MADE EASY

India's Best Institute for IES, GATE & PSUs

UPSC ESE 2019

Main Exam Detailed Solutions

Electronics & Telecom. Engineering

PAPER-I

EXAM DATE : 30-06-2019 | 10:00 AM to 1:00 PM

MADE EASY has taken due care in making solutions. If you find any discrepency/ error/typo or want to contest the solution given by us, kindly send your suggested answer with detailed explanations at info@madeeasy.in

Corporate Office : 44-A/1, Kalu Sarai, Near Hauz khas metro station, New Delhi-110016

011-45124612, 9958995830 www.madeeasy.in

Electronics and Telecom. Engineering Paper Analysis ESE 2019 Main Examination

Sl.	Subjects	Marks
1.	Materials Science	84
2.	Electronic Devices and Circuits	22
3.	Analog Circuits	121
4.	Digital Circuits	25
5.	Network Theory	112
6.	Basic Electrical Engineering	20
7.	Electronic Measurements and Instrumentation	96
	Total	**480**

Scroll down for detailed solutions

1. (a) (i) Calculate the temperature at which silicon (Si) semiconductor tends to behave like a metal.

[6 Marks]

(ii) Prove that reverse saturation current approximately doubles for every 10 °C rise in temperature in a semiconductor diode.

[6 Marks]

Solution:

(i) The forbidden region E_g in a semiconductor depends upon temperature

$\therefore$ $$E_g(T) = 1.21 - 3.60 \times 10^{-4}\ T$$

For silicon.

Now, for a conductor the conduction bond and valence bond should overlap.

$\therefore$ $E_g(T) \approx 0$ for conductors.

$\therefore$ $1.21\ \text{eV} - 3.60 \times 10^{-4}\ T = 0$

$$T = \frac{1.21}{3.6} \times 10^{-4}$$

$$T = 3361.1°K$$

Note : It is theoretical value but silicon will not remain solid after 1414°C or 1687°K and after that its morphology will change.

(ii) The reverse saturation current for a diode can be given as

$$I_o = KT^m \exp\left(\frac{-V_g}{\eta V_T}\right)$$

$$ln(I_o) = lnK + m\,lnT - \frac{V_g}{\eta V_T}$$

$\Rightarrow$ $$ln(I_o) = lnK + m\,lnT - \frac{V_g}{\eta KT}$$

differentiating w.r.t. T we get

$$\frac{d\,ln(I_o)}{dT} = 0 + \frac{m}{T} - \frac{V_g}{\eta K}\left(-\frac{1}{T^2}\right)$$

$$\frac{d\,ln(I_o)}{dT} = \frac{m}{T} + \frac{V_g}{\eta KT^2}$$

$$\frac{1}{I_0}\frac{d(I_o)}{dT} = \frac{m}{T} + \frac{V_g}{\eta V_T T}$$

For silicon $\eta = 2$, $m = 1.5$ and $V_g = 1.21$ V

$\therefore$ $$\frac{1}{I_o}\frac{d(I_o)}{dT} = \frac{1.5}{300} + \frac{1.21}{2 \times 26 \times 10^{-3} \times 300}$$

$= 0.082$ per degree

Thus, the reverse saturation current charge by an approx 8% per degree.

$\therefore \quad I_{new} = (I_{old} + 8\% \ I_{out})$

$I_{new} = (1.08)I_{old}$

New for 10°C

$I_{new} = (1.08)^{10} I_{old}$

$I_{new} \approx 2 \, I_{old}$

Thus, for every 10° rise the reverse saturation current nearby doubles.

End of Solution

1. (b) (i) Prove that when two resistors are connected in parallel, the equivalent resistance of the combination is always smaller than that of smaller resistor.

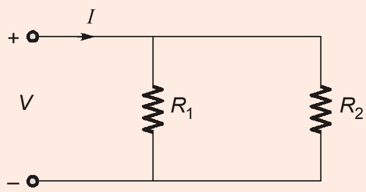
[6 Marks]

(ii) A conductor has resistance 5.4Ω at 20°C and 7Ω at 100°C. Determine the resistance of the conductor at 0°C.

[6 Marks]

Solution:

(i) Let the two resistors are R_1 and R_2 connected in parallel as



with $R_1 > R_2$ as $R_1 = KR_2$ $(K > 1)$

By using KCL in above circuit, we get

$$I = \frac{V}{R_1} + \frac{V}{R_2} \Rightarrow V\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

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

or
$$R_{eq} = \frac{KR_2 R_2}{KR_2 + R_2} = \frac{K}{(1+K)} R_2$$

$\because \quad K > 1$

$\therefore \quad \frac{K}{1+K} < 1$

Hence $\quad R_{eq} < R_2 \quad$ Hence proved.

(ii) The resistance R is related with temperature T as

$$R = R_0(1 + \alpha \Delta T)$$

where, $\quad \alpha =$ temperature coefficient

$$\Delta T = T_1 - T_0$$

$$R_0 = \text{Resistance at } T_0\ (0°)$$

According to the question

at $T = 20°C,\ R = 5.74\ \Omega$

and at $T = 100°C,\ R = 7\ \Omega$

For condition (i), $5.4 = R_0[(1 + \alpha(20° - 0°)]$ ...(i)

Similarly for condition (ii), $7 = R_0[1 + \alpha(100° - 0°)]$ ...(ii)

From (i) and (ii), $\dfrac{5.4}{7} = \dfrac{1+20\alpha}{1+100\alpha}$

$$7 + 140\ \alpha = 5.4 + 540\ \alpha$$

or $7 - 5.4 = (540 - 140)\ \alpha$

or $\alpha = \dfrac{1.6}{400} = 4\times10^{-3}$

$\therefore$ From equation (i), $5.4 = R_0[1 + 4 \times 10^{-3}\ (20° - 0°)]$

We get, $R_0 = 5\Omega$

MADE EASY Source

- **Theory Book 2020:** Network Theory (Page No. 15)
- **MCQ Practice Book:** (Q.33, Page 4)

End of Solution

1. (c) What is 'line imperfection defect' in a crystal? How does it affect the properties of a metal?

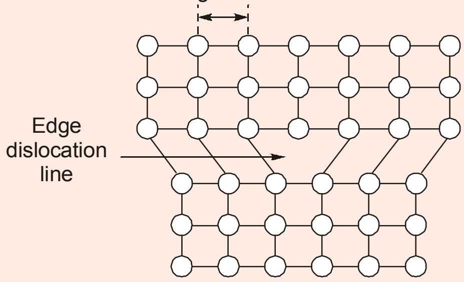
[12 Marks]

Solution:

Line defect is the defect confined to more number of atoms in a lattice.

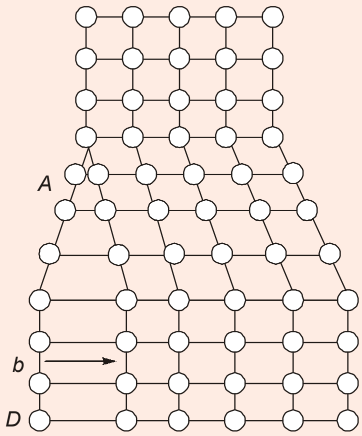
Linear defect: A dislocation is a linear or one dimensional defect around which some of the atoms are misaligned. There are following types of linear dislocation as given below:

1. **Edge dislocation:** In an edge dislocation, an extra portion of a plane of atoms, or half-plane appears and the edge of which terminates within the crystal. It is a linear defect that centers around the line that is defined along the end of the extra half plane of atoms. This is sometimes termed as dislocation line, which for the edge dislocation as shown in figure, is perpendicular to the plane of the page. Within the region around the dislocation line there is some localized lattice distortion. The atoms above the dislocation line are squeezed together and those below are pulled apart. This is reflected in the slight curvature for the vertical planes of atoms as they bend around this extra half plane. The magnitude of this dislocation decreases with distance away from the dislocation line. An edge dislocation may also be formed by an extra half plane of atoms that is included in the bottom portion of the crystal.



Edge dislocation

2. **Screw dislocation:** Screw dislocation is formed by shear stress that is applied to produce the distortion. The upper front region of the crystal is shifted one atomic distance to the right relative to the bottom portion. The atomic distortion associated with a screw dislocation is also linear and along a dislocation line. The screw dislocation derivers its name from the spiral or helical path or ramp that is traced around the dislocation line by the atomic planes of atoms.



Screw dislocation

3. **Mixed dislocation:** Most dislocations found in crystalline materials are probably neither pure edge nor pure screw, but exhibit components of both types, these are termed as mixed dislocations.
   The nature of a dislocation is defined by the relative orientations of dislocation line and Burger's vector. For an edge, they are perpendicular, whereas for a screw, they are parallel. They are neither parallel nor perpendicular for a mixed dislocation. Also, even though a dislocation changes direction and nature within a crystal (e.g. from edge to mixed to screw), the Burger's vector will be the same at all points along its line.

End of Solution

1. (d) (i) Enumerate the different performance indices based on which an engineer selects an instrument.

[5 Marks]

(ii) What is the SI system of units? Mention some (at least four) well-defined units maintained by the International System of Units.

[7 Marks]

Solution:

(i) An engineer selects an instrument based on the following performance indices

1. Sensitivity
2. Accuracy
3. Resolution
4. Speed of response
5. Dynamic error

(a) Sensitivity : An engineer has to select the high sensitivity instrument to avoid the loading effect on measuring quantity.

(b) Accuracy : Accuracy of the instrument has to be high so that the error in that instrument is negligible.

(c) Resolution : to measure even a small variation in measuring quantity, the resolution of instrument should be high.

(d) Speed of response : the instrument should have fast response while measuring a quantity.

(e) Dynamic error : The dynamic error for an instrument should be small.

MADE EASY Source

- **Theory Book 2020 :** EMI (Page No. 3, Ch-1)

(ii) The SI system of units so called the international system of units. It consists of six base units, two supplementary units and 27 derived units.

The six base units have already been adopted in the standards of weights and measures.

Seven base units of SI:

1. Meter (*m*) :
   - It is the unit of length.
   - The meter is the length equal to 1,650,763.73 wave-lengths in vacuum of radiation corresponding to the transition between the level 2_{p10} and 5_{d5} of krypton 86 atom.

2. Kilogramme (kg) :
   - It is the unit of mass.
   - A kilogramme is equal to the mass of the international prototype of mass.

3. Second (*s*) :
   - It is the unit of time.

- Defined as the duration of 9,192,631,770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

4. Ampere (*A*) :
   - It is the unit of electric current.
   - The Ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross-section and placed one meter apart in vacuum, would produce between them a face equal to 2×10^{-7} newton per meter length.

5. Kelvin (*K*) :
   - It is the unit of temperature.
   - It is the fraction of $\frac{1}{273.16}$ of the thermodynamic temperature of triple point of water.

6. Candela (*Cd*) :
   - It is the unit of luminous intensity.
   - It is the luminous intensity, in a perpendicular direction of a surface of $\frac{1}{600,000}$ square meter of a blackbody at the temperature of freezing platinum under a pressure of 101,325 newton per square meter.

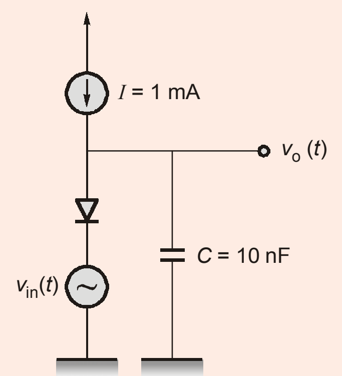
7. Mole (mol) :
   - It is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon 12.
   The elementary entities may be atoms, ions, molecules, electrons, other particles, or specified groups of such particles.

MADE EASY Source

- **Theory Book 2020 :** EMI (Page No. 17, Ch-1)

End of Solution

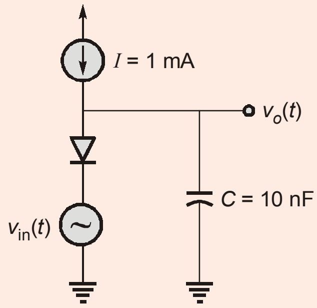
1. (e) In the circuit shown in the figure below, I = 1 mA is a DC current and $v_{in}(t)$ is a sinusoidal voltage with small amplitude:



Representing the diode by its small signal resistance r_d, which is a function of I, sketch the circuit for determining $v_0(t)$ and thus find out cutoff frequency f_H. (Assume V_T = 25 mV at room temperature)

[12 Marks]

Solution:

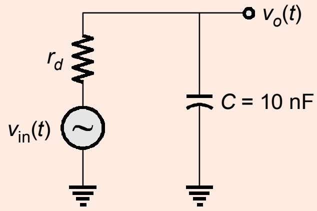


Now, we can find the small signal equivalent resistance of diode as

$$r_d = \frac{\eta V_T}{I_{DC}} = \frac{25 \times 10^{-3}}{1 \times 10^{-3}} = 25\ \Omega$$

(where V_T = 26 mV, I_{DC} = 1 mA and assuming η = 1)

Then, the equivalent circuit can be drawn as



Taking the Laplace transform, we can write

$$\frac{V_o(s)}{V_i(s)} = \frac{1/sC}{r_d + \frac{1}{sC}} = \frac{1}{1 + sr_dC} = \frac{1}{1 + sr_dC}$$

Now, for 3 dB cut-off, the magnitude of output voltage to that of input voltage will be equal to $\frac{1}{\sqrt{2}}$

$$\therefore \quad \frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1 + \omega_H^2 r_d^2 C^2}}$$

$$\omega_H^2 r_d^2 C^2 = 1$$

$$\omega_H^2 = \frac{1}{r_d^2 C^2}$$

$$\omega_H = \frac{1}{r_d C}$$

$$\therefore \quad f_H = \frac{1}{2\pi r_d C} = \frac{1}{2\pi \times 25 \times 10 \times 10^{-9}}$$

$$f_H = 636.619 \text{ kHz}$$

MADE EASY Source

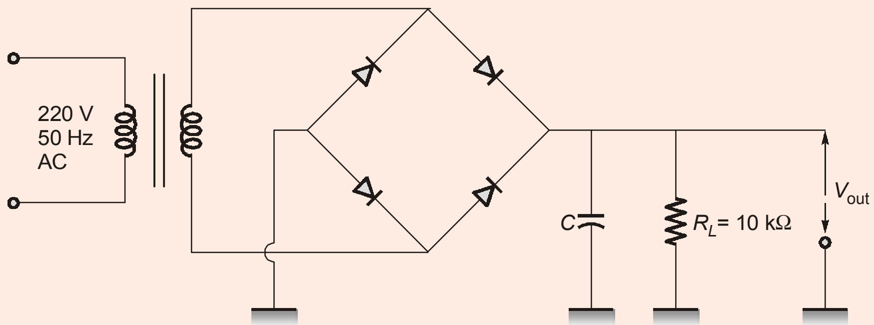
- **ESE 2019 Mains Test Series:** Q.4(b) of Test-5

End of Solution

2. (a) (i) Find the equilibrium hole concentration p_0 at 300 K of Si sample doped with phosphorus impurity if Fermi level energy (E_F) of doped Si is 0.407 eV more than intrinsic level energy (E_i). Given n_i = 1.5 × 10^{10} atoms/cm^3 and kT = 0.0259eV.

[10 Marks]

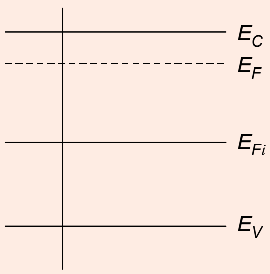
(ii) A filter capacitor C is used to smooth out the pulses from the full-wave rectifier as shown in the figure below:
Find the value of C so that the steady current supply to load R_L can be maintained.



[10 Marks]

Solution:

(i)



Now,
$$E_F - E_{fi} = KT\ln\left(\frac{N_d}{n_i}\right)$$

∴
$$N_d = n_i \exp\left[\frac{E_F - E_{fi}}{KT}\right]$$

$$= 1.5 \times 10^{10} \times \exp\left[\frac{0.407}{0.0259}\right]$$

$$N_d = 1 \times 10^{17} \text{ atoms/cm}^3$$

Now, for an n-type device

$$n = N_d = 1 \times 10^{17} \text{ electrons/cm}^3$$

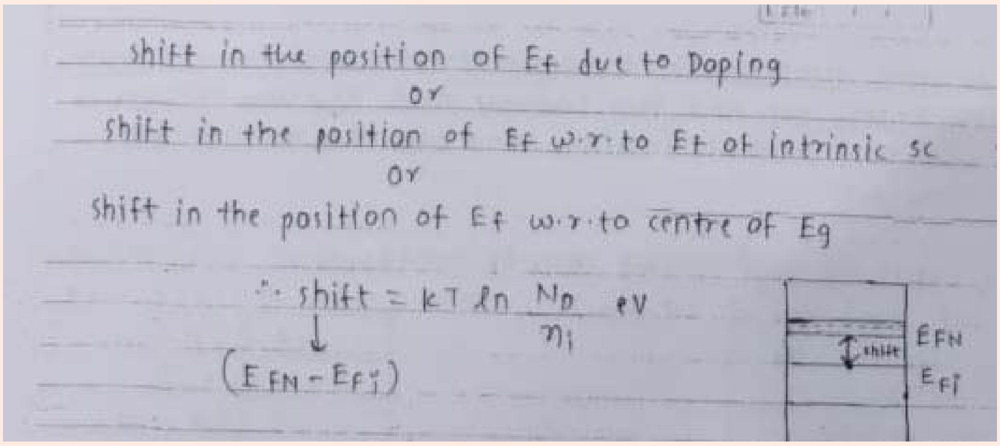
According to mass action low

$$np = n_i^2 \quad \text{(at equilibrium)}$$

$$p = \frac{(1.5 \times 10^{10})^2}{1 \times 10^{17}} = 2250 \text{ holes/cm}^3$$

MADE EASY Source

- **MADE EASY Classnotes**



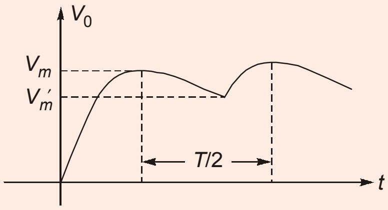
shift in the position of Ef due to Doping
or
shift in the position of Ef w.r.to Ef of intrinsic sc
or
shift in the position of Ef w.r.to centre of Eg

∴ shift = kT ln $\frac{N_D}{n_i}$ eV
↓
($E_{FN} - E_{Fi}$)

(ii) For the rectifier

$$V_{m(\text{out})} = 220\sqrt{2} = 311.12 \text{ V}$$

Now, since the output is a rectified wave, we have



$$V_m = V_m\left(1 - \frac{T}{2RC}\right)$$

$$\therefore \quad r \approx \frac{V_m T}{2RC} = \frac{311.12}{2 \times 10 \times 10^3 \times C \times 50}$$

$$r = \frac{31 \times 10^{-5}}{C}$$

Assuming, peak to peak ripple voltage as 1%

$$\therefore \quad r = 0.01 \times 311.12$$

$$r = 3.112 \text{ V}$$

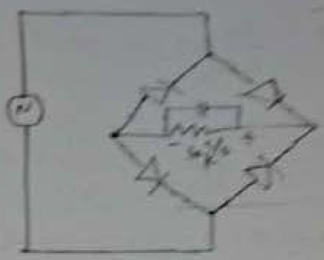
$$\therefore \quad 3.112 = \frac{31 \times 10^{-5}}{C}$$

$$C = \frac{31 \times 10^{-5}}{3.112} \approx 100 \ \mu\text{F}$$

MADE EASY Source

- **MADE EASY Classnotes**

Q] In bridge rectifier shown, diode have cut-in voltage 0.7V and peak to peak ripple is 2V calculate the value of capacitor.



Soln:

$V_s = 60 \sin 2\pi f_0 t$ Volt

$f_0 = 60\,Hz$

$V_m = 60\,V, \; V_r = 2\,V$

$V_{DC} = V_m - \frac{V_r}{2} - 2V_\gamma$ (take this as it (since two diode are used))

$V_{DC} = 60 - \frac{2}{2} - 2 \times 0.7$ $\quad \therefore V_{DC} = 57.6$

$V_{DC} = I_{DC} \cdot R_L$ $\quad \therefore I_{DC} = \frac{57.6}{10 \times 10^3}$ $\quad \therefore I_{DC} = 5.76\,mA$

$V_r = \frac{I_{DC}}{2 f_0 C}$ $\quad \therefore C = \frac{I_{DC}}{2 f_0 V_r}$ $\quad \therefore C = \frac{5.76 \times 10^{-3}}{2 \times 60 \times 2}$

$\therefore C = 24\,\mu F$

End of Solution

2. (b) (i) What is the principle of nanomagnetism? Based on the specific properties of nanomagnetism, write its applications in engineering field.

[12 Marks]

(ii) Classify insulating materials according to their temperature stability limit and give few examples of each grade.

[8 Marks]

Solution:

(i) **Principle of nanomagnetism**

Nanomagnetism is deals with the magnetic properties of objects that have at least one dimension in the nanoscopic range. Nanomagnetism includes in its scope the study of properties and applications of the magnetism of isolated nanoparticles, nanodots, nanowires, thin films and multilayers and also macroscopic samples that contain nanoscale particles.

Nanomagnetism has many practical applications:

- Magnetic nanoparticles are present in many rocks and soils. The alignment of their magnetic moments under the influence of the geomagnetic field allows the study of evaluation of Earth's magnetism and determination of their age.
- Nanoparticles of magnetic materials, usually of magnetic, also occur in living beings, perhaps the best studied example is that of magnetotactic bacteria.
- The most successful application of nanomagnetism is magnetic recording.
- Used particularly in spintronic devices, which is based on the interaction of the spin degree of freedom of an electric current with the magnetic materials and also uses films and other structures with nanometric dimensions.

(ii) Classification of insulating materials according to temperature:

Class	Insulating materials included	Assigned limiting insulating temperature
Y (Formerly O)	Cotton, silk, paper, cellulose, wood, etc, neither impregnated nor immersed in oil. Materials of Y class are unsuitable for electrical machines and apparatus as they deteriorate rapidly and are extremely hygroscopic.	90°C
A	Materials of class Y impregnated with natural resin, cellulose esters, insulating oils etc. Also included in this list are laminated wool, varnished paper.	105°C
E	Synthetic resin enamels, cotton and paper laminates with formaldehyde bonding etc.	120°C
B	Mica, glass fibres, asbestos with suitable bonding substances, built up mica, glass fibre and asbestos laminates.	130°C
F	Materials of class B with bonding materials of higher thermal stability.	155°C
H	Glass fibre and asbestos materials, and built up mica, with silicon resins.	180°C
C	Mica, ceramics, glass, quartz without binders or with silicon resins of higher thermal stability.	above 180°C

MADE EASY Source

- **Theory Book 2019:** Material Science (Page No. 2, Ch.1)

End of Solution

2. (c) (i) What are the signal conditioning requirements for measurements with strain gauges? How can you compensate errors due to temperature in strain gauge measurements?

