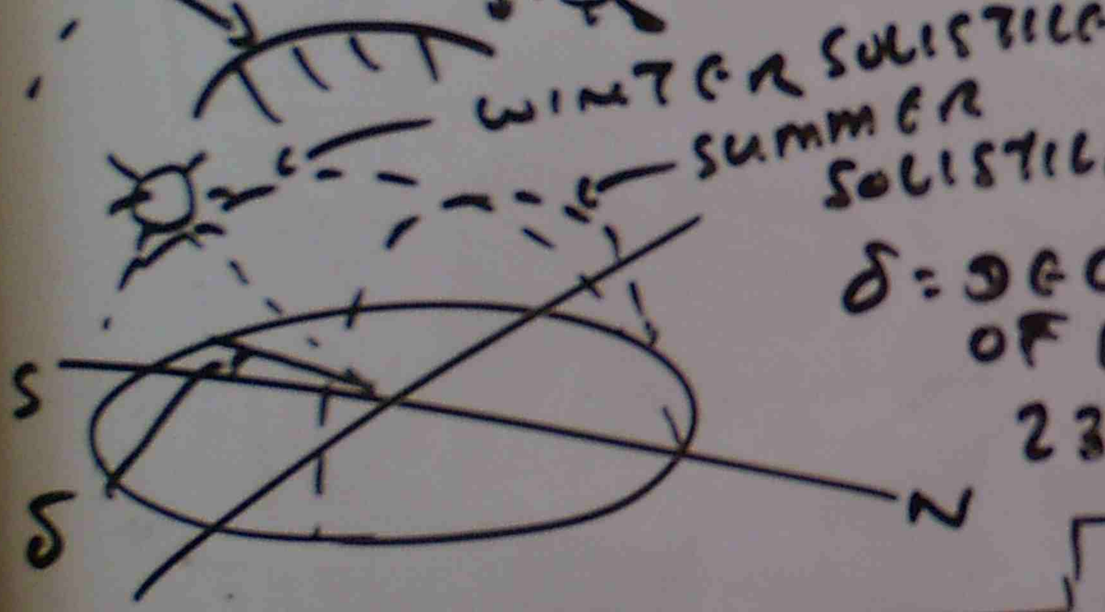
PATH LENGTH = AIR MASS (Am) $= \frac{1}{\cos\phi} = \sqrt{1 + \left(\frac{S}{h}\right)^2}$

A_{M_0} = 1.367 KW/m2 (AIR MASS ZERO CONSTANT)

ENERGY DISTRIBUTION

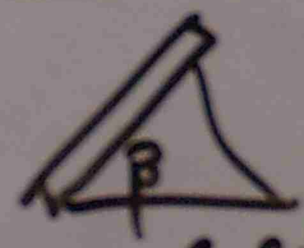






δ = DECLINATION OF EARTH 23° 27'

SOLAR INSOLATION MEASUREMENT



$S_\beta = S \frac{\sin(\alpha+\beta)}{\sin\alpha}$

$\alpha = 90 - \phi - \delta$

ϕ = NORTHERN HEMISPHERE LATITUDE

δ = DECLINATION OF SUN

$\delta = 23.45 \sin\left[\frac{(d-S_1)\times 360}{365}\right]$

d = DAY NUMBER

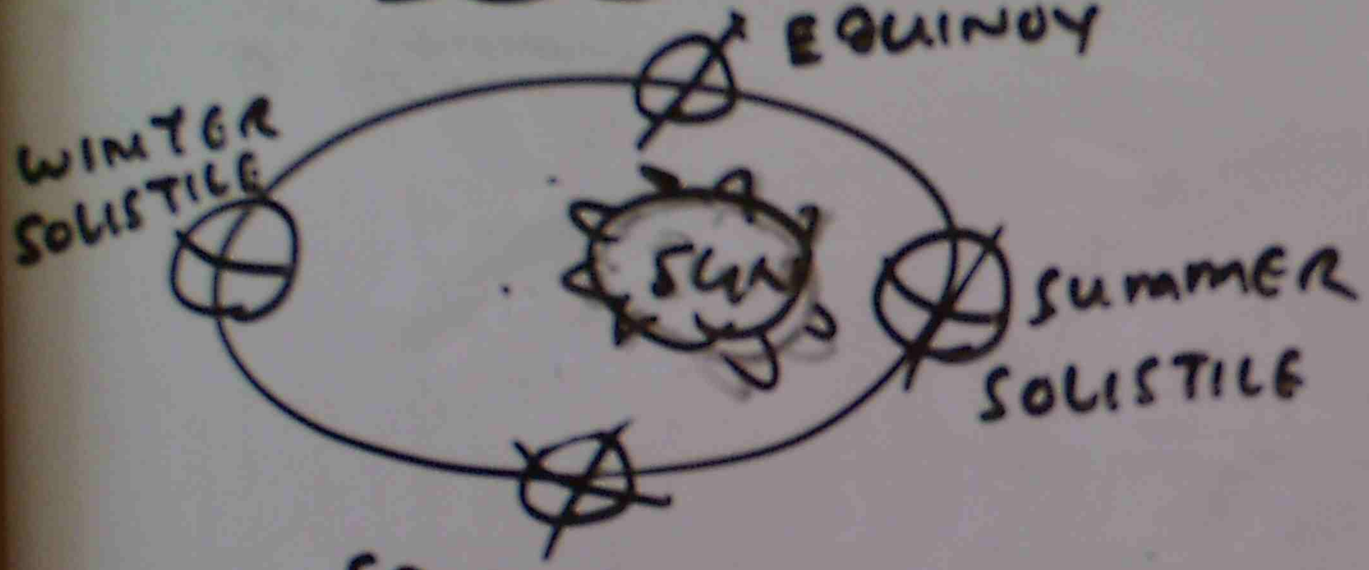
$\frac{\Delta H_{GR}}{S}$ { H_{GR} = DAILY GLOBAL RADIATION
R_0 = DAILY EXTRA TERRESTRIAL RADIATION

$\frac{R}{R_0} = \alpha + \beta \frac{n}{N}$

$\alpha = 0.24, \beta = 0.48$

n = SUNSHINE IN DAY $_{HR}$ | N = MAX SUNSHINE $_{HR}$

SOLAR GEOMETRY

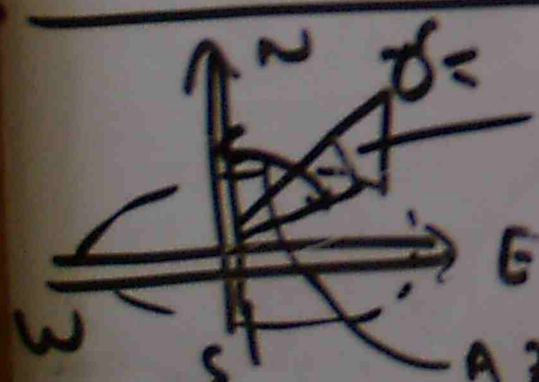


MARCH 21 - AUTUMN
JUNE 22 - WINTER
SEPTEMBER 23 - SPRING
DECEMBER 21 - SUMMER

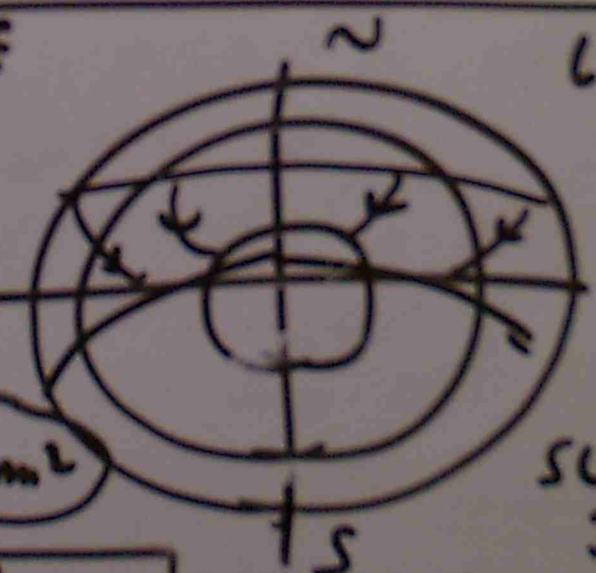
THE SUN RISE & SUN SET DEPENDS ON THE TIME OF THE YEAR

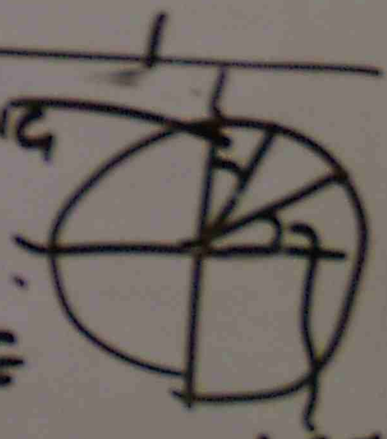


ALTITUDE & AZIMATH ANGLE



$G = 1000\ W/m^2$

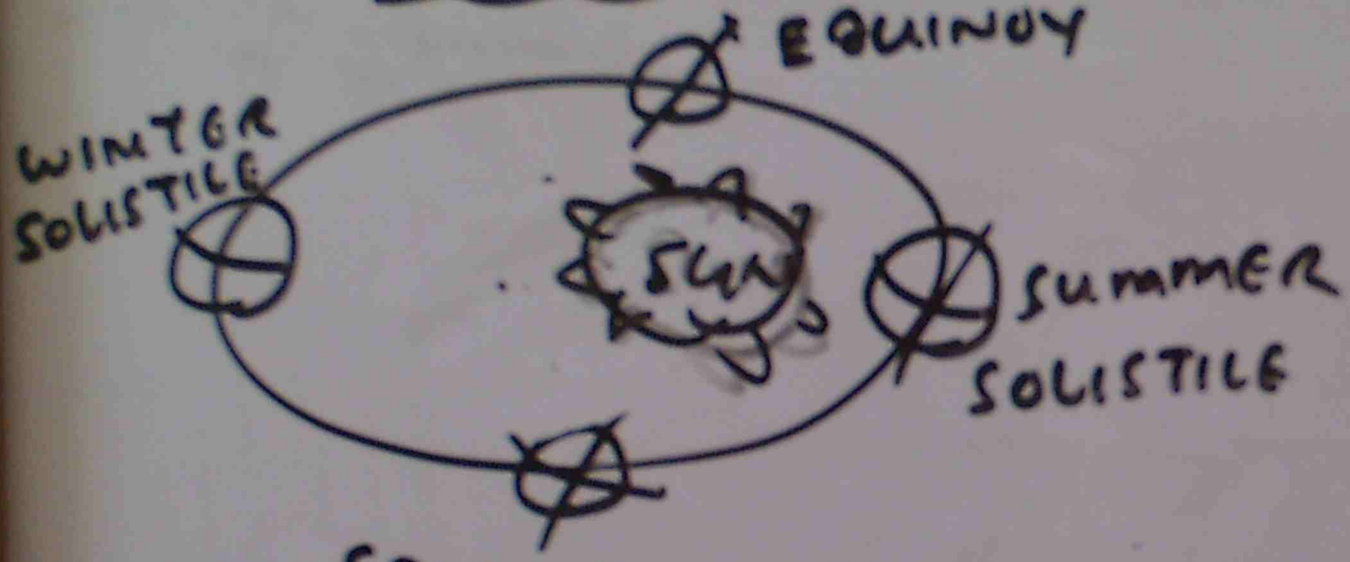




SUN PATH DIAGRAM

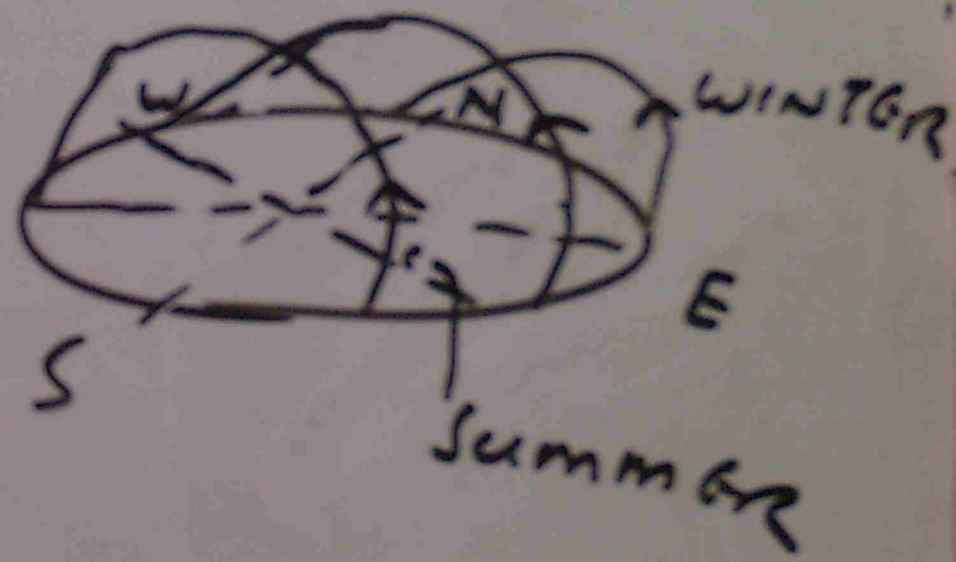
STd Time = Solar Time $\pm 4 (L_{oc} - L_{st}) E$ | E CORRECTION

SOLAR GEOMETRY

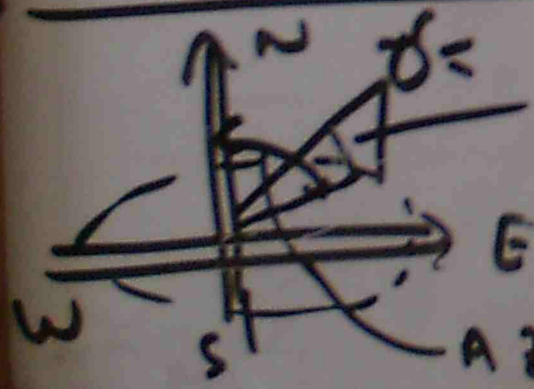


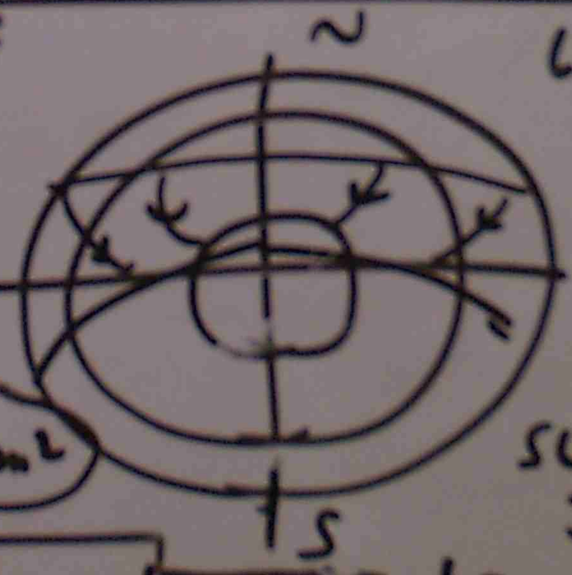
MARCH 21 - AUTUMN
JUNE 22 - WINTER
SEPTEMBER 23 - SPRING
DECEMBER 21 - SUMMER

THE SUN RISE & SUN SET DEPENDS ON THE TIME OF THE YEAR

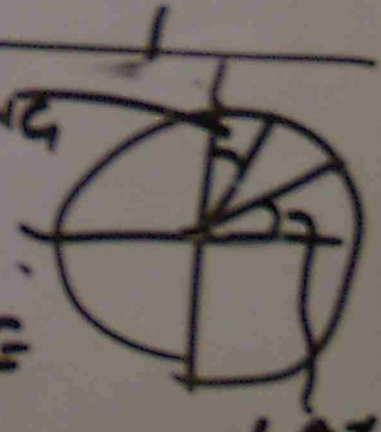


ALTITUDE & AZIMATH ANGLE





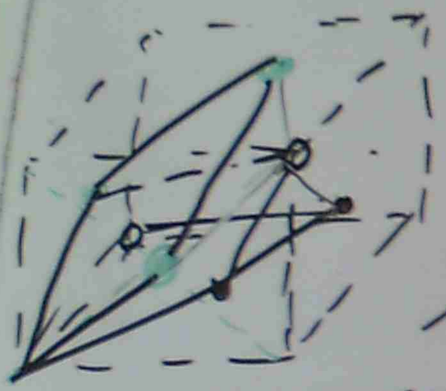
$G = 1000\ W/m^2$

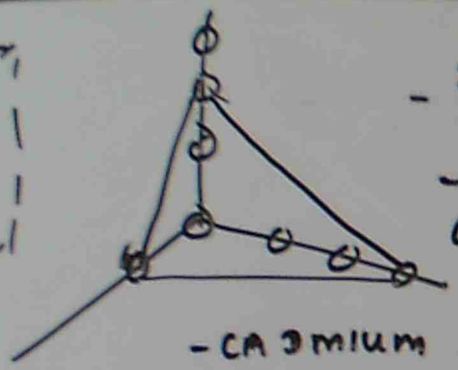


SUN PATH DIAGRAM

$\text{STd Time} = \text{Solar Time} \pm 4\,(L_{oc} - L_{st})\,E$ | E CORRECTION

REVIEW OF SEMI CONDUCTOR PROPERTIES

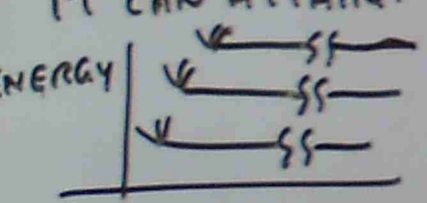




- DIAMOND LATTICE
- SILICON
- GALLIUM ARSENIDE
- CADMIUM SULFIDE

FORBIDDEN ENERGY GAP

AN ELECTRON IN FREE SPACE HAS AN ESSENTIALLY CONTINUOUS RANGE OF ENERGY VALUE THAN IT CAN ATTAIN.



FERMI LEVEL

TWO ELECTRONS OF EACH OF OPPOSITE SPIN AT LOW TEMPERATURE THE ENERGY OCCUPIED BY TWO ELECTRONS

$$f(E) = \frac{1}{1 + e^{(E-EF)/KT}}$$

$f(E)$: FERMI DISTRIBUTION FUNCTION

K = BOLTZMANN'S CONSTANT

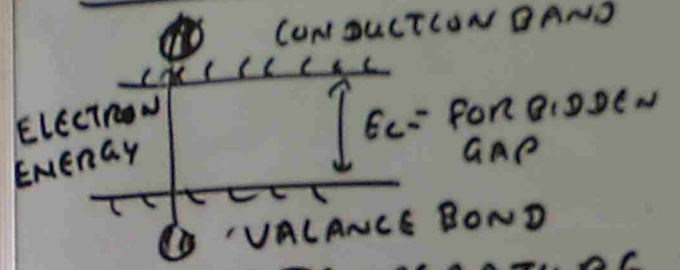
T = ABSOLUTE TEMPERATURE ('K)

NO. OF ELECTRONS IN CONDUCTION BAND

$$n = N_c e^{(E_f - E_c)/KT}$$

NO. OF HOLES = $P = N_v e^{(E_f - E_i)/KT}$

BOND MODEL



AT LOW TEMPERATURE THE BONDS ARE INTACT AND THE SILICON BEHAVES AS INSULATOR.

AT HIGH TEMPERATURE, SOME BONDS ARE BROKEN - ELECTRONS FROM BROKEN BONDS ARE FREE TO MOVE AND ELECTRONS FROM NEIGHBOURING BONDS CAN ALSO MOVE INTO THE HOLE CREATED IN THE BROKEN BOND, ALLOWING THE BROKEN BOND (OR) HOLE TO PROPAGATE AS IT HAD A POSITION CHANGE

DOPING — TO SHIFT THE BALANCE OF ELECTRON

CRYSTALLINE SILICON, AMORPHOUS,

ABSORPTION OF LIGHT

LIGHT FALLS ON TO SEMICONDUCTOR

- PHOTON WITH ENERGY (EPH) LESS THAN BOND GAP ENERGY (Eg) INTERACT WITH SEMICONDUCTOR
- PHOTON WITH ENERGY GREATER BOND GAP ENERGY Eg INTERACT WITH ELECTRONS IN COVALENT BOND

RECOMBINATION

LIGHT SWITCH OFF ↓ RETURN TO EQUILIBRIUM STATE

$$V_{OC} = \frac{KT}{q} \ln\left[\frac{I_L}{I_0} + 1\right]$$

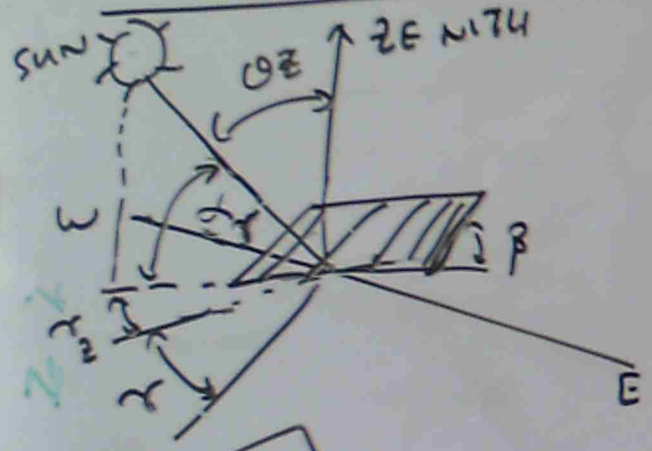
q = CHARGE

K = BOLTZMAN'S CONSTANT

I_0 - DARK CURRENT

I_L - ILLUMINATED CURRENT

SOLAR RADIATION & SHADING ASSESSMENT

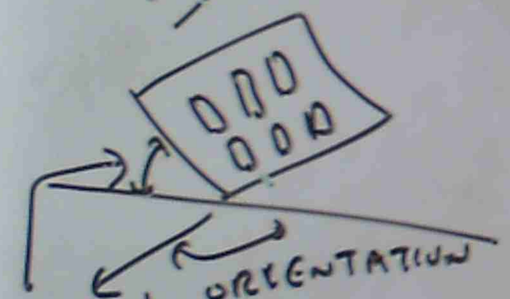


β = ANGLE OF TILTED PLANE

θ_z = INCIDENCE ANGLE FOR TILTED SURFACE

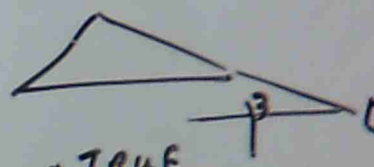
γ_s = AZIMATH ANGLE OF SUN

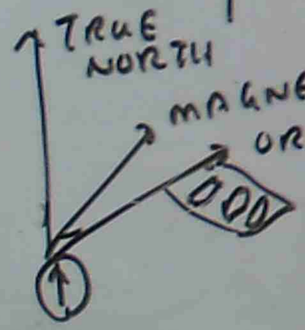
γ = ORIENTATION ANGLE OF TILTED PLANE

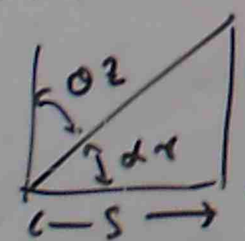


β - TO BE MEASURED BY CLINOMETER

γ = ORIENTATION OF TILTED PLANE TO BE MEASURED BY COMPASS







$\alpha_\gamma = \tan^{-1} \frac{h}{s}$

$\theta_z = 90 - \alpha_\gamma$

COMPUTER SOFTWARE

RAD, SolPV DESIGN

DATA INPUT

LOCATION, LATITUDE

TILT (β), ORIENTATION

OUTPUT - IRRIDATION

H - HORIZONTAL IRRIDATION

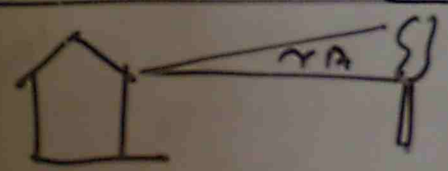
H_i - INCLINED PLANE HORIZONTAL

SR - TIME OF SUNRISE

SS - TIME OF SUNSET

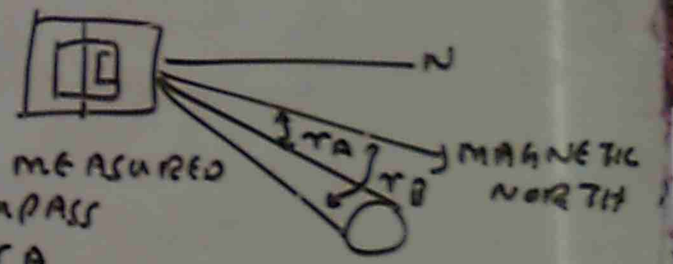
SHADING ASSESSMENT < METHOD (1) SOLAR CHART
METHOD (2) COMPUTER SOFT WARE

METHOD (1) SOLAR CHART

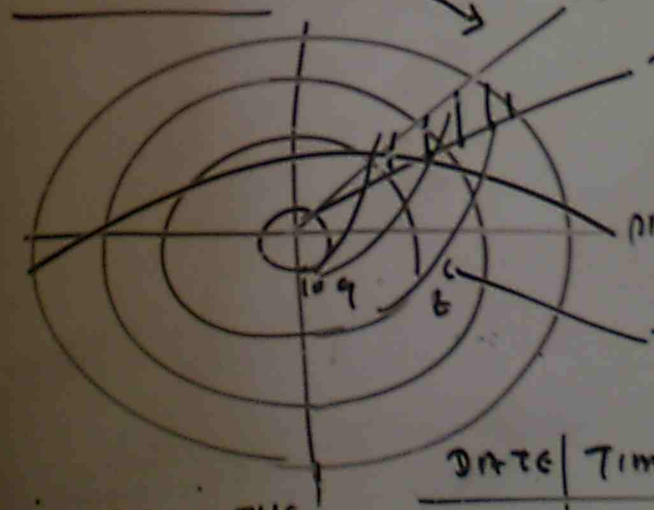


γ_A - TO BE MEASURED BY COMPASS

$\gamma_B = 90 - \gamma_A$



SOLAR CHART



READ THE TABLE

DATE	TIME	W/m² IRRADIATION

COMPUTER SOFTWARE

ENTER THE LOCATION CITY

POSSUN

DATE (ENTER --) LATITUDE ( )

SLOPE = 27.5 (DEPEND ON LOCATION CITY

AZIMATH = 0 ← TRUE NORTH

A = BEARING * 1 > YA

B BEARING * 2 > YB

B ALT ANGLE => 0

B BGARING *1 => 0

B BGARING *2 ⇒ 0

OUTPUT

DAY LENGTH

SHADE LENGTH

ETC.