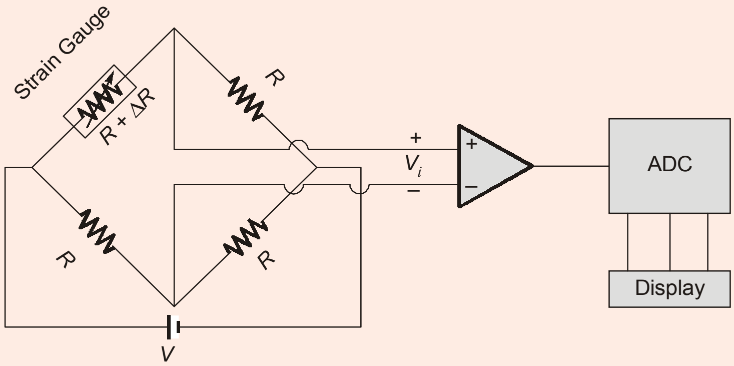
[10 Marks]

(ii) A piezoelectric transducer is subjected to a force of 6 N. The dimension of the transducer is given as 6 mm × 6 mm × 1.3 mm. The charge sensitivity and the dielectric constant of the transducer are given as 160 pC/N and 1250×10^{-11} F/m respectively. Calculate the voltage generated and the deflection caused to the surface. The Young's modulus of elasticity of the material is given as 12×10^{6} N/m^2.

[10 Marks]

Solution:

(i) Strain Gauges are sensing devices that change resistance at their output terminals when stretched or compressed. To obtain accurate strain data, extremely small resistance changes must be measured. A Wheatstone bridge circuit is widely used to convert the Gauge's microstrain into a voltage change that can be fed to the input of A/D converter.

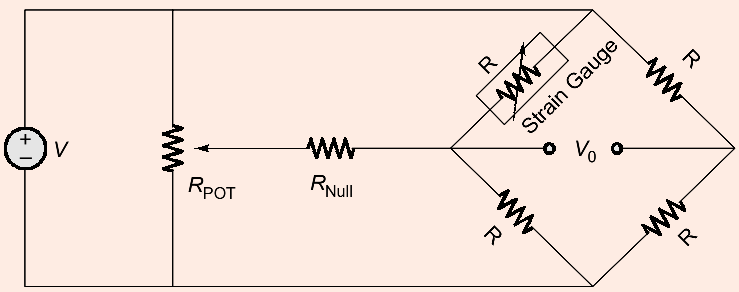


Input to Op-Amp, $V_i = \left(\frac{R+\Delta R}{2R+\Delta R} - \frac{1}{2}\right)V = \frac{V\Delta R}{4R+2\Delta R}$

$$V_i \simeq \frac{V\Delta R}{4R}$$

Signal Conditioning Requirements:

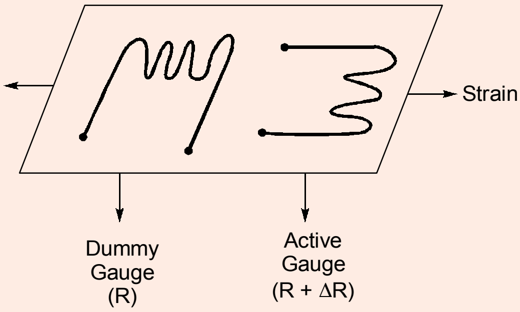
1. **Bridge Balancing, Offset Nulling :** When a bridge is installed, it is very unlikely that the bridge will output exactly 0 volts when no strain is applied. Rather, slight variations in resistance among the bridge arms and lead resistance will generate some non-zero initial offset voltage. To overcome this, offset nulling circuit shown below can be added which uses an adjustable resistance to physically, adjust the output of bridge to zero.



2. **Signal Amplification :** The output of strain gauge is relatively small. Therefore, strain gauge signal conditioners usually include amplifiers to boost the signal level to increase measurement resolution and improve signal to noise ratios.
3. **Excitation of Bridge :** Strain gauge signal conditioners typically provide a constant voltage source to power the bridge. The excitation voltage should be very accurate and stable.

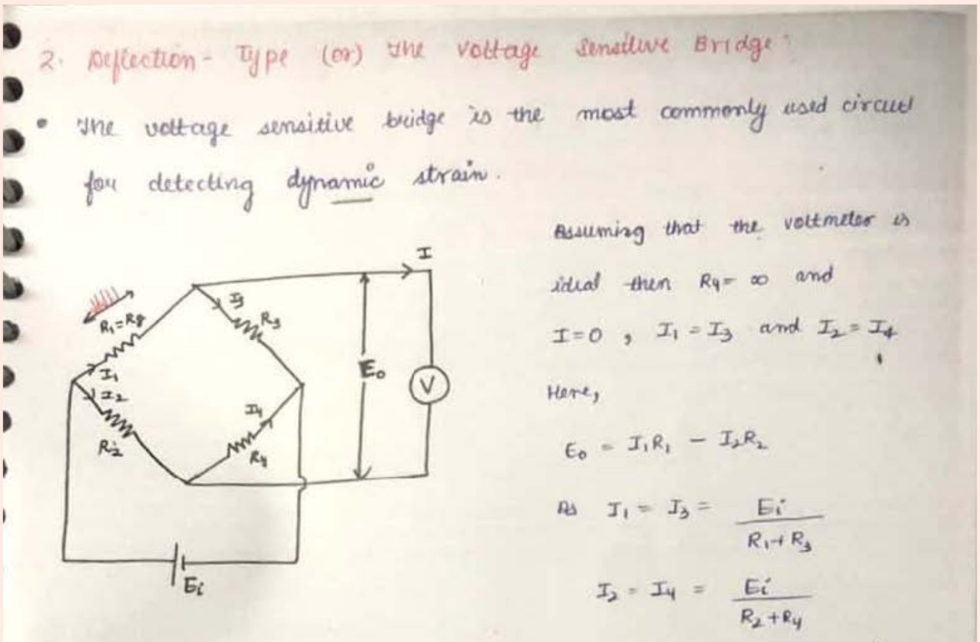
4. **Temperature Compensation :** The resistance of the strain gauge varies with the temperature. The effect of temperature can be avoided by using two strain gauges in the bridge. Figure illustrates a strain-gauge configuration where one gauge is active ($R + \Delta R$) and a second gauge is placed transverse to the applied strain. Therefore, the strain has little effect on the second gauge, called as the Dummy Gauge.

   Any changes in temperature will affect both gauges in some way. Because the temperature changes are identical in two gauges, the effects of the temperatures change are minimized.



MADE EASY Source ______________________________

- **Theory Book:** Measurement and Instrumentation(Page No. 230)
- **Conventional Practice Question Book:** (Q.27, Page 100)
- **MADE EASY Classnotes**


2. Deflection - Type (or) The voltage sensitive Bridge :

• The voltage sensitive bridge is the most commonly used circuit for detecting dynamic strain.

Assuming that the voltmeter is ideal then $R_4 = \infty$ and

$I = 0$, $I_1 = I_3$ and $I_2 = I_4$

Here,

$E_0 = I_1R_1 - I_2R_2$

As $I_1 = I_3 = \dfrac{E_i}{R_1 + R_3}$

$I_2 = I_4 = \dfrac{E_i}{R_2 + R_4}$

▶ Temperature Compensation in Strain Guages

- Errors due to temperature variations in strain guages occur because of
  1: The change in resistance due to the heating effect of electric current as the strain guage has a positive temperature of coefficient for resistance.

(ii) Given, dimension of piezoelectric transducer, 6 mm × 6 mm × 1.3 mm

Charge sensitivity, $d = 160$ pC/N

Dielectric constant, $\in = 1250 \times 10^{-11}$ F/m

Young's modulus, $Y = 12 \times 10^{6}$ N/m^2

Voltage generated by the piezoelectric transducer,

$$V_0 = g.p.t = \frac{d}{\in}.\frac{F}{A}.t$$

Where,
$$g = \frac{d}{\in} = \frac{160\times10^{-12}}{1250\times10^{-11}}$$

$$\therefore \quad V_0 = \frac{160\times10^{-12}}{1250\times10^{-11}}\times\frac{6}{6\times6\times10^{-6}}\times1.3\times10^{-3}$$

$$V_0 = 2.77 \text{ V}$$

Let, the deflection caused is 'X'

$$\frac{F}{A} = Y.\frac{X}{t}$$

$$\frac{F}{A}.\frac{t}{Y} = X$$

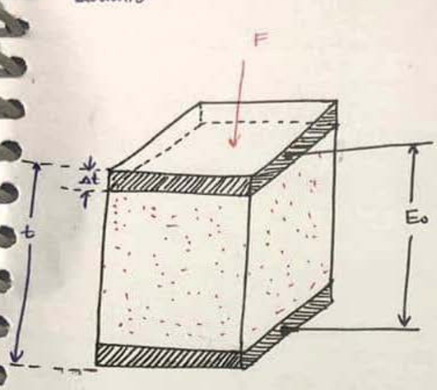
$$X = \frac{6}{6\times6\times10^{-6}}\times\frac{1.3\times10^{-3}}{12\times10^{6}}$$

$\therefore$ deflection, $X = 18.05$ μm (or) 0.018 mm

MADE EASY Source

- **Theory Book 2019:** EMI (Page No. 238, Ex. 8.21)
- **MADE EASY Classnotes**

The various crystals which exhibits this property are quartz crystal, Barium Titanate, Lithium sulphate, Roshelle salt, ADP crystals etc (Ammonium Dihydrogen Phosphate)



By the definition of Piezo electric effect

$$Q \propto F$$

$$Q = dF \quad \{d : \text{charge sensitivity}\} \quad (1)$$

The magnitude of charges induced can be expressed as

$$Q = C_p E_o$$

where C_p is the capacitance and E_o is the o/p voltage

$$E_o = \frac{Q}{C_p} \quad (2)$$

The crystal capacitance C_p can be expressed as

$$C_p = \frac{\epsilon A}{d} \quad \text{where}$$

$$d = t \quad \{\text{unstressed thickness}\}$$

$$\therefore C_p = \frac{\epsilon A}{t} \quad (3)$$

Substituting (3) and (1) in (2) we have

$$E_o = \frac{dFt}{\epsilon A} \quad (4)$$

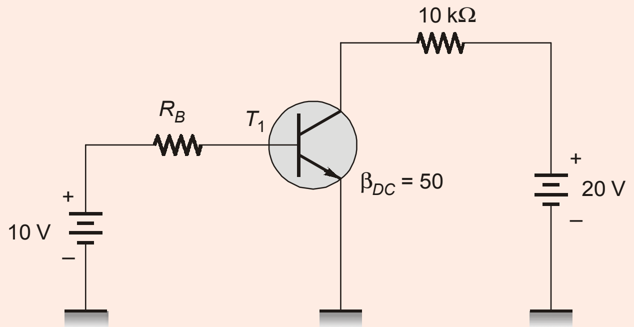
In expression (4)

$$\frac{d}{\epsilon} = g \text{ (voltage sensitivity)}$$

$$\frac{F}{A} = P \text{ (Pressure)}$$

End of Solution

3. (a) (i) Calculate the range of base resistance (R_B) so that transistor T_1 never operates in saturation region:



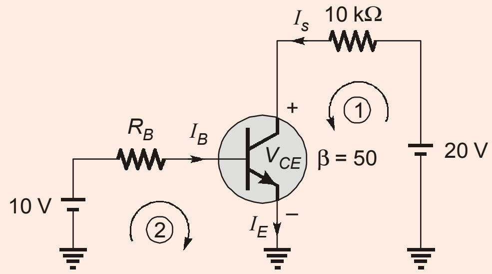
[10 Marks]

(ii) An amplifier has a bandwidth of 500 kHz and voltage gain of 100. What should be the amount of negative feedback if the amplifier bandwidth is extended to 5 MHz? What will be the new gain after negative feedback is introduced?

[10 Marks]

Solution:

(i)



Assuming that the cut-in voltage of the transistor $V_{BE\,(on)}$ = 0.7 V and the value of saturation voltage $V_{CE\,(sat)}$ = 0 V.

Thus, the transistor will enter into saturation region for $V_{CE\,(sat)}$ = 0 V. Applying KVL in loop 1, we get,

$$\therefore \qquad I_{C\,(max)} = \frac{20 - V_{CE(sat)}}{10\text{ k}\Omega} = \frac{20}{10} \times 10^{-3} = 2\text{ mA}$$

Thus,
$$I_B = \frac{I_C}{\beta} = \frac{2 \times 10^{-3}}{50} = 40\,\mu\text{A}$$

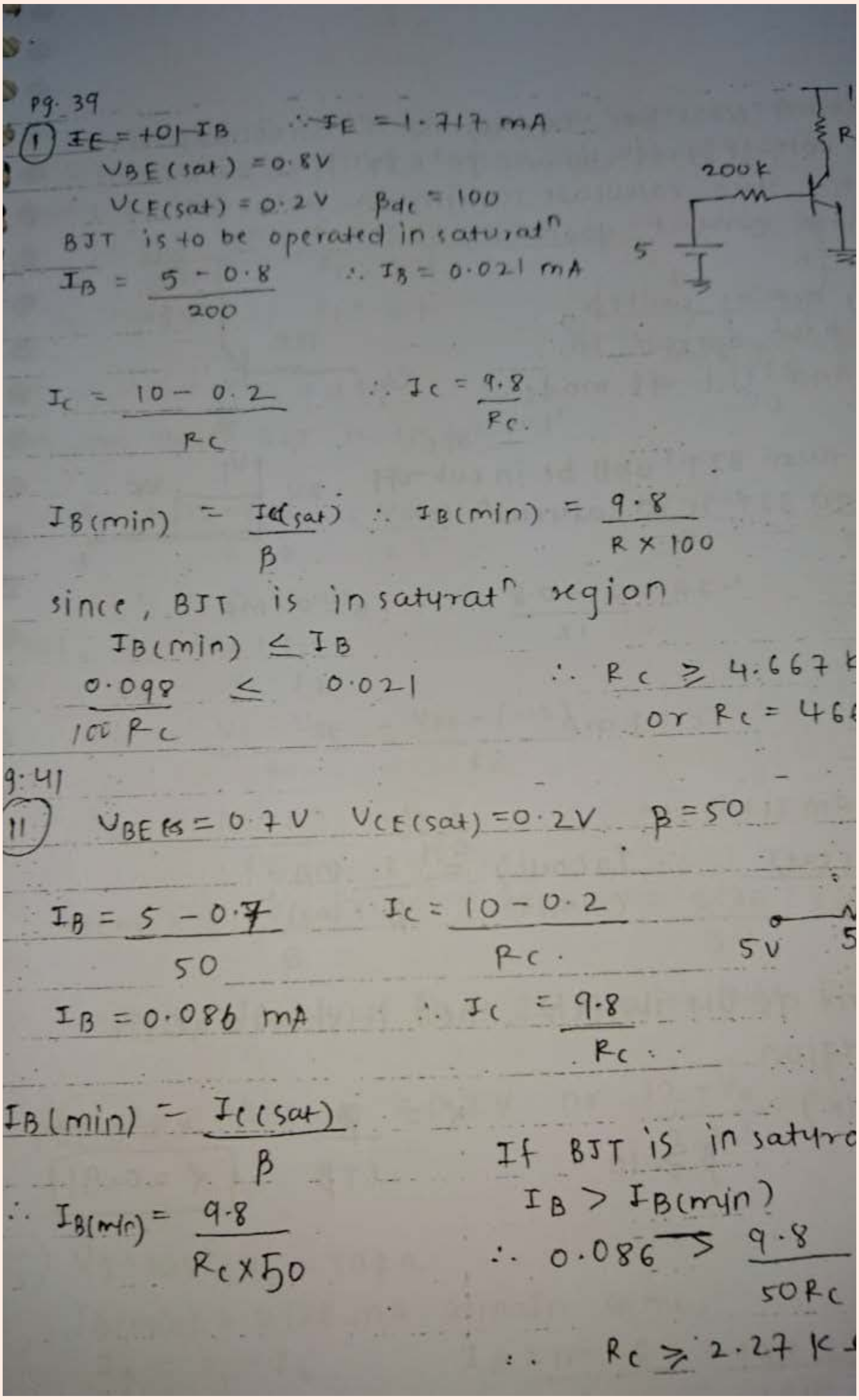
Now, applying KVL in loop 2, we get,

$$\therefore \qquad R_B = \frac{10 - 0.8}{40} \times 10^6 = 230\text{ k}\Omega$$

∴ For all the values of R_B > 230 kΩ the transistor will not operate in saturation region.

MADE EASY Source

- **MADE EASY Classnotes**



pg. 39

(1) $I_E = 101\, I_B$ $\quad \therefore I_E = 1.717$ mA

$V_{BE(sat)} = 0.8$ V

$V_{CE(sat)} = 0.2$ V $\quad \beta_{dc} = 100$

BJT is to be operated in saturatⁿ

$I_B = \dfrac{5 - 0.8}{200}$ $\quad \therefore I_B = 0.021$ mA

$I_C = \dfrac{10 - 0.2}{R_C}$ $\quad \therefore I_C = \dfrac{9.8}{R_C}$

$I_{B(min)} = \dfrac{I_{C(sat)}}{\beta}$ $\quad \therefore I_{B(min)} = \dfrac{9.8}{R \times 100}$

since, BJT is in saturatⁿ region

$I_{B(min)} \le I_B$

$\dfrac{0.098}{100\, R_C} \le 0.021$ $\quad \therefore R_C \geq 4.667$ k

or $R_C = 46$

pg. 41

(11) $V_{BE(s)} = 0.7$ V $\quad V_{CE(sat)} = 0.2$ V $\quad \beta = 50$

$I_B = \dfrac{5 - 0.7}{50}$ $\quad I_C = \dfrac{10 - 0.2}{R_C}$

$I_B = 0.086$ mA $\quad \therefore I_C = \dfrac{9.8}{R_C}$

$I_{B(min)} = \dfrac{I_{C(sat)}}{\beta}$

$\therefore I_{B(min)} = \dfrac{9.8}{R_C \times 50}$

If BJT is in saturatⁿ

$I_B > I_{B(min)}$

$\therefore 0.086 > \dfrac{9.8}{50 R_C}$

$\therefore R_C \geq 2.27$ k

(ii) Bandwidth of amplifier without feedback = BW = 500 kHz

Now, let us assume that the amplifier is provided with passive negative feedback with feedback factor β.

Thus, the new modified bandwidth will be given as

$$BW_{new} = BW(1 + A\beta)$$

$$\therefore \quad 5000 \times 10^3 = 500 \times 10^3\,(1 + \beta(100))$$

$$10 = 1 + 100\,\beta$$

$$9 = 100\,\beta$$

$$\beta = 0.09$$

∴ New gain,

$$A_f = \frac{A}{1+A\beta} = \frac{100}{1+100\times 0.9} = \frac{100}{10}$$

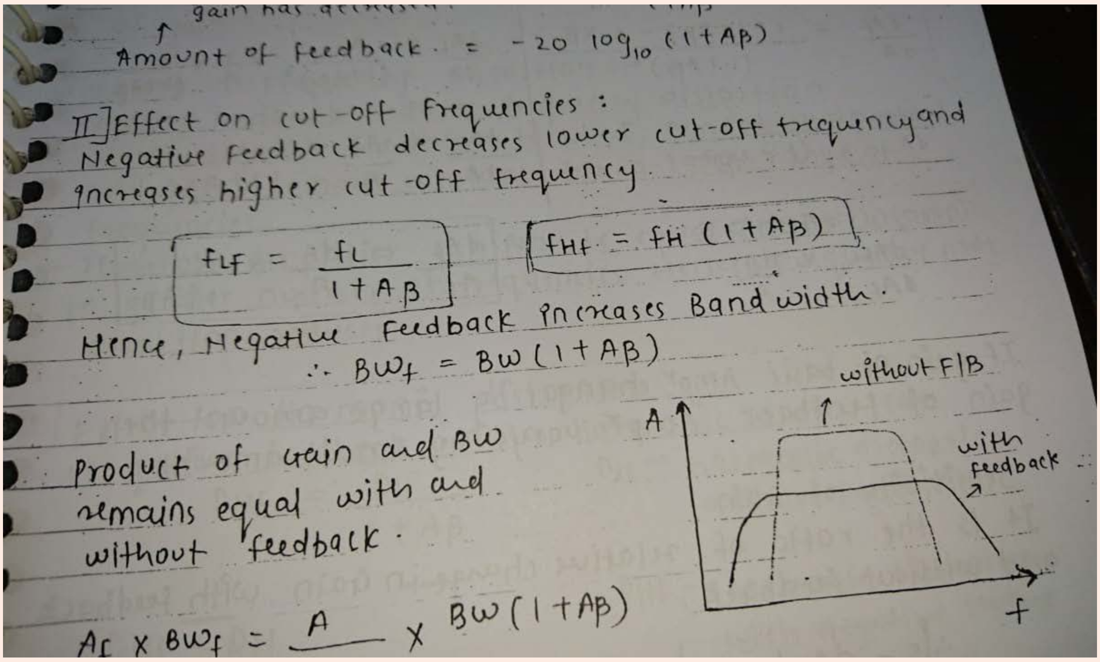
$$= 10 \text{ V/V}$$

∴ The amplifier gain with feedback

$$A_f = 10 \text{ V/V}$$

MADE EASY Source

- **MADE EASY Classnotes**



End of Solution

3. (b) (i) What are HTSC? Write the important applications of superconducting materials and HTSC.

[10 Marks]

(ii) "A ceramist can alter the properties of ceramic" Justify the statement.

[10 Marks]

Solution:

(i) **HTSC : High Temperature Superconductors**

The high temperature superconductors represents a new class of material which bear extraordinary superconducting and magnetic properties and great potential for wide-ranging technological applications.

Called high T_C superconductors on basis of critical temperature is greater than boiling temperature of liquid Nitrogen (77 k or – 196°C). However, a number of material-including the original discovery and recently discovered superconductors had critical temperature below 77 k but are commonly referred to in publication as being in the high T_C class.

Application of superconducting materials

- Magnetic Resonance Imaging (MRI)
- Nuclear Magnetic Resonance Spectroscopy
- Accelerators in particle physics
- Reactors for nuclear fusion
- Magnetic levitated trains

Application of HTSC

- Mechanical flexible conductor (for coils etc.)
- High current transport capability at higher application temperature (> 77 k) highest magnetic fields.
- Used for low ac-losses, high mechanical strength, reduced anisotropy.
- Development of conductor based on HTSC
- As current limiter
- As fusion magnets

(ii) Following are the methods to alter the properties of ceramics:

1. Make starting materials more uniform.
2. Decrease grain size in polycrystalline ceramic products.
3. Maximize porosity.
4. Introduce compressive surface stresses.
5. Use fibre reinforcement.
6. Heat treat.