RAD INPUT - LOCATION OF CITY LATITUDE

TILT ANGLE) —

ORIENTATION OF COLLECTOR = 0 ← NORTH

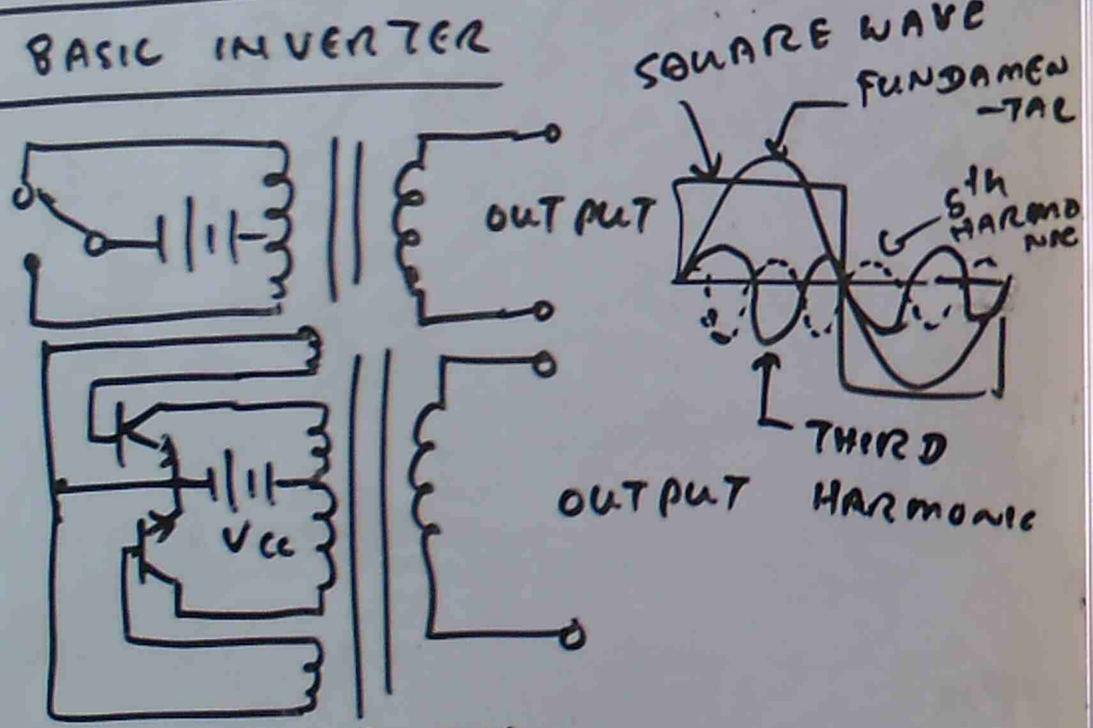
MONTH	lt	H COLLECTOR

PUT THESE INTO POSSUN SHADING EFFECT CELL

INUBRTER

AN INVERTER IS AN ELECTRICAL DEVICE THAT CONVERTS DIRECT CURRENT TO ALTERNATING CURRENT, THE RESULTING AC CAN BE AT ANY REQUIRED VOLTAGE & FREQUENCY WITH THE USE OF APPROPRIATE TRANSFORMERS, SWITCHING & CONTROL CIRCUITS

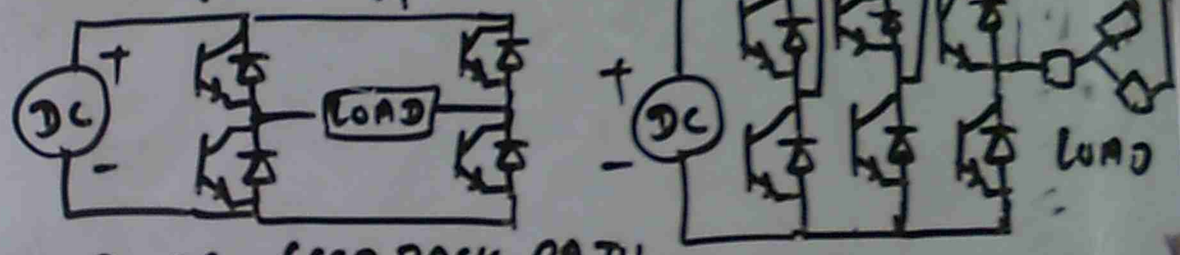
BASIC INVERTER



A SWITCH IS RAPIDLY SWITCHED BACK AND FORTH TO ALLOW CURRENT TO FLOW BACK TO DC SOURCE FOLLOWING TWO ALTERNATE PATHS THROUGH ONE END OF THE PRIMARY WINDING & THEN THE OTHER

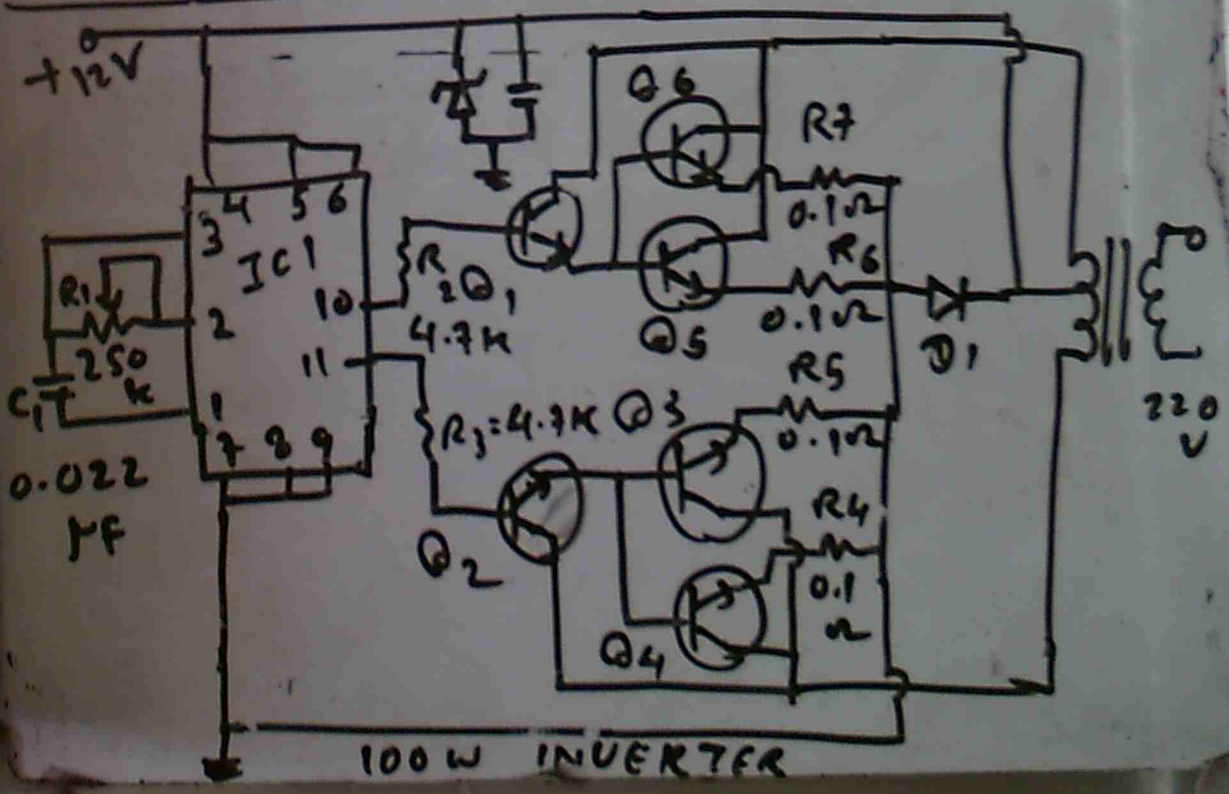
TOTAL HARMONIC DISTORTION

$$THD = \sqrt{\frac{V_2^2 + V_3^2 + \cdots V_m^2}{V_1}}$$

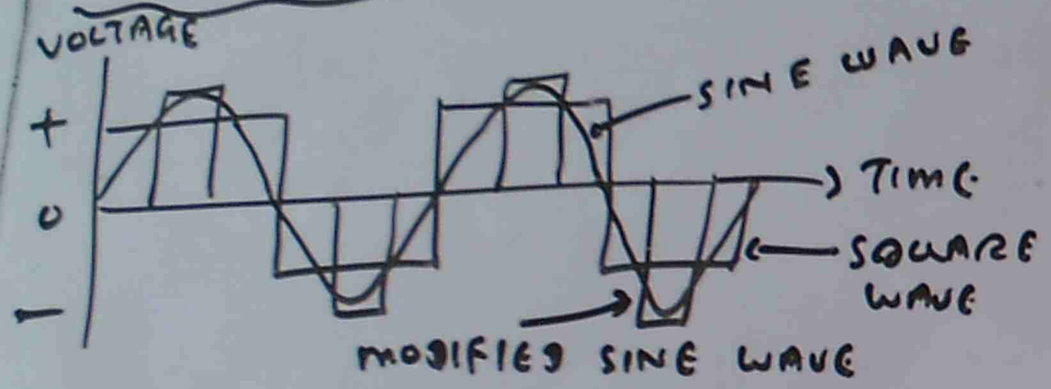


DIODE - FEED BACK PATH

PWM - PULSE WIDTH MODULATION, REGULATING THE WIDTH of A SQUARE WAVE PULSE TO REGULATE (OR) ADJUST INVERTER'S OUTPUT VOLTAGE

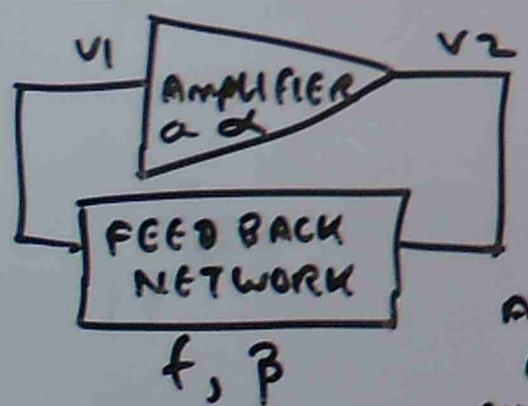


MODIFIED SINE WAVE INVERTER



NON SANE WAVE – HIGH LEVEL HARMONIC DISTORTION, OVER HEATING, OPERATING DIFFICULTIES

OSCILLATOR



$|f| \times |a| \, e^{j(\alpha+\beta)} \geq 1$

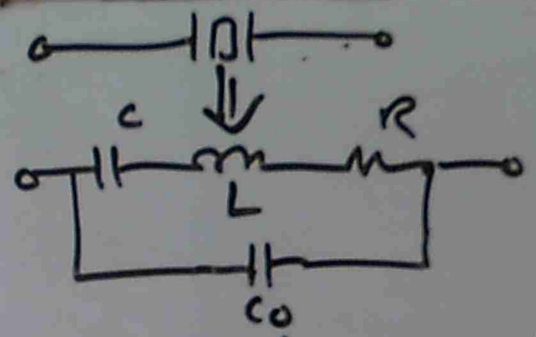
$\alpha + \beta = 2\pi$

AMPLIFIER VOLTAGE GAIN – a

PHASE SHIFT α

FEED BACK NETWORK FREQUENCY f

PHASE SHIFT β



f_{ser} = SERIES RESONANT FREQUENCY

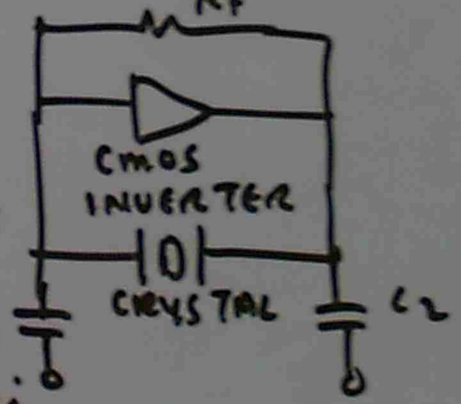
f_{par} = PARALLEL RESONANT FREQUENCY

$f_{ser} = \frac{1}{2\pi\sqrt{LC}}$, $f_{par} = f_{ser}\sqrt{1+\frac{C}{C0}}$

$f_{par} = \frac{1}{2\pi\sqrt{LC}}\sqrt{1+\frac{C}{Cp+C0}}$, $f = \frac{C1}{C2}$

$Cp = \frac{C_1 C_2}{C_1 + C_2}$

PIERCE OSCILLATOR USING CMOS INVERTER



CMOS PHASE SHIFT 180°

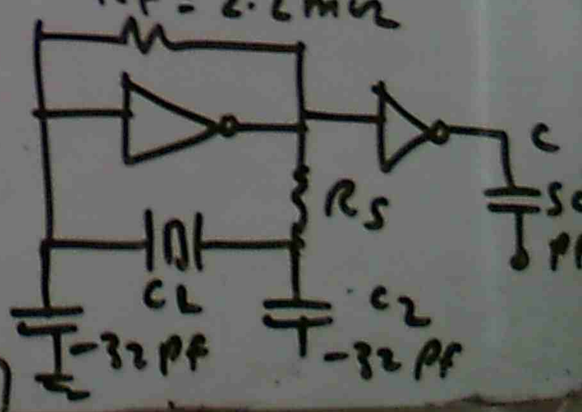
$R_p = \frac{1}{R_\omega^2 (\omega + C_p)^2}$

$R_f = R_p \times \alpha$

$Z_i = \frac{R_f}{\alpha}$

$R_F = 2.2\,M\Omega$

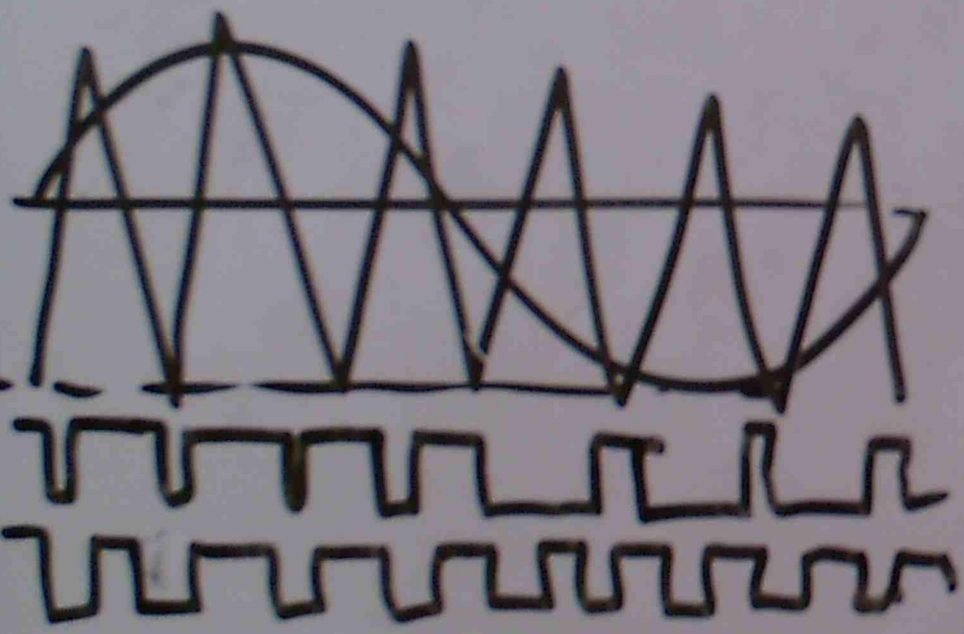
OSCILLATOR USING A SCHMITT TRIGGER. INPUT INVERTER



LVC1404 DUAL INPUT INVERTER GATE

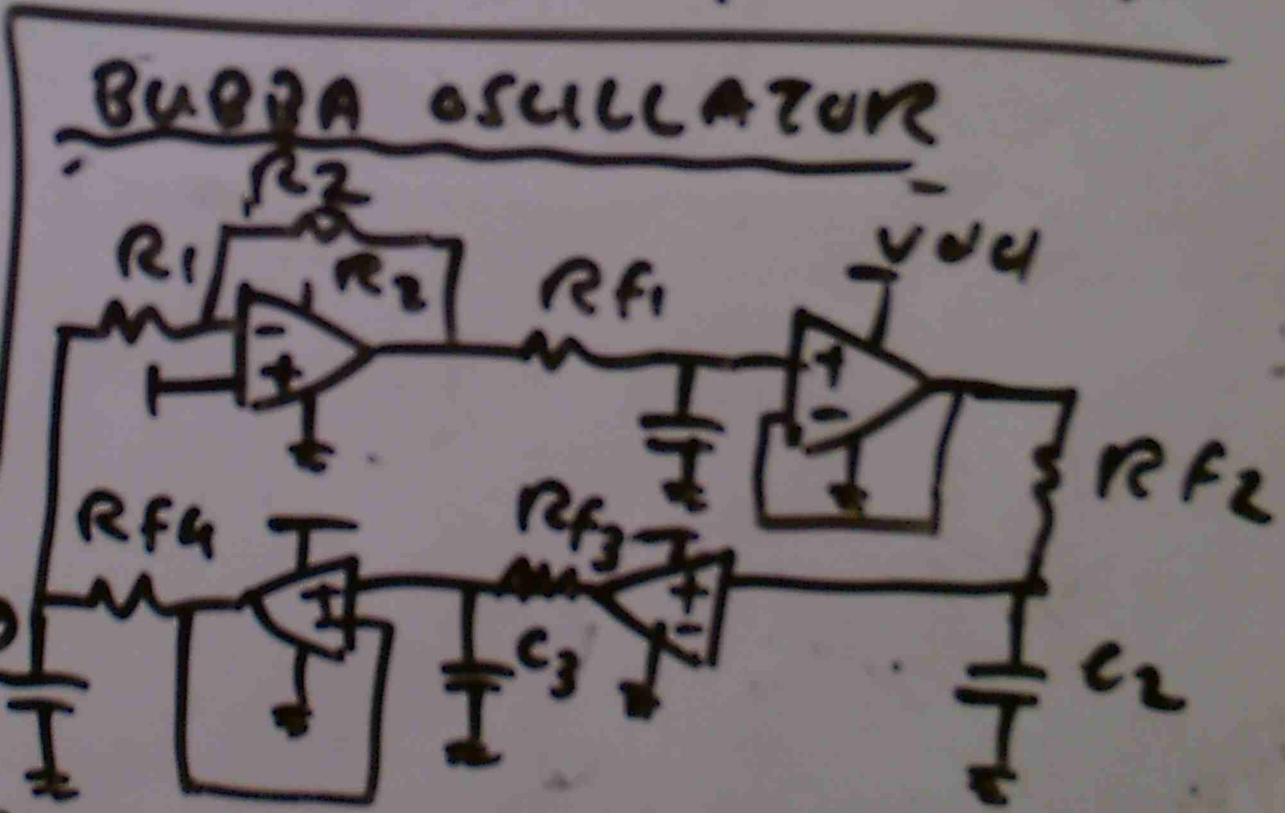
PULSE WIDTH MODULATION

ANALOG PULSE WIDTH MODULATION REQUIRES THE GENERATION OF BOTH REFERENCE & CARRIER SIGNALS THAT FEED IN TO A COMPARATOR WHICH CREATES OUT PUT SIGNAL BASED ON THE DIFFERENCE SIGNALS.



TRANSISTOR / SWITCHING TECHNOLOGY IS USED

BUBBA OSCILLATOR



H-BRIDGE CONFIGURATION

P CHANNEL MOSFET.

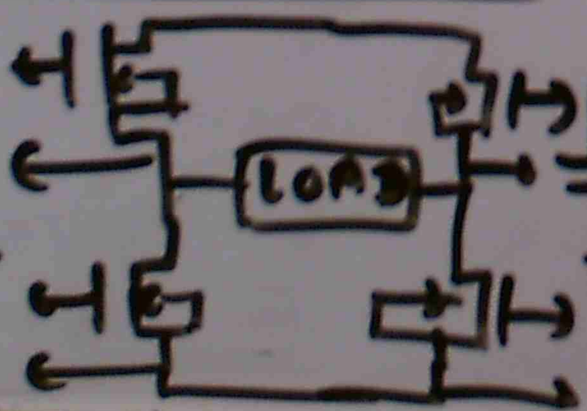
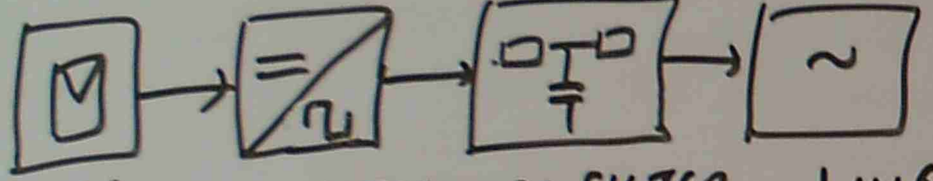
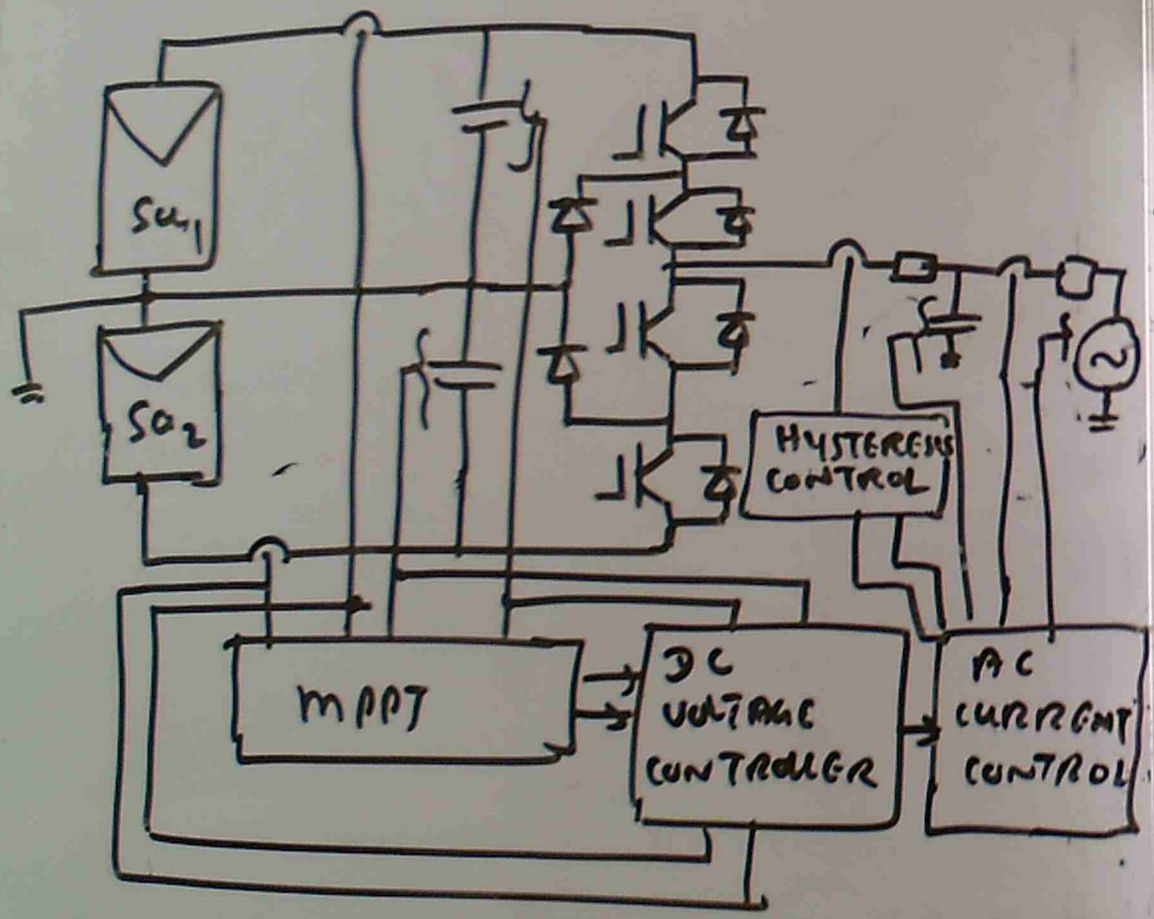
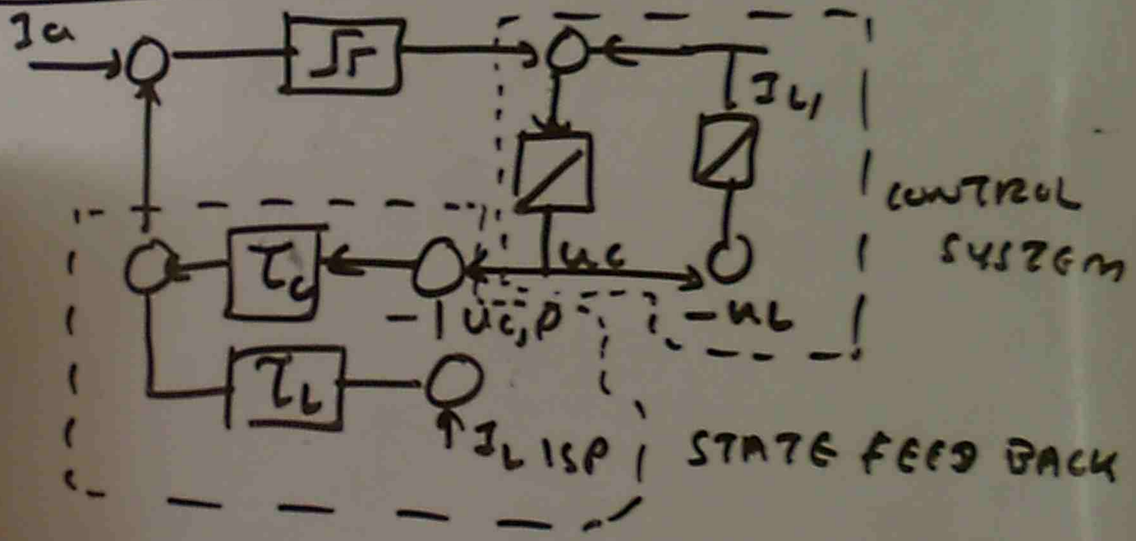


PHOTO VOLTAIC INVERTER





THE SOLAR ARRAY IS SPLITTED INTO TWO STRINGS. THE MID POINT IS CONNECTED TO GROUND SO THAT THE DESCRIBED INFLUENCE OF THE CAPACITANCE BETWEEN SOLAR ARRAY AND GROUND WILL BE ELIMINATED

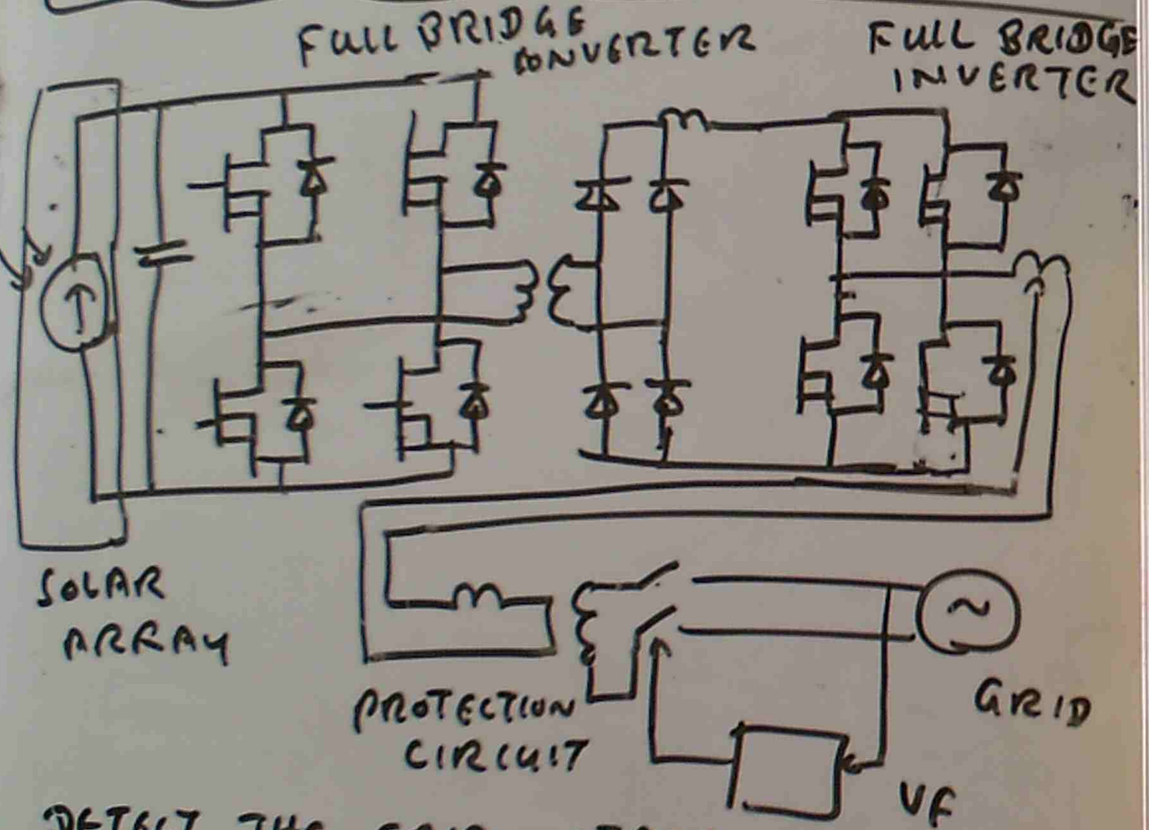


AC FILTER ELEMENTS AND SWITCHING FREQUENCY AT WHICH THE HARMONIC COMPONENT CAN BE LIMITED AND OVERALL LOSSES CAN BE MINIMIZED

THE DC VOLTAGE CONTROLLER IS CAPABLE TO TRACK THE LOAD BY AN ABRUPT CHANGE OF TEMPERATURE

CURRENT CONTROL — FILTER ELEMENT & SWITCHING FREQUENCY PARAMETERS ARE CHOSEN.

ISLANDING DETECTION FOR PHOTO VOLTAIC GRID CONNECTED INVERTER



DETECT THE GRID VOLTAGE

WHEN GRID VOLTAGE IS ZERO, IT SWITCHES OFF INVERTER CIRCUIT.

(1) INVERTER INTRODUCTION

SLIDE (1) → (6), Q1 → Q5

(2) INVERTER

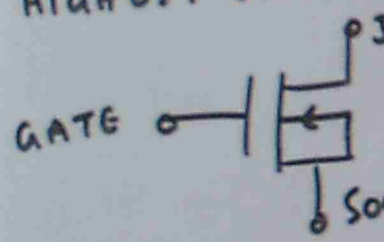
SLIDE (1) → (16) Q6 → Q13

(3) SINE WAVE INVERTER

SLIDE (1) → (8) $Q_{14} \rightarrow Q_{19}$

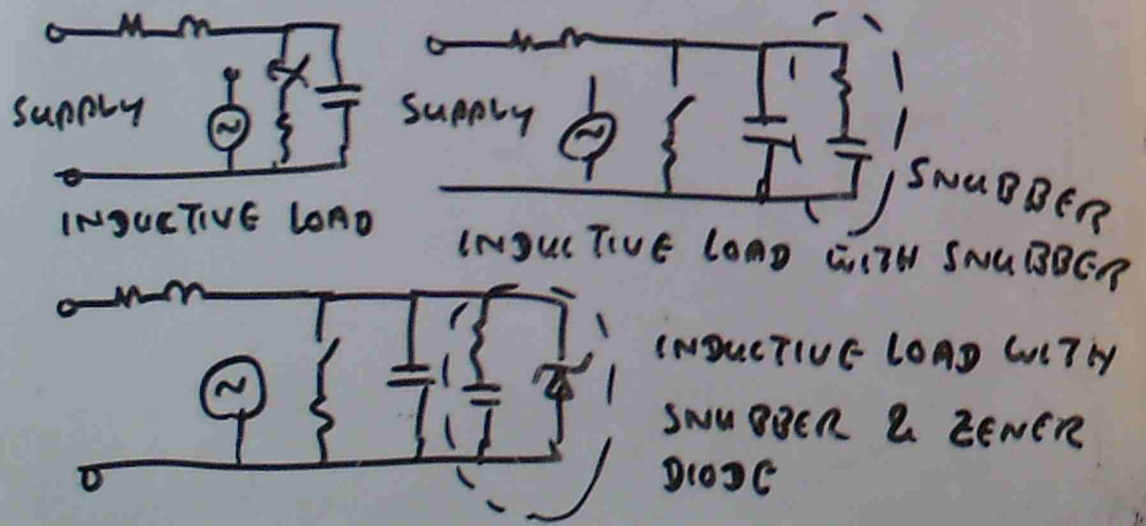
MOSFET DRIVES

WHEN UTILIZING N-CHANNEL MOSFET TO SWITCH A DC VOLTAGE ACROSS A LOAD, THE DRAIN TERMINALS OF THE HIGH SIDE MOSFETS ARE OFTEN CONNECTED TO THE HIGHEST VOLTAGE IN THE SYSTEM.



CIRCUIT PROTECTION AND SNUBBERS

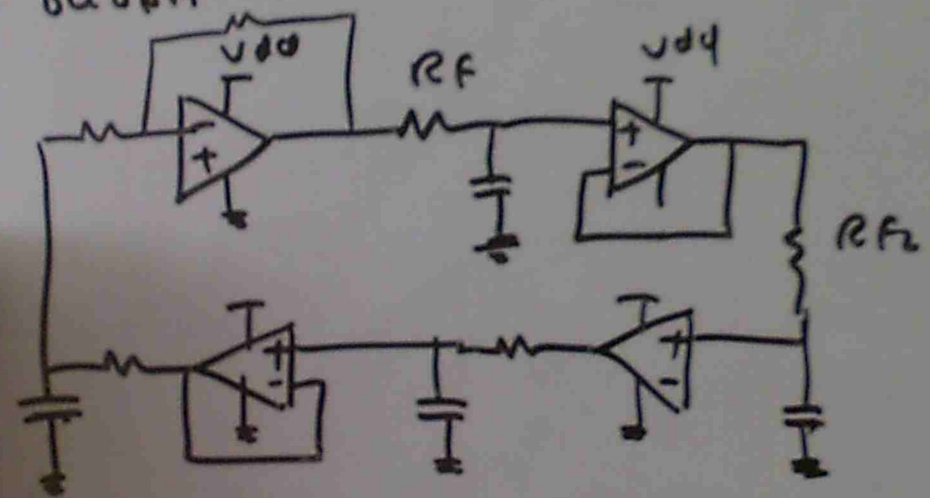
- TO PROTECT ITSELF FROM SURGES THAT COULD DAMAGE THE CIRCUITRY
- CRITICALLY DAMPING THE SURGE



FILTER — HIGH / LOW PASS / BAND PASS
PASSIVE FILTER - HIGHER RESISTANCE AT LOW FREQUENCY.

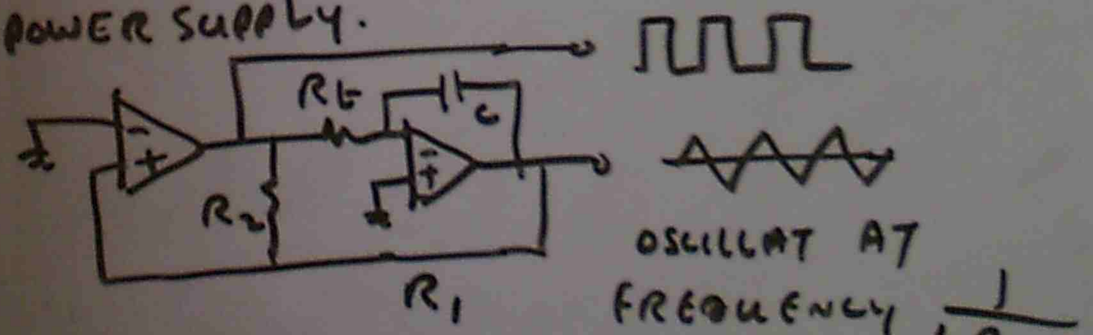
SINGWAVE GENERATOR

BUBBA OSCILLATOR



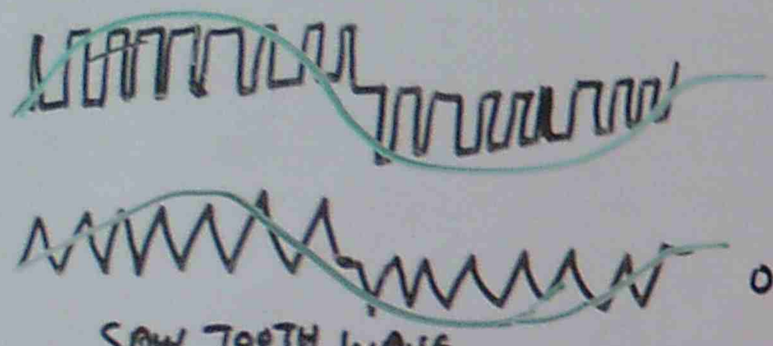
CARRIER WAVE GENERATOR

GENERATING A SINE WAVE AT 60HZ REQUIRES BOTH THE REFERENCE SINE WAVE AND A CARRIER WAVE AT THE SWITCHING SPEED OF POWER SUPPLY.



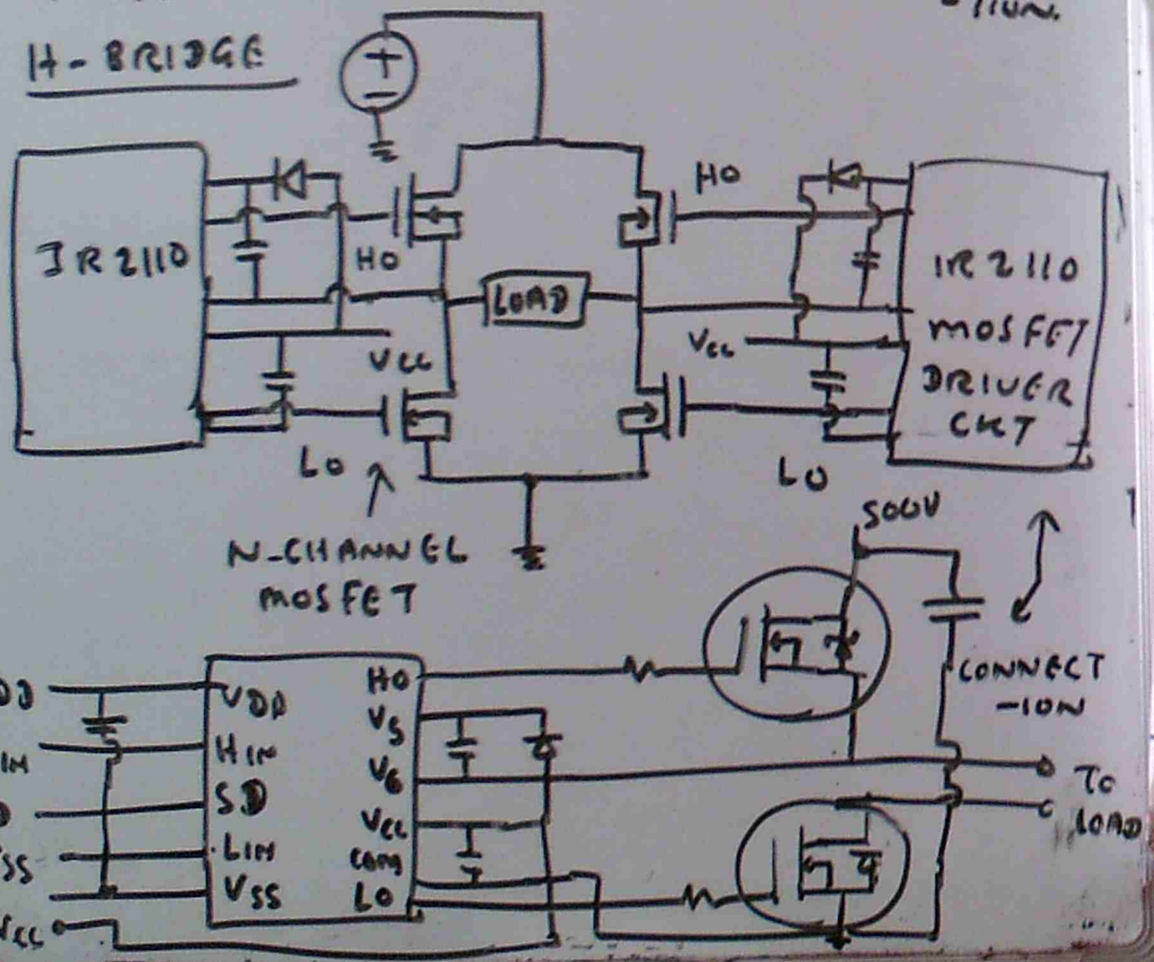
OSCILLAT AT FREQUENCY $\frac{1}{4R_fC}$

PULSE WIDTH MODULATION



THIS SIGNAL WILL BE USED TO CONTROL MOSFET. USING H-BRIDGE MOSFET CONFIGURATION.

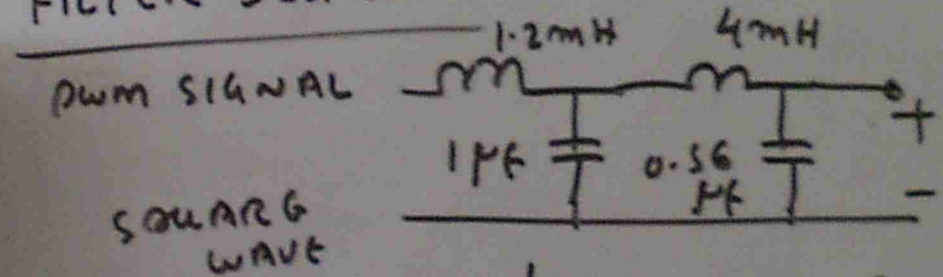
H-BRIDGE



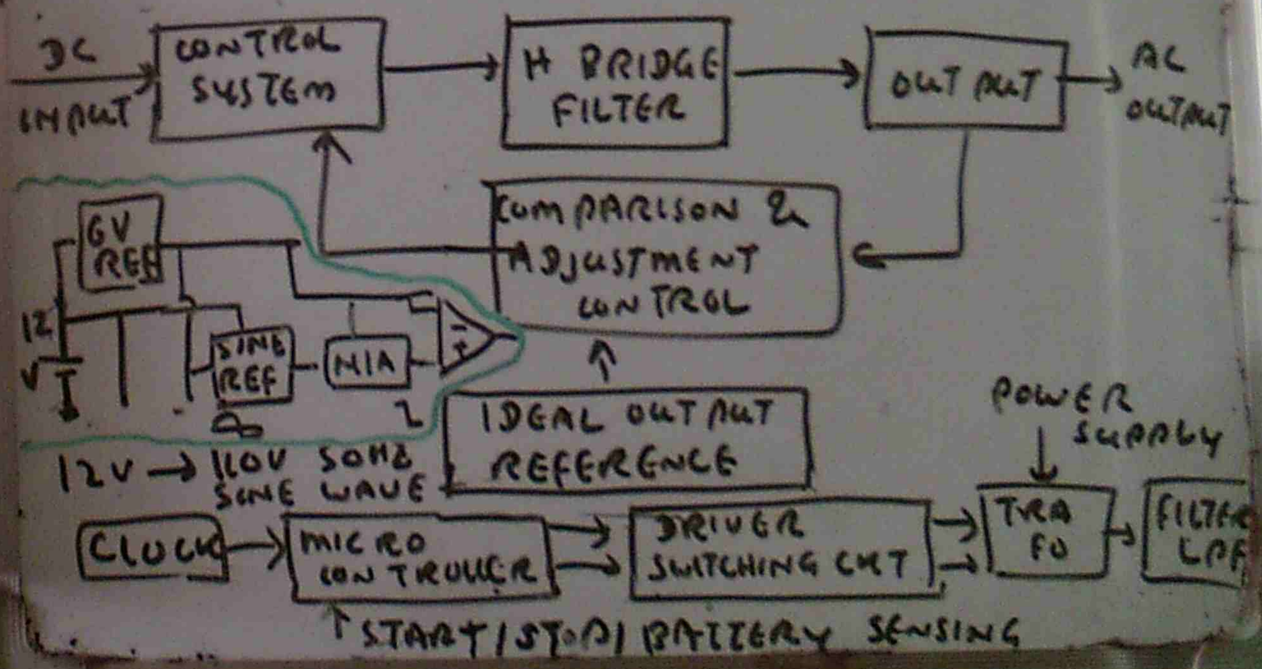
FILTER

IN ORDER TO OPTIMIZE THE FREQUENCY, A SWITCHING FREQUENCY MUST BE CHOSEN WHICH IS LOW ENOUGH TO KEEP THE SWITCHES IN LINE, BUT HIGH ENOUGH TO MAKE SURE THE FILTER INDUCTOR IS NOT UNNECESSARILY LARGE

FILTER DESIGN



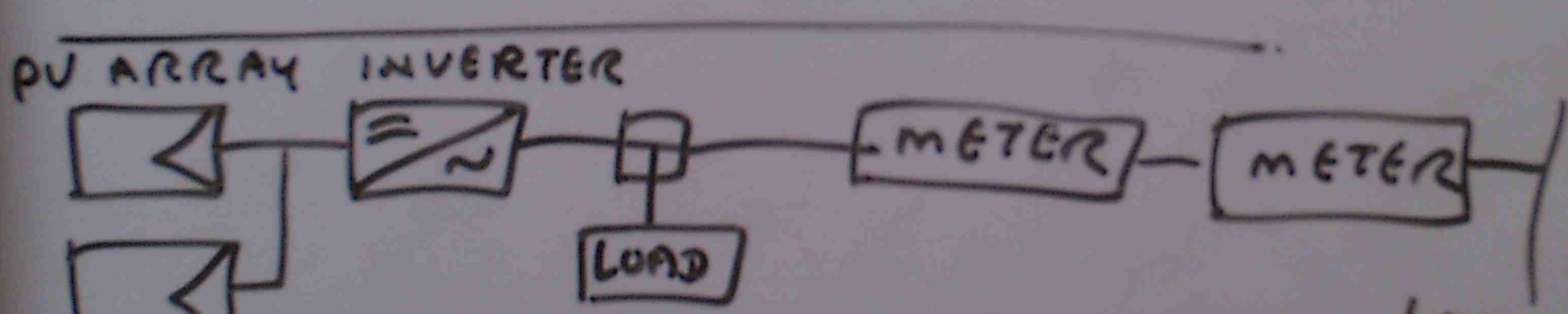
LOW PASS FILTER | TWO POLES FILTER



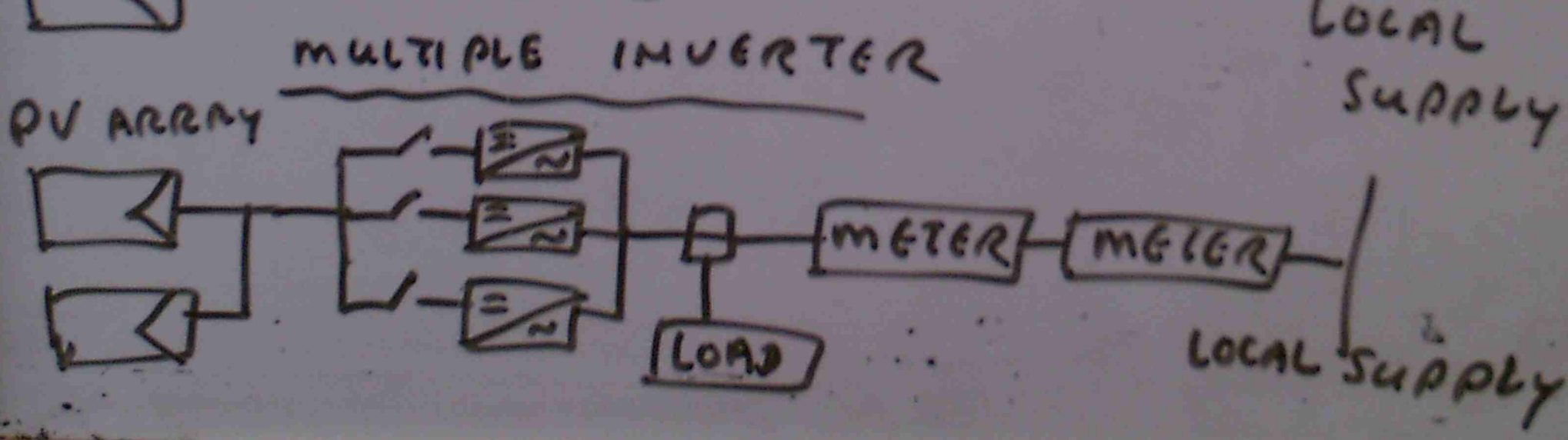
GRID CONNECTED INVERTER

THE OUT PUT FROM THE RENEWABLE ENERGY CONVERSION DEVICES IS EXPORTED TO THE GRID (AFTER BEING CONVERTED TO AC AT THE CORRECT VOLTAGE AND SYNCHRONISED WITH THE GRID FREQUENCY) DURING TIMES OF EXCESS SUPPLY.