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.5(d) of Test-6
- **Theory Book 2020:** Material Science (Page No. 118)

End of Solution

3. (c) (i) Explain, with necessary diagrams, how you can detect the proximity of an object.

[12 Marks]

(ii) The spring constant and seismic mass of an accelerometer are 3300 N/m and 5×10^{-2} kg respectively. The maximum displacement is ±0.25 m (before the mass hits the stops). Calculate (1) the maximum measurable acceleration in g and (2) the natural frequency.

[8 Marks]

Solution:

(i) 1. Eddy current proximity sensors:

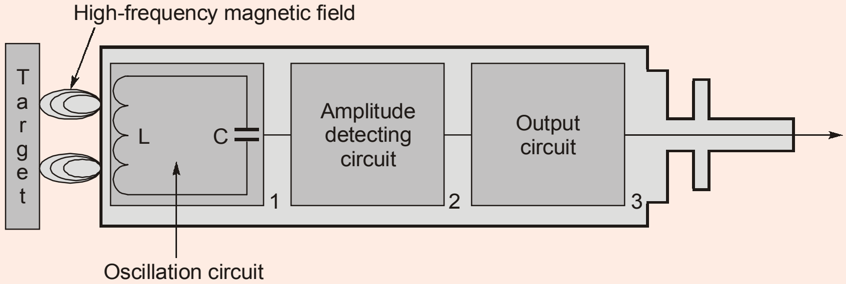


Fig. (i): Schematic of Inductive Proximity Sensor

Eddy current proximity sensors are used to detect non-magnetic but conductive materials. They comprise of a coil, an oscillator, a detector and a triggering circuit. Fig. (i) shows the construction of eddy current proximity switch. When an alternating current is passed through this coil, an alternative magnetic field is generated. If a metal object comes in the close proximity of the coil, then eddy currents are induced in the object due to the magnetic field. These eddy currents create their own magnetic field which distorts the magnetic field responsible for their generation. As a result, impedance of the coil changes and so the amplitude of alternating current. This can be used to trigger a switch at some pre-determined level of change in current.

Eddy current sensors are relatively inexpensive, available in small in size, highly reliable and have high sensitivity for small displacements.

Applications of eddy current proximity sensors

- Automation requiring precise location
- Machine tool monitoring
- Final assembly of precision equipment such as disk drives
- Measuring the dynamics of a continuously moving target, such as a vibrating element
- Drive shaft monitoring
- Vibration measurements

2. Inductive proximity switch

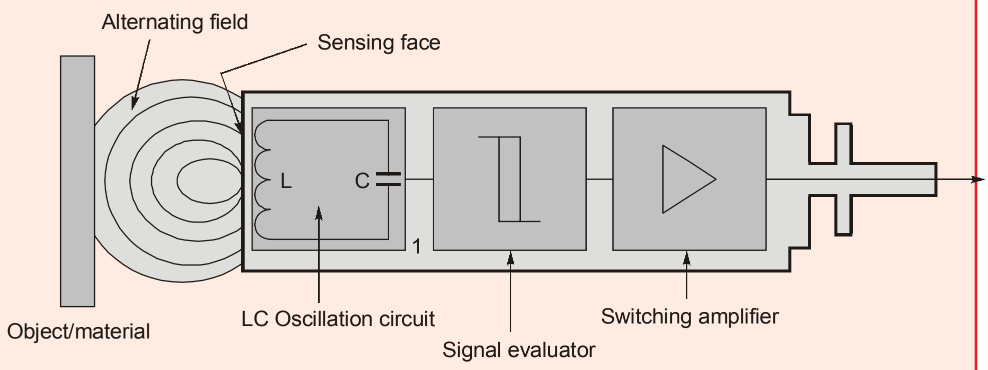


Fig. (ii): Schematic of Inductive Proximity Switch

Inductive proximity switches are basically used for detection of metallic objects. Fig. (ii) shows the construction of inductive proximity switch. An inductive proximity sensor has four components; the coil, oscillator, detection circuit and output circuit. An alternating current is supplied to the coil which generates a magnetic field. When, a metal object comes closer to the end of the coil, inductance of the coil changes. This is continuously monitored by a circuit which triggers a switch when a preset value of inductance change is occurred.

Applications of inductive proximity switches

- Industrial automation: counting of products during production or transfer
- Security: detection of metal objects, arms, land mines.

(ii) Given,

Spring constant, $k = 3300$ N/m

Seismic mass, $M = 5 \times 10^{-2}$ kg

Maximum displacement, $d = \pm\ 0.25$ m

1. Steady state sensitivity,

$$S_{ss} = \frac{M}{K} = \frac{d}{a}$$

where, d = displacement, a = acceleration

Acceleration, $$a = \frac{K}{M} \cdot d$$

$$a = \frac{0.25 \times 3300}{5 \times 10^{-2}} = 16{,}500 \text{ m/s}^2$$

$$a_{\text{interms } g} = 1683.679$$

2. Natural frequency, $$\omega_n = \sqrt{\frac{K}{M}}$$

$$\omega_n = \sqrt{\frac{3300}{5 \times 10^{-2}}}$$

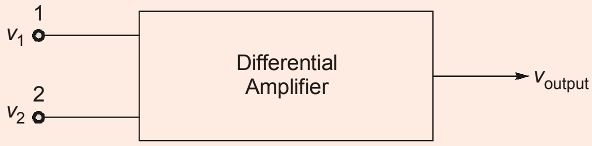
$$\omega_n = 256.904 \text{ rad/sec}$$

MADE EASY Source

- **Theory Book:** EMI (Transducers)

End of Solution

4. (a) (i) Consider a differential amplifier as shown in the figure.



where the first set of signals is v_1 = 50 μV, v_2 = –50 μV and the second set of signals is v_1 = 1050 μV, v_2 = 950 μV. If the common-mode rejection ratio is 100, calculate the percentage difference in output voltage obtained for the two sets of input signals.

[10 Marks]

(ii) 1. Repeat part (a) (i), if the common mode rejection ratio is 10^5.

[3 Marks]

2. Draw the conclusion by comparing part (a)(i) and part (a)(ii)(1).

[2 Marks]

(iii) Explain photovoltaic potential in short. [5 Marks]

Solution:

(i) The output voltage of a differential amplifier is given as

$$v_o = A_d v_d + A_c v_c$$

where,

A_d = Differential gain

A_c = Common mode gain

v_d = Differential input voltage = $v_1 - v_2$

v_c = Common mode input voltage = $\dfrac{v_1 + v_2}{2}$

$$v_o = A_d v_d \left[1 + \frac{A_c}{A_d} \cdot \frac{v_c}{v_d}\right] = A_d v_d \left[1 + \frac{1}{\rho} \cdot \frac{v_c}{v_d}\right]$$

where, ρ = Common mode rejection ratio = $\dfrac{A_d}{A_c}$

Now, for set of signal 1, we have,

$$v_d = 50\ \mu\text{V} - (-50\ \mu\text{V}) = 100\ \mu\text{V}$$

$$v_c = \frac{50\ \mu\text{V} - 50\ \mu\text{V}}{2} = 0$$

$$\therefore \quad v_{o_1} = A_d \times (100 \times 10^{-6})\left[1 + \frac{1}{100} \times \frac{0}{100 \times 10^{-6}}\right]$$

$$= 100\ A_d\ \mu\text{V}$$

For set of signal 2, we have,

$$v_d = 1050\ \mu\text{V} - 950\ \mu\text{V} = 100\ \mu\text{V}$$

$$v_c = \frac{1050\,\mu V + 950\,\mu V}{2} = 1000\,\mu V$$

$$\therefore \qquad v_{o_2} = A_d(100\times10^{-6})\left[1+\frac{1}{100}\times\frac{1000\times10^{-6}}{100\times10^{-6}}\right] = 110\,A_d\,\mu V$$

$$\therefore \qquad \%\text{ difference} = \frac{v_{o_2}-v_{o_1}}{v_{o_1}}\times100 = \frac{110A_d-100A_d}{100A_d} = \frac{1.1-1}{1}\times100$$

$$= 10\%$$

Thus the percentage difference in the output is equal to 10%.

(ii) For $\rho = 10^5$, we have,

$$v_{o_1} = (100\times10^{-6})A_d\left[1+\frac{1}{10^5}\times\frac{0}{100\times10^{-6}}\right] = 100A_d\,\mu V$$

and

$$v_{o_2} = (100\times10^{-6})\,A_d\left[1+\frac{1}{10^5}\times\frac{1000\times10^{-6}}{100\times10^{-6}}\right]$$

$$= 100\times10^{-6}A_d\,[1.0001] = 100.01A_d\,\mu V$$

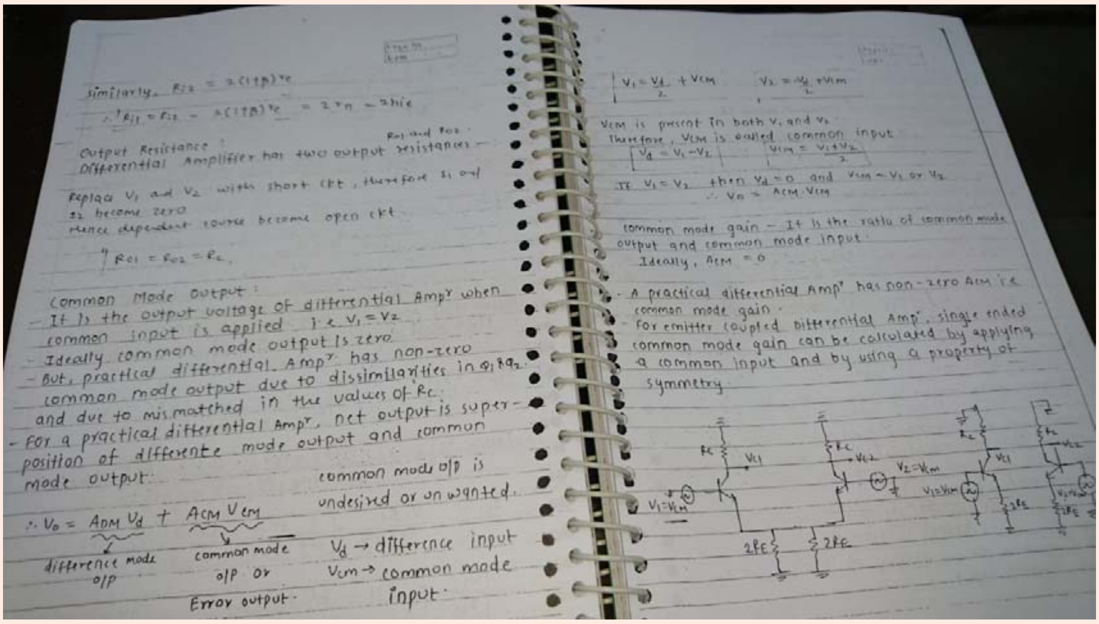
$$\therefore \qquad \%\text{ change} = \frac{v_{o_2}-v_{o_1}}{v_{o_1}}\times100 = \frac{100.01A_d-100A_d}{100A_d}\times100$$

$$= 0.01\%$$

Even though differential mode input v_{id} is same, if common mode input increases percentage error in output increases which can be minimized only with larger value of CMRR.

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.2(a) (ii) of Test-5
- **MADE EASY Classnotes**



(iii) **Photovoltaic Potential :** When light falls on the surface of the junction of the photovoltic cell the minority carriers are injected, and because of which the minority current increases. Since under open-circuited conditions the total current must remain zero, the majority current i.e. the hole current in the p side and the electron in the must increase the same amount as the minority current. This rise in majority current is possible only if the retarding, field at the junction is reduced. Thus across the diode terminals there appears a Voltage just equal to the amount by which the barrier potential is decreased. This potential is the photovoltaic emf and is of the order of magnitude of 0.5 V for a silicon cell.

The maximum value of photovoltaic emf can be given as

$$V_{max} = \eta V_T \ln\left(1+\frac{I_s}{I_0}\right)$$

End of Solution

4. (b) (i) What is polarization mechanism in dielectric material? Explain active and passive dielectrics with suitable example.

[10 Marks]

(ii) Explain cermets. How are they different from fibre reinforced composites? Write four applications of each.

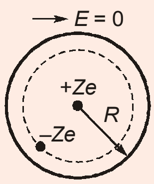
[10 Marks]

Solution:

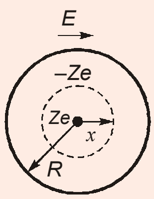
(i) Polarization mechanism in dielectric materials is of four types:

1. Electronic Polarization:

- Electronic polarization is observed in inert gases in which it is assumed that interaction among the atoms is negligible.
- A simple model of an atom is shown below in which a positive nucleus of charge *Ze* (*Z* is the atomic number of the atom and e is the charge of an electron) is surrounded by a spherical negative cloud of charge having a magnitude –*Ze*, having atomic radius equals to '*R*'.



- When external field (*E*) is applied then, under equilibrium, the positive charge remains at a distance x from the centre due to forces: one is the coulombic attraction between the charges and the other is the force on the nucleus due to the field *E*, equal to *ZeE*.



i.e. $F_e = ZeE$

The charge enclosed in the sphere of radius x is given by Δq,

$$\Rightarrow \Delta q = \frac{-Ze}{\frac{4}{3}\pi R^3} \cdot \frac{4}{3}\pi x^3 = \frac{-Zex^3}{R^3} \quad \text{...(i)}$$

The magnitude of coulombic attraction force between this charge treated concentrated at a point, and the nucleus will be

$$F = \frac{\left(\frac{-Zex^3}{R^3}\right)(Ze)}{(4\pi\varepsilon_0 x^2)} = \frac{-(Ze)^2 x}{4\pi\varepsilon_0 R^3} \quad \text{...(ii)}$$

The total force on the nucleus must be zero in equilibrium, so we obtain (equating two forces)

i.e. $|F_{att.}| = |F_e|$

$$\Rightarrow ZeE = \frac{(Ze)^2 x}{4\pi\varepsilon_0 R^3}$$

or $x = (4\pi\varepsilon_0 R^3/Ze)E$...(iii)

The dipole moment induced by the field, will be given by

$$P_{ind} = Ze\,x = 4\pi\varepsilon_0 R^3 E = \alpha_e E \quad \text{...(iv)}$$

This dipole is induced by the field and never existed in the absence of the field. The induced dipole moment is proportional to the field strength and proportionality factor **α_e is called the electronic polarizability.**

We see that α_e is proportional to R^3, i.e., to the volume of electron cloud.

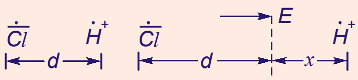
Because the electronic structure of an atom is relatively temperature independent, the variation of α_e with the temperature is expected to be zero.

Note: Since, $R_{He} < R_{Ne} < R_{Ar} < R_{Kr} < R_{Xe}$ (where R = radius of an atom)

then, $\alpha_{e(He)} < \alpha_{e(Ne)} < \alpha_{e(Ar)} < \alpha_{e(kr)} < \alpha_{e(Xe)}$

2. Ionic Polarization:

- Ionic polarization occurs in the materials having ionic bonds. E.g. NaCl, HCl etc. Even in the absence of an applied field, these molecules have a permanent dipole moment ($e \times d$) where d is the distance of separation of ions.
- The field produces force on the two charges $\pm e$, as well as a torque on the dipole. The distance between ions increases from d to $d + x$,



- The field has induced an additional dipole moment, $p_{ind} = e \cdot x$ in the molecule. The induced dipole moment is proportional to the applied electric field, and the proportionality constant is the ionic polarizability. So, we have,

$$p_{ind} = \sigma_i E$$

where α_i is the ionic polarizability.

3. Orientational Polarization:

- Orientational polarization is found in the material having covalent bond with partly ionic bonds, i.e. polar type of covalent bond.

  For moderate fields and all but very low temperatures, the orientational polarization P_0 may be written

$$P_0 = \frac{Np_p^2 E}{3\,kT}$$

But $P_0 = N\alpha_0 E$

where α_0 = Orientational polarizability

Therefore, $$\alpha_0 = \frac{p_p^2}{3\,kT}$$

where, p_p = Permanent dipole moment

T = Temperature in Kelvin

k = Boltzmann's constant = 1.38×10^{-23} J/K

N = Number of dipoles/m^3.

4. Space-charge polarization, α_s:

- Space-charge polarization occurs due to the accumulation of charges at the electrodes or at the interfaces in a multi phases material. The ions diffuse over appreciable distances in response to the applied field, giving rise to redistribution of charges in the dielectric medium. It is found in ferrites and semiconductors and is negligibly small.

Active dielectrics

- Active dielectrics can easily adopt itself to store electrical energy in it.
- These are used to production of ultrasonics.
- When subjected to external electric field, these are actively accept electricity.
- Examples: piezo-electrics, ferro-electrics etc.

Passive dielectrics

- Also called insulating materials because conduction will not taken place through this dielectrics.
- Passive dielectrics restricts the flow of electrical energy in it.
- Examples : All insulating materials like glass, mica etc.

MADE EASY Source

- **Theory Book 2020:** Material Science (Page No. 22)
- **MADE EASY Classnotes**

Polarization —

→ In dielectric materials the bound $\bar{e}$ are predominant. Under the application of an external E_F, the bound $\bar{e}$ of an atom are displaced such that the centroid of electronic cloud is seperated from centroid of nucleous. the atom is then said to be polarized thereby creating an electric dipole. This phenomenon is called electronic polarization.

→ On macroscopic scale we define polarization as electric dipole moment per unit volume.

p_j → Elec. dipole moment of j^{th} dipole

So polarization —

$$\vec{P} = \frac{1}{\Delta V}\sum_{j=1}^{N\Delta V} \vec{p_j}$$

$\{\text{Unit} = C/m^2\}$

N → No. of electric dipole/m^3

ΔV → Volume

Mechanism of Polarization :-

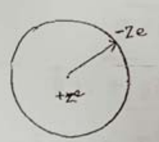
1) Electronic Polarization (OR) Induced Polarization
2) Ionic polarization (OR) molecular "
3) Orientational "
4) Space charge (OR) Interfacial "

1) Electronic polarization — This type of polarization is material having no interaction among the molecules.

Ex- Inert Gas

Consider simple model of atom.

Here nucleous has $+Ze$ charge and $\bar{e}$ are distributed in a spherical volume of Radius R.



Z → Atomic no of element

e → magnitude of electronic charge 1.6×10^{-19} C.

(ii) CERMETS:

- Cermets are composite materials are composed of ceramic and metallic materials. A cermet is ideally designed to have the optimal properties of both a ceramic, such as high temperature resistance and hardness and those of a metal, such as the ability to undergo plastic deformation.

Application of Cermets:

- Manufacturing: Resistors, capacitors, and other electronic components, also vacuum-tubes and for joints and seals.
- Spacecrafts : Shielding.
- Bioceramics : Play an extensive role in biomedical materials (prosthesis).
- In transportation : As friction materials for brakes and clutches.
- Armor : Lightweight ceramic projectile proof armor.
- Nuclear : Storage of nuclear waste, fabrication of engines and nuclear reactors.

Fiber reinforced composites : In fibre reinforce composites, the reinforcement phase materials are in the form of wires, fibers and whiskers surrounded by these fibers polymer matrix phase present.

Applications of fiber reinforced composites:

1. Optical fiber (GFRP)
2. Transportation Vehicle glasses (GFRP)
3. Sports goods (CFPR)
4. Bullet proof jackets (AFRP)

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.5(d) of Test-6
- **Theory Book 2020:** Material Science (Page No. 118)
- **Conventional Practice Question Book:** (Q.4, Page 50)
- **MADE EASY Classnotes**

End of Solution

4. (c) (i) What are the elements of a generalized data acquisition system? Draw a multi-channel data acquisition system using single A/D converter and briefly explain its working.

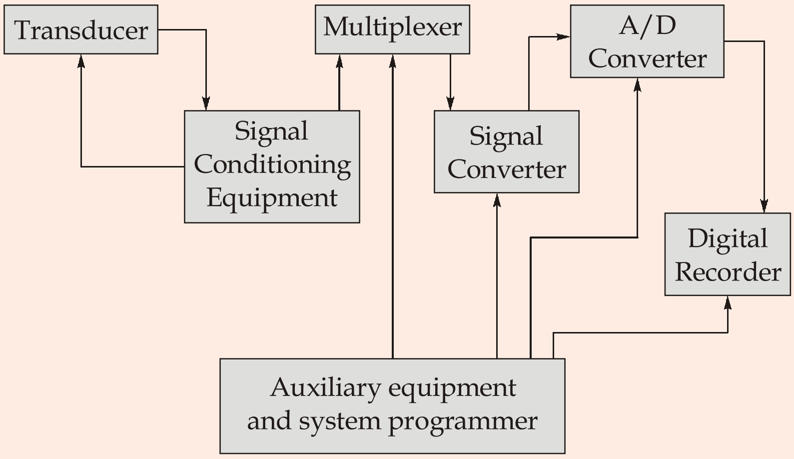
[14 Marks]

(ii) Explain, with a diagram, the operation of a force balance current telemetering system.

[6 Marks]

Solution:

(i) Generalized Data Acquisition System (Digital):



The essential functional operations of a digital data acquisition system are

(i) Handling of analog signals.

(ii) Making the measurement.

(iii) Converting the data to digital form and handling it, and

(iv) Internal programming and control.

The various components and their functions are described below.

Transducer: They convert a physical quantity into an electrical signal which is acceptable by the data acquisition system.

Signal Conditioning Equipment: Signal conditioning equipment includes any equipment that assists in transforming the output of transducer to the desired magnitude or form required by the next state of the data acquisition system.

Multiplexer: Multiplexing is the process of sharing a single channel with more than one input. Thus a multiplexer accepts multiple analog inputs and connects them sequentially to one measuring instrument. Another name for a multiplexer is "scanner".

Signal Converter: A signal converter translates the analog signal to a form acceptable by the analog to digital converter. An example of the signal converter is an amplifier for amplifying the low-level signal voltages produced by transducers.

Analog to Digital Converter (A/D converter): An A/D converter converts the analog voltage to its equivalent digital form. The output of the A/D converter may be fed to digital display devices for visual display or may be fed to digital recorders for recording. It may be fed to a digital computer for data reduction and further processing.

Auxiliary Equipment: This contains devices for system programming functions and digital data processing. Some of the typical functions done by auxiliary equipment are linearization and limit comparison of signals. These functions may be performed by individual devices or by a digital computer.

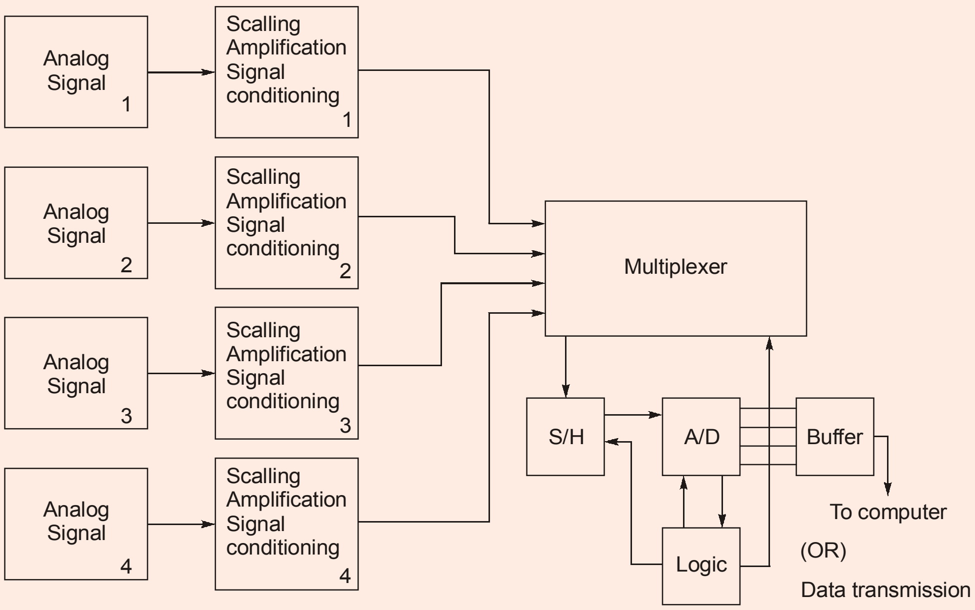
Digital Recorders: Records of information in digital form may be stored on punched cards, perforated paper tapes, type written pages, floppy, discs, magnetic tape, or a combination of these systems.

Digital Printers: After all the tests have been completed and the data is generated, it becomes necessary to record the numbers and in some cases reduce the data to a more meaningful form. A digital printer can be specified to interface with an electronic instrumentation system in order to perform this work, and thus provide a high quality hard copy for records and minimizing the labour of the operating staff.

Uses:

- Digital data acquisition systems are used when the physical quantity being monitored has a narrow bandwidth (i.e., when the quantity varies slowly).
- Digital data acquisition systems are in general, more complex than analog systems, both in terms of instrumentation involved and the volume and complexity of the data they can handle.

Multi-channel data acquisition system



The multichannel DAS system is shown in above figure. It has a single A/D converter preceded by a multiplexer. As can be seen from the figure there are four inputs analog in nature. There can be number of inputs. Each signal is given to individual amplifiers. The output of the amplifiers is given to signal condition circuits. From the output of the signal conditioning circuits the signals go to the multiplexer. The multiplexer output is converted into digital signal by the A/D converts sequentially.

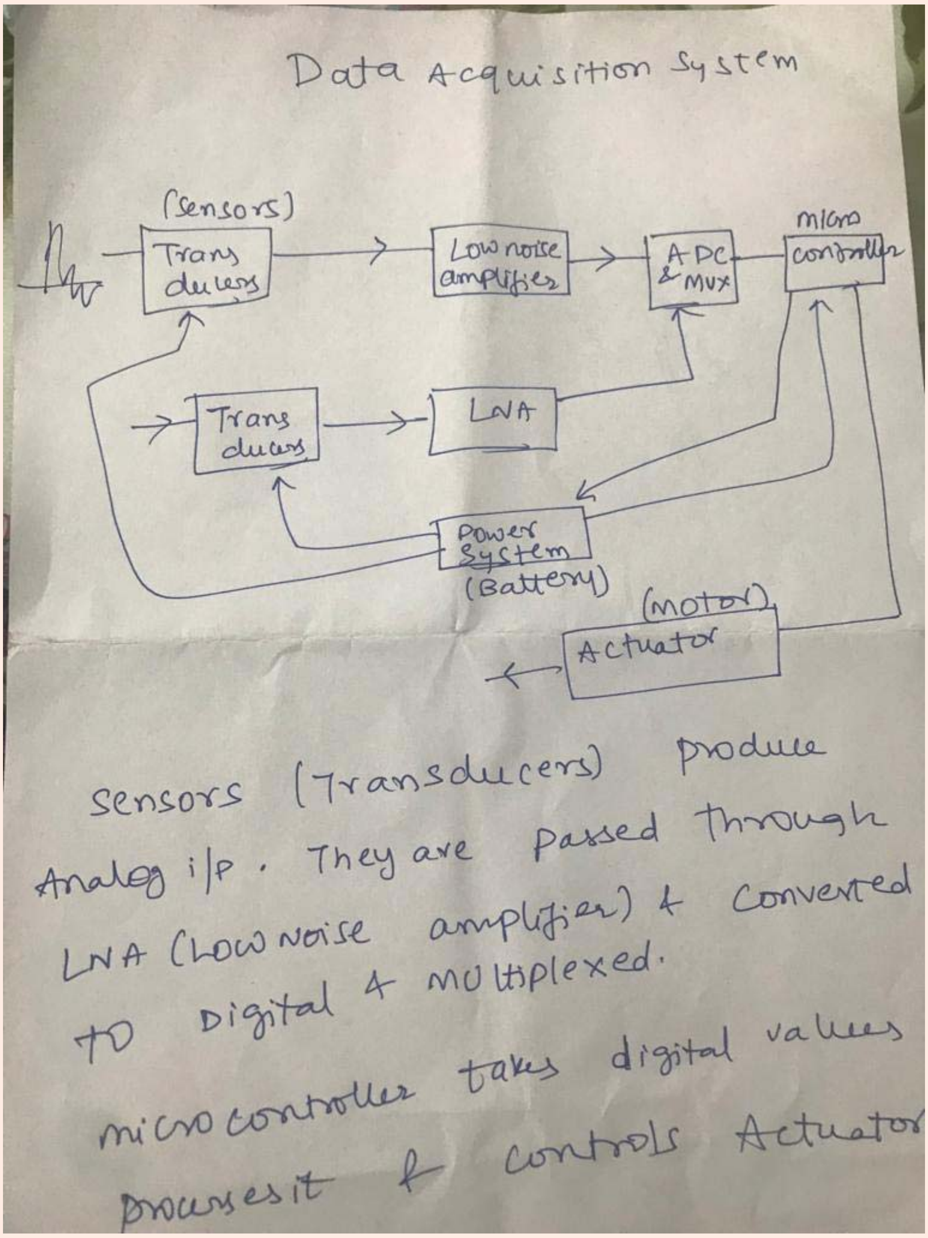
The multiplexers stores the data say of the first channel in the sample hold circuit. It then seeks the second channel. During this interval the data of the first channel will be converted into digital form. This permits utilization of time more efficiently.

When once the conversion is complete, the status line from the converter causes the sample/hold circuit to return to the sample mode. It then accepts the signal of the next channel .After acquisition of data either immediately or an a command the sample hold circuit will be switched to the hold mode. Now conversion begins and the multiplexer selects the next channel.

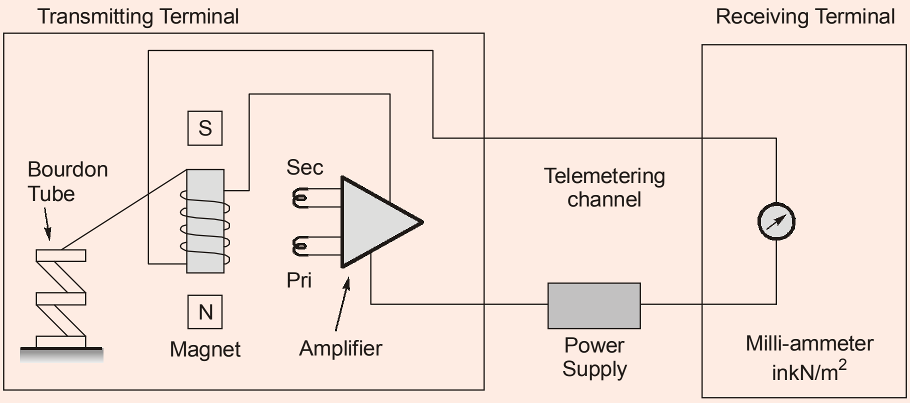
This method is slow, sample hold circuits or A/D converters are multiplexed for faster operation. However this method is less costly as majority of subsystems are shared. If the signal variations are very slow satisfactory accuracy can be obtained even without the sample hold circuit.

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.6(c) of Test-9
- **Theory Book :** EMI (Page No. 277)
- **MADE EASY Classnotes**



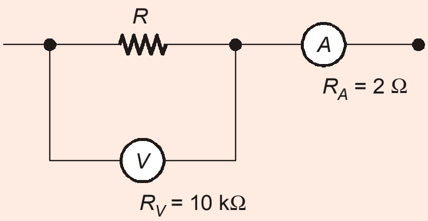
(ii)



In the above system, a part of the current output is feedback to oppose the motion of the input variable. The system is operated by the bourdon tube which rotates the feedback force coil which in turn changes the flux linkages between the primary and the secondary coils. The change in flux linkages varies the amplitude of the amplifier. The output signal is connected to the feedback force coil which produces a force opposing the bourdon tube input.

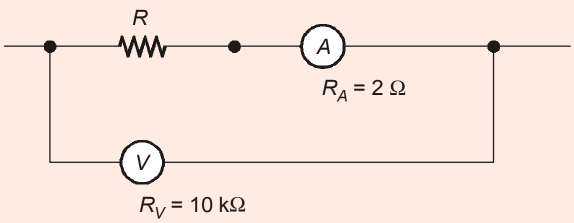
End of Solution

5. (a) (i) Find the value of resistance R in the figure below if the voltmeter reads 12 V and ammeter reads 0.100A:



[6 Marks]

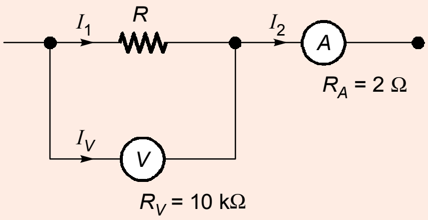
(ii) Repeat part (a)(i) for the circuit arrangement given in the figure below:



[6 Marks]

Solution:

(i)



Given, $I_2 = 0.1 \text{ A} = 100 \text{ mA}$

$$I_V = \frac{V}{R_V} = \frac{12}{10 \text{ k}\Omega} = 1.2 \text{ mA}$$

$$I_2 = I_1 + I_V$$

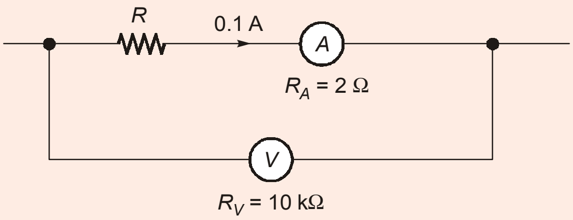
$\therefore$ $I_1 = I_2 - I_V$

$$= (100 - 1.2) \text{ mA}$$

$$I_1 = 98.8 \text{ mA}$$

$\therefore$ $$R = \frac{V}{I_1} = \frac{12}{98.8 \times 10^{-3}} = 121.45 \ \Omega$$

(ii)



$$0.1 = \frac{V}{R+2}$$

$$R + 2 = \frac{12}{0.1}$$

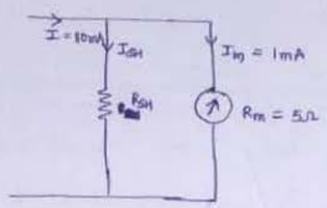
$$R = 120 - 2 = 118 \ \Omega$$

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.2(b) of Test-7
- **Theory Book 2020 :** EMI (Page No. 40, 34 Ex.2.10, 2.11)
- **Conventional Practice Question Book:** (Q.8, Q.9, Page 87)
- **MADE EASY Classnotes**

Ques: You are given a 1 mA – meter movement with an internal resistance of 5 Ω. How would you make this instrument suitable to measure currents upto 10 mA. (10 marks)

Ans: In order to extend the range of this instrument to measure upto 10 mA, a low resistance is connected across the meter movement. This low resistance is known as shunt resistance, bypasses a major portion of current through it thereby, protecting the meter from damage.



Here,

$$I_m R_m = I_{SH} R_{SH}$$

$$R_{SH} = \frac{I_m R_m}{I_{SH}}$$

But $I_{SH} = I - I_m$

$$\therefore R_{SH} = \frac{I_m R_m}{(I - I_m)} \quad (1)$$

Substituting the given value i.e $R_m = 5Ω$, $I_m = 1mA$, $I = 10 mA$

$$R_{SH} = \frac{5 \times 10^{-3}}{(10-1)\times 10^{-3}} = \frac{5}{9} = .555 Ω$$

Inspite of connecting a resistance of .555Ω across the meter, the meter still measures 1mA only. In order to make the meter suitable for measuring 10 mA, the scale of a meter is multiplied by a multiplication factor of shunt (m), which is calculated by taking reciprocal of (1) and multiply R_m on both

$$\frac{R_m}{R_{SH}} = \frac{(I - I_m) R_m}{I_m R_m}$$

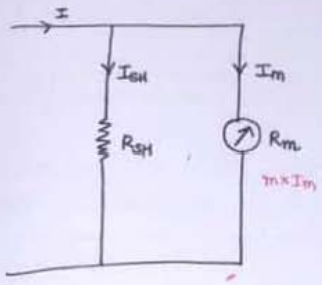
$$\frac{R_m}{R_{SH}} = \frac{I}{I_m} - 1 \Rightarrow m = \frac{I}{I_m} = 1 + \frac{R_m}{R_{SH}}$$

$$m = \frac{I}{I_m} = \frac{10}{1} = 10$$

...erefore, a 1 mA - meter movement instrument can be used to measure ...rents upto 10 mA by:

...necting a .555 Ω shunt resistance across the meter would be limited to 100 mA.

- In order to extend the range of this instrument to measure current beyond 100 mA, a low-resistance is connected across the meter movement. • This low-resistance known as shunt Resistance by-passes a major portion of current through it. thereby, protecting the meter from damage.



Here,

$$I_{SH} R_{SH} = I_m R_m$$

$$R_{SH} = \frac{I_m R_m}{I_{SH}}$$

But $I_{SH} = I - I_m$

$$R_{SH} = \frac{I_m R_m}{I - I_m} \quad (1)$$

Inspite of connecting R_{SH}, the meter still measures I_m only.

In order to make the meter suitable to measure I, the scale of the meter is multiplied by a multiplication factor of the shunt (m), which can be calculated by taking the reciprocal of (1) and multiply on both sides by R_m.

$$\frac{R_m}{R_{SH}} = \frac{(I - I_m) R_m}{I_m R_m}$$

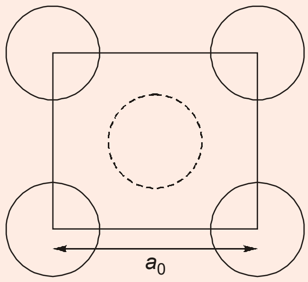
$$\frac{R_m}{R_{SH}} = \frac{I}{I_m} - 1$$

End of Solution

5. (b) Copper has an atomic radius of 0.1278 mm. Calculate the atomic density (number of atoms per unit) in (1 0 0) plane of copper (FCC).

[12 Marks]

Solution:



FCC : 100 plane

Given, atomic radius of copper, $r = 0.1278$ mm

Lattice parameter, $a_0(\text{FCC}) = \frac{4r}{\sqrt{2}}$

$$a_0 = \frac{4 \times 0.1278 \times 10^{-9}}{\sqrt{2}}$$

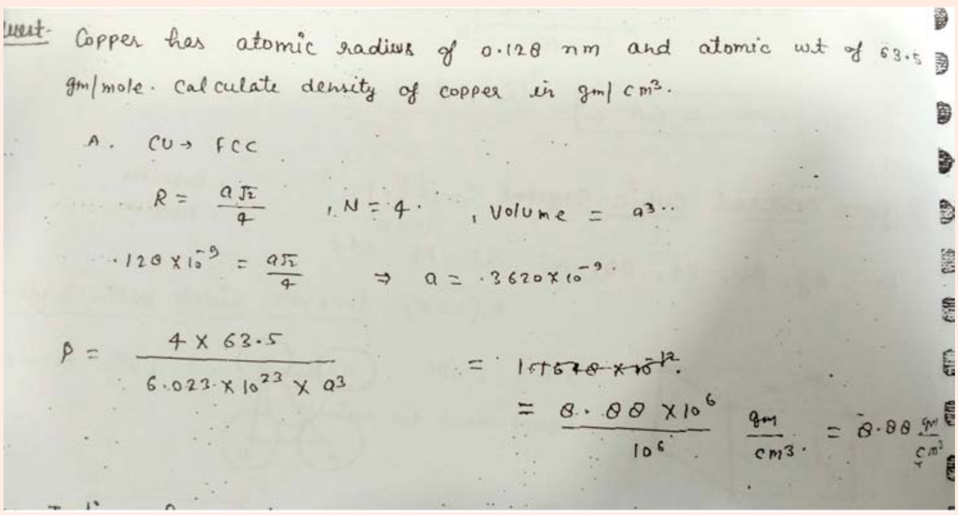
$$a_0 = 0.361 \text{ nm}$$

Atomic density, $= \frac{2 \text{ atoms}}{(a_0)^2} = \frac{2}{(0.361 \times 10^{-7})^2}$

$= 15.34 \times 10^{14}$ atoms/cm^2

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.5(e) of Test-6
- **Theory Book 2019:** Materials Science
- **MADE EASY Classnotes**



Quest. Copper has atomic radius of 0.128 nm and atomic wt of 63.5 gm/mole. Calculate density of copper in gm/cm^3.

A. Cu → FCC

$R = \frac{a\sqrt{2}}{4}$, N = 4, Volume = a^3

$.128 \times 10^{-9} = \frac{a\sqrt{2}}{4}$ ⇒ $a = .3620 \times 10^{-9}$

$\rho = \frac{4 \times 63.5}{6.023 \times 10^{23} \times a^3}$ = ~~15.570 × 10⁻¹²~~

$= \frac{8.88 \times 10^6}{10^6} \frac{gm}{cm^3} = 8.88 \frac{gm}{cm^3}$

End of Solution

5. (c) How can you convert a galvanometer into an ammeter and a voltmeter? A PMMC galvanometer of 6Ω resistance reads up to 60 mA. Determine the value of the resistance (i) when connected in parallel to enable the instrument to read up to 1.20 A and (ii) when connected in series to enable it to read 12 V.

[12 Marks]

Solution:

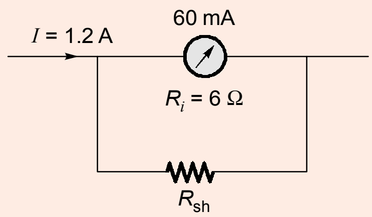
Given, resistance of galvanometer, $R_i = 6\ \Omega$

Current, $I_{FSD} = 60$ mA

Voltage, $V = I_{FSD} \times R_i$

$= 60 \times 10^{-3} \times 6 = 360$ mV

(i) Galvanometer used as Ammeter:

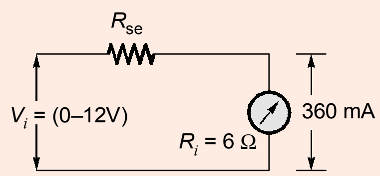


We know that,

Shunt resistance,
$$R_{sh} = \frac{R_i}{\left(\frac{I}{I_{FSD}} - 1\right)} = \frac{6}{\left(\frac{1.2}{60\text{ mA}} - 1\right)}$$

$$R_{sh} = 0.316\ \Omega$$

(ii) Galvanometer used as voltmeter:



We know that,

Series resistance,
$$R_{se} = R_i\left(\frac{V_i}{V} - 1\right) = 6\left(\frac{12}{360 \times 10^{-3}} - 1\right)$$

$$R_{se} = 194\ \Omega$$

MADE EASY Source ____

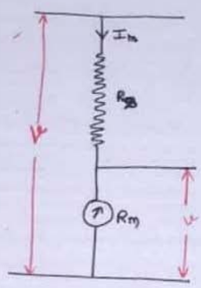
- **ESE 2019 Mains Test Series:** Q.7(b) of Test-7
- **Theory Book 2020 :** EMI (Page No. 40, 34 Ex.2.10, 2.11)
- **Conventional Practice Question Book:** (Q.8, Q.9, Page 87)

• **MADE EASY Classnotes**

1. VOLTMETER

(a) Design:

- The basic PMMC instrument is modified as a voltmeter by connecting a high resistance in series with the meter-movement.
- This high resistance known as the multiplier resistance limits the current through the meter to a small value. Thereby, protecting the meter from large currents.



Here,

$V = I_m (R_s + R_m)$

$V = I_m R_s + I_m R_m$

$I_m R_s = V - I_m R_m$

$R_s = \frac{V}{I_m} - R_m$ ... ①

The scale of the meter is multiplied by the multiplication factor of the multiplier which is

$m = \frac{V}{v}$

$m = \frac{I_m (R_s + R_m)}{I_m R_m}$

(If R_s & R_m are given) $m = \frac{V}{v} = \frac{R_s}{R_m} + 1$ ... ②

Expressing R_s in terms of m, we have,

$R_s = (m-1) R_m$; $m = \frac{V}{v}$ ... ③

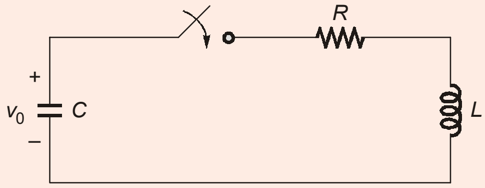
1. AMMETER

(a) Design:

- As $\theta \propto I$, a basic PMMC instrument can be directly used as an ammeter.
- But as a thin and a light-wire is used to wind the mo[...] coil of the instrument, the maximum current carrying c[...]

End of Solution

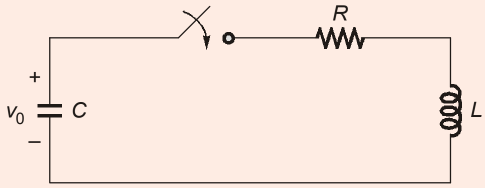
5. (d) In the circuit given below, $v_C(0^-) = v_0$, while the inductor is not charged. The switch that is initially open is closed at $t = 0$. Also $L = C$ in terms of numerical value. Find R (positive value) so that the circuit is critically damped.