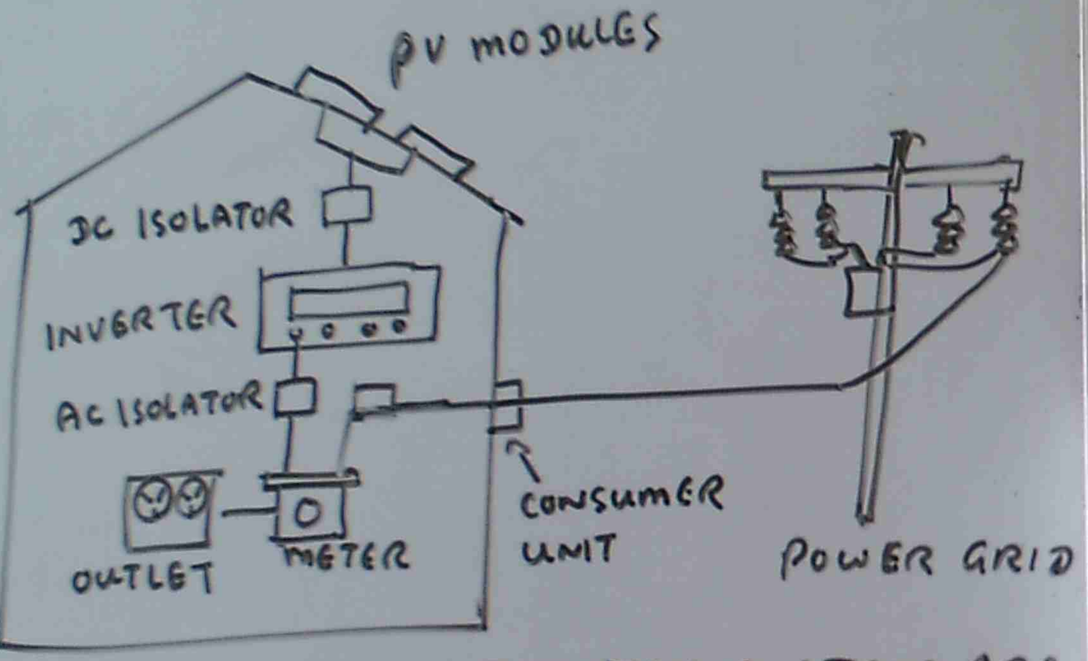
BASIC GRID CONNECTED NETWORK



MULTIPLE INVERTER



GRID CONNECTED SYSTEMS

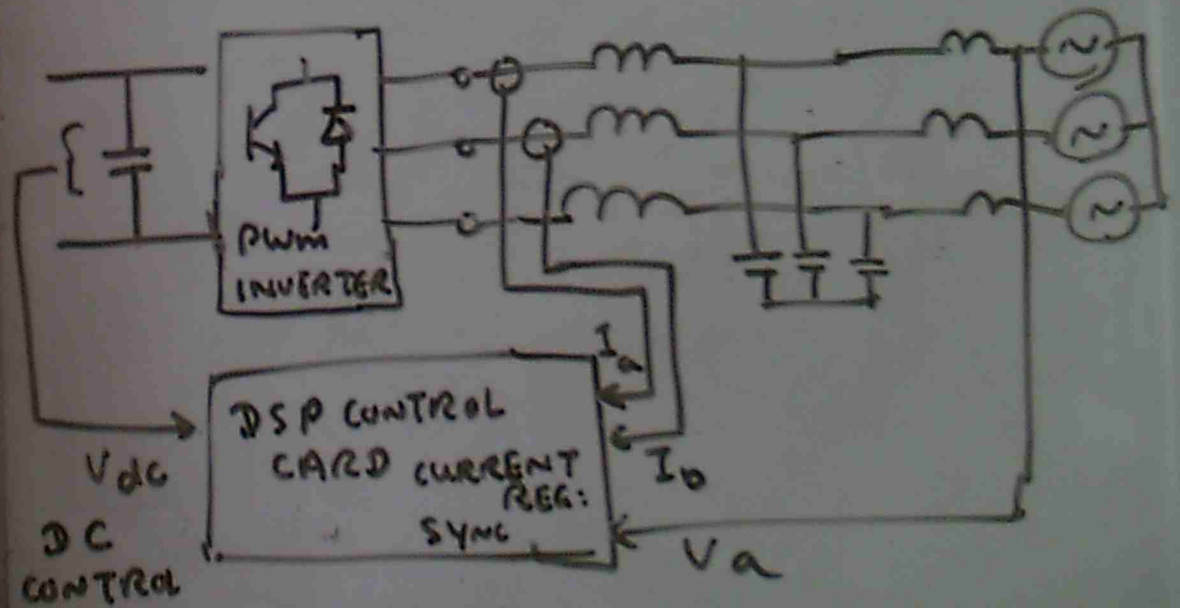


GRID CONNECTED PHOTOVOLTAIC SYSTEMS ARE THE MOST COMMON TYPE OF GRID CONNECTED SYSTEM. AS ELECTRICITY PRODUCED DURING THE DAY TIME IS EITHER USED (OR) DIRECTED BACK INTO THE ELECTRICITY GRID, AND AT NIGHT ELECTRICITY IS PURCHASED FROM THE GRID, THERE IS NO NEED FOR EXPENSIVE BATTERY BANK.

- AS 4777.1 (2002) GRID CONNECTION OF ENERGY SYSTEM VIA INVERTER PART(1) - INSTALLATION
- AS 4777.2 (2002) GRID CONNECTION OF ENERGY SYSTEM VIA INVERTER PART(2) - INVERTER REQUIREMENT
- AS 4777.3 (2002) GRID CONNECTION OF ENERGY SYSTEM VIA INVERTER PART(3) - GRID PROTECTION REQUIREMENT

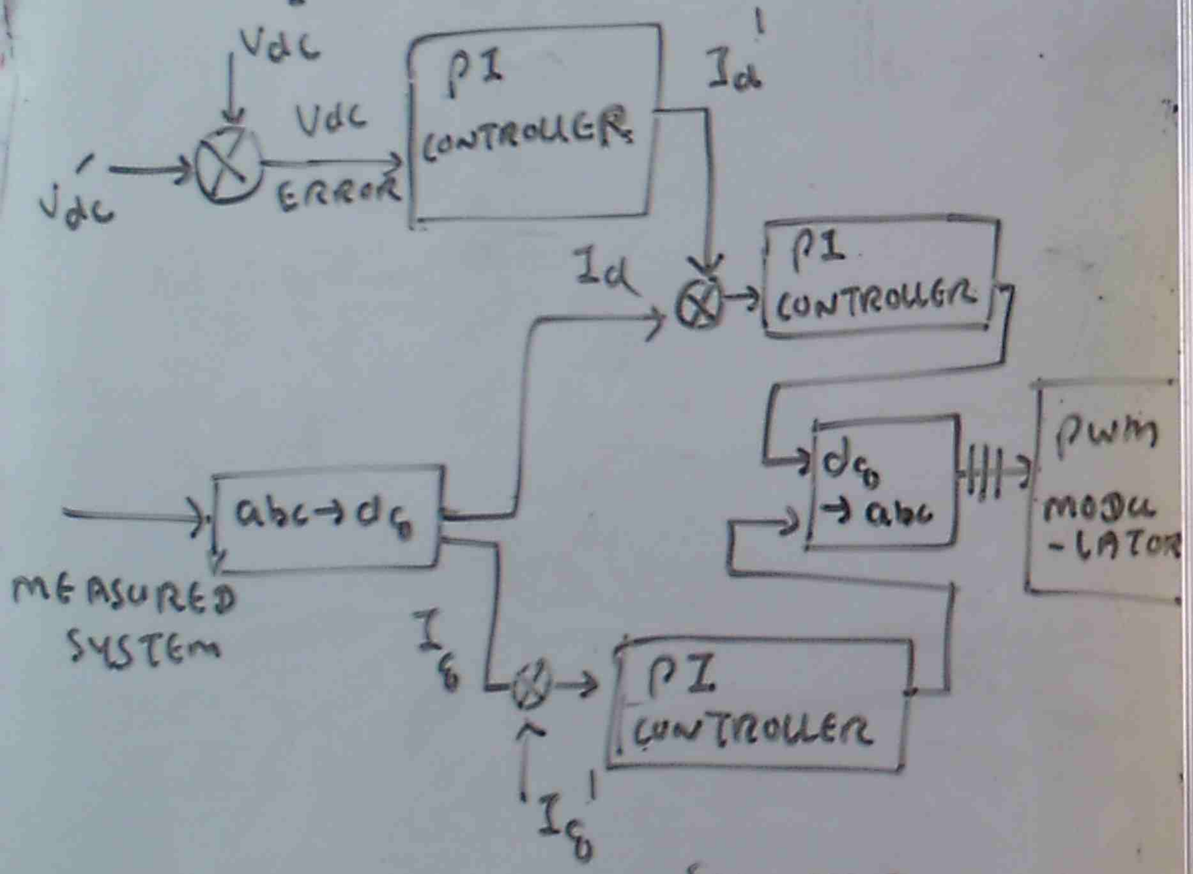
ISLANDING PROTECTION

MONITORING THE RATE OF FREQUENCY, VOLTAGE DROP, VOLTAGE JUMP



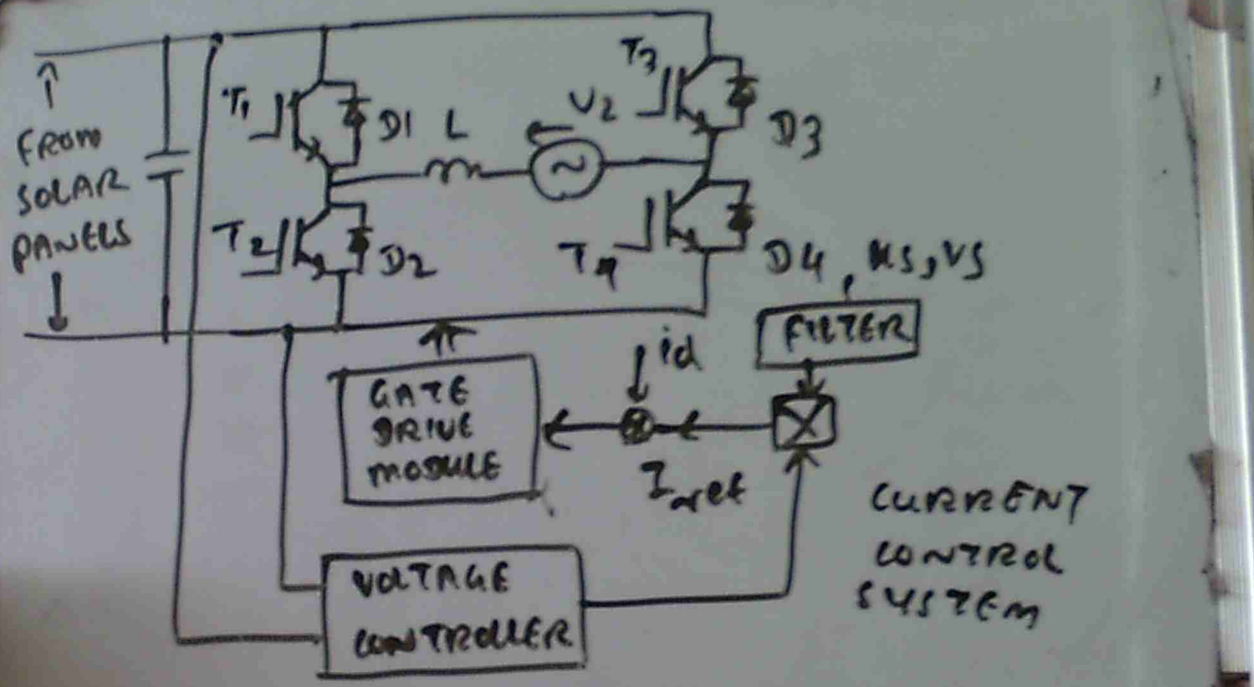
REAL & REACTIVE POWER FLOW

$$\begin{bmatrix} id \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix}$$



SYNCHRONOUS FRAME CONTROL

GRID CONNECTED SINGLE PHASE PHOTO VOLTAIC SYSTEMS MAY BE UNIPOLAR (OR) BIPOLAR SWITCH THEY CAN BE CURRENT (OR) VOLTAGE CONTROL.



THE OUT PUT TERMINALS OF SOLAR PANEL → DC INPUT BUS OF INVERTER

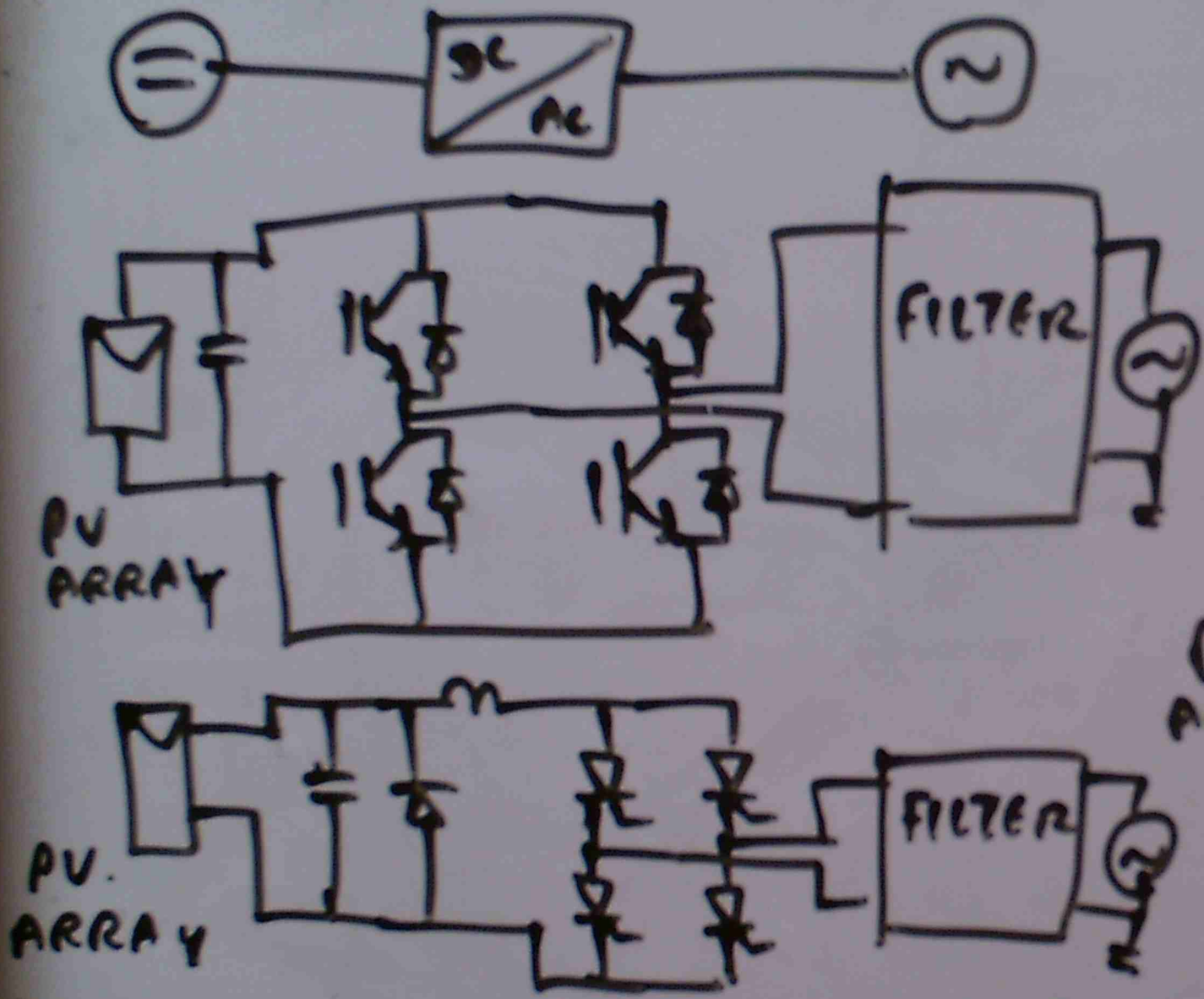
OUTPUT POWER FROM THE P.V ARRAY TENDS TO RAISE DC BUS VOLTAGE BY CHARGING THE STORAGE CAPACITOR.

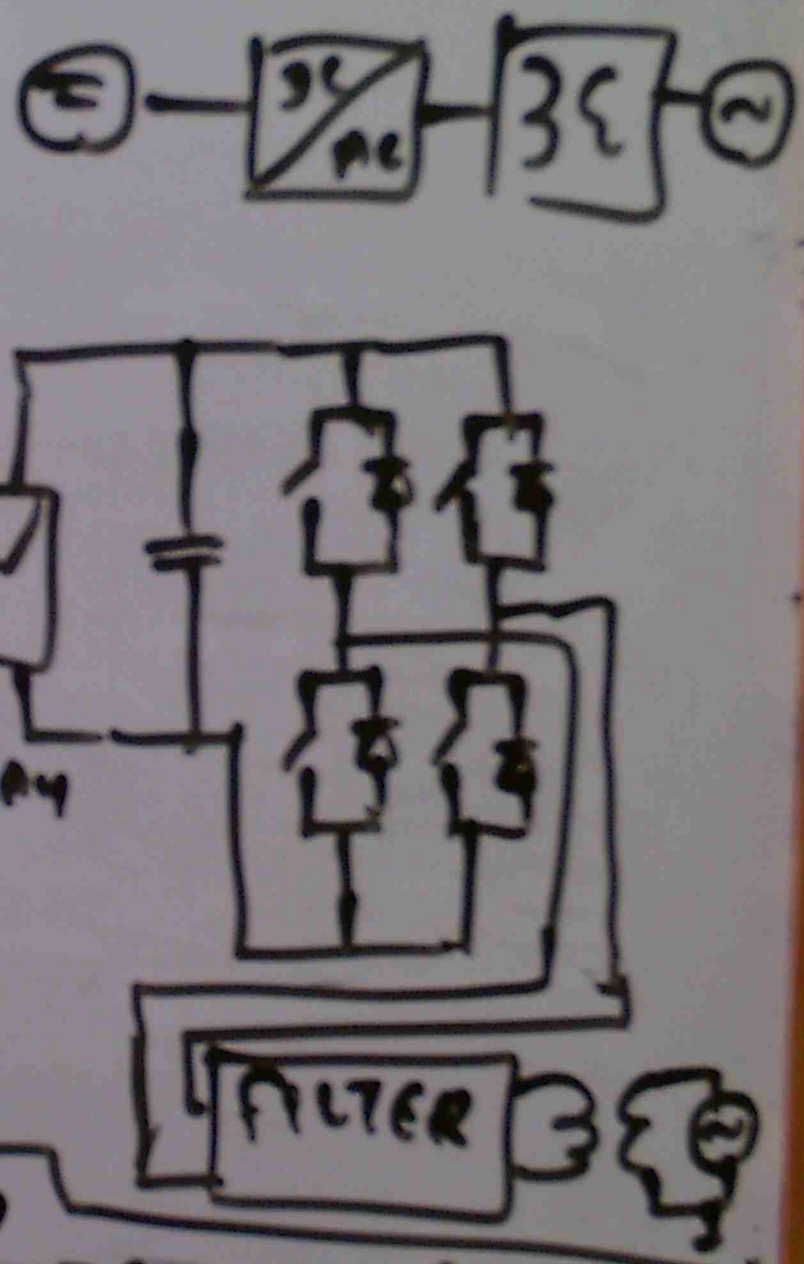
(+) ½ CYCLE T_3 - OFF, T_4 - ON, T_1 SWITCH ON CURRENT FLOWS THROUGH T_1 & T_4

(-) ½ CYCLE T_4 OFF, T_3 ON, T_2 SWITCH ON CURRENT FLOWS THROUGH T_3 & T_2

CAUSES OF LOW FREQUENCY HARMONIC

(a) HARMONIC CONTENT IN SIGNAL VOLTAGE V_{ref}
(b) HARMONIC CONTENT IN VOLTAGE CONTROLLER INPUT
(c) SWITCHING DELAY (d) INDUCTOR NON LINEARITY





(4) PWM

SLIDE (1) → 16

$Q_{20} \rightarrow Q_{29}$

(6) SWITCHING MODE + PV INVERTER

SLIDE (1) → (4)

$Q_{30} \rightarrow Q_{33}$

(9) GRID CONNECTED INVERTER SYSTEM

SLIDE (1) → (18)

$Q_{37} \rightarrow Q_{47}$

SOLAR DESIGN → ACTIVE
SOLAR DESIGN → PASSIVE

PASSIVE DESIGN - ORIENTATION, WINDOWS POSITIONING, VENTILATION, INSULATION SHADING, CONSTRUCTION MATERIALS, LAYOUT OF BUILDING

LOCATION TOPOGRAPHY, SOLAR ACCESS LANDSCAPING, DESIGN DEPENDS ON CLIMATE.

ACTIVE SOLAR SYSTEM

SOLAR WATER, SPACE HEATING, USING COLLECTOR PANEL, HEAT STORAGE

SOLAR EFFICIENT HOUSING

USE SUN SHADE TO BEST HEATING & COOLING, COMFORTABLE INDOOR ENVIRONMENT
- MINIMAL USE OF OTHER ENERGY.