[12 Marks]

Solution:

The given circuit is,

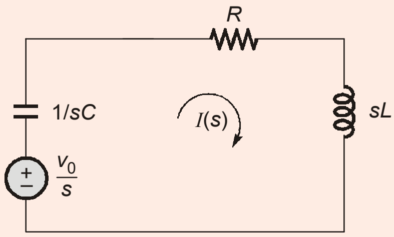


Here, $v_C(0^-) = v_C(0^+) = v_0$

and $L = C$

at $t > 0$,

Transforming the given circuit in s-domain, we get,



Writing the KVL equation, we get,

$$\frac{v_0}{s} = I(s)\left[R + sL + \frac{1}{sC}\right]$$

or
$$I(s) = \frac{v_0}{s^2 L + Rs + \frac{1}{C}}$$

or
$$I(s) = \frac{\frac{v_0}{L}}{s^2 + \frac{R}{L}s + \frac{1}{LC}}$$

Comparing the above equation with standard equation, we have

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

and,
$$\xi = \frac{R}{L} \times \frac{1}{2} \times \sqrt{LC}$$

$$\xi = \frac{R}{2}\sqrt{\frac{C}{L}}$$

For critical damping $\xi = 1$

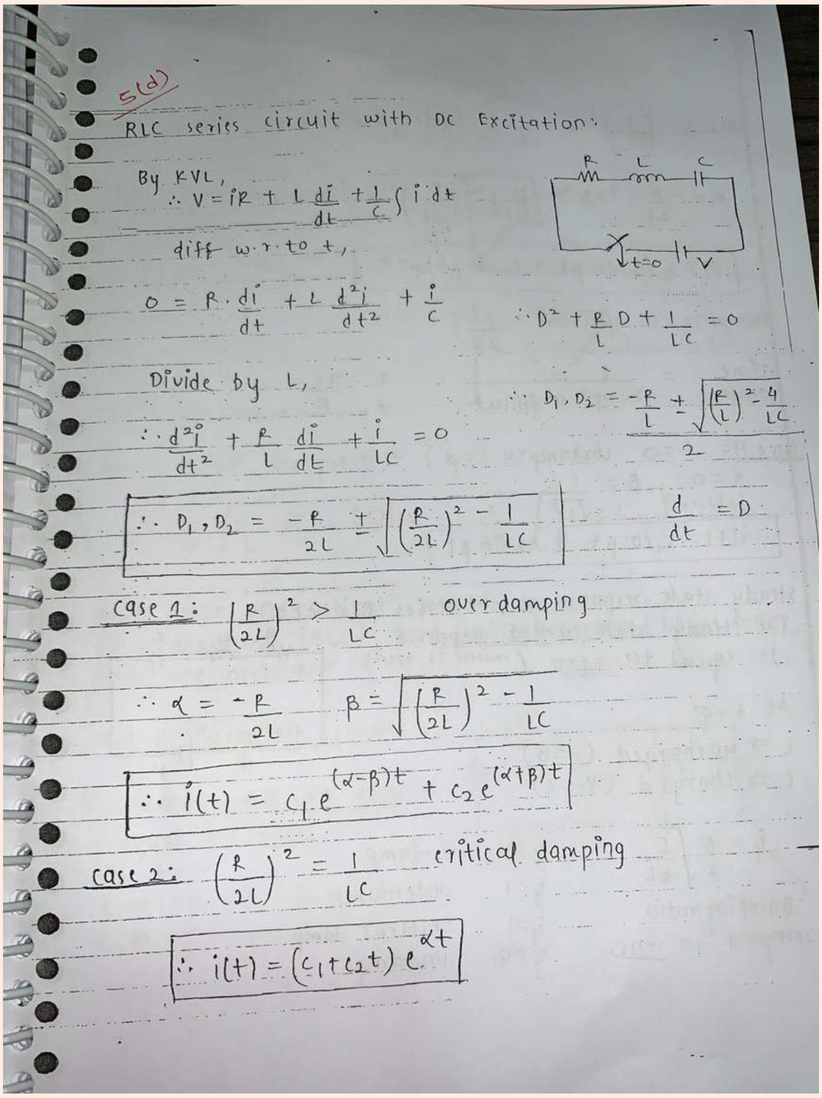
$\therefore$ $R = 2\sqrt{\frac{L}{C}}$

as $L = C$

Hence, $R = 2\Omega$

MADE EASY Source

- **Theory Book 2020:** Network Theory (Page No. 119)
- **MCQ Practice Book:** (Q.24, Page 223)
- **MADE EASY Classnotes**



5(d)

RLC series circuit with DC Excitation:

By KVL,

$\therefore V = iR + L\frac{di}{dt} + \frac{1}{C}\int i\,dt$

diff w.r.to t,

$0 = R\cdot\frac{di}{dt} + L\frac{d^2i}{dt^2} + \frac{i}{C}$

Divide by L,

$\therefore \frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{i}{LC} = 0$

$\therefore D^2 + \frac{R}{L}D + \frac{1}{LC} = 0$

$\therefore D_1, D_2 = \frac{-\frac{R}{L} \pm \sqrt{\left(\frac{R}{L}\right)^2 - \frac{4}{LC}}}{2}$

$\frac{d}{dt} = D$

$\therefore D_1, D_2 = -\frac{R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}$

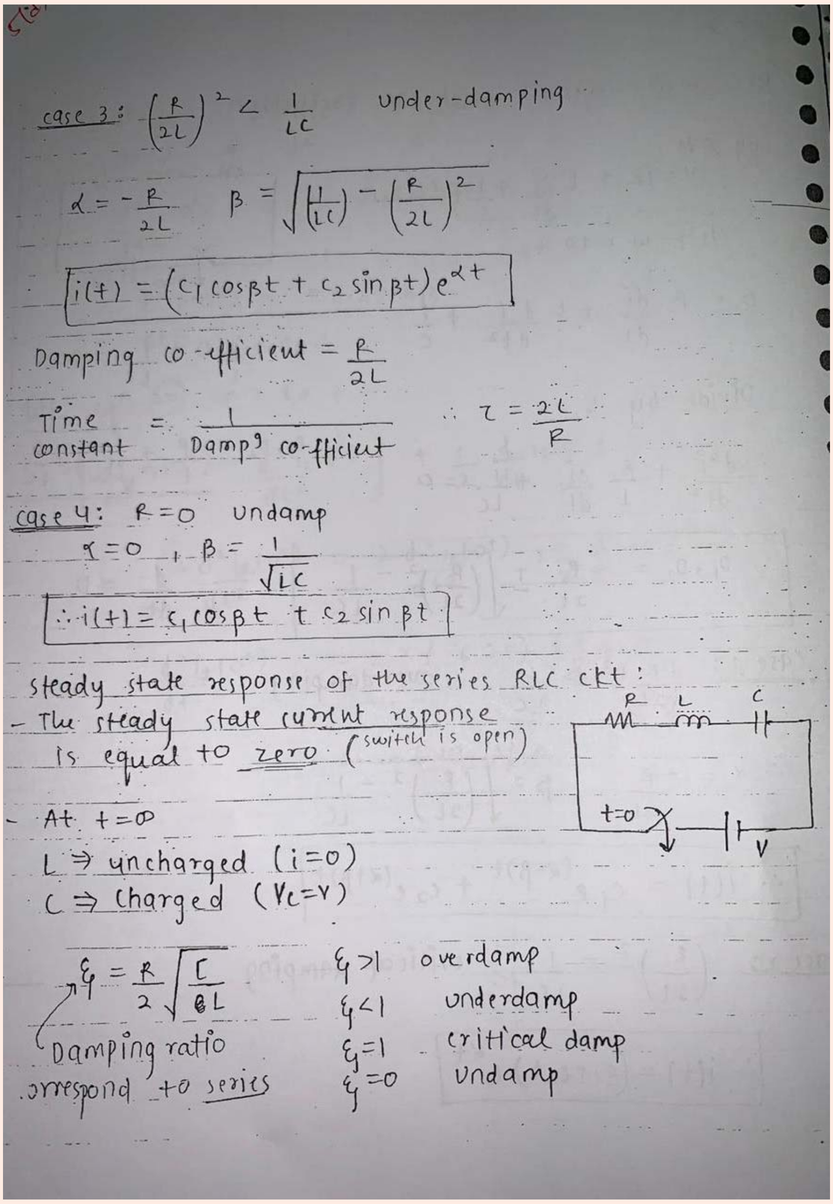
case 1: $\left(\frac{R}{2L}\right)^2 > \frac{1}{LC}$ over damping

$\therefore \alpha = -\frac{R}{2L}$ $\beta = \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}}$

$\therefore i(t) = C_1 e^{(\alpha-\beta)t} + C_2 e^{(\alpha+\beta)t}$

case 2: $\left(\frac{R}{2L}\right)^2 = \frac{1}{LC}$ critical damping

$\therefore i(t) = (C_1 + C_2 t)e^{\alpha t}$



case 3: $\left(\frac{R}{2L}\right)^2 < \frac{1}{LC}$ under-damping

$\alpha = -\frac{R}{2L}$ $\beta = \sqrt{\left(\frac{1}{LC}\right) - \left(\frac{R}{2L}\right)^2}$

$i(t) = (c_1 \cos\beta t + c_2 \sin\beta t)e^{\alpha t}$

Damping co-efficient $= \frac{R}{2L}$

Time constant $= \frac{1}{\text{Damp}^g \text{ co-fficient}}$ $\therefore \tau = \frac{2L}{R}$

case 4: $R = 0$ undamp

$\alpha = 0$, $\beta = \frac{1}{\sqrt{LC}}$

$\therefore i(t) = c_1 \cos\beta t + c_2 \sin\beta t$

steady state response of the series RLC ckt:

- The steady state current response is equal to zero (switch is open)

- At $t = \infty$

$L \Rightarrow$ uncharged $(i = 0)$

$C \Rightarrow$ charged $(V_C = V)$

$\xi = \frac{R}{2}\sqrt{\frac{C}{L}}$ Damping ratio correspond to series

$\xi > 1$ overdamp

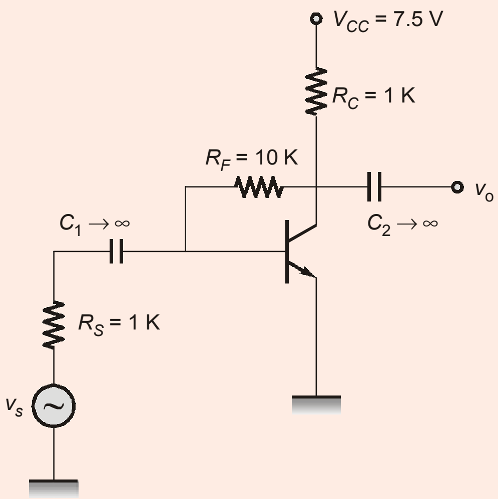
$\xi < 1$ underdamp

$\xi = 1$ critical damp

$\xi = 0$ undamp

End of Solution

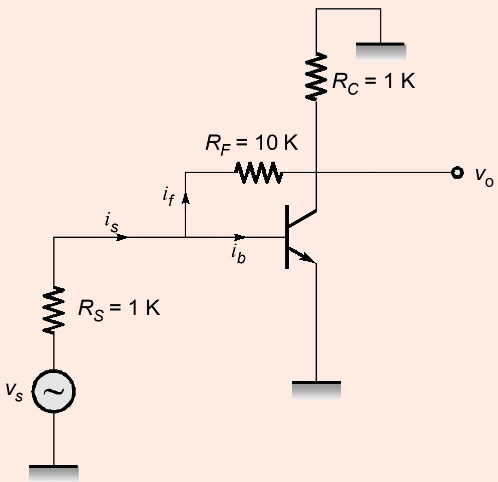
5. (e) In the feedback circuit shown in the figure below, h_{fe} is very large. Identify the type of feedback, and (i) find the feedback factor β and overall transresistance with feedback and (ii) overall voltage gain, $A_{vs} = \frac{V_0}{V_s}$:



[12 Marks]

Solution:

Assuming the transistor to be base in active region the small signal currents and voltage can be represented as



Above circuit is an example fo shunt-shunt or voltage shunt feedback topology. As h_{fe} is very large i_b is neglected.

$\Rightarrow$ $$v_{be} = i_b r_\pi \simeq 0$$

$$i_f = \frac{v_{be} - v_0}{R_F} = -\frac{v_0}{R_F}$$

$\Rightarrow$ Feedback factor $$\beta = \frac{i_f}{v_0} = -\frac{1}{R_F} = -\frac{1}{10k} = -0.1 \text{ m℧}$$

Overall transresistance $$R_{Mf} = \frac{v_0}{i_s} = \frac{v_0}{i_b + i_f} \simeq \frac{v_0}{i_f} = -R_f = -10 \text{ k}\Omega$$

Applying kCL at the base of transistor we get,

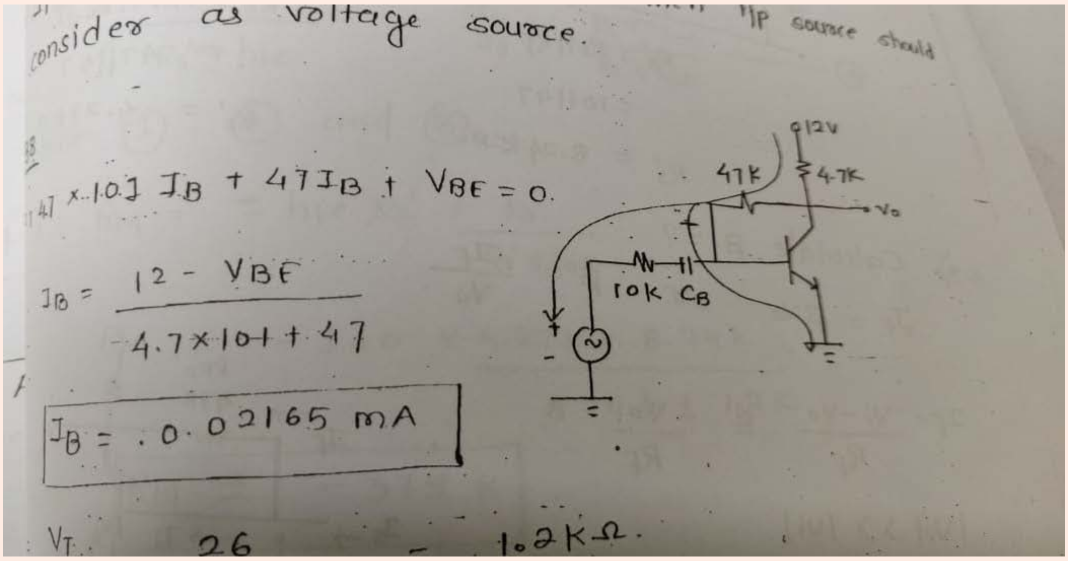
$$\frac{V_{be}-V_s}{R_C}+\frac{V_{be}-V_0}{R_F} = 0$$

$$\Rightarrow \qquad \frac{0-V_s}{1k}+\frac{0-V_0}{10k} = 0$$

$\Rightarrow$ Overall voltage gain $\quad A_{vs} = \dfrac{V_0}{V_s} = -\dfrac{10k}{1k} = -10 \text{ V/V}$

MADE EASY Source

- **Classroom Workbook:** Analog Electronics (Page No. 46)
- **MADE EASY Classnotes**

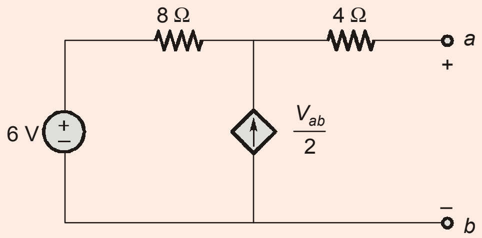


End of Solution

6. (a) (i) A voltage source delivers 4 A when the load connected is 5 Ω and 2 A when the load is 20 Ω . What is the maximum power it can deliver? Also calculate power transfer efficiency with R_L = 5 Ω and power transfer efficiency when it delivers 50 W.

[10 Marks]

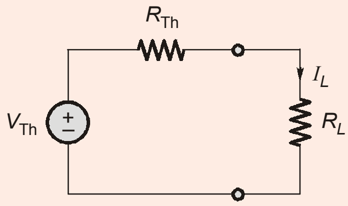
(ii) Find the Thevenin equivalent of the circuit at *a*-*b*:



[10 Marks]

Solution:

(i) The Thevenin's equivalent the circuit described in the question can be given by,



$$I_L = \frac{V_{Th}}{R_{Th} + R_L}$$

$$V_{Th} = I_L(R_{Th} + R_L) = 4(R_{Th} + 5) = 2(R_{Th} + 20)$$

$$2R_{Th} = 40 - 20$$

$$R_{Th} = 10\ \Omega$$

$$V_{Th} = 4(10 + 5) = 60\ \text{V}$$

Maximum power will be delivered to the load when $R_L = R_{Th} = 10\ \Omega$

$$P_{L(max)} = \frac{V_{Th}^2}{4R_{Th}} = \frac{(60)^2}{4 \times 10} = 90\ \text{W}$$

When $R_L = 5\ \Omega$:

$$I_L = \frac{V_{Th}}{R_L + R_{Th}} = \frac{60}{5 + 10} = 4\ \text{A}$$

$$P_L = I_L^2 R_L = (4)^2 (5) = 80\ \text{W}$$

$$P_S = V_{Th}\, I_L = (60)\,(4) = 240\ \text{W}$$

Power transfer efficiency $(\eta) = \frac{P_L}{P_S} \times 100 = \frac{80}{240} \times 100 = 33.33\%$

When $P_L = 50$ W:

$$I_L^2 R_L = 50$$

$$I_L = \frac{V_{Th}}{R_L + R_{Th}} = \frac{60}{10 + R_L}$$

$$\left(\frac{60}{10 + R_L}\right)^2 R_L = 50$$

$$\frac{3600}{50} R_L = R_L^2 + 20R_L + 100$$

$$72R_L = R_L^2 + 20R_L + 100$$

$$R_L^2 - 52R_L + 100 = 0$$

Solving yields, $R_L = 2\ \Omega,\ 50\ \Omega$

When $R_L = 2\ \Omega$, $I_L = \frac{60}{10 + 2} = 5\ \text{A}$; $P_s = V_{Th}\, I_L = (60)\,(5) = 300\ \text{W}$

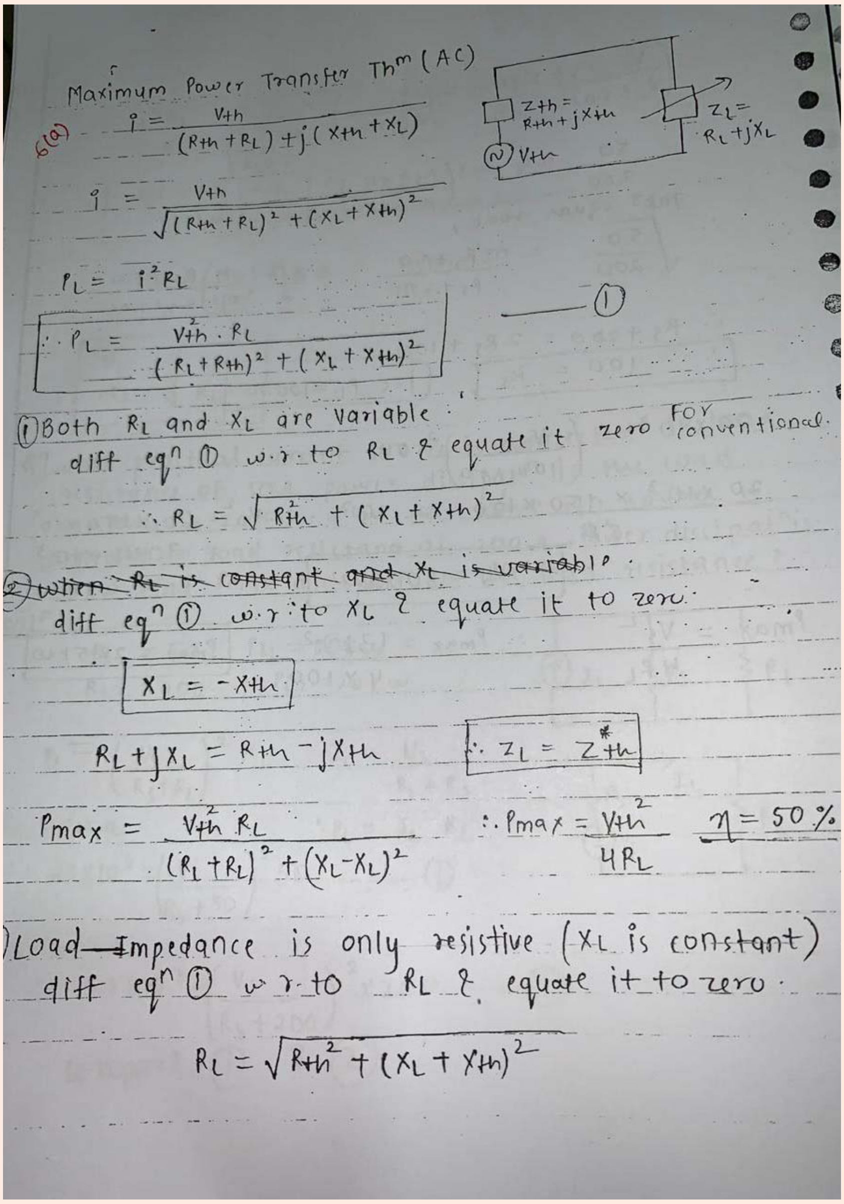
$$\eta = \frac{50}{300} \times 100 = 16.67\%$$

When $R_L = 50\ \Omega$, $I_L = \dfrac{60}{10+50} = 1\text{ A}$; $P_s = V_{Th}\, I_L = (60)\ (1) = 60\text{ W}$

$$\eta = \frac{50}{60} \times 100 = 83.33\%$$

MADE EASY Source

- **MADE EASY Classnotes**



Maximum Power Transfer Th^m (AC)

6(a)

$i = \dfrac{V_{th}}{(R_{th}+R_L) + j(X_{th}+X_L)}$

$i = \dfrac{V_{th}}{\sqrt{(R_{th}+R_L)^2 + (X_L+X_{th})^2}}$

$Z_{th} = R_{th} + jX_{th}$, V_{th}, $Z_L = R_L + jX_L$

$P_L = i^2 R_L$

$\therefore P_L = \dfrac{V_{th}^2 \cdot R_L}{(R_L+R_{th})^2 + (X_L+X_{th})^2}$ —— (1)

(1) Both R_L and X_L are variable
diff eq^n (1) w.r.to R_L & equate it zero For conventional.

$\therefore R_L = \sqrt{R_{th}^2 + (X_L + X_{th})^2}$

(2) ~~when R_L is constant and X_L is variable~~
diff eq^n (1) w.r.to X_L & equate it to zero.

$X_L = -X_{th}$

$R_L + jX_L = R_{th} - jX_{th}$ $\quad \therefore Z_L = Z_{th}^*$

$P_{max} = \dfrac{V_{th}^2 R_L}{(R_L+R_L)^2 + (X_L-X_L)^2}$ $\quad \therefore P_{max} = \dfrac{V_{th}^2}{4R_L}$ $\quad \eta = 50\%$

(3) Load Impedance is only resistive (X_L is constant)
diff eq^n (1) w.r.to R_L & equate it to zero.