AUSTRALIAN CLIMATE ZONES

HOT HUMID, HOT ARID, TEMPERATE

PASSIVE SOLAR DESIGN

TRUE NORTH ORIENTATION. MAXIMUM SUN ENTRY IN WINTER

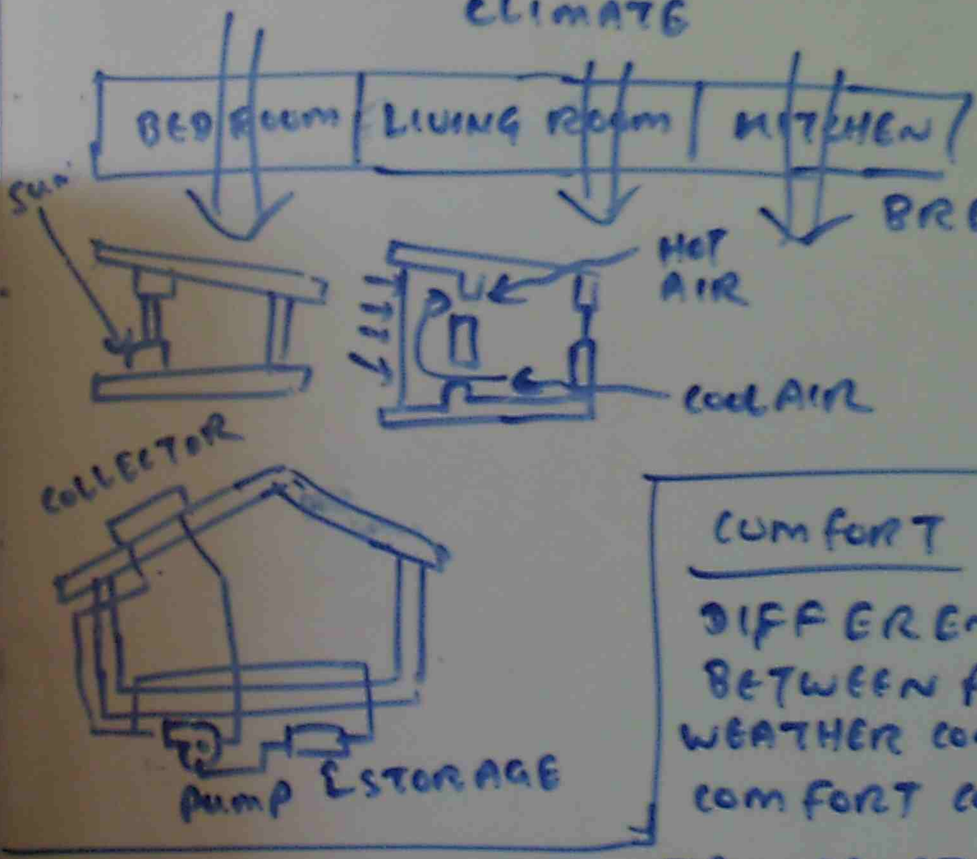
THERMAL MASS - MASSIVE BUILDING MATERIAL

GLASS - SUN/ HEAT

EAST FACING GLASS - SPEEDUP MORNING WARMING

INSULATION - R-VALUE - EFFECTIVENESS OF INSULATION RESISTING HEAT FLOW

VENTILATION - IMPORTANT IN HOT HUMID CLIMATE



COMFORT

DIFFERENCE BETWEEN PREVAILING WEATHER CONDITION & COMFORT CONDITION.

HOT HUMID, HOT ARID, TEMPERATE ZONE TEMPERATURES IN SUMMER & WINTER

THERMAL COMFORT CONTROLLED BY AIR TEMPERATURE, RADIANT HEAT, HUMIDITY AIR FLOW.

HEAT LOSS - DEPENDS ON
(i) AREA OF ELEMENT (ii) AIR SPACE IN CEILING
(iii) THE RESISTANCE TO HEAT FLOW OF ELEMENT

R VALUE



$T_2 \equiv T_1$ — R-TOTAL — T_2



NATURE OF BONDING	POSITION OF AIR SPACE	DIRECTION HEAT FLOW UP/DOWN	R

THERMAL RESISTANCE

VENTILATED SPACE	DIRECTION OF HEAT FLOW	RESISTANCE HIGH HEAT EMITTANCE SURFACE	RESISTANCE LOW HEAT EMITTANCE

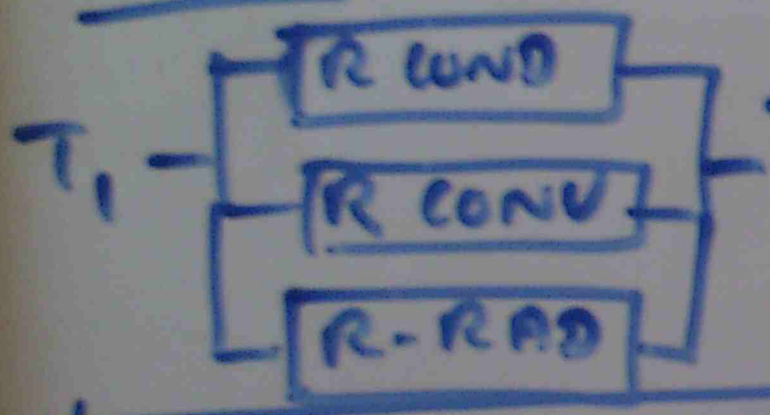
SURFACE RESISTANCE

STILL AIR	POSITION - HORIZONTAL 45°, 22.5°	HEAT FLOW DIRECTION	R

$U = \frac{1}{R_T}$

HEAT LOSS - DEPENDS ON
(i) AREA OF ELEMENT (ii) AIR SPACE IN CEILING
(iii) THE RESISTANCE TO HEAT FLOW OF ELEMENT

R VALUE



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NATURE OF BONDING	POSITION OF AIR SPACE	DIRECTION HEAT FLOW UP/DOWN	R

THERMAL RESISTANCE

VENTILATED SPACE	DIRECTION OF HEAT FLOW	RESISTANCE HIGH HEAT EMITTANCE SURFACE	LOW HEAT EMITTANCE

SURFACE RESISTANCE

STILL AIR	POSITION - HORIZONTAL 45°, 22.5°	HEAT FLOW DIRECTION	R

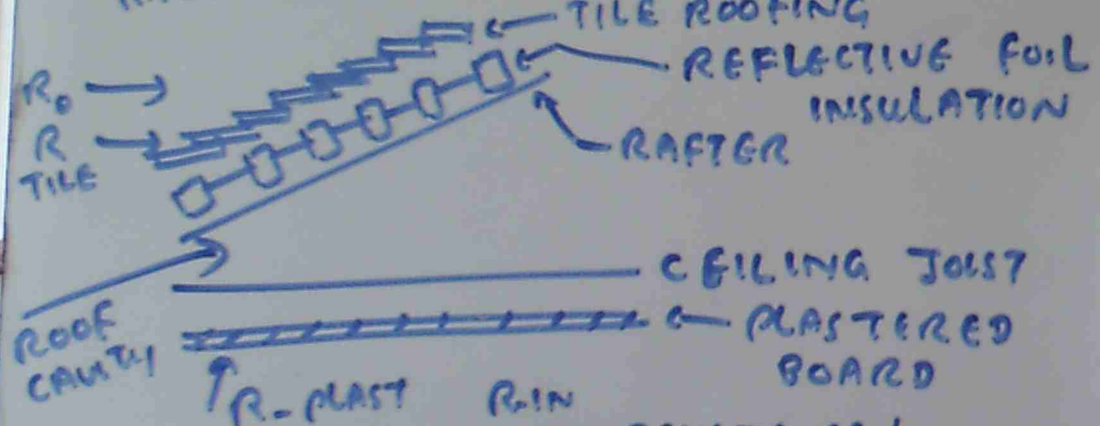
$U = \frac{1}{R_T}$

pb CALCULATE 'U' VALUE FOR A PITCHED AND VENTED TILED ROOF WITH REFLECTIVE FOIL LAMINATE UNDER THE TILES.

USE THE FOLLOWINGS

TILE = K = 0.87
PLASTER = K = 0.17

THICKNESS OF TILES = 19mm
THICKNESS of PLASTERED BOARD = 13 mm.



	ELEMENT	RESISTANCE SUMMER DOWN	RESISTANCE WINTER UP	SOURCE
4 m/s	OUTSIDE AIR R_O	0.04	0.04	TABLE (6)
	R_{TILE}	0.02	0.02	(i)
45°	R_L			
ROOF CAVITY LOW EMITTANCE	CAVITY R_{CAVITY}	1.36	0.34	TABLE (5)
	R_{PLAST}	0.08	0.08	(i)
STILL HORIZONTAL	INSIDE AIR	0.16	0.11	TABLE (6)

$R_{TILE} = \frac{d}{k} = \frac{19\times10^{-3}}{0.87} = 0.02$

$R_{PLASTER} = \frac{d}{k} = \frac{13\times10^{-3}}{0.17} = 0.08$

SUMMER

$R_T = R_O + R_{TILE} + R_L + R_{CAVITY} + R_{PLAST} + R_{INSIDE}$

$= 0.04 + 0.02 + 0 + 1.36 + 0.08 + 0.16$

$= 1.66$

$U = \frac{1}{R_T} = \frac{1}{1.66} = 0.6 \text{ w/m}^2$ (SUMMER)

WINTER $R_T = 0.04 + 0.02 + 0.34 + 0.08 + 0.11$

$= 0.59$

$U = \frac{1}{R_T} = \frac{1}{0.59} = 1.69 \text{ w/m}^2$ (WINTER)

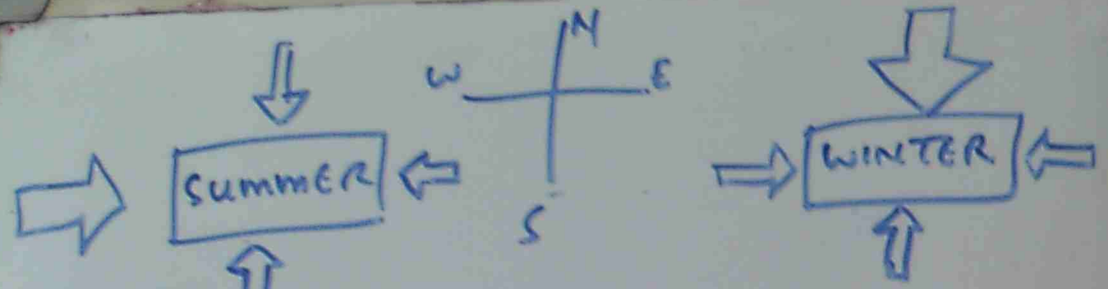
WINDOWS

- TO ALLOW NATURAL LIGHT TO ILLUMINATE
- TO HEAT UP BUILDING
- NATURAL VENTILATION

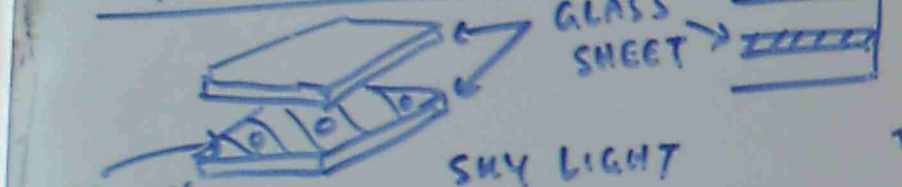
TO REDUCE SUMMER HEAT GAIN THROUGH WINDOWS

ORIENTING, SHADING, LIGHT COLOURED WA





TYPE OF GLAZING

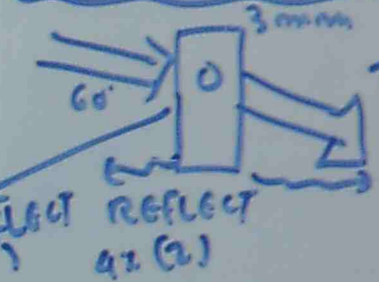


SKY LIGHT

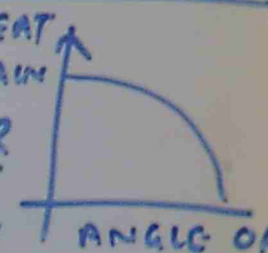


- MAXIMIZE LIGHT ENTRY
- VIRTUALLY IMPOSSIBLE TO SHADE OBLIQUE UPWARD FACING PLANES SO SUMMER OVER HEATING CAN HAPPEN.

ENERGY BALANCE DIAGRAM



SOLAR HEAT GAIN 88%



HYDRONIC HEAT EMITTING EQUIPMENT.

$P_c = CA(T_s - T_a)^n$ $n = 1.25$

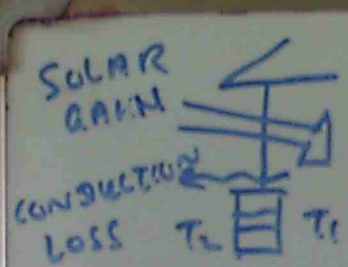
$P_r = \delta A \varepsilon (T_s^4 - T_a^4)$ ε = EMITTANCE

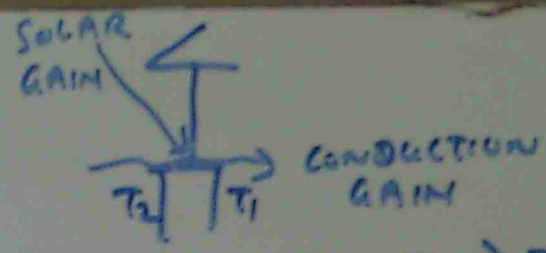
$\delta = 5.67 \times 10^{-8}$

$P_T = \frac{(T_w - T_a)^m}{60}$ $m = 1.3$

P_T - TEMPERATURE CORRECTION

HEAT FLOW
P_c = CONDUCTION
P_r = RADIATION





P1) CALCULATE THE NET GAIN (OR) LOSS OF HEAT THROUGH A NORTH FACING SINGLE GLAZED WINDOW FOR JANUARY AND JULY IN SYDNEY. THE WINDOW IS 0.9m HIGH AND 0.2m FROM THE BOTTOM OF THE EAVES WHICH ARE 0.6m WIDE. ASSUME FOR THE WINDOW THAT 90% OF IT IS GLASS. THE TRANSMITTANCE IS 0.76. U VALUE IS 6.14

JULY DAILY IRRADIATION H_D: 8.8 MJ/d-m²
NORTH - H_U: 12.87 MJ/d-m², SHADED H_{US}: 12.67 MJ/d-m²
JULY MAX TEMP 16.8°C, MIN TEMP: 6.5°C

DAILY HEAT GAIN FOR WINDOW
$Q_{WG} = H_{US} \times \%GLASS \times TRANSMITTANCE$
$= 12.67 \times 0.9 \times 0.76$
$= 8.67$ MJ/d-m²

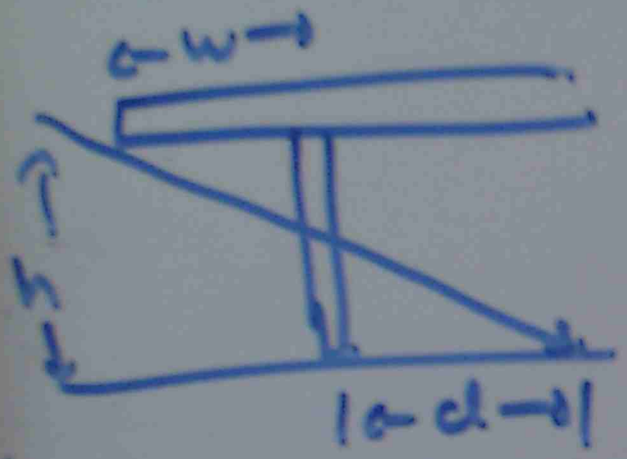
HEAT LOSS $Q_{WL} = U$ VALUE $\times \Delta T \times 0.0864$

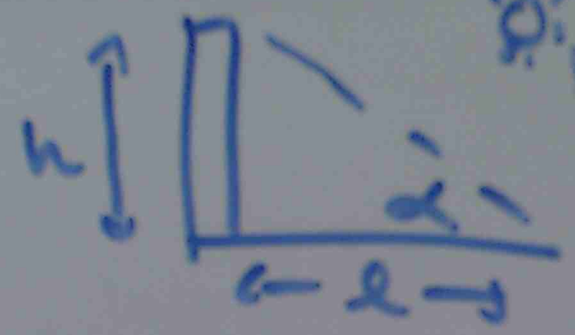
$\Delta T = T_i - T_{avg}$, $T_{avg} = \frac{T_{MAX} + T_{MIN}}{2} = \frac{16.8 + 6.5}{2} = 11.7°C$

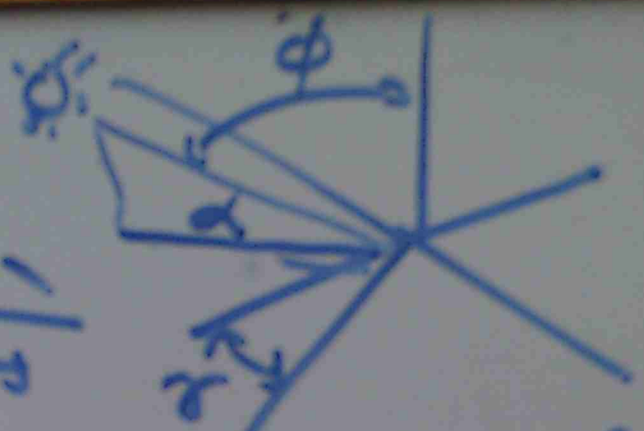
$T_i = 17.6 + 0.31 \times T_{avg}$
$= 17.6 + 0.31 \times 11.7 = 21.2°C$

$\Delta T = T_i - T_{avg} = 21.2 - 11.7 = 9.5°C$

$Q_{WL} = 6.4 \times 9.5 \times 0.0864 = 5.04$ MJ/d-m²







$l = \frac{h}{\tan\alpha}$ { ϕ = AZIMATH ANGLE, γ = ORIENTATION ANGLE, α = ALTITUDE

d = DEPTH OF SUN LIGHT IN TO ROOM = $\frac{h\cos(\gamma+\phi)}{\tan\alpha}$

$d = \frac{h\cos(\phi+\gamma)}{\tan\alpha}$



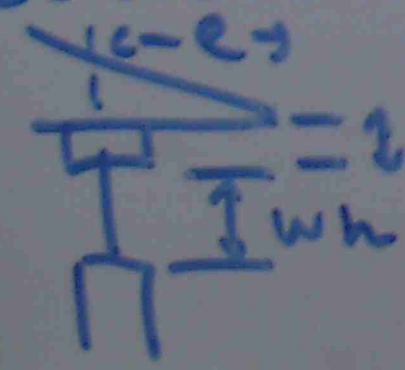
HSA = $\phi+\gamma$

$\tan VSA = \frac{\tan\alpha}{\cos HSA}$

COEFFICIENT OF SHADING ON HEAT GAIN

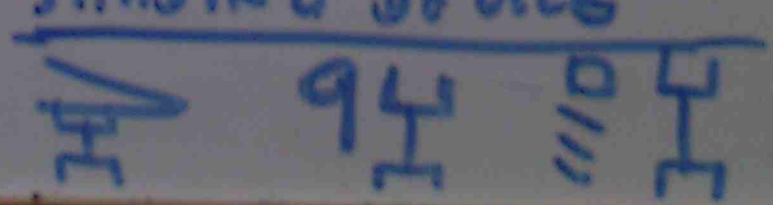
e = WIDTH OF EAVE, We = DISTANCE BETWEEN TOP OF WINDOW & EAVE

Wh = HEIGHT OF WINDOW



$\frac{e}{We+Wh}$

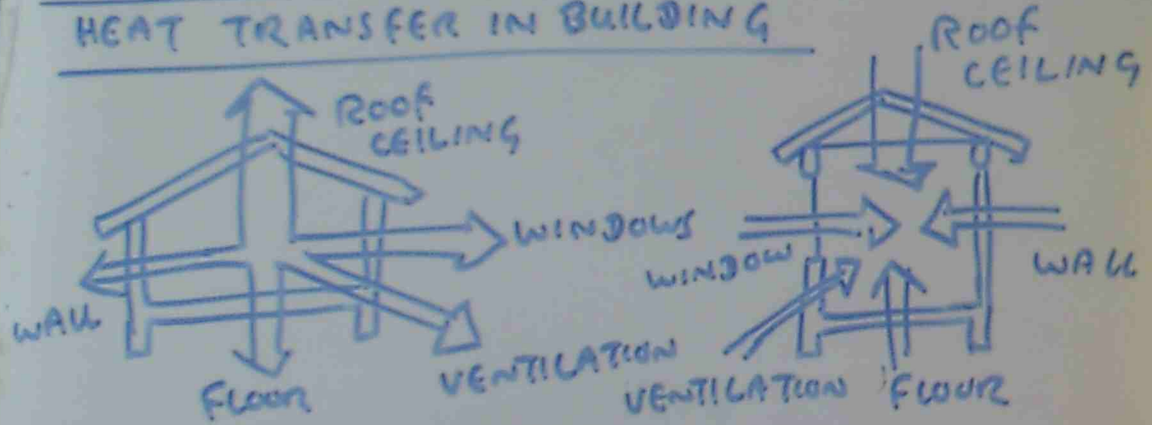
SHADING DEVICE



INSULATION

INSULATION PRODUCTS MAY ACT AS SOUND PROOFING (OR) FIRE RETARDANTS BUT ARE PRIMARILY USED TO REDUCE HEAT FLOW. INSULATION REDUCES HEAT LOSS IN WINTER AND REDUCES HEAT GAIN IN SUMMER. IT THEREFORE REDUCES HEATING & COOLING ENERGY REQUIREMENT & THERMAL COMFORT.

HEAT TRANSFER IN BUILDING



BRICK VENEER DWELLING

WARM PLASTER BOARD RADIATES HEAT TO COOLER TILES (RADIATION)

AIR HEATED BY WARMED PLASTER BOARD RISES AND COMES INTO CONTACT WITH COLD TILES WHERE IT COOLS DOWN BY LOSING SOME OF IT'S HEAT TO TILES

TYPES OF INSULATION

REFLECTIVE FOIL LAMINATE (RFL), BULK INSULATION

INSULATION MATERIAL / CONDUCTIVITY

AUSTRALIAN STANDARDS

AS1366.3, AS1366.4, AS1903, AS1904
AS2352, AS2459, AS2461, AS2462,
AS2463, AS2627, AS3000

THERMAL MASS AND STORAGE

THERMAL MASS MAY BE USED IN BUILDINGS TO MODERATE THE INTERNAL SWINGS IN TEMPERATURE DUE TO CHANGING OF EXTERNAL TEMPERTURE.

VARIATIONS IN HEAT FLOW + TEMPERATURE
→ HEAT STORAGE & RELEASE

CHANGE IN OUT DOOR TEMPERATURE
→ DECAY & REDUCE IN DOOR TEMPERATURE CHANGE

SENSIBLE HEAT = SPECIFIC HEAT J/m^3K × VOLUME

THERMAL CAPACITY $C = c \times L$

c = VOLUMETRIC HEAT CAPACITY, L = THICKNESS

THERMAL RESISTANCE (R) = $\frac{L}{K}$

MATERIALS USED FOR SENSIBLE HEAT STORAGE IN PASSIVE SOLAR SYSTEM

ROCK, BRICK, CONCRETE, WATER

RESPONSE FACTOR $F_r = \frac{\Sigma(AY) + 0.33NV}{\Sigma(AU) + 0.33NV}$

0.33NV - FLOW RATE

ΣAU - TOTAL HE TRANSMITTA

ΣAY: TOTAL HE ADMITTANCE

P2 CALCULATE THE HEAT GAIN PER DAY FROM THE CONSUMER IN A 150 m^2 GYM. THE GYM IS 50 CUSTOMERS AND THE GYM IS FULL BETWEEN 6 AM - 8 AM AND 5 PM - 8:30 PM AT ALL OTHER TIMES, BETWEEN 5:30 AM & 10PM IT IS 30% FULL ON AVERAGE.