$R_L = \sqrt{R_{th}^2 + (X_L + X_{th})^2}$

6(a)

$$\boxed{R_L = |z_{th} + jX_L|}$$

$$R_L = |R_{th} + jX_{th} + jX_L| \qquad \therefore R_L = R_{th} + j(X_{th} + X_L)$$

$$\boxed{\therefore R_L = \sqrt{R_{th}^2 + (X_{th} + X_L)^2}} \qquad \eta \geq 50\%$$

$R_L > R_{th}$

(3) Load impedance is resitive (X_L is ~~or~~ zero)
Put $X_L = 0$ in eq^n (1),

$$P_L = \frac{V_{th}^2 \cdot R_L}{(R_L + R_{th})^2 + X_{th}^2} \quad \text{——— (2)}$$

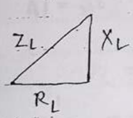
diff eq^n (2) w.r.to R_L and equate it to zero, $R_L > R_{th}$

$$\boxed{R_L = \sqrt{R_{th}^2 + X_{th}^2}} \qquad \therefore R_L = |Z_{th}| \qquad \eta > 50\%$$

(4) Both R_L and X_L are variable and load impedance angle is constant.

$$Z_L = R_L + jX_L$$

load impedance angle $= \theta_L = \tan^{-1}\left(\frac{X_L}{R_L}\right) = \text{constant}$



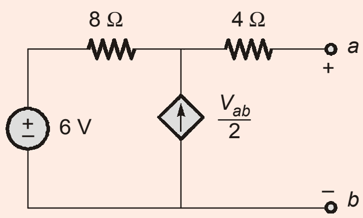
$$\left.\begin{aligned} R_L &= Z_L \cos\theta_L \\ X_L &= Z_L \sin\theta_L \end{aligned}\right\} \text{substitute in eq}^n \text{ (1)}$$

$$P_L = \frac{V_{th}^2 \, Z_L \cos\theta_L}{(Z_L \cos\theta_L + R_{th})^2 + (Z_L \sin\theta_L + X_{th})^2} \quad \text{——— (3)}$$

Eq^n (3) is obtained from eq^n (1).
diff eq^n (3) w.r.to Z_L and equate it to zero.

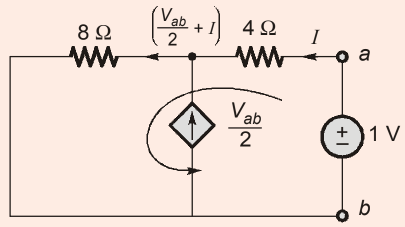
$$\boxed{|Z_L| = |Z_{th}|}$$

(ii) The given circuit can be drawn as



We have to find the Thevenin's equivalent across terminal a and b. For finding R_{th}, the independent sources has to be replaced with their internal impedance.

∴ The circuit can be redrawn as



By applying KVL in loop, we get,

$$-1+4I+8\left(I+\frac{V_{ab}}{2}\right) = 0 \quad \text{...(i)}$$

Also, $V_{ab} = 1$ (assumed) ...(ii)

∴ From equation (i) and (ii), we get

$$-1+4I+8I+\frac{8}{2} = 0$$

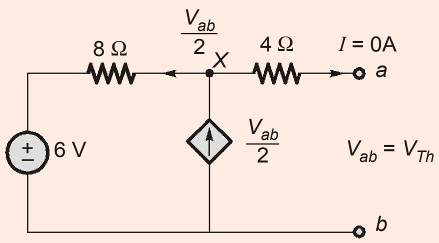
or $12I + 3 = 0$

or $I = -\frac{3}{12} = \frac{-1}{4}$

∴ $R_{Th} = \frac{1}{I} = -4\,\Omega$

Finding V_{Th},

By KCL at point 'X'

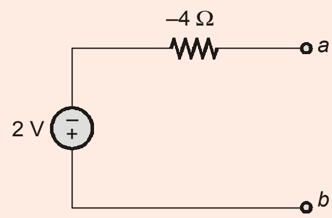


$$\frac{V_{ab}-6}{8} = \frac{V_{ab}}{2}$$

or $V_{ab} - 6 = 4\,V_{ab}$

or $V_{ab} = V_{Th} = -2V$

∴ The Thevenin's equivalent is

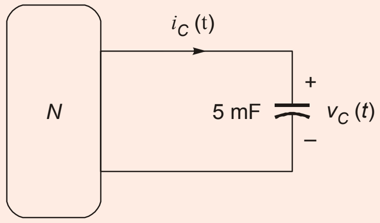


MADE EASY Source

- **ESE 2018 Mains Test Series:** Q.5(b) of Test-14
- **Theory Book 2020:** (Q.11, Page 70)
- **MCQ Practice Book:** (Q.171, Page 18)

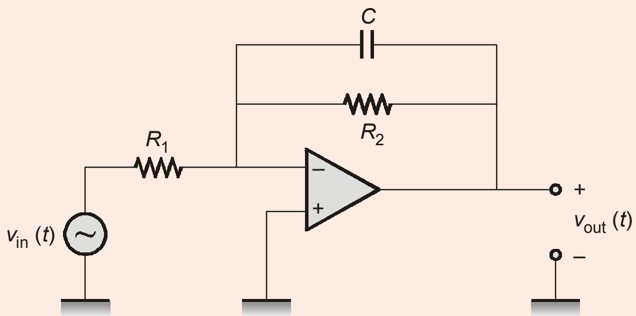
End of Solution

6. (b) (i) For the circuit shown in the figure below, it is known that the voltage across the capacitor is $v_C(t) = 20\sin\left(2t + \frac{\pi}{6}\right)$ V for $t \geq 0$. Compute and plot the instantaneous power absorbed by the capacitor and energy stored by the capacitor over [0, t]:



[8 Marks]

(ii) The op-amp in the figure assumed to be ideal R_1 = 20 kΩ, R_2 = 40 Ω and C = 10 μF:

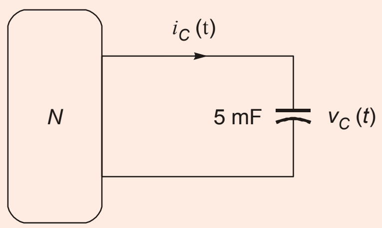


1. Use nodal to construct a first-order differential equation describing the input-output relationship of the voltage.
2. Laplace transform your equation of (1) and solve $v_{out}(s)$ in terms of $v_{in}(s)$ and $v_C(0^-)$.
3. If $v_{in}(t) = 2e^{-2t}\,u(t)$V and $v_C(0) = 0$, find $v_{out}(t)$.

[12 Marks]

Solution:

(i) The circuit given is



Here, $$v_c(t) = 20\sin\left(2t + \frac{\pi}{6}\right) \text{V}$$

$\therefore$ $$i_c(t) = \frac{Cdv_c(t)}{dt}$$

$$= C \times \frac{d}{dt} 20\sin\left(2t + \frac{\pi}{6}\right)$$

$$= C \times 20 \times 2\cos\left(2t + \frac{\pi}{6}\right)$$

$\because$ C = 5 mF

$$\therefore \qquad i_c(t) = 5\times10^{-3}\times 40\cos\left(2t+\frac{\pi}{6}\right)$$

$$\Rightarrow \qquad i_c(t) = 0.2\cos\left(2t+\frac{\pi}{6}\right)\text{A} \qquad \text{...(i)}$$

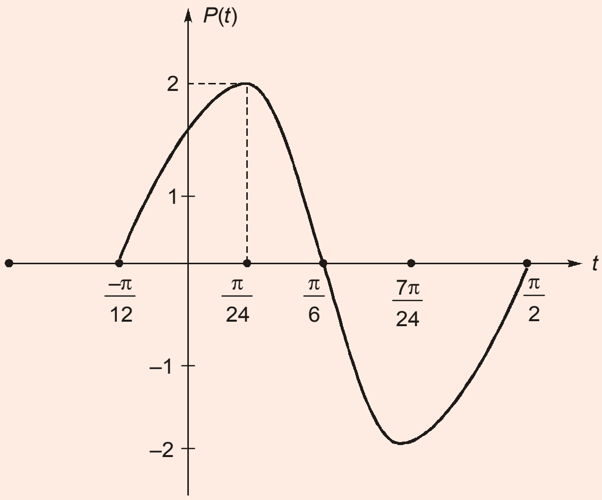
Instantaneous power absorbed is,

$$P_c(t) = i_c(t)\times v_c(t)$$

$$= 0.2\cos\left(2t+\frac{\pi}{6}\right)\times 20\sin\left(2t+\frac{\pi}{6}\right)$$

$$= 2\sin 2\left(2t+\frac{\pi}{6}\right)$$

$$P_c(t) = 2\sin\left(4t+\frac{\pi}{3}\right)\text{W} \qquad \text{...(ii)}$$



Energy stored by capacitor over [0, t] is,

$$W_c(t) = \int_0^t P_c(t)dt$$

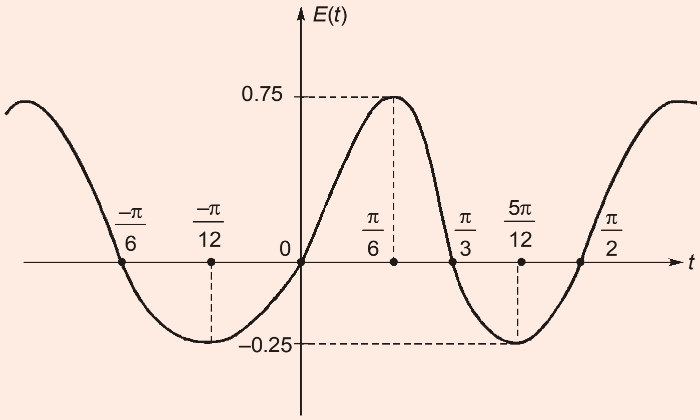
$$= \int_0^t 2\sin\left(4t+\frac{\pi}{3}\right)dt = \frac{-2}{4}\cos\left(4t+\frac{\pi}{3}\right)\Bigg|_0^t$$

$$= -\frac{1}{2}\cos\left(4t+\frac{\pi}{3}\right)\Bigg|_0^t$$

$$= -\frac{1}{2}\left[\cos\left(4t+\frac{\pi}{3}\right)-\cos\frac{\pi}{3}\right]$$

$$= -\frac{1}{2}\left[\cos\left(4t+\frac{\pi}{3}\right)-\frac{1}{2}\right]$$

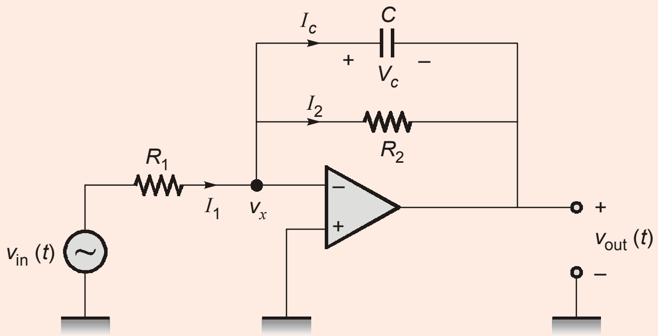
$$W_c(t) = \frac{1}{4}\left[1 - 2\cos\left(4t + \frac{\pi}{3}\right)\right] \text{J}$$



MADE EASY Source

- **ESE 2018 Mains Test Series:** Q.5(a) of Test-12
- **Theory Book:** Network Theory (Page No. 85)
- **MCQ Practice Book:** (Q.108, Page 12)

(ii)



Due to virtual ground $v_x = 0$ V and $v_{out} = -v_c(t)$

From the diagram it is clear that

$$I_1 = \frac{v_{in} - v_x}{R_1} = \frac{V_{in}(t)}{R_1} \qquad (\because V_x = 0)$$

$$I_2 = \frac{v_x - v_{out}(t)}{R_2} = -\frac{v_{out}(t)}{R_2} = \frac{v_c(t)}{R_2}$$

$$I_2 = C\frac{dv_c(t)}{dt}$$

Applying KCL at node v_x we get

$$I_2 = I_c + I_2$$

$$\frac{v_{in}(t)}{R_1} = C\frac{dv_c(t)}{dt} + \frac{v_c(t)}{R_2}$$

$$\frac{dv_c(t)}{dt}+\frac{v_c(t)}{R_2C} = \frac{v_{in}(t)}{R_1C} \quad \text{...(i)}$$

Now, $v_c(t) = -v_{out}(t)$

$$\therefore \quad \frac{dv_{out}(t)}{dt}+\frac{v_{out}(t)}{R_2C} = -\frac{v_{in}(t)}{R_1C} \quad \text{...(ii)}$$

From equation (i) we get,

$$\frac{dv_c(t)}{dt}+\frac{v_c(t)}{R_2C} = \frac{v_{in}(t)}{R_1C}$$

taking the Laplace transform we get,

$$sV_c(s) - v(0^-) + \frac{v_c(t)}{R_2C} = \frac{V_{in}(s)}{R_1C}$$

$$\left(s+\frac{1}{R_2C}\right)V_c(s) = \frac{V_{in}(s)}{R_1C}+v(0^-)$$

$$V_c(s) = \frac{V_{in}(s)}{R_1C\left(s+\frac{1}{R_2C}\right)}+\frac{v(0^-)}{\left(s+\frac{1}{R_2C}\right)} \quad \text{...(iii)}$$

Now $v_{in}(t) = 2e^{-2t}\,u(t)$

$$\therefore \quad V_{in}(s) = \frac{2}{(s+2)}$$

Substituting the value of $V_{in}(s)$ in equation (iii) we get,

$$V_c(s) = \frac{2}{R_1C\left(s+\frac{1}{R_2C}\right)(s+2)} \quad (\because v(0^-) = 0)$$

$$V_c(s) = \frac{2/0.2}{(s+2.5)(s+2)} = \frac{10}{(s+2.5)(s+2)}$$

$$V_c(s) = \frac{20}{(s+2)}-\frac{20}{(s+2.5)}$$

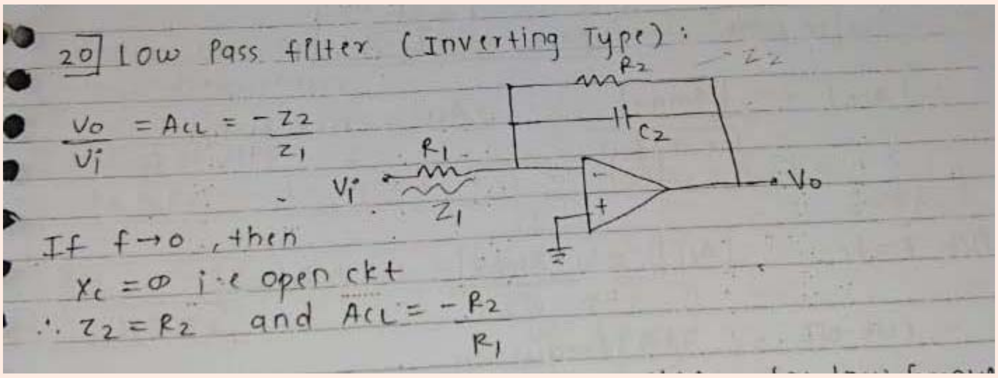
$$v_c(t) = 20\,e^{-2t}\,u(t) - 20\,e^{-2.5t}\,u(t)$$

$$\therefore \quad v_{out}(t) = -\,v_c(t) = 20\,e^{-2.5t}\,u(t) - 20\,e^{-2t}\,u(t)$$

$$\therefore \quad v_{out}(t) = 20\,e^{-2.5t}\,u(t) - 20\,e^{-2t}\,u(t)$$

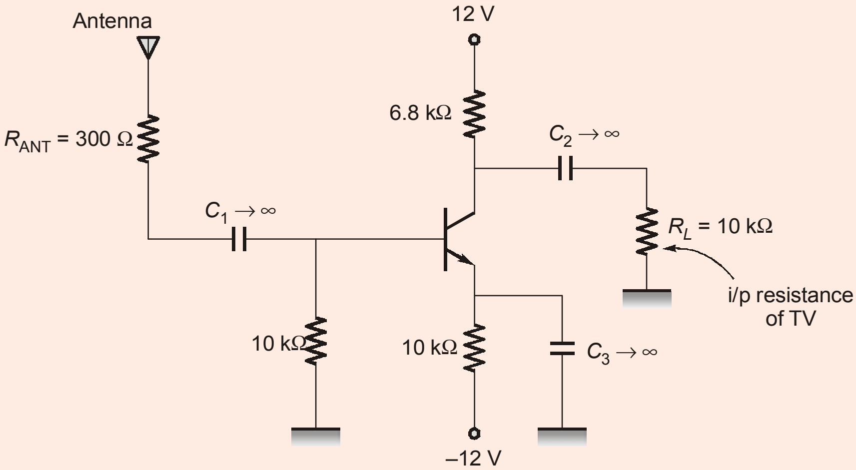
MADE EASY Source

- **GATE 2018 Online Test Series:** Q.49 of FST-8
- **MADE EASY Classnotes**



End of Solution

6. (c) A certain person with poor television reception and no access to cable TV intends to use the amplifier in the figure shown below as booster amplifier between his antenna and his television:

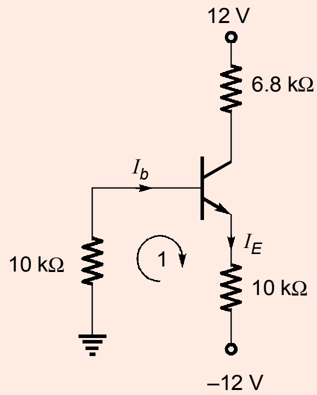


The transistor has high frequency capacitances with C_{bc} = 4 pF, C_{be} = 2 pF, C_{ce} = 1 pF and $\beta \cong 100$. Calculate low-pass dominant pole frequency and determine whether this amplifier performs adequately. (Assume V_T = 26 mV at room temperature)

[20 Marks]

Solution:

Applying DC analysis we get



Applying kVL in loop (1) we get,

$$(10\text{ k}\Omega)I_B - V_{BE} + (10\text{ k}\Omega)I_E - 12 = 0$$

Assuming $V_{BE} = 0.7$ V and $I_B = \dfrac{I_E}{\beta+1}$ we get

$$I_E = \frac{12-0.7}{10+\dfrac{10}{100}} \times 10^{-3}\text{ A}$$

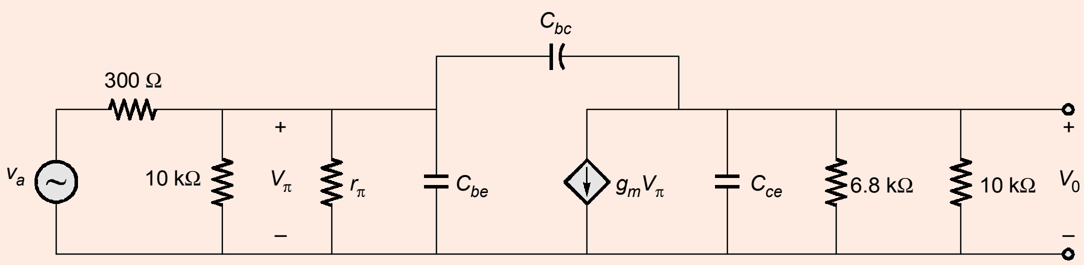
$$I_E = 1.119\text{ mA}$$

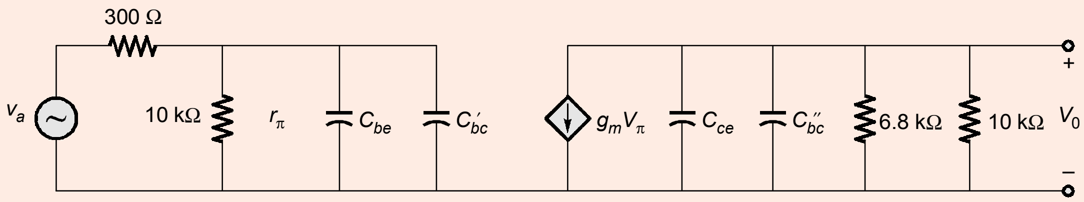
$$\therefore \quad I_C = 1.11\text{ mA}$$

Now, $$g_m = \frac{I_C}{V_T} = \frac{1.11\times 10^{-3}}{26\times 10^{-3}} = 42.7\text{ mA/V}$$

and $$r_\pi = \frac{V_T}{I_B} = \beta\frac{V_T}{I_C} = 2.34\text{ k}\Omega$$

Now, we can draw, the small signal hybrid model. Assuming antenna to be a voltage source generator with voltage V_a we get,





Where
$$C'_{bc} = C_{bc}(1 - A_v)$$

$$C''_{bc} = \frac{C_{bc}}{(1 - 1/A_v)} \approx C_{bc} \; (\because Av >> 1)$$

Now A_v is open circuit gain and can be given as

$$A_v = \frac{V_o}{V_\pi} = -g_m(6.8\text{ k}\Omega \parallel 10\text{ k}\Omega)$$

$$A_v = \frac{V_o}{V_\pi} = -42.7 \times 10^{-3} \times 4.048 \times 10^3$$

$$A_v = -172.85$$

$\therefore$
$$C'_{bc} = 4 \times \text{pF}(1 + 172.85)$$

$$C'_{bc} = 695.39\text{ pF}$$

Now at input

$$f_{H(in)} = \frac{1}{2\pi R_{eq}C_{eq}}$$

Where
$$C_{eq} = C_{be} + C'_{be} = 2\text{pF} + 695.39\text{ pF} = 697.39\text{ pF}$$
$$R_{eq} = 300 \parallel 10\text{ k}\Omega \parallel 2.34\text{ k}\Omega$$
$$R_{eq} = 259\ \Omega$$

$\therefore$
$$f_{H(in)} = \frac{1}{2\pi \times 259 \times 697.39 \times 10^{-12}} = 881.13\text{ kHz}$$

Now,
$$f_{H(out)} = \frac{1}{2\pi R_{out}C_{out}}$$

$$C_{out} = C_{ce} + C''_{bc} = 1 + 4 = 5\text{ pF}$$
$$R_{out} = 6.8\text{ k}\Omega \parallel 10\text{ k}\Omega = 4.047\text{ k}\Omega$$

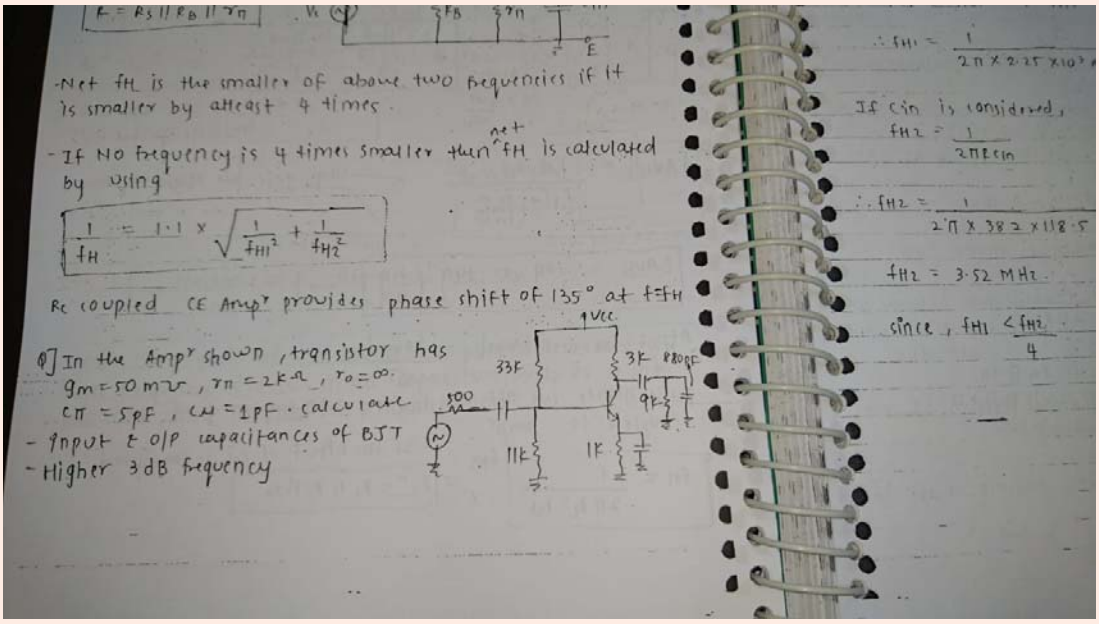
$\therefore$
$$f_{H(out)} = \frac{1}{2\pi \times 4.047 \times 10^3 \times 5 \times 10^{-12}}$$

$$f_{H(out)} = 7.865\text{ MHz}$$

Thus, the cutoff frequency is equal to 881.13 kHz and it is the lower dominant pole. Since the TV transmission occur in the VHF range i.e. from 54 MHz to 88 MHz, thus the amplifier will not work properly as it will not be a uniform amplifier for all the frequencies above 881.13 kHz.

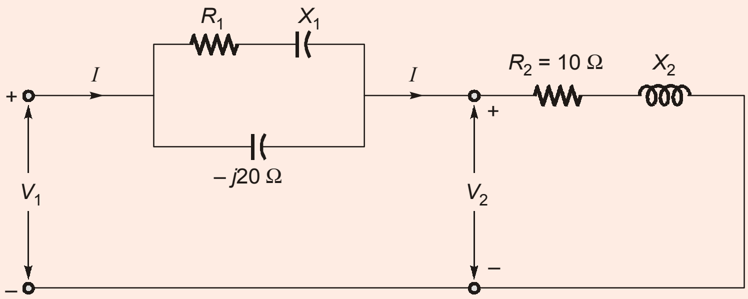
MADE EASY Source

- **Classroom Workbook:** Analog Circuits (Page No. 46)
- **MADE EASY Classnotes**



End of Solution

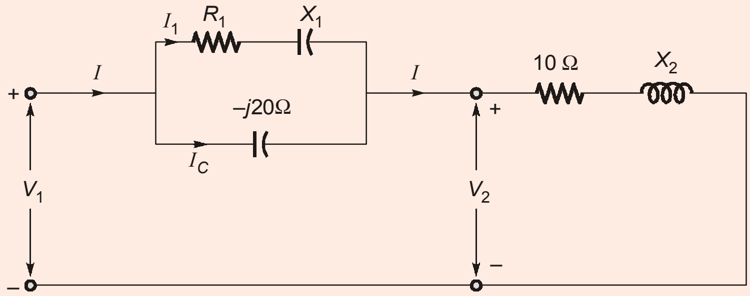
7. (a) In the circuit shown in the figure below, $|V_1| = 200$ V, $V_2 = 200\angle 0°$ V and $|I| = 12$ A. The total power absorbed by the circuit is 1.8 kW. Find R_1, X_1 and X_2:



[20 Marks]

Solution:

The given circuit is,

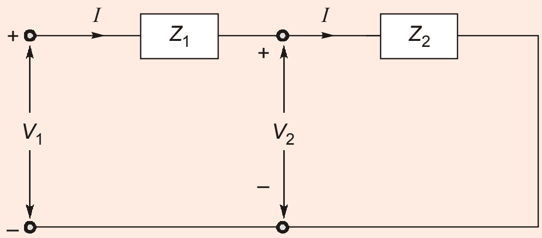


Given $|V_1| = 200$ V and $V_2 = 200 \angle 0°$ V

also $|I| = 12$ A

$P_T = 1.8$ kW

Now, the circuit can be redrawn as



where,
$$\frac{1}{Z_1} = \frac{1}{Z} + \frac{1}{-j20\Omega}$$

and,
$$Z_2 = R_2 + jX_2$$
$$= 10 + jX_2 = Z_2 \angle\theta_2$$

$\therefore$
$$I = \frac{V_2}{Z_2} = \frac{200\angle 0°}{Z_2\angle\theta_2}$$

$$|I| = \frac{200}{Z_2} = 12$$

Hence,
$$Z_2 = \frac{200}{12} = 16.67\Omega$$

$\because$
$$|Z_2| = \sqrt{10^2 + X_2^2}$$

$\therefore$
$$(16.67)^2 = 100 + X_2^2$$

or
$$X_2^2 = 177.68$$

or
$$X_2 = \sqrt{177.68} = 13.33\Omega$$

and
$$\theta_2 = \tan^{-1}\left(\frac{X_2}{10}\right) = \tan^{-1}\left(\frac{13.33}{10}\right) = 53.13°$$

$$\theta_2 = 53.13°$$

angle between I and V_2 is 53.13°

$\therefore \quad I = 12\angle{-53.13°}A$

Now, $\quad P_T = V_1 \times I \cos\theta_T$

where, $\quad \cos\theta_T = \dfrac{P_T}{V_1 \times I} = \dfrac{1800}{200 \times 12}$ (given)

$\cos\theta_T = 0.75$

or $\quad \theta_T = 41.4°$

$\because$ This is the angle between current I and voltage V_1

$\therefore \quad V_1 = 200\angle{-53.13 + 41.4°}$

or $\quad V_1 = 200\angle{-11.73°}$ V

and $\quad V_{z1} = V_1 - V_2 = 200\angle{-11.73°} - 200\angle{0°}$

$= 195.82 - 40.659j - 200 = -4.18 - 40.659j$

$= 40.87\angle{-95.86°}$

Current through capacitor ($-j20\ \Omega$ is)

$$I_C = \frac{V_{z1}}{jX_c} = \frac{40.87\angle -95.86°}{20\angle -90°}$$

$= 2.0436\angle{-5.86°}$ A

Now, current through R_1 and X_1 are

$I_1 = I - I_C$

$= 12\angle{-53.13°} - 2.0436\angle{-5.86°}$

$I_1 = 10.718\angle{61.18°}$ A

$$\therefore \quad Z_1 = \frac{V_{z1}}{I_1} = \frac{40.87\angle -95.86°}{10.718\angle -61.18°}$$

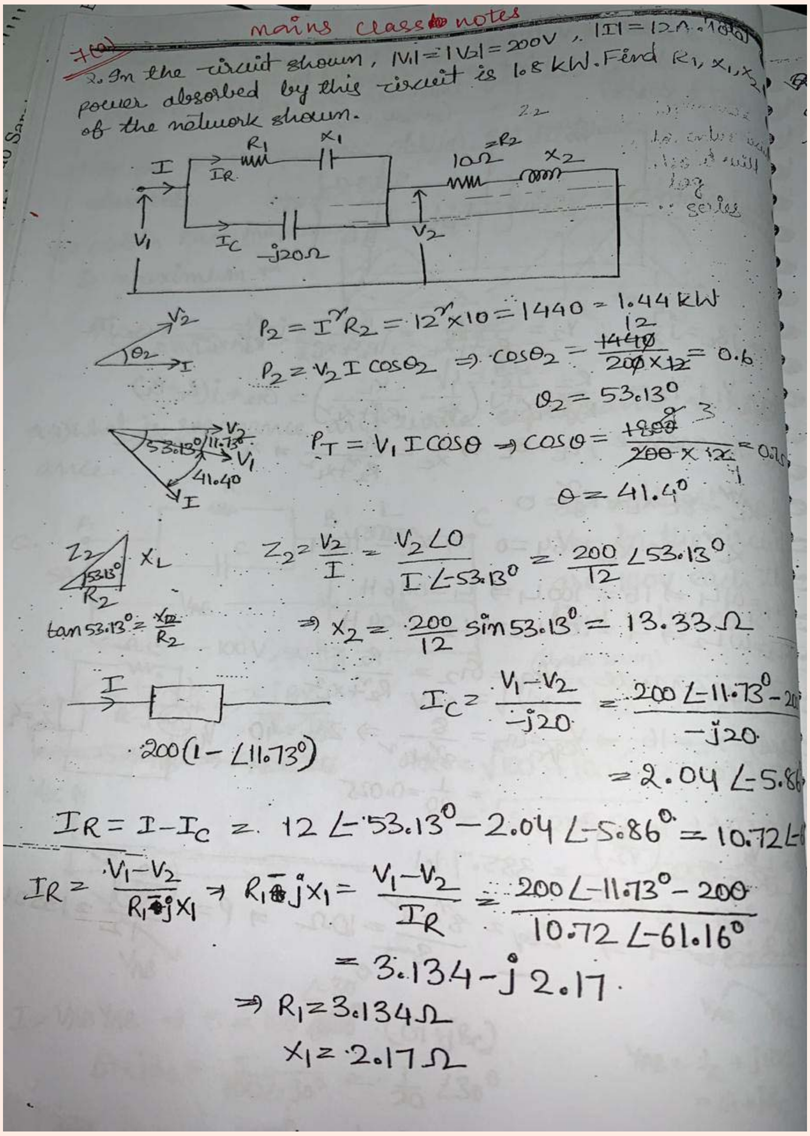
$= 3.813\angle{-34.68} = 3.813 - 2.169j$

$\therefore \quad R_1 = 3.813\Omega$

$X_1 = 2.169\Omega$

MADE EASY Source

- **Conventional Practice Question Book:** (Q.21, Page 33)
- **MADE EASY Classnotes**



mains class notes

7(a) Q. In the circuit shown, $|V_1| = |V_2| = 200V$, $|I| = 12A$. 1.8 kW. Total power absorbed by this circuit is 1.8 kW. Find R_1, X_1, X_2 of the network shown.

$P_2 = I^2 R_2 = 12^2 \times 10 = 1440 = 1.44$ kW

$P_2 = V_2 I \cos\theta_2 \Rightarrow \cos\theta_2 = \frac{1440}{200 \times 12} = 0.6$

$\theta_2 = 53.13^\circ$

$P_T = V_1 I \cos\theta \rightarrow \cos\theta = \frac{1800}{200 \times 12} = 0.75$

$\theta = 41.4^\circ$

$Z_2 = \frac{V_2}{I} = \frac{V_2 \angle 0}{I \angle -53.13^\circ} = \frac{200}{12} \angle 53.13^\circ$

$\tan 53.13^\circ = \frac{X_2}{R_2}$

$\Rightarrow X_2 = \frac{200}{12} \sin 53.13^\circ = 13.33\,\Omega$

$200(1 - \angle 11.73^\circ)$

$I_C = \frac{V_1 - V_2}{-j20} = \frac{200\angle -11.73^\circ - 200}{-j20}$

$= 2.04 \angle -5.86^\circ$

$I_R = I - I_C = 12\angle -53.13^\circ - 2.04\angle -5.86^\circ = 10.72\angle -61.16^\circ$

$I_R = \frac{V_1 - V_2}{R_1 - jX_1} \Rightarrow R_1 - jX_1 = \frac{V_1 - V_2}{I_R} = \frac{200\angle -11.73^\circ - 200}{10.72\angle -61.16^\circ}$

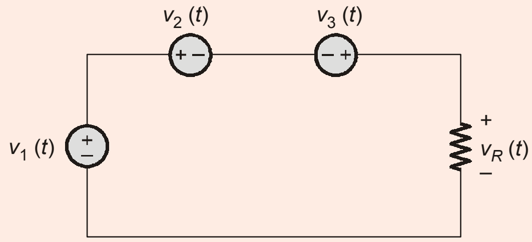
$= 3.134 - j2.17$

$\Rightarrow R_1 = 3.134\,\Omega$

$X_1 = 2.17\,\Omega$

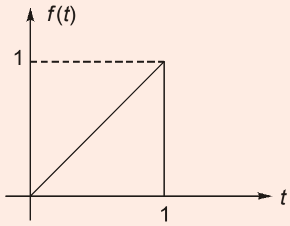
End of Solution

7. (b) (i) Determine the voltage across the resistor in the circuit of the figure shown below using phasor concept for $v_1(t) = 20\cos(\omega t + 53.13°)$V, $v_2(t) = 19.68\sin(\omega t + 152.8°)$V and $v_3(t) = 4.215\cos(\omega t + 71.61°)$V:



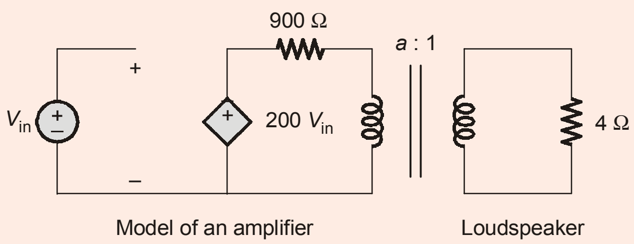
[6 Marks]

(ii) Find the Laplace transform of the sawtooth sketched in the figure below:



[4 Marks]

(iii) The figure below shows a simplified model of an audio amplifier containing and ideal transformer. The input voltage is at 2 kHz with a magnitude 1 V r.m.s. The load is a loudspeaker, represented by 4 Ω resistance:

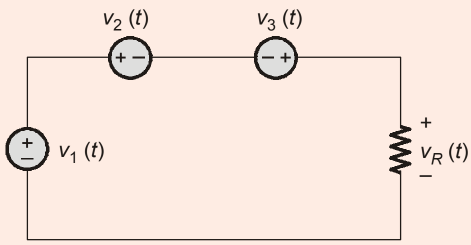


1. Find the average power delivered to the 4 Ω load if it is directly connected to the amplifier (i.e., with the transformer removed).
2. With the transformer connected and with turns ratio a = 5, find the average power delivered to the load.

[10 Marks]

Solution:

(i) The circuit is given as,



where, $v_1(t) = 20\cos(\omega t + 53.13°)$ V

$v_1(t) = 20\sin(\omega t + 90° + 53.13°)$

$v_1(t) = 20\sin(\omega t + 143.13°)$V

$v_2(t) = 19.68\sin(\omega t + 152.8°)$ V

$v_3(t) = 4.215\cos(\omega t + 71.61°)$ V

$v_3(t) = 4.45\sin(\omega t + 161.16°)$V

In phasor domain, $\vec{V}_R = \vec{V}_1 - \vec{V}_2 + \vec{V}_3$

$= 20\angle 143.13° - 19.68\angle 152.8° + 4.215\angle 161.16°$

$\vec{V}_R = -15.99 + 12j + 17.50 - 8.99j - 3.989 + 1.36j$

$= -2.479 + 4.37j$

$V_R = 5.02\angle -60.43° = 5.02\angle 119.56°$

or $v_R(t) = 5.02\sin(\omega t + 119.56°)$V

MADE EASY Source

- **Theory Book:** Network Theory (Page No. 145, 149)
- **GATE 2019 Online Test Series:** Q.2 of Test-1

(ii) $f(t) = t\,u(t) - (t-1)\,u(t-1) - u(t-1)$

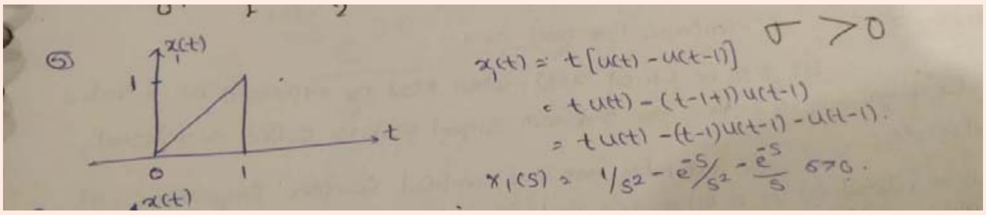
By taking Laplace Transform,

$$F(s) = \frac{1}{s^2} - \frac{e^{-s}}{s^2} - \frac{e^{-s}}{s}$$

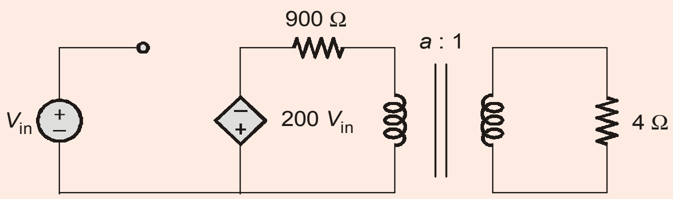
$$F(s) = \frac{1}{s^2}\left[1 - e^{-s} - se^{-s}\right]$$

MADE EASY Source

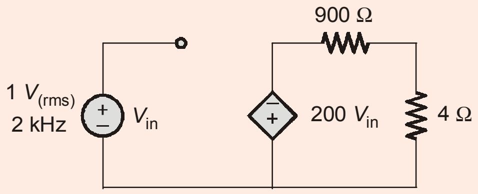
- **MADE EASY Classnotes**



(iii) The given circuit is,

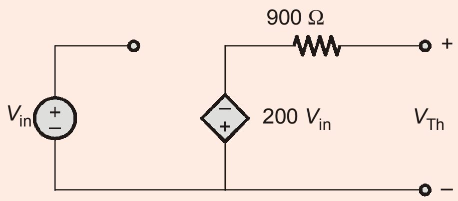


(1) When the load is directly connected to the amplifier, the circuit can be redrawn as,



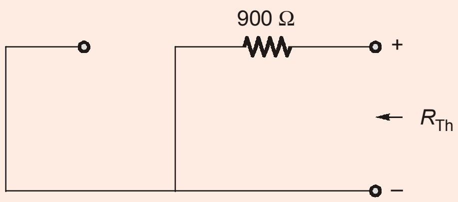
Using Thevenin's theorem, let us first calculate the value of V_{th} across load.

∴ The circuit can be redrawn as

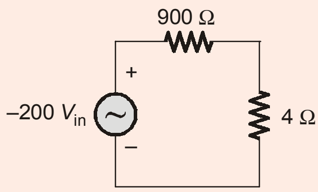


Here, $$V_{th} = -200\ V_{in} = -200\ V_{(rms)} \quad \text{...(i)}$$

For calculating R_{Th}, the circuit can be redrawn as



∴ $$R_{Th} = 900\ \Omega \quad \text{...(ii)}$$



∴ $$I = \frac{V_{Th}}{R_{th} + R_L} = \frac{-200}{900 + 4} \quad \text{...(iii)}$$

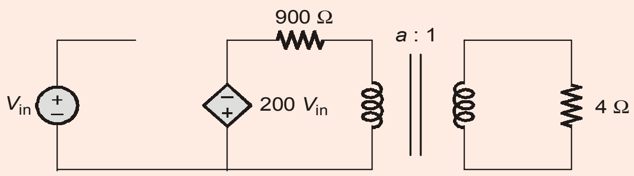
$$= \frac{-200}{904} = -0.221\ \text{A}$$

∴ Average power delivered to the load,

$$P_L = I_{rms}^2 \times R_L = (-0.221)^2 \times 4 = 0.196\ \text{W}$$

$$P_L = 196\ \text{mW}$$

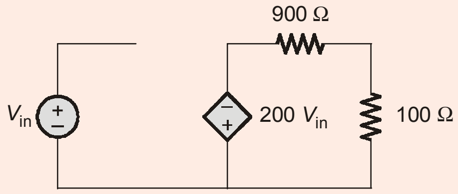
(2) When transformer is connected with $a = 5$, the circuit can be redrawn as,



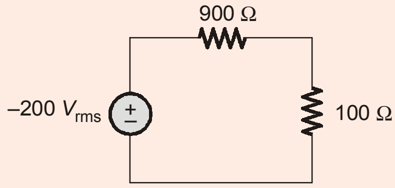
The load can be transferred toward the primary side as

$$R_L' = R_L\left(\frac{a}{1}\right)^2 = 4\left(\frac{5}{1}\right)^2 = 100\Omega$$

∴ The resultant circuit is



∴ The equivalent Thevenin's circuit becomes



from equation (iii),
$$I_L = \frac{V_{rms}}{R_{Th}+R_L'} = \frac{-200}{900+100} = \frac{-200}{1000} = -0.2\text{ A}$$

hence, the average power delivered to the load,

$$P_L = I_{rms}^2 \times R_L = (-0.2)^2 \times 100 = 4\text{ W}$$
$$P_L = 4\text{ W}$$

MADE EASY Source

- **Rank Improvement Workbook:** Q.12
- **GATE Online Test Series 2019:** Q.25 of Test-25

End of Solution

7. (c) (i) Implement the logic function shown below with a static CMOS gate:

$$\text{Out} = \overline{AB\bar{C} + ABC + \bar{A}BC}$$

[10 Marks]

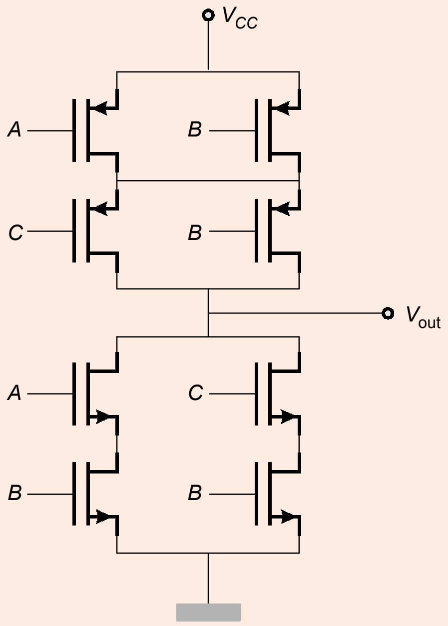
(ii) A certain counting type 12 bit ADC operates with FSR = 0 to 10 V and clock frequency f_{clk} = 1 MHz. Determine the dynamic range of the converter, conversion time, conversion rate and Nyquist frequency of the converter.