HEAT GAIN DUE TO PEOPLE IN GYM

HEAVY WORK HEAT GAIN 400

50 USERS HEAVY WORK

PEAK TIME 50 PEOPLE, 5.5 HR = $\frac{50 \times 400 \times 5.5\ HR}{1000}$ = 110 KWH/DAY

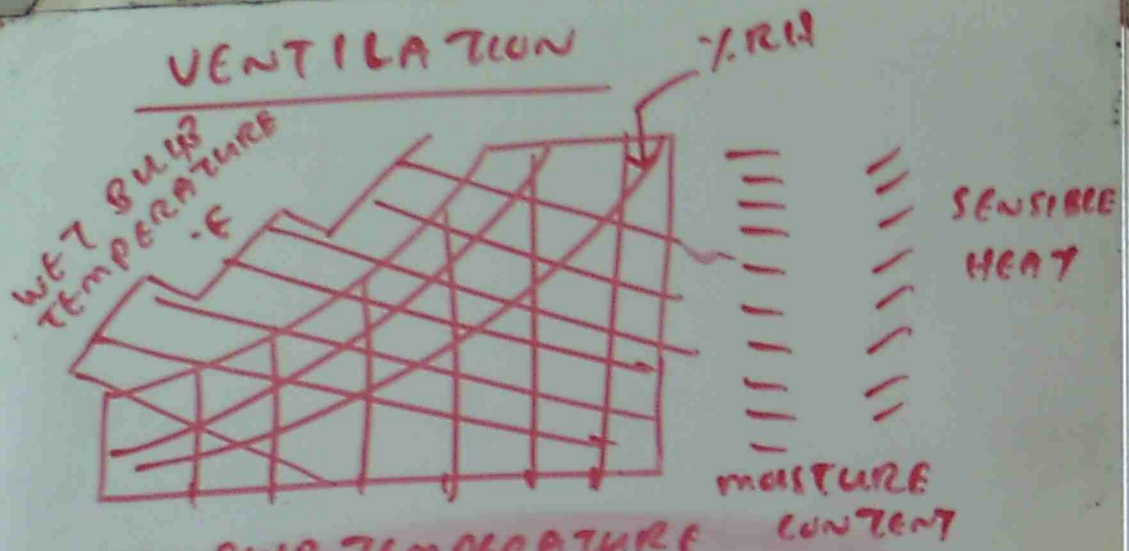
OFF PEAK 30% → $\frac{0.3 \times 50 \times 400 \times 11\ HR}{1000}$ = 66 KWH/DAY

TOTAL HEAT GAIN = 110 + 66 = 176 KWH/DAY

(6) VENTILATION + APPLICATION OF PSYCHROMETRIC CHART

SLIDE (1) → (20) @62 → @71

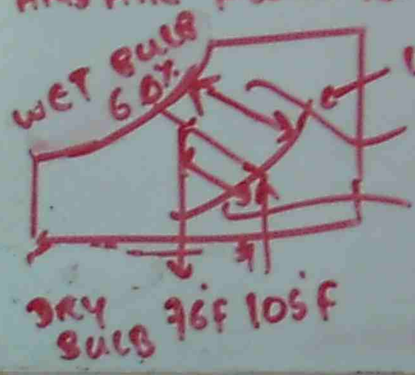
VENTILATION





By A 4000 ft² RETAIL STORE NEAR TUSON, ARIZONA HAS BEEN CALCULATED TO HAVE SENSIBLE HEAT GAIN OF 100,000 BTU/H AT SUMMER. DESIGN CONDITION (105 DB, 66 WB)

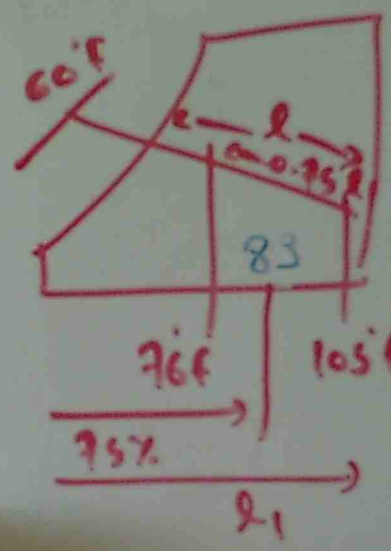
FOR THIS LOCATION. CALCULATE HEAT REMOVED AND AIR FLOW RATE IN DOOR.



FINAL TEMP = 76°F

(l_2) 75% OF HORIZONTAL

83°F



HEAT GAIN = TO BE CALCULATED BY USING WORKSHEET

HEAT GAIN = 100,000 BTU

$\Delta T = 83 - 76 = 7°F$

TO REMOVE THE HEAT

AIR FLOW REQUIRED = $\frac{\text{HEAT}}{1.08 \times \Delta T}$

$= \frac{100,000}{1.08 \times 7°F} = 13227$ CFM

AIR REQUIRED = 13227 ft³/min BLOWER

PORTION OF AIR VOLUME FOR EACH PART OF BUILDING = TOTAL AIR VOLUME × $\frac{\text{FLOOR AREA OF PARTICULAR PART}}{\text{TOTAL FLOOR AREA}}$

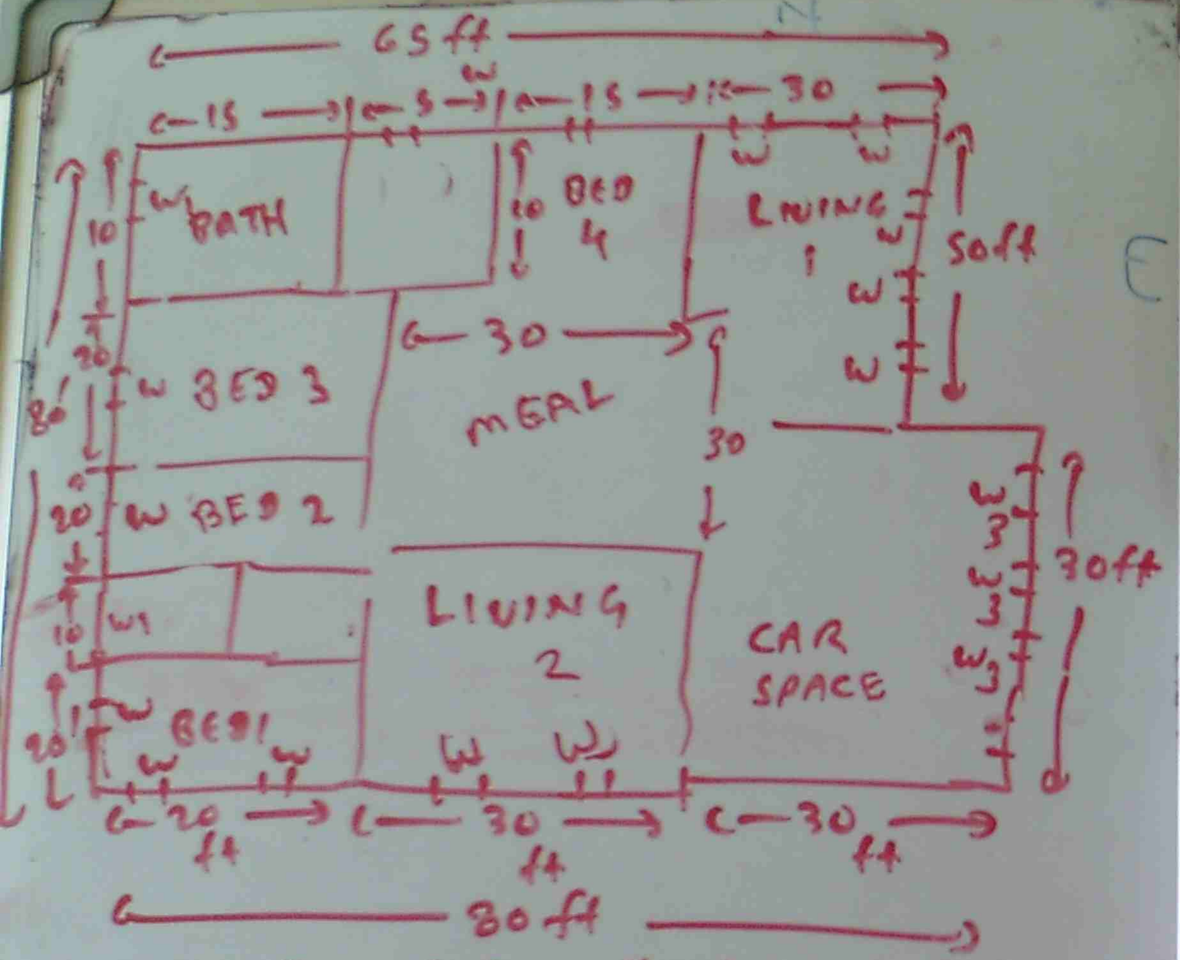
Ex

BED ROOM 44 ft² (1)	BED ROOM 50 ft²	LIVING 55 ft²	FAMILY 60 ft²
BATH	44 ft² BED	DINING 52 ft²	KITCHEN 72 ft²

TOTAL 4000 sq ft, 13227 CFM, 66% OF AIR APPLIED

BED ROOM (1) = $\frac{44}{4000} \times 13227 \times 0.66$

= 96 CFM



W = WINDOW 6×7
Wp = WINDOW 3×3

HEIGHT = 10

EAST WALL = 7.8
(C)

HEAT GAIN (C)

SOUTH WINDOW = 21
SOUTH WALL = 1.6
WEST WINDOW = 40
WEST WALL = 1.6
CEILING = 1.1
FLOOR = 0

NORTH WINDOW C = 13
EAST WINDOW C = 40

LIVING (1) + MEAL

EAST WALL

7.8(50×10 − 3×6×7) = 374

NORTH WALL 1.6(30×10 − 2×6×7) = 345.6

CEILING = (30×50 + 30×30) × 1.1 = 2640

NORTH WINDOW 2×13×6×7 = 1092

EAST WINDOW 3×40×6×7 = 3360

FLOOR = 2400×0 = 0

AREA HEIGHT

INFILTRATION (30×50 + 30×30) × 10 × 0.01833 × ΔT × 0.4

= 4751 BTU

(95 − 68)

FACTOR

PEOPLE = 4×300 = 1200

APPLIANCES = 1200

TOTAL HEAT = 374 + 345.6 + 2640 + 1092 + 3360 + 4751 + 1200 + 1200

= 14962 BTU

SIMILARLY CALCULATE FOR OTHER ROOMS BY INSERTING TEMPERATURE COEFFICIENT (C) AND RESPECTIVE AREA.

COOLING CAPACITY

$$\frac{\text{TOTAL GAIN}}{\text{ARI RATING}} \times \text{FACTOR} = \text{BTUH TOTAL}$$

$$\frac{\text{ARI RATING}}{12000\ \text{BTUH/TON}} = \text{TONS OF COOLING}$$

COMFORT

BALANCE OF FEELING IN THE BODY IN RELATIONSHIP TO IT'S SURROUNDINGS.

— TEMPERATURE, HUMIDITY, AIR MOVEMENT AIR CLEANLINESS

BODY TEMPERATURE 98.6°F

SURROUNDING MUST BE COOLER THAN BODY TO BE COMFORTABLE

---

(7) THERMAL MASS + CENTRALISED AIR + COOLING LOAD

SLIDE (1) → (23) | Q72 → Q74

---

(8) VENTILATION SLIDE (1) → (6)

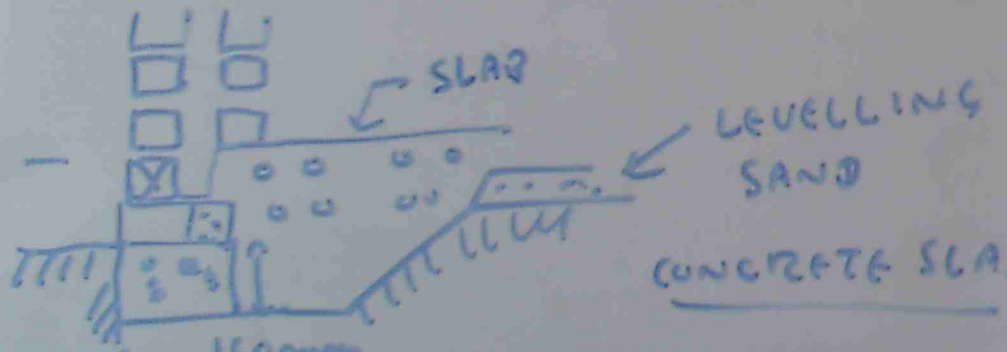
Q80 + Q81

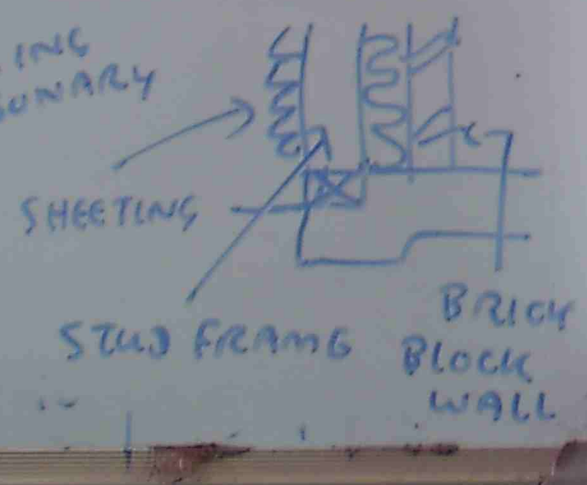


NORTH FACING GLASS, INTERNAL MASONARY
% OF FLOOR AREA

THERMAL MASS INSTALLATION

INSIDE THE INSULATED FABRIC OF THE BUILDING, NORTH FACING LIVING ZONE





(1) PASSIVE SOLAR DESIGN

SLIDE (1) → (19)
Q1 → Q16

(2) CLIMATE & HUMAN COMFORT

SLIDE (1) → (27)
Q17 → Q34

(3) SOLAR CALCULATION + THERMODYNAMIC PRINCIPLE

SLIDE (1) → (23)
Q35 → Q42

(4) WINDOWS & SHADING

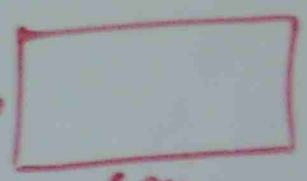
SLIDE (1) → (23)
Q43 → Q55

(5) INSULATION, AUSTRALIAN STANDARD FOR ENERGY EFFICIENT BUILDING DESIGN

SLIDE (1) → (24)
Q56 → Q67

AIR CONDITIONING LOAD CALCULATION

Pb CALCULATE THE TOTAL HEAT LOSS BY CONDUCTION FOR A SIMPLE ONE ROOM HOUSE IN MELBOURNE DURING THE MONTH OF JANUARY AND JULY.



ROOF 15° THICKNESS OF TILE 14mm
K=0.81

WALL AERATED CONCRETE 200 mm THICK K=0.13

PLASTER BOARD THICKNESS 13mm, K=0.17

OUTSIDE AIR (R_{OUT}) = 0.04 m^2K/W

INSIDE AIR (R_{IN}) = 0.12 m^2K/W

THE HOUSE HAS 1m^2 WINDOW ON WALL AVERAGE SEALING, NO OPEN FIRE PLACE, WEATHER STRIPPING AT BOTTOM. 4m x 5m WIDE, 2.4m CEILING HEIGHT.

ROOF CAVITY Rfl (U) SUMMER = 1.36

U_{WINTER} = 0.34

THE ROOF IS DOUBLE PITCHED VENTED TILE. U_{GLASS} = 6.19, FLOOR - CARPET ON CONCRETE.

TOTAL HEAT LOSS:) $Q_c = \sum U A (T_i - T_o) \times N \times 0.0864$

(A) AREA OF WALLS = $[4 \times 2.4 - 1m^2_{(WINDOW)}] \times 2$ (EAST + WEST)

$+ [5 \times 2.4 - 1m^2] \times 2$ [NORTH/SOUTH]

$= 39.2 m^2$

WALL $R = \frac{d}{K} = \frac{200 \times 10^{-3}}{0.13 \text{ (AERATED CONCRETE)}} = 1.538$ m^2K/W

OUTSIDE AIR FILM - R_{OUT} = 0.04 m^2K/W

INSIDE AIR FILM - R_{IN} = 0.12 m^2K/W

$R_{TOTAL\ WALL} = 1.538 + 0.04 + 0.12 = 1.698$

$U = \frac{1}{R_T} = \frac{1}{1.698} = 0.59$ W/m^2K

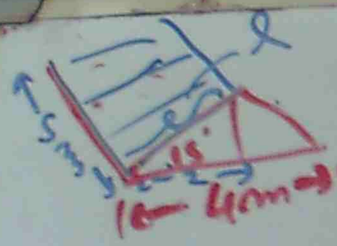
Roof $R_{TILE} = \frac{d}{K} = \frac{0.014}{0.81} = 0.02$ m^2K/W

$R_{PLASTER} = \frac{d}{K} = \frac{0.013}{0.17} = 0.08 m^2K/W$

ELEMENT	RESISTANCE SUMMER DOWN	RESISTANCE WINTER	SOURCE
OUTSIDE AIR	0.04	0.04	TABLE 6 (1)
TILE 14mm	0.02	0.02	
ROOF VENTED Rfl	1.36	0.34	TABLE 5
PLASTER BOARD	0.08	0.08	
INSIDE AIR FILM	0.12	0.11	
R_T =	1.66	0.59	

U FOR SUMMER = $\frac{1}{R_{SUMMER}} = \frac{1}{1.66} = 0.6$ W/m^2K

U FOR WINTER = $\frac{1}{R_{WINTER}} = \frac{1}{0.59} = 1.69$



AREA = $\frac{4/2}{\cos 15} \times 5 \times 2$

$= 20.7\ m^2$

FLOOR AREA OF FLOOR = $4 \times 5 = 20\ m^2$

U-VALUE (CARPET ON FLOOR) = $U_1 = 0.41$

$U_0 = 4$

WINDOWS AREA = $4 \times 1m^2 = 4m^2$

$U = 6.17$

Ti & Ta THERMAL NEUTRALITY FOR JULY & JAN

$T_i = 17.6 + 0.37 \times T_{avg}$

JULY MEAN DAILY MAX: TEMP = 13.3

MEAN DAILY MIN: TEMP: = 5.7

T_{avg} (JULY) = $\frac{13.3 + 5.7}{2} = 9.5^\circ C$ (JULY)

JAN MEAN DAILY MAX: TEMP: = 25.8

MIN = 14

T_{avg} (JAN) = $\frac{25.8 + 14}{2} = 19.4^\circ C$

$T_{JULY} = 17.6 + 0.37 \times 9.5 = 20.55^\circ C$ (T_i JUL)

$T_{JAN} = 17.6 + 0.37 \times 19.4 = 23.77^\circ C$ (T_i JAN)

TOTAL HEAT LOSS (JULY)

$Q_c = \Sigma UA\ (T_i - T_a)\ N \times 0.0864$

$= [(\text{WALL}(U) \times \text{WALL}(A) + \text{ROOF}(U) \times \text{ROOF}(A) + \text{FLOOR}(U) \times \text{FLOOR}(A) + \text{WINDOW}(U) \times \text{WINDOW}(A)] \times [T_i - T_a] \times \text{DAY IN MONTH} \times 0.0864$

$= [39.2 \times 0.54 + 20.7 \times 1.64 + 20 \times 0.4 + 4 \times 6.17]\ [20.55 - 9.5] \times 30 \times 0.0864$

$Q_c = [0.54 \times 39.2 + 20.7 \times 0.6 + 20 \times 0.41 + 4 \times 6.17]\ [23.37 - 19.4] \times 31 \times 0.0864$

$= 709.28\ MJ$

Q4 IN ABOVE PROBLEM, CALCULATE INFILTRATION HEAT GAIN

$Q_V = A_c \times U\ (T_i - T_a) \times N \times 0.0286$

Q_V = HEAT LOSS DUE TO INFILTRATION

A_c = AIR CHANGE / HR = 1.5

V = VOLUME = $H \times W \times L$

JULY $Q_V = 1.5 [4 \times 5 \times 2.4] \times (20.55 - 9.5) \times 31 \times 0.0286$

$= 705.4\ MJ$

JAN $Q_V = 1.5 [4 \times 5 \times 2.4] [23.77 - 19.4] \times 31 \times 0.0286$

$= 247\ MJ$

DESIGN & ASSESSMENT TOOL

PRE-DEFINED CLIMATE ZONE, THERMAL CONSIDERATION, DESIGNING FOR GENERAL & PARTICULAR CLIMATE ZONES.

CONCRETE SLAB FLOOR WITH MASONARY WALL (OR) TIMBER FLOOR WITH FRAMED EXTERNAL WALL.

CEILING INSULATION AS 2627 PART (1)

EXTERNAL WALL R1.0

WINDOWS R ≥ 0.2 , NORTH SHADING S ≤ 0.3

EAST/WEST / SOUTH GLASS NOT EXCEEDING 15% of TOTAL FLOOR AREA

UPPER FLOOR of MULTI STOREY HOUSES TO HAVE NO EAST/WEST GLASS.

SOLAR DESIGN — RAD / SOL POS / RADTEMP

STEADY STATE THERMAL ANALYSIS / DYNAMIC.

THERMAL ANALYSIS — CHUTAH, TEMPER HARMAN

DESIGN FOR CLIMATE

THE DESIGN of BUILDING THAT MAY WORK WELL IN ONE CLIMATE REGION CAN CAUSE OVERHEATING IN ANOTHER REGION.

USE OF VARANDAH, SHADED WALL, ROOF SPACE

CLIMATE VARIABLE

TEMPERATURE, HUMIDITY, AIR SPEED, SOLAR RADIATION, MICROCLIMATE EFFECT.

THERMAL COMFORT INSIDE BUILDING

HEAT EXCHANGE PROCESS → THERMAL COMFORT

- AIR TEMPERATURE
- AIR MOVEMENT HUMIDITY
- TEMPERATURE of INSIDE SURFACE

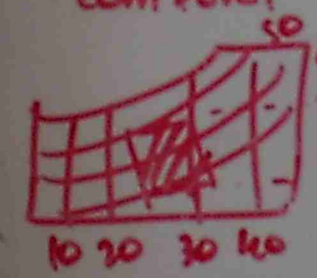
HEAT ABSORBING GLASS WINDOW
↳ QUITE HOT, RADIATE HEAT INTO ROOM

COMFORT CONDITION — DETERMINED BY AIR MOVEMENT, AIR TEMPERATURE

THERMAL NEUTRALITY $T_n = 17.6 + 0.31\, T_{avg}$

$18.5 < T_n < 28.5$

COMFORT ZONE ± 2°C



AH $T_n + 2$

AH $T_n - 2$

RH 50% & T_n MEETING POINT

UPPER LIMIT $T_n + 2$

LOWER LIMIT $T_n - 2$

AH - ABSOLUTE HUMIDITY

AIR MOVEMENT $T = 6V - V^2$ V = AIR SPEED

EVAPORATIVE COOLING

CONVERT SENSIBLE HEAT TO LATENT HEAT

REDUCE DRY BULB TEMPERATURE

DESIGNING FOR AUSTRALIAN CLIMATE

- INSULATE CEILING & WALL IF U VALUE IS TOO HIGH
- WEATHER SEAL EXTERNAL WALL AND WINDOWS
- MINIMIZE WEST AND TO A LESSER EXTENT EAST FACING GLAZING.
- PROVIDE APPROPRIATE SHADING FOR ALL NORTH, EAST AND WEST FACING GLAZING
- PROVIDE TINTED (OR) REFLECTIVE GLAZING FOR EAST & WEST
- PROVIDE APPROPRIATE DOOR & WINDOW OPENING FOR CROSS VENTILATION
- NORTH FACING WINDOW - 20% of TOTAL FLOOR
  AIR MOVEMENT 1-5 m/s

NIGHT TIME VENTILATION of EFFECTIVENESS 0.8

CITY	NORTH FACING GLASS	INSULATION	CEILING INSULATION
HOBART	20 → 35% FLOOR AREA	R 1.0	3.5
SYD	20 → 30%	R1.0	1-5 - 2
MEL	25 — 40%	R1.0	2.5

TYPICAL DESIGN FOR TEMPERATE, HOT ARID CLIMATES

VENTILATION (V) = 0.119 A h ΔT $(m^3)/sec/m^2$

V = VENTILATION RATE m^3/s | A = INLET AREA h = HEIGHT

ΔT - TEMPERATURE DIFFERENCE

CEILING FAN - 3m HEIGHT, 2.2m BLADE



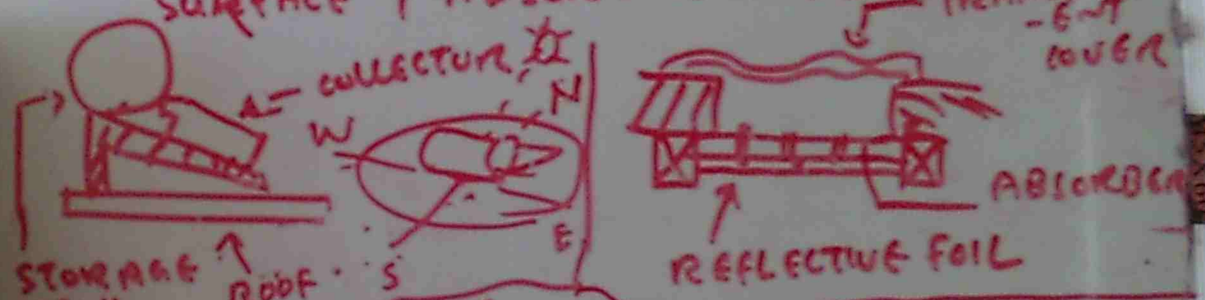
HIGH SET WINDOWS TO PROVIDE NATURAL LIGHTING

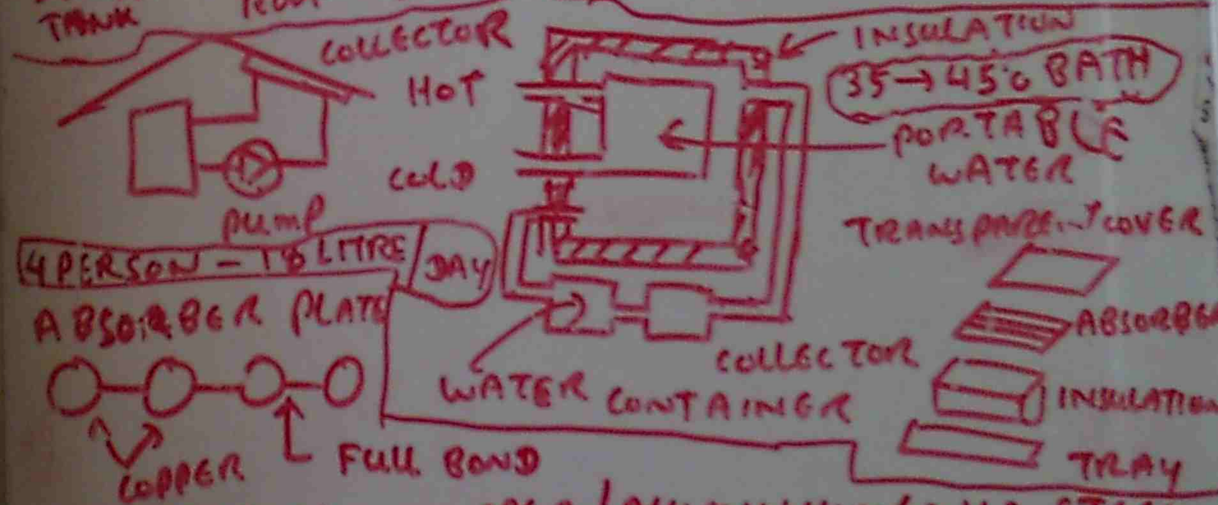
DOMESTIC SOLAR HOT WATER SYSTEM

AS 1056, 3500.4, 2718, 2535, 2813, 2984

COLLECTOR - MOUNTED ON ROOF

SOLAR RADIATION - COLLECTOR - PARABOLIC SURFACE / ABSORBER TUBE





MATERIAL - COPPER / ALUMINIUM / MILD STEEL
STAINLESS STEEL

10% → 20% of SUN IS ABSORBED TO PRODUCE ENERGY

INSULATION - FIBRE / ROCKWOOL

TANK 75 LITRE / m^2 | HYDROSONIC CIRCUIT | LOCATION

(11) DESIGN FOR CLIMATE

SLIDE 1 → 6, @ 93 + @ 94

(12) AIR MOVEMENT

SLIDE 1 → 3 @ 95 → @ 97

(13) SOLAR EFFECT + WIND CONDITION

SLIDE 1 → 5 @ 98 → @ 102

(15) SOLAR HOT WATER SYSTEM

SLIDE 1 → 11, @ 107 → @ 115

ENERGY EFFICIENCY

STAR RATING FOR ENERGY EFFICIENCY.
TECHNICAL DEVELOPMENT FOR EFFICIENCY OF GAS FURNACE, GAS WATER HEATER, CENTRAL AIR CONDITIONER, REFRIGERATOR, FREEZER, WATER HEATER, AIR CONDITIONING HEAT PUMP, LIGHT BULB,

BARRIERS TO INCREASE ENERGY EFFICIENCY

CAPITAL

- INVESTMENTS IN INCREASING EFFICIENCY OF FACILITY ARE OF LOW PRIORITY
- REGULATORY AND POTENTIAL COST OF BORROWING ARE TOO HIGH TO JUSTIFY USING DEBT CAPITAL

RISK

- BUILDING OWNERS ARE SKEPTICAL OF PERFORMANCE CLAIMS FOR ENERGY EFFICIENCY TECHNOLOGY
- BUILDING OWNERS CAN NOT MAKE INDEPENDENT JUDGEMENT OF PERFORMAN-CE CLAIMS
- BUILDING OWNERS AND OCCUPANTS ARE CONCERNED THAT EFFICIENCY IMPROVEMENT WILL LOWER PRODUCTIVITY & NEGATIVE SIDE EFFECT.