[10 Marks]

Solution:

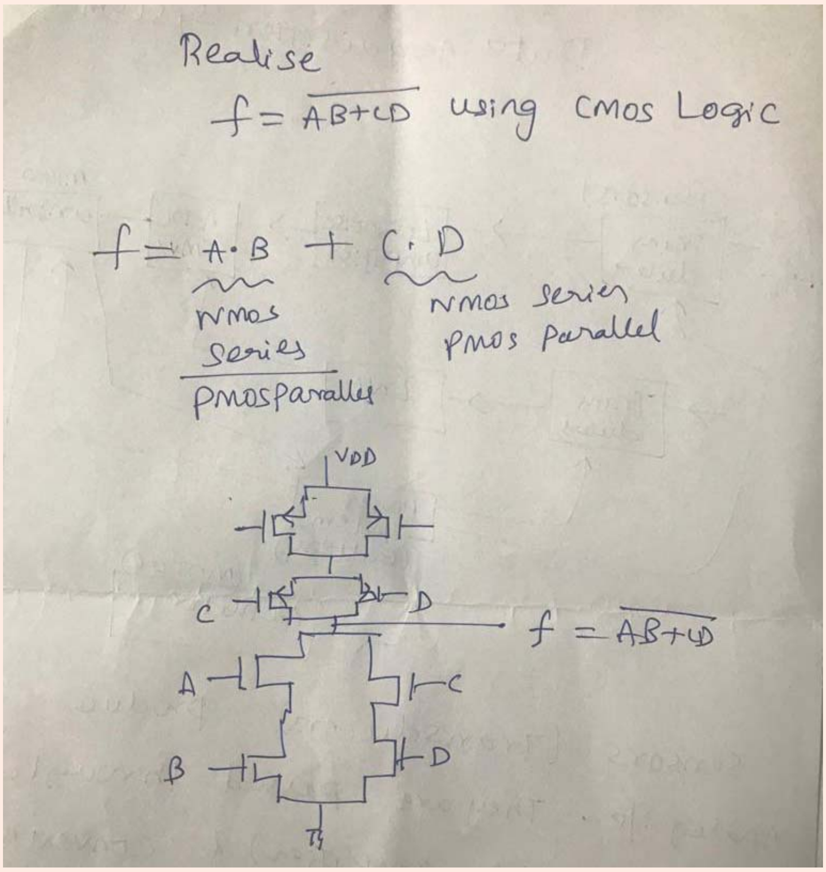
(i)
$$\text{Output} = \overline{AB\bar{C} + ABC + \bar{A}BC}$$
$$= \overline{AB\bar{C} + ABC + ABC + \bar{A}BC}$$
$$= \overline{AB + BC}$$

The MOS circuit can be implemented as



MADE EASY Source

- **MADE EASY Classnotes**



(ii) For 12-bit ADC the dynamic range can be given as

$$\text{Dynamic range} = \frac{\text{max voltage}}{\text{step size}}$$

Now, $$\text{step size} = \frac{V_{max} - V_{min}}{\text{resolution}} = \frac{10-0}{2^n - 1}$$

$\therefore$ $$\text{dynamic range} = 2^n - 1 = 2^{12} - 1 = 4095$$

$$\text{Dynamic range in dB} = 20 \log(4095) = 72.25 \text{ dB}$$

Maximum conversion time for counter type ADC $= (2^n - 1)T$

$$= (2^{12} - 1)\ 1\mu s = 4.095 \text{ ms}$$

Sampling period $T_s \geq$ max conversion time

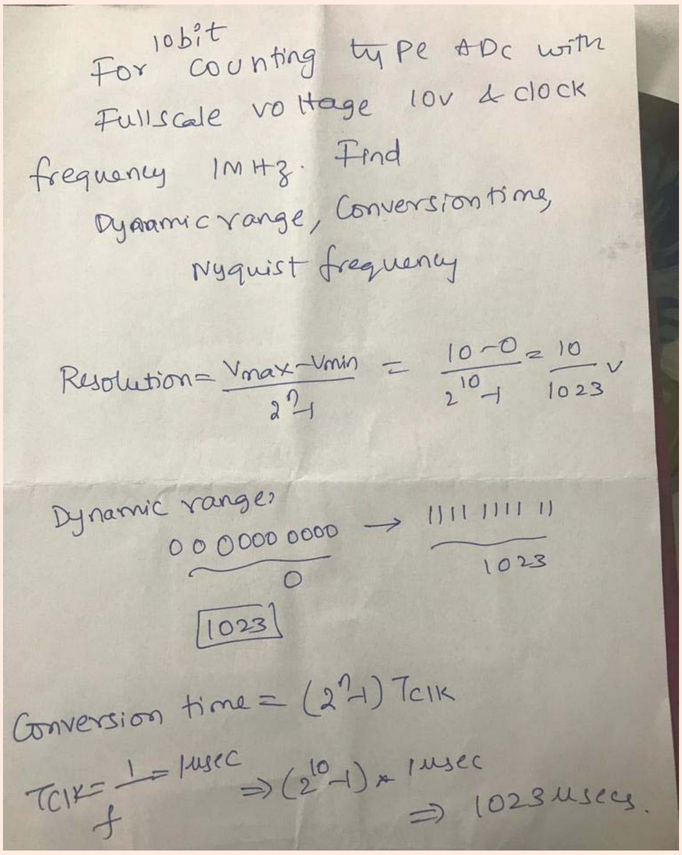
$$T_s = 4.095 \text{ ms}$$

Conversion rate $$f_s = \frac{1}{T_s} = \frac{1}{4.095 \times 10^{-3}} = 244.2 \text{ Hz}$$

Nyquist frequency of the converter $= \frac{244.2}{2} = 122.1$ Hz

MADE EASY Source

- **ESE 2018 Mains Test Series:** Q.1(e) of Test-1
- **MADE EASY Classnotes**


For 10bit counting type ADC with Fullscale voltage 10V & clock frequency 1MHz. Find Dynamic range, Conversion time, Nyquist frequency

Resolution = $\frac{V_{max} - V_{min}}{2^n - 1} = \frac{10-0}{2^{10}-1} = \frac{10}{1023}$ V

Dynamic range,
00 0000 0000 → 11 1111 1111
0 → 1023

[1023]

Conversion time = $(2^n - 1) T_{clk}$

$T_{clk} = \frac{1}{f} = 1\mu sec$ ⇒ $(2^{10} - 1) \times 1\mu sec$
⇒ 1023 µsecs.

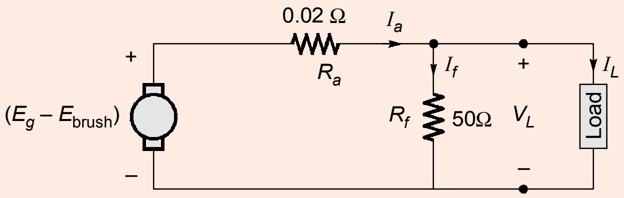
End of Solution

8. (a) A shunt generator delivers 50 kW at 250 V when running at 400 r.p.m. The armature and field resistance are 0.02 Ω and 50 Ω respectively. Calculate the speed of the machine when running as a shunt motor and taking 50 kW at 250 V. Given, total voltage drop in the brushes is 2 V.

[20 Marks]

Solution:

When acting as generator:



$$V_L = 250 \text{ V and } P_L = 50 \text{ kW}$$

$$I_L = \frac{P_L}{V_L} = \frac{50 \times 1000}{250} = 200 \text{ A}$$

$$I_f = \frac{V_L}{R_f} = \frac{250}{50} = 5 \text{ A}$$

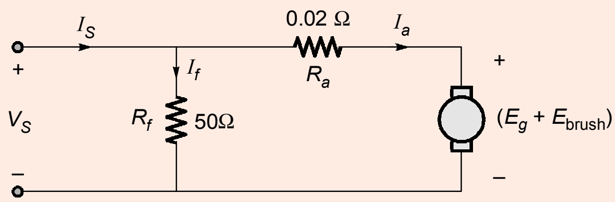
$$I_a = I_f + I_L = 205 \text{ A}$$

$$(E_g - E_{brush}) = I_a R_a + V_L = (205 \times 0.02) + 250 = 254.1 \text{ V}$$

$$E_{brush} = \text{total brush drop} = 2 \text{ V}$$

So, $$E_g = 254.1 \text{ V} + E_{brush} = 256.1 \text{ V}$$

When acting as motor:



$$V_S = 250 \text{ V and } P_S = 50 \text{ kW}$$

$$I_S = \frac{50 \times 1000}{250} = 200 \text{ A}$$

$$I_f = \frac{V_S}{R_f} = \frac{250}{50} = 5 \text{ A}$$

$$I_a = I_S - I_f = 195 \text{ A}$$

$$(E_b + E_{brush}) = V_s - (I_a R_a) = 250 - (195 \times 0.02) = 246.1 \text{ V}$$

$$E_b = 246.1 \text{ V} - E_{brush} = 244.1 \text{ V}$$

For a DC shunt machine, the back emf (E_g or E_b) is directly proportional to the speed.

So, $$\frac{E_b}{E_g} = \frac{N_m}{N_g}$$

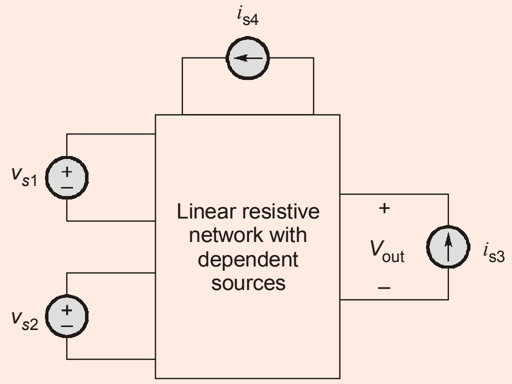
Motor speed, $$N_m = \frac{E_b}{E_g} N_g = \frac{244.1}{256.1} \times 400 \simeq 381 \text{ rpm}$$

MADE EASY Source

- **Mains Workbook:** Basic Electrical Engg. (Page No. 66)

End of Solution

8. (b) (i) The linear resistive circuit shown in the figure below has four independent sources. Three of them have fixed value, only one i_{s3} is adjustable:



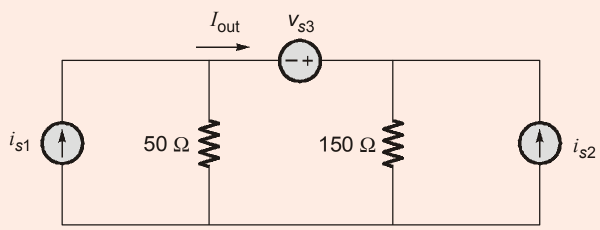
The table shows the four sets of measurements taken in a laboratory:

i_{s3}(mA)	V_{out}(V)
1	6
2	10
5	?
?	0

Complete the last two rows of the table. For the data in row 3, find the power delivered by the current source i_{s3}.

[12 Marks]

(ii) Consider the three-source circuit in the figure below:

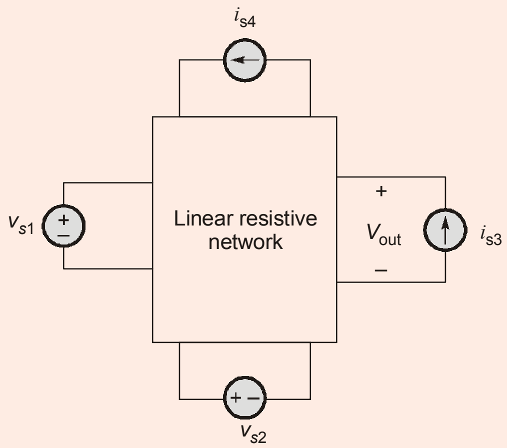


Compute I_{out} using superposition theorem.

[8 Marks]

Solution:

(i) The given circuit is



i_{s3} (mA)	V_{out} (V)
1	6
2	10
5	?
?	0

As the given network composed of resistive elements which are linear hence the principle of super position can be applied.

Here, $$V_{out} = -AV_{s1} - BV_{s2} + Ci_{s3} + Di_{s4} \quad ...(i)$$

where A, B, C and D are constants and V_{s1}, V_{s2} and i_{s4} are fixed.

$\therefore \quad -AV_{s1} - BV_{s2} + Di_{s4} = K$ (constant)

The equation (i) becomes,

$$V_{out} = K + Ci_{s3} \quad ...(ii)$$

Now, from the table given,

when, $V_{out} = 6$ V,

$$6 = K + C \times 10^{-3} \quad ...(iii)$$

when, $V_{out} = 10$ V,

$$10 = K + C \times 2 \times 10^{-3} \quad ...(iv)$$

On solving the above two equations we get,

$$K = 2 \quad \text{and} \quad C = 4000$$

$\therefore$ When, $V_{out} = 0$,

$$0 = 2 + 4000\, i_{s3}$$

$$i_{s3} = -\frac{2}{4000} = -\frac{1}{2}\text{mA}$$

and when, $i_{s3} = 5$A,

$$V_{out} = 2 + 4 \times 5 = 22 \text{ V}$$

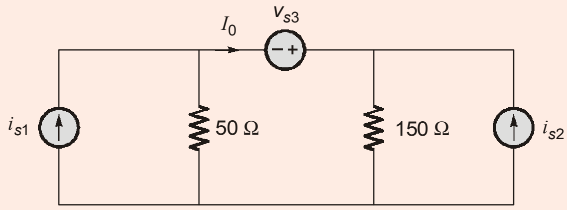
$\therefore$ Power delivered by i_{s3} is

$$P_{s3} = V_0 \times i_{s3}$$
$$= 22 \times 5 = 110 \text{ mW}$$

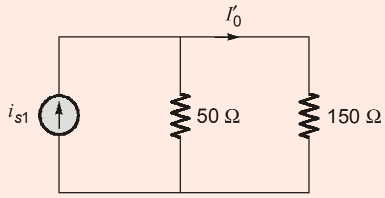
MADE EASY Source

- **ESE 2018 Mains Test Series:** Q.2(b) of Test-2
- **Theory Book 2020:** Network Theory (Page No. 65)

(ii) The given circuit is,



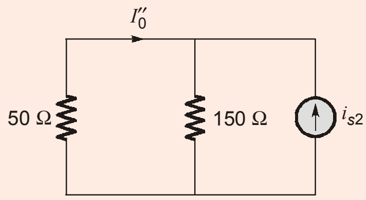
Consider i_{s1} source only, we have



From current division rule,

$$I_0' = \frac{i_{s1} \times 50}{200} = \frac{i_{s1}}{4} \qquad \text{...(i)}$$

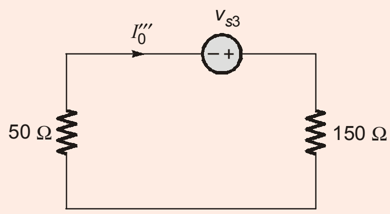
Considering i_{s2} source alone



using current division rule,

$$\Rightarrow \qquad I_0'' = -\frac{i_{s2} \times 150}{200} = -i_{s2} \times \frac{3}{4} \qquad \text{...(ii)}$$

Considering V_{s3} source alone,



$$I_0''' = \frac{V_{s3}}{150 + 50} = \frac{V_{s3}}{200} \qquad \text{...(iii)}$$

∴ By superposition theorem, we have,

$$I_0 = I_0' + I_0'' + I_0''' = \frac{i_{s1}}{4} + \frac{-3i_{s2}}{4} + \frac{V_{s3}}{200}$$

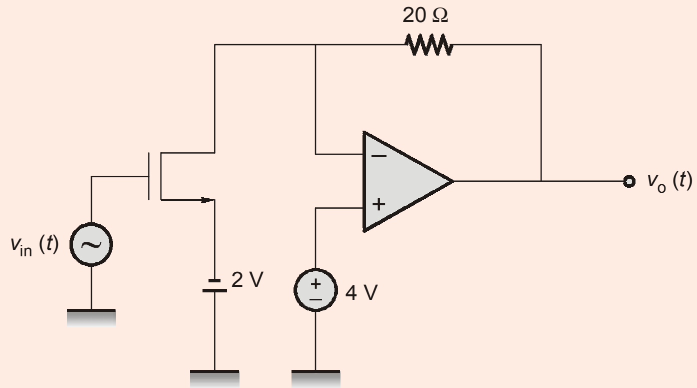
$$I_0 = \frac{i_{s1}}{4} - \frac{3i_{s2}}{4} + \frac{V_{s3}}{200}$$

MADE EASY Source

- **ESE 2018 Mains Test Series:** Q.2(b) of Test-2
- **Theory Book 2020:** Network Theory (Page No. 65, 54)

End of Solution

8. (c) (i) For the circuit shown in the figure below, determine the output voltage if the input $v_{in}(t)$ = 100 sin ($2\pi \times 10^3 t$) mV. Assume that the op-amp is an ideal op-amp and MOSFET parameters are μ_n cox = 100 $\mu A/V^2$, V_{tn} = 1 V, W = 10 μm and L = 2.5 μm.



[15 Marks]

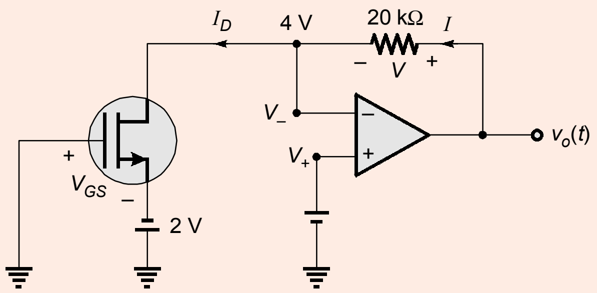
(ii) Draw a block diagram of a 4 to 2 encoder. Label all inputs and outputs. How is the 4 to 2 encoder different from 4 to 1 multiplexer?

[5 Marks]

Solution:

Applying DC analysis we get

(i)



Thus, the MOS will operate in saturation region for all values of input voltage v_{in}.

$$\therefore \quad I_D = \frac{\mu_n C_{ox} \omega}{2L}(V_{GS} - V_T)^2$$

$$= \frac{1}{2} \times 100 \times 10^{-6} \left(\frac{10}{2.5}\right)(V_{GS} - V_T)^2$$

$$I_D = 200 \times 10^{-6}[2-1]^2$$

$$I_D = 200\ \mu A$$

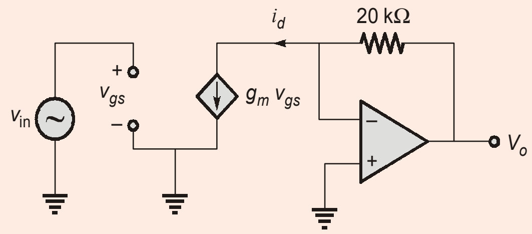
Now, the output voltage V_{out} will be equal to

$$V_o = V + V_- = I_D R_f + 4$$

$$V_o = 20 \times 10^3 \times 200 \times 10^{-6} + 4$$

$$V_o(t) = 8$$

Now applying small signal analysis we get



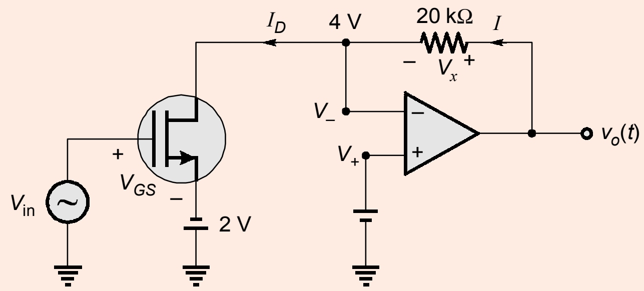
$$v_o = 20\ \text{k}\Omega \times i_d = 20\ \text{k}\Omega \times g_m V_{gs}$$
$$= 20 \times 10^3 \times 0.4 \times 10^{-3} \times 100\sin\,[2\pi \times 10^3\ \text{k}\Omega] \times 10^{-3}$$
$$= 0.8\sin[2\pi \times 10^3 t]$$

$\therefore \quad V_o(t) = V_o + v_o$

$\therefore \quad V_o(t) = 8 + 0.8\sin[2\pi \times 10^3 t]$

Alternate Solution:

(i)



Since, the op-amp is connected in negative feedback configuration. Thus,

$$V_+ = V_- = 4\ \text{V}$$

$\therefore \quad V_{GS} = V_{in}(t) - (2\ \text{V}) = 100\sin(2\pi \times 10^3 t)\ \text{mV} - (2)$

$$= 2 + 100\sin\,(2\pi \times 10^3 t)\ \text{mV}$$

$\therefore \quad V_{GS\,(min)} = 2 - 0.1 = 1.9\ \text{V}$

Now, for $V_{GS\,(min)}$, $\quad V_{DS} = 4 + 2 = 6\ \text{V}$

$\therefore \quad V_{DS} = V_{GS} - V_T \quad$ (Always true)

Thus, the MOS will operate in saturation region for all values of input voltage v_{in}.

$\therefore \quad I_D = \dfrac{\mu_n C_{ox} W}{2L}(V_{GS} - V_T)^2$

$$= \frac{1}{2} \times 100 \times 10^{-6}\left(\frac{10}{2.5}\right)(V_{GS} - V_T)^2$$

$$I_D = 200 \times 10^{-6}\,[v_{in}(t) + 2 - 1]^2$$

$$I_D = 200\,[v_{in}(t) + 1]^2\ \mu\text{A}$$

Now, the output voltage V_{out} will be equal to

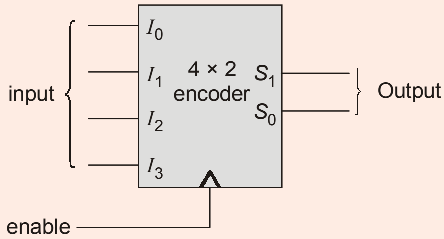
$$v_o = V_x + V_- = I_D R_f + 4$$
$$v_o = 20 \times 10^3 \times 200 \times 10^{-6}\,(v_{in}(t) + 1)^2 + 4$$
$$V_o(t) = 4 + 4\,(v_{in}(t) + 1)^2$$
$$V_o(t) = 4 + 4\left[v_{in}^2(t) + 1 + 2v_{in}(t)\right]$$

$$= 4 + 4\left[0.01\sin^2(20\pi\times10^3 t) + 0.2\sin(2\pi\times10^3 t) + 1\right]$$

$$V_o(t) = 8 + 0.8\sin(2\pi \times 10^3 t) + 0.04\sin 2\,(2\pi \times 10^3)$$

$$V_o(t) \approx 8 + 0.8\sin(2\pi \times 10^3 t)$$

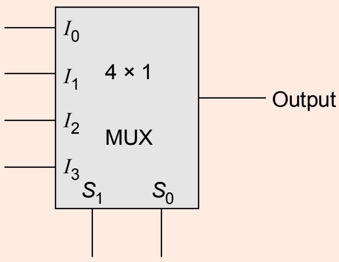
(ii) Block diagram of a 4 to 2 encoder.



The truth table of an encoder circuit can be constructed as

Enable	I_0	I_1	I_2	I_3	S_1	S_0
1	1	0	0	0	0	0
1	0	1	0	0	0	1
1	0	0	1	0	1	0
1	0	0	0	1	1	1

The encoder encodes a 4 bit signal to a 2 bit signal thus reducing the number of data lines to transmit the data. It just reduces the size of the data line and not the way in which data is transmitted i.e., it supports parallel data flow.



Unlike an encoder circuit, 4 × 1 MUX will select one input at a time and reflect it at the output terminal. It is a selective device and hence is used to convert parallel data flow into serial data flow.

MADE EASY Source

- **Theory Book:** Digital Electronics (Page No. 95, 105)

End of Solution