MANAGEMENT

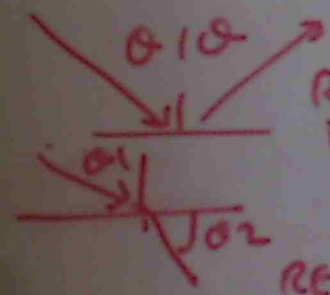
- CAN NOT AFFORD THE TIME TO MANAGE, PLANNING AND IMPLEMENTATION OF TASKS
- STAFF TRAINING
- OPERATING COST
- TENNANTS CAN NOT MAKE THE MODIFICATION FOR CENTRALISED METERING

BUILDING LIGHTING

AS 1140-1972, AS1680-1976, AS2900 PART(G)

$V = m\lambda$

V = PROPAGATION SPEED
m = NO. OF OSCILLATION/SEC
λ = WAVE LENGTH (cm)



$$\text{REFLECTION FACTOR} = \frac{\text{TOTAL FLUX LEAVING THE SURFACE}}{\text{TOTAL FLUX REACHING THE SURFACE}}$$

$$\text{REFRACTION INDEX} = \frac{\text{SINE ANGLE OF INCIDENCE}}{\text{SINE ANGLE OF REFRACTION}}$$

ILLUMINATION

AS1680, AS1158, AS1798, AS2560
RECOMMENDED ILLUMINATION (Lx) FOR PLACES

$$\text{ROOM RATIO} = \frac{L \times W}{h(L+W)}$$

L = LENGTH OF ROOM (m)
W = WIDTH OF ROO
h = HEIGHT OF LUMINAIRE

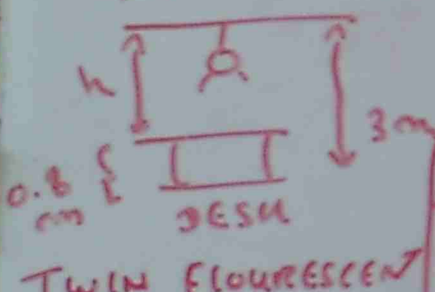
(COEFFICIENT OF UTILIZATION)

PD/ DESIGN THE ILLUMINATION FOR A CLASS 10m LONG 6m WIDE WITH A CEILING HEIGHT OF 3m. THE CEILING IS PAINTED WHITE AND WALLS A LIGHT COLOUR HAVING REFLECTION FACTOR 50%.

CLASS ROOM = 250 Lux (E)

ROOM INDEX = $\frac{ab}{h(a+b)} = \frac{10 \times 6}{(3-0.8)(10+6)}$

$= 1.7$



TWIN FLOURESCENT LIGHT

CEILING REFLECTION FACTOR = 0.75

WALL REFLECTION FACTOR = 0.5

ROOM RATIO	INDEX UK	INDEX US
<0.7	A	J
0.7 – 0.9	B	I
0.9 – 1.12	C	H
1.12 – 1.38	D	G
1.38 – 1.75	E	F
1.75 – 2.25	F	E
2.25 – 2.75	G	D
2.75 – 3.50	H	C
3.50 – 4.50	I	B
>4.50	J	A

UTILISATION FACTOR (UK) WALL 50%

A — 0.28
B — 0.32
C — 0.37
D — 0.40
E — 0.42
F — 0.44
G — 0.46
H — 0.48
I — 0.49
J — 0.51

MAINTENANCE FACTOR = 0.8

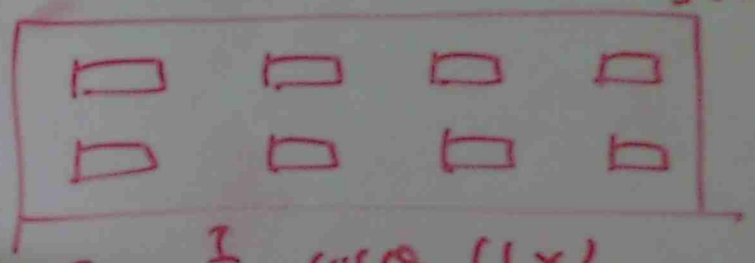
FLOURESCENT LAMP (WHITE) 3000 LUMEN EACH

TWIN F = 2×3000 = 6000 LUMEN

NO. OF LUMINAIRES $N = \frac{E \times A}{F \, CM}$

$N = \frac{250 \times (10 \times 6)}{6000 \times 0.42 \times 0.8} = 7.3$

DECIDE 8



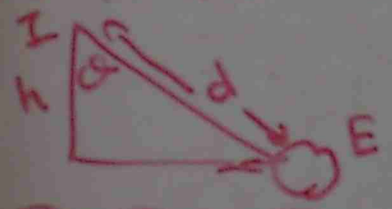
$E = \frac{I}{d^2} \cos\theta \; (Lx)$

E = ILLUMINATION LUMEN/m^2 (Lx)

I = INTENSITY OF SOURCE CANDELAS

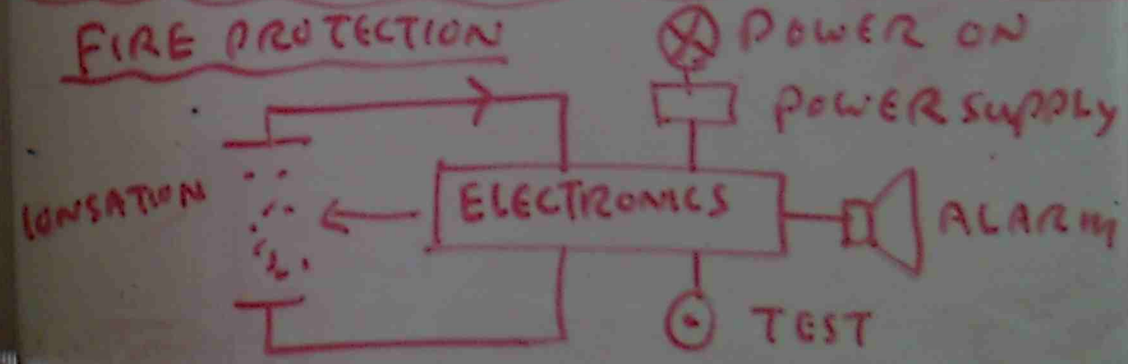
d = DISTANCE FROM THE SOURCE TO THE SURFACE CONSIDERED

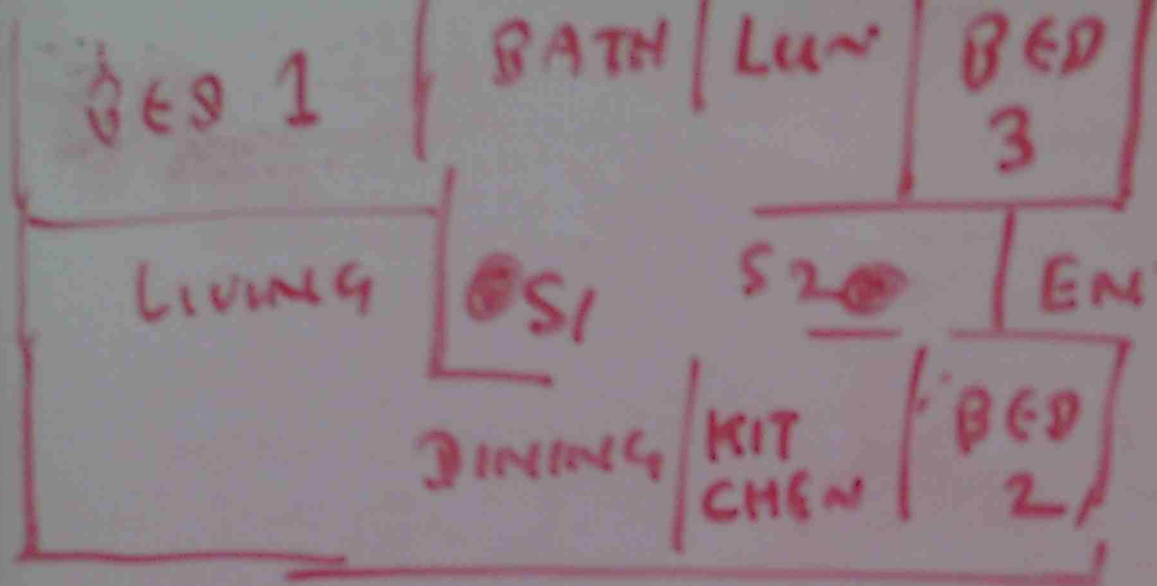
θ = ANGLE OF INCIDENT TO SURFACE



CONTROL OF GLARE

FIRE PROTECTION





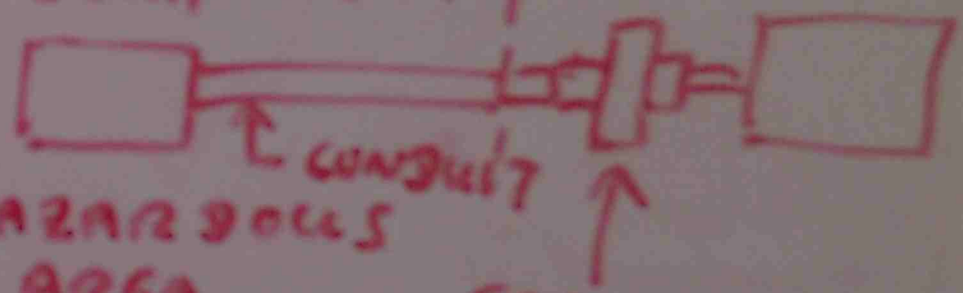
S1 S2 - SMOKE ALARM

NO SMOKE ALARM IN
- KITCHEN
- GARAGE
- WATER HEATER
- BATH ROOM



HAZARDOUS
ZONE 0, 1, 2
AS2236

INTRINSICALLY SAFE EQUIPMENT, EQPT



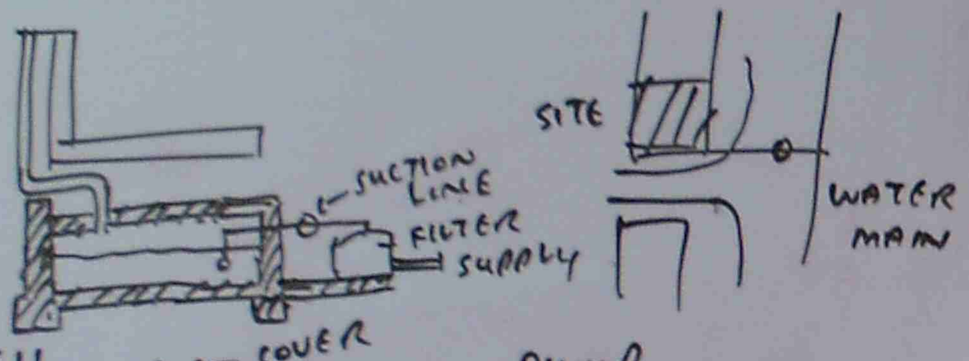
NO - BARE CONDUCTOR / OPEN WIRING
CABLE TRUNKING / BUSWAY
AERIAL
NO SODIUM DISCHARGE LAMP
BATTERY CHARGER

(10) BUILDING ENERGY MANAGEMENT
SLIDE (1) → (11)
@84 → @92

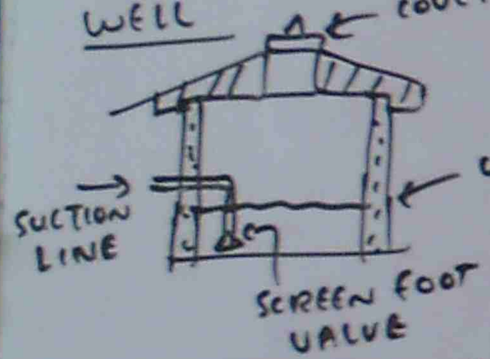
(16) LIGHTING
SLIDE (1) → (5)
@116 → @119

(17) FIRE PROTECTION
SLIDE (1) → (13)
@120 → @126

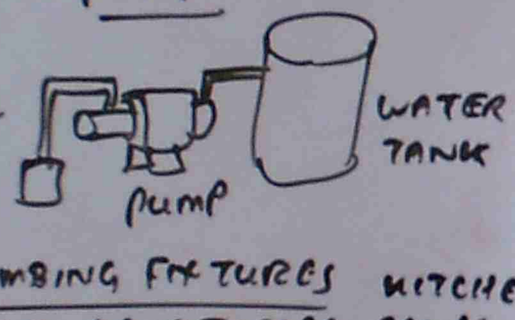
WATER SUPPLY



WELL



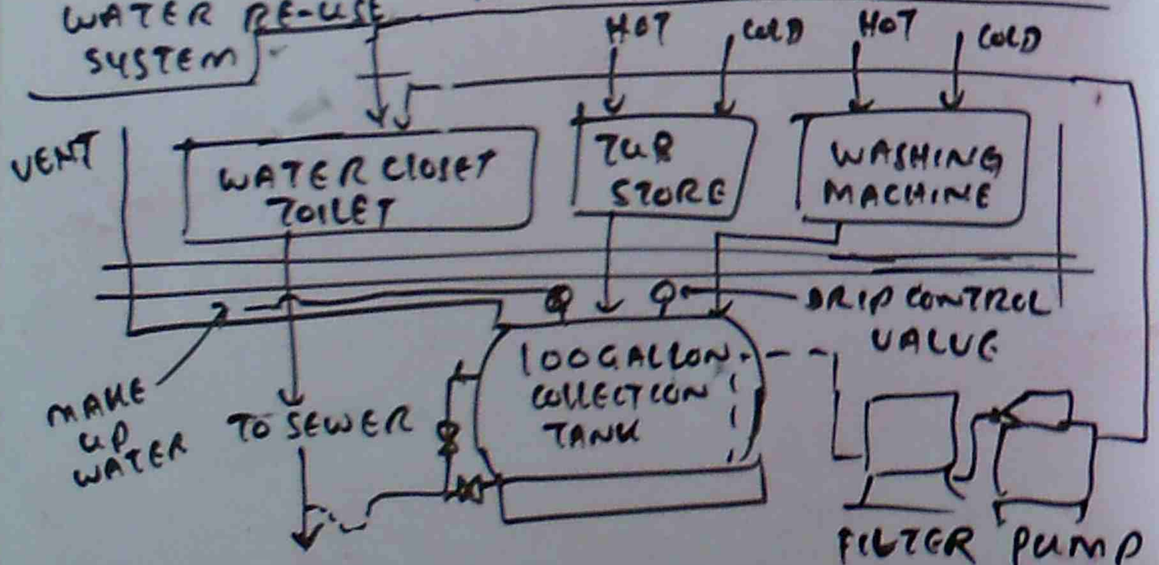
PUMP



PLUMBING FIXTURES

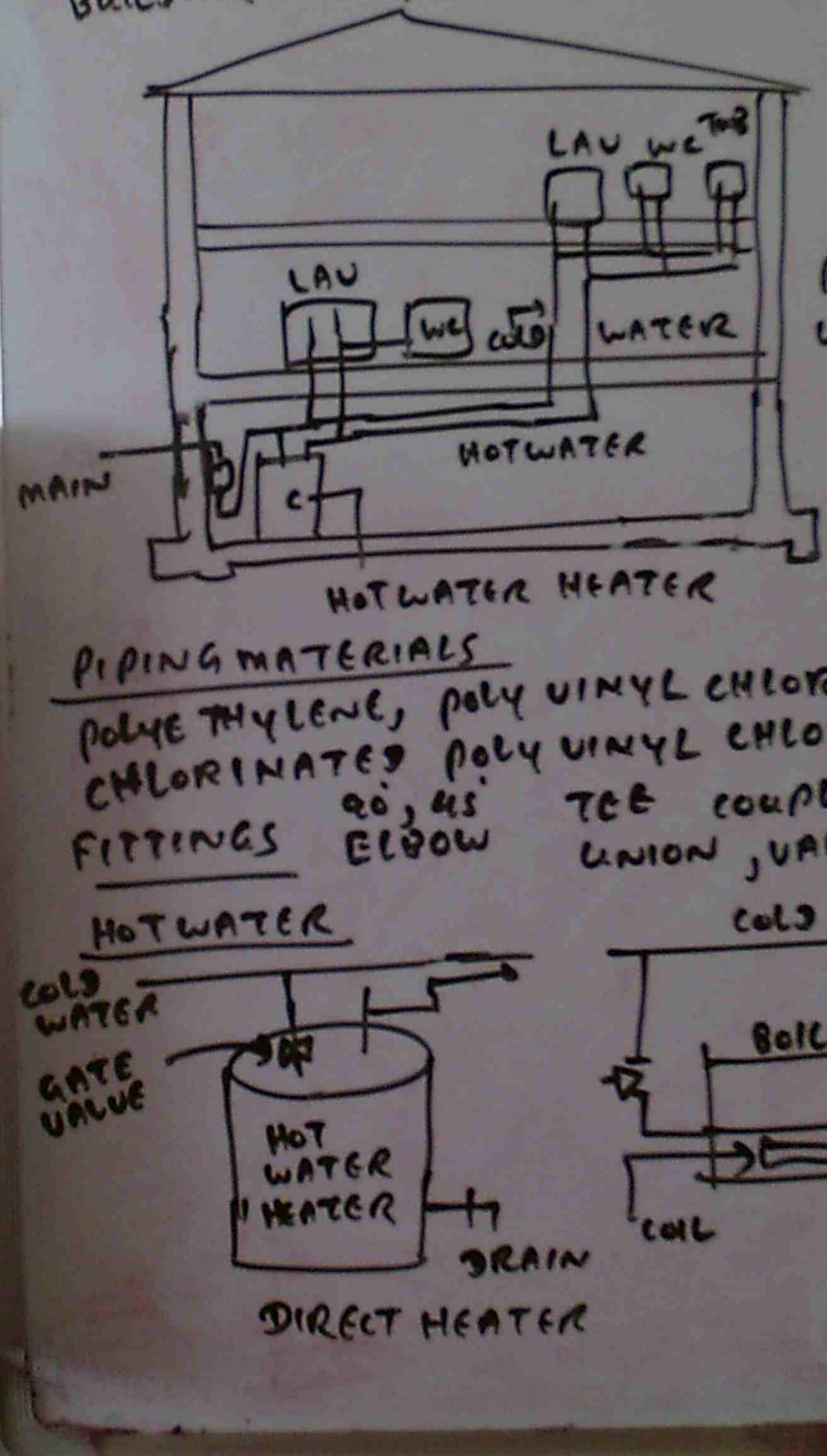
SHOWER, LAVATORIES, SINK, KITCHEN SINK

WATER RE-USE SYSTEM



BUILDING WATER SUPPLY SYSTEM

BUILDING MAIN, RISER, FIXTURE CONNECTION



PARTS OF TYPICAL WATER SUPPLY SYSTEM

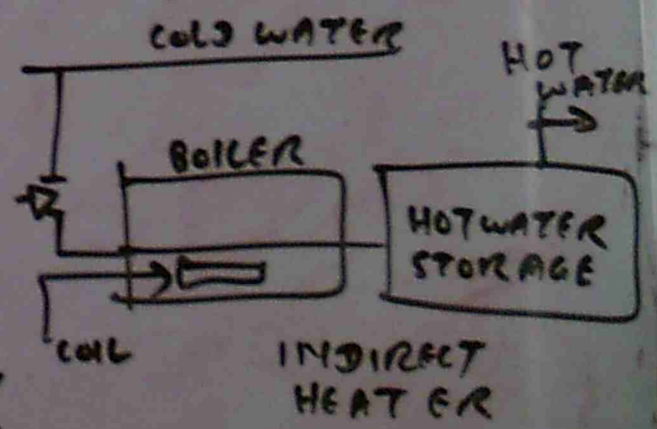
PIPING MATERIALS

POLYETHYLENE, POLY VINYL CHLORIDE, CHLORINATED POLY VINYL CHLORIDE

FITTINGS 90°, 45° ELBOW, TEE COUPLING, REDUCER UNION, VALVE

HOT WATER

DIRECT HEATER



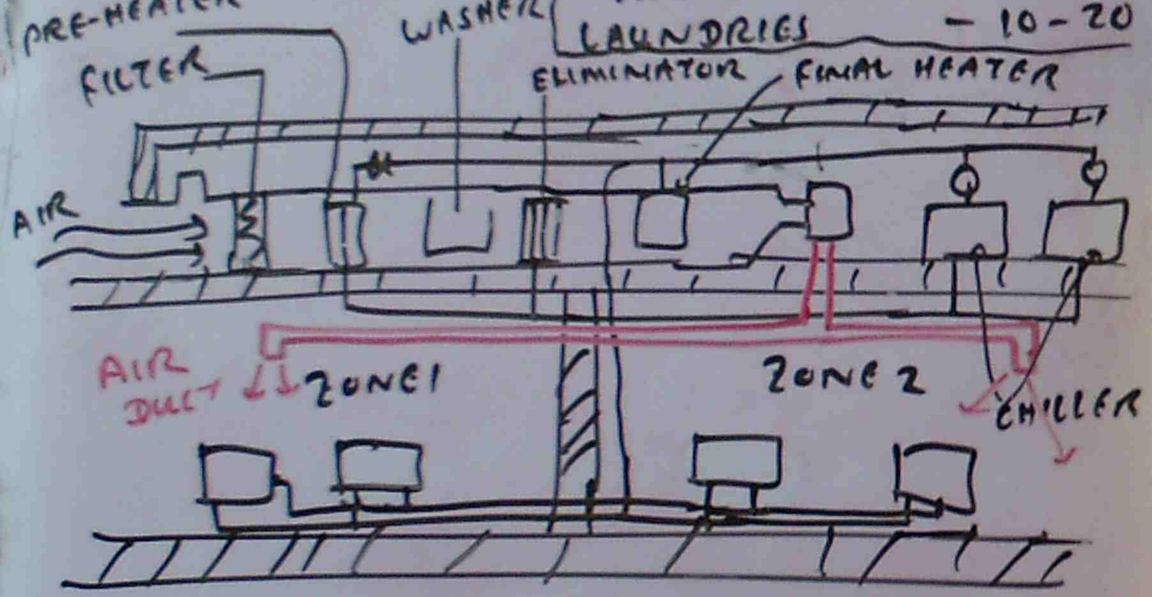
INDIRECT HEATER

VENTILATION

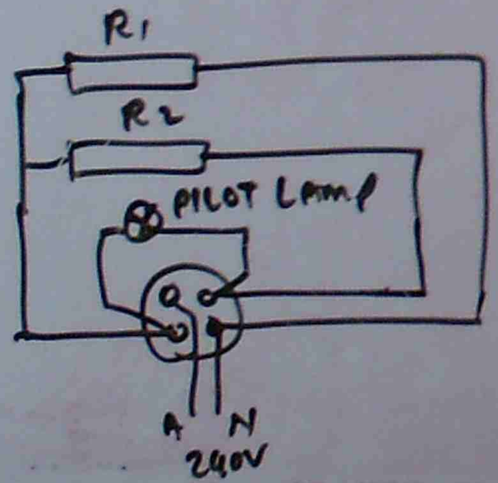


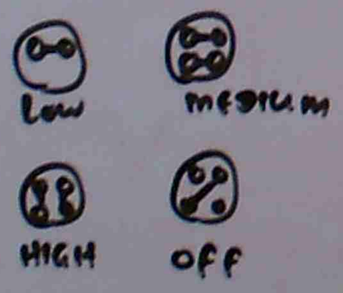
AIR CHANGE / HOUR

SCHOOL CLASSROOM	– 6
HOSPITAL WARDS	– 3
OPERATING THEATRE	– 10
KITCHEN	– 20–40
LAUNDRIES	– 10–20



ELECTRICAL HEATING





AUTOMATIC CONTROL

THERMOSTATIC CONTROL, SIMMERSTATIC (OR)
CHARGE REGULATOR CONTROL

THERMOSTATIC CONTROL

- BIMETAL, EXPANDING TUBE, VAPOUR PRESSURE

WATER HEATER

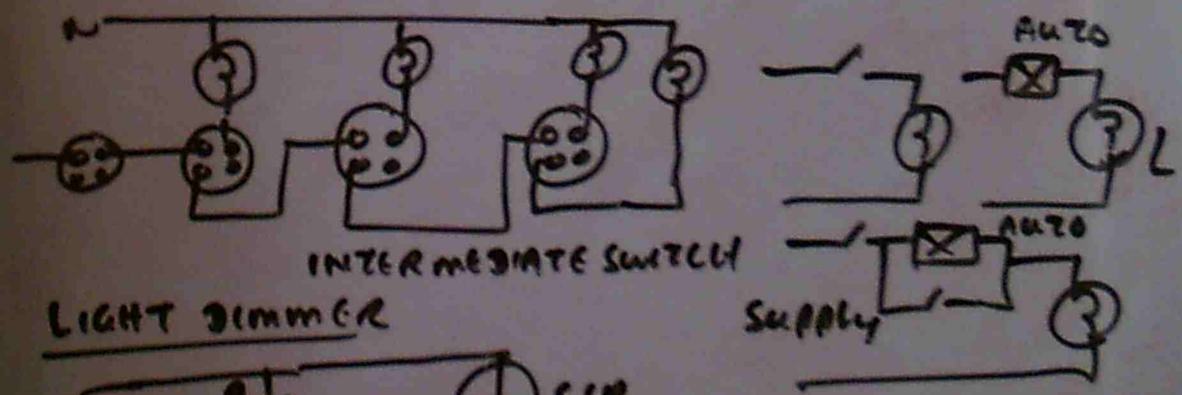
INSTANTANEOUS HEATER, STORAGE HEATER

SPACE HEATING

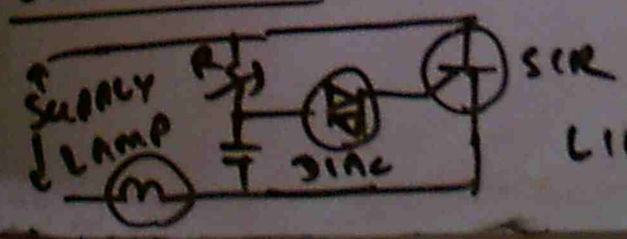
- HIGH TEMPERATURE RADIANT PANEL / RADIATOR
- LOW TEMPERATURE PANEL CONVECTION UNIT HEATER
- THERMAL STORAGE TYPE HEATER

LIGHTING CONTROL

TIME SWITCH – ANALOGUE / DIGITAL

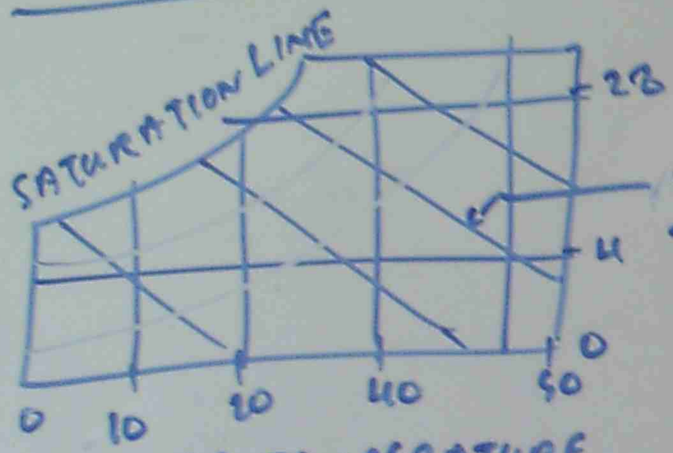


LIGHT DIMMER



LIGHTING MANAGEMENT SYSTEM

BASIC PSYCHROMETRICS



WET BULB TEMPERATURE = MOISTURE

PSYCHROMETRIC CHART → TEMPERATURE
→ HUMIDITY
→ COMFORT ZONE

TO REGULE HUMIDITY → RE HEATING

HIGH HUMIDITY - ABOVE 12g/kg

LOW HUMIDITY → BELOW 4g/kg

HUMAN COMFORT - MEAN RADIANT TEMPERATURE - (THE AVERAGE TEMPERATURE OF THE SURROUNDINGS TO WHICH THE BODY IS EXPOSED) IS 2°C HIGHER THAN DRY BULB TEMPERATURE

THERMAL NEUTRALITY

TEMPERATURE AVERAGED FOR A LARGE SAMPLE OF PEOPLE WHEN THE INDIVIDUAL FEELS NEITHER HOT NOR COLD

$T_n = 17.6 + 0.31\ T_{avg}$

SUN MOTION, DECLINATION ANGLE, SOLAR RADIATION, AIR MASS - OPTICAL THICKNESS of ATMOSPHERE.
SOLAR RADIATION TERMINOLOGY, FORMULA

THERMODYNAMICS

FIRST LAW $\boxed{\Delta U = Q - W}$ Q = HEAT, W = WORK DONE

ΔU - INCREASE IN INTERNAL ENERGY

SECOND LAW $Q = mc(T_{FINAL} - T_{INITIAL})$

$T(K) = T(^\circ C) + 273$

CONDUCTION

$\boxed{P = \frac{KA\Delta T}{d}}$

P = HEAT FLOW RATE (W), K = THERMAL CONDUCTIVITY W/mK

A = AREA (m^2), ΔT = TEMP. DIFFERENCE, d = PATH LENGTH

$Res = \frac{1}{K}$, RESISTIVITY

$R = d \times Res = \frac{d}{K}$, C = CONDUCTANCE = $\frac{1}{R}$

CONVECTION

$\boxed{P_{convi/cond} = h_c A \Delta T}$

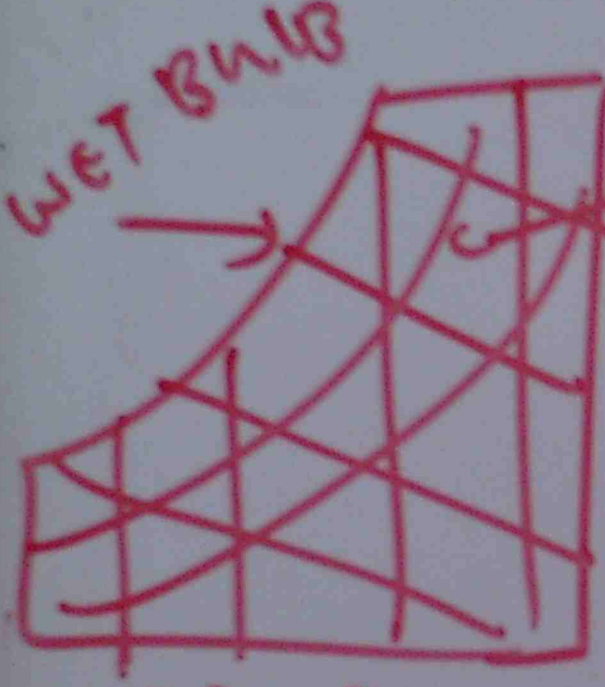
h_c = COMBINED CONDUCTION & CONVECTION HEAT TRANSFER COEFFICIENT

RADIATION

$\boxed{E_V = h \times V}$ E_V = PHOTON ENERGY, h = PLANK CONSTANT, V = PHOTON FREQ:

EMISSIVE POWER: $P_r = \delta A T^4$

BASIC PSYCHROMETRIC CHART



TEMPERATURE
HUMIDITY
COMFORT ZONE

MOISTURE | HIGH HUMIDITY 12g/kg
LOW ——— 4g/kg

BODY TEMPERATURE – 2°C HIGHER THAN SURROUNDING

COMFORT

THERMAL NEUTRALITY – NO HEAT GAIN / LOSS

$T_N = 17.6 + 0.31\,T_{avg}$

SUN MOTION + SOLAR RADIATION + AIRMASS

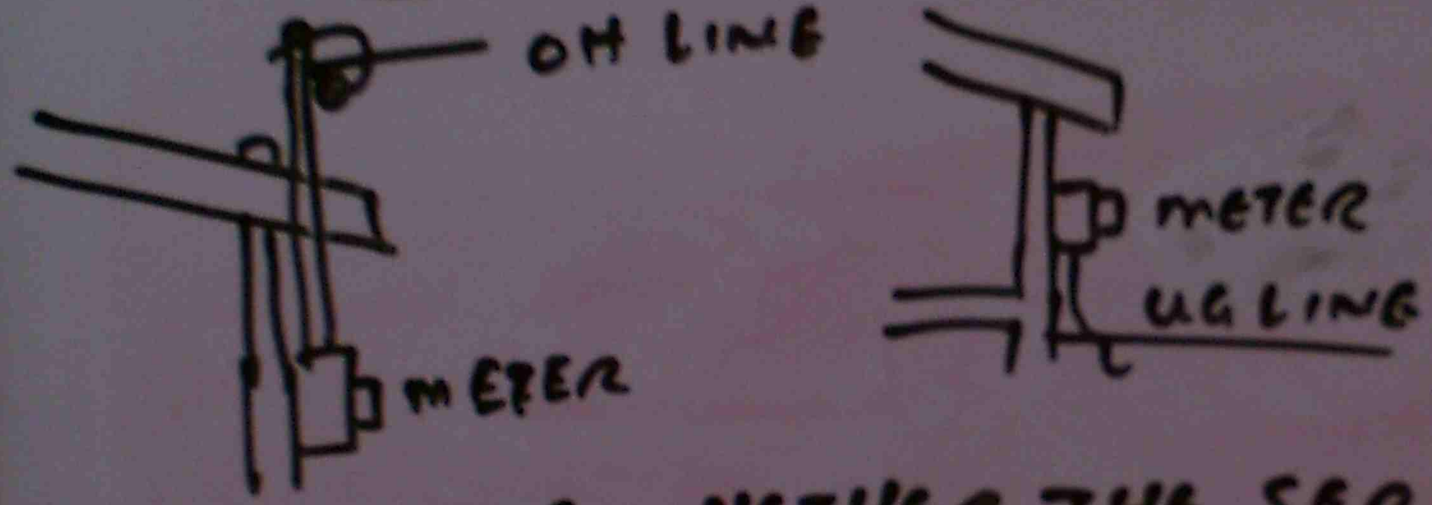
THERMODYNAMIC 1st LAW $\Delta U = Q - W$

2nd LAW $Q = mc(T_f - T_i)$

CONDUCTION $P = \frac{KA\Delta T}{d}$ | $P_{cond/conv} = hcA\Delta T$

RADIATION $E_v = h.v$ | EMISSIVE POWER $= \delta AT^4$

ELECTRICAL SYSTEM DESIGN



- DETERMINE WHETHER THE SERVICE IS AVAILABLE
- LIST OF SUPPLIERS
- WORKING WITH ARCHITECT

STEP BY STEP APPROACH

- THE OUTLETS ARE LOCATED FIRST
- LOCATE ALL EQUIPMENTS ON FLOOR PLAN
- LOCATE LIGHTING FIXTURES
- CIRCUIT LAYOUT
- DB, WIRING
- MAIN SERVICE MAIN
- CABLE SIZE, VOLTAGE DROP
- MAXIMUM DEMAND
- DEMAND FACTOR

(14) HUAC

SLIDE (1) → (8)

@103 → @106

(15) HOT WATER

SLIDE (1) → (10)

@129 → @134

(18) EMERGY MANAGEMENT

SLIDE (1) → (3) @127

(19) (20) ENERGY SAVING

SLIDE 1 → 2

1 → 5

@128 / 135 → 137

SECURITY ALARM

SENSOR → CONTROL PANEL → ALARM

FIRE ALARM IPHONE DIALER

PHOTOELECTRIC SYSTEM

MOTION DETECTOR

BUILDING MATERIALS

FERROUS, NON FERROUS, WOOD
PLASTICS RUBBER
CORROSION PREVENTION

- TENSILE TESTING
- COMPRESSION TESTING
- IMPACT TESTING
- HARDNESS TESTING
- FATIGUE TESTING

$$\text{YOUNG MODULUS} = \frac{\text{STRESS}}{\text{STRAIN}}$$

WORKING

COLD, HOT, PRESSING, CASTING
EXTRUDING FORGING, BOLTING
MACHINING

TENSILE STRENGTH, COMPRESSIVE STRENGTH, YOUNG MODULUS ELONGATION

FERROUS ALLOY

STRUCTURAL STEEL + CAST STEEL + OTHER METAL = MACHINA-BILITY

TIMBER

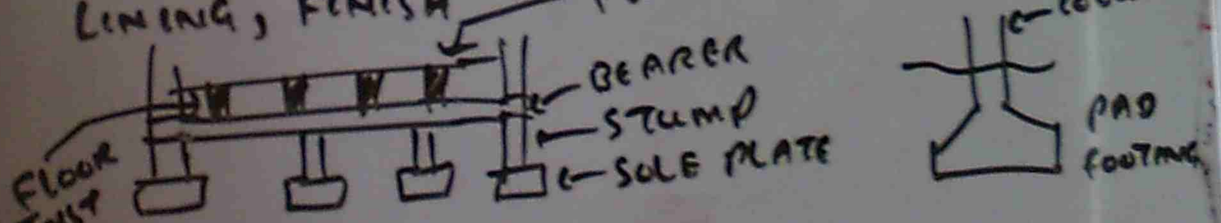
RED DEAL, SCOTS PINE, YELLOW PINE
YELLOW DEAL, WHITE DEAL
TIMBER MUST BE APPROPRIATELY SEASONED BEFORE USE

STRUCTURAL USE OF TIMBER

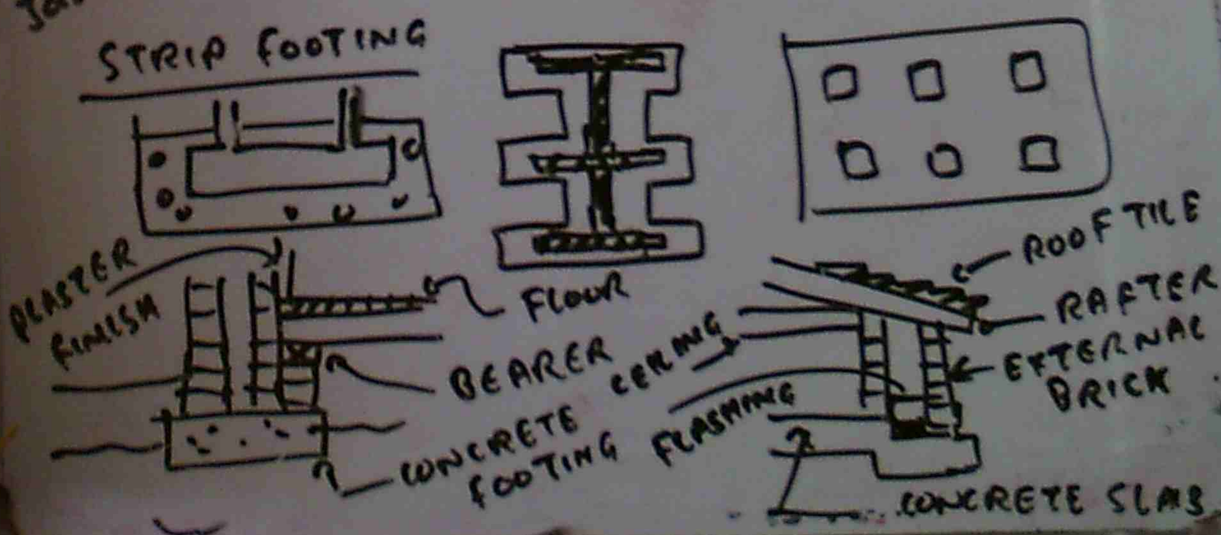
DEPTH TO BREADTH RATIO, STRESS, TIMBER DECAY IN SEASONING PROCESS

BUILDING SEQUENCE

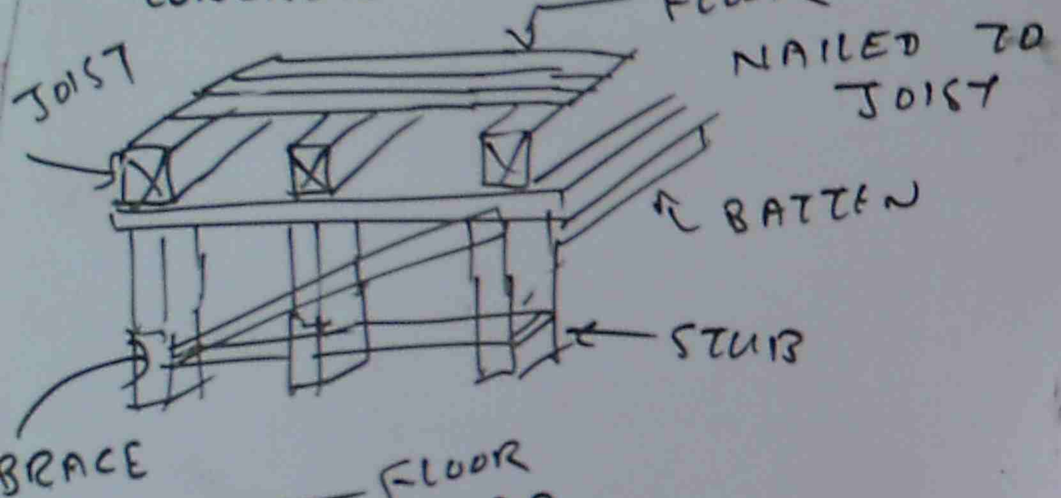
SET OUT, FOUNDATION, FOOTING, FLOOR, WALL, ROOF, CLADDING LINING, FINISH
- STUMP
- STRIP
- CONCRETE SLAB

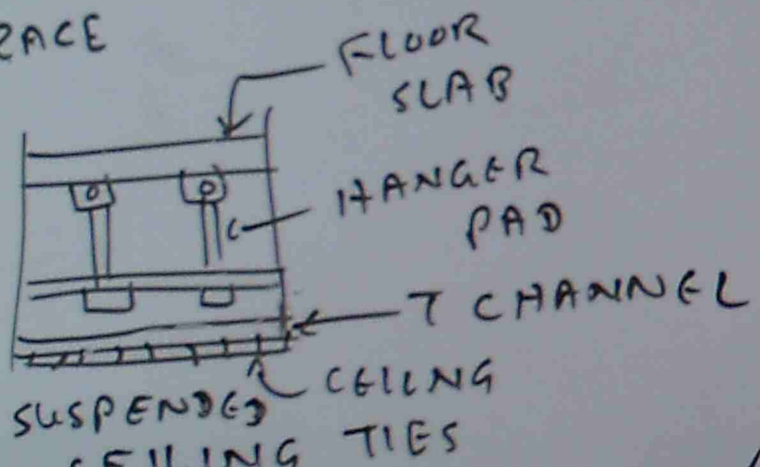


STRIP FOOTING

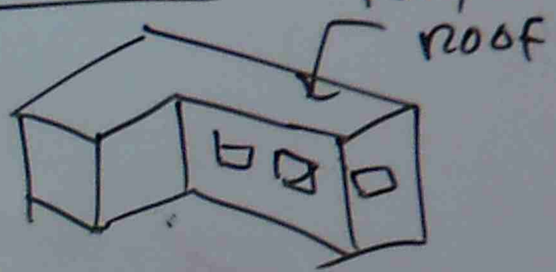


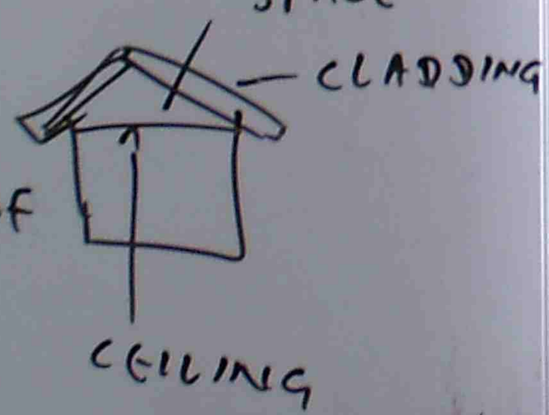
BRICK VENEER WALL
CONCRETE WALL

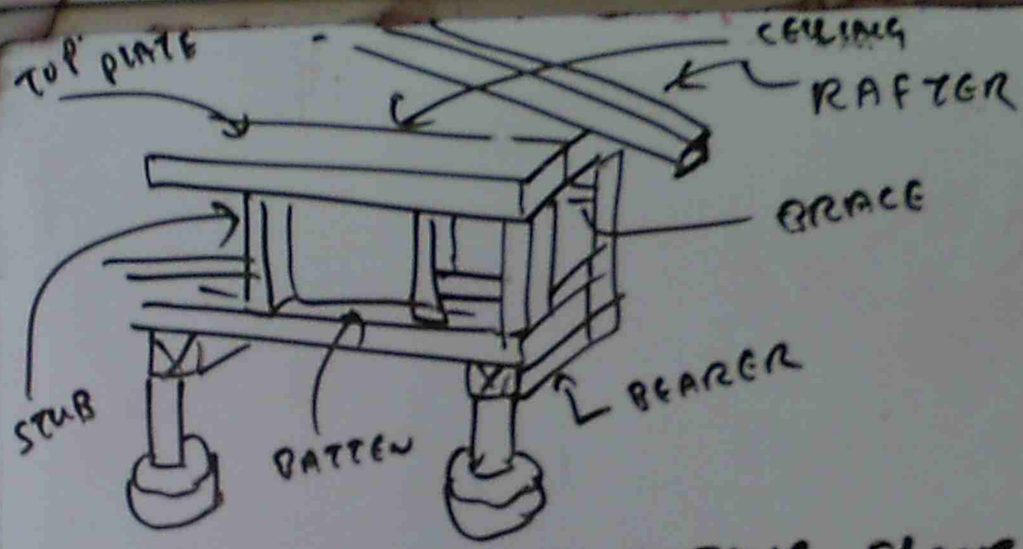




ROOF







SETOUT, FOUNDATION, FOOTING, FLOOR, WALL
ROOF, CLADDING, LINING, SERVICE
PLUMBING GAS ELECTRICAL

STUDY E047 + K041 MATERIALS + BUILDING-1
E047 + K041 MATERIALS + BUILDING-2
E047 MATERIAL SCIENCE