

Circuits and Networks (313325)

Model Question Paper — Set B · Model Answers

Q.1

a) Branch and loop.

2 M

i) Branch: A branch is a part of the network between two nodes which contains one or more circuit elements (R, L, C or source) connected in series.

ii) Loop: A loop is any closed path in a network, starting from a node and returning to the same node without passing through any node twice.

(Each 1 M)

b) Maximum power transfer theorem.

2 M

Maximum power is transferred from a source (active network) to a load resistance R_L when the load resistance is equal to the Thevenin (internal) resistance of the network seen from the load terminals, i.e. $R_L = R_{th}$.

$P_{max} = V_{th}^2 / (4 R_{th})$; efficiency at maximum power transfer = 50 %.

c) Active and passive network.

2 M

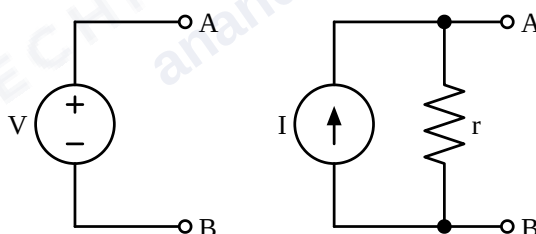
Active network: A network which contains one or more sources of energy (voltage or current source). Example: a battery with resistors, a transistor amplifier circuit.

Passive network: A network which contains no source of energy, only passive elements R, L, C. Example: a resistive ladder, an RC filter.

(Each definition with example 1 M)

d) Symbols: ideal voltage source, practical current source.

2 M



(a) Ideal voltage source (d) Practical current source

(Each symbol 1 M)

e) Apparent power and power factor.

2 M

Apparent power S: The product of r.m.s. voltage and r.m.s. current, $S = V I$. Unit: volt-ampere (VA). It is the hypotenuse of the power triangle, $S = \sqrt{P^2 + Q^2}$.

Power factor: The cosine of the phase angle ϕ between voltage and current; also the ratio of active power to apparent power: $pf = \cos \phi = P/S = R/Z$.

f) Y-parameter equations.

2 M

Taking V_1 and V_2 as independent variables:

$$I_1 = Y_{11} V_1 + Y_{12} V_2$$

$$I_2 = Y_{21} V_1 + Y_{22} V_2$$

$Y_{11} = I_1/V_1 |_{V_2=0}$, $Y_{21} = I_2/V_1 |_{V_2=0}$, $Y_{12} = I_1/V_2 |_{V_1=0}$, $Y_{22} = I_2/V_2 |_{V_1=0}$ (short-circuit parameters, unit siemens).

g) Parallel circuit as rejector.

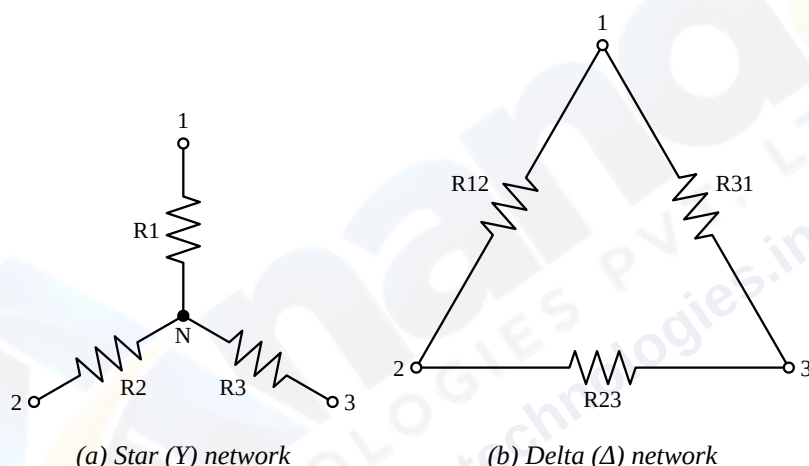
2 M

At resonance, the impedance of a parallel resonant circuit is **maximum** (dynamic impedance $Z_D = L/CR$) and therefore the line current drawn from the supply is **minimum**. Thus the circuit rejects (does not allow) the current at the resonant frequency, while it allows currents of other frequencies. Hence it is called a **rejector circuit**.

Q.2

a) Star and delta networks; conversion equations.

4 M



i) Delta to star: each star arm = product of the two delta arms meeting at that terminal ÷ sum of all three delta arms.

$$R_1 = R_{12} R_{31} / (R_{12} + R_{23} + R_{31}), \quad R_2 = R_{12} R_{23} / (R_{12} + R_{23} + R_{31}), \quad R_3 = R_{23} R_{31} / (R_{12} + R_{23} + R_{31})$$

ii) Star to delta: each delta arm = sum of the two star arms connected to its terminals + their product ÷ third star arm.

$$R_{12} = R_1 + R_2 + R_1 R_2 / R_3, \quad R_{23} = R_2 + R_3 + R_2 R_3 / R_1, \quad R_{31} = R_3 + R_1 + R_3 R_1 / R_2$$

(Diagrams 1 M, delta-star 1.5 M, star-delta 1.5 M)

b) Thevenin's theorem and steps.

4 M

Statement: Any linear, bilateral, active two-terminal network can be replaced by an equivalent circuit consisting of a single voltage source V_{th} in series with a resistance R_{th} , where V_{th} is the open-circuit voltage across the load terminals and R_{th} is the resistance seen from the load terminals with all sources replaced by their internal resistances.

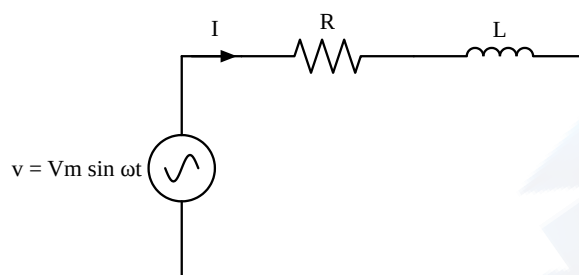
Steps:

1. Remove the load resistance R_L and mark the terminals A-B.
2. Find the open-circuit voltage across A-B; this is V_{th} .
3. Replace voltage sources by short circuit and current sources by open circuit (keep internal resistances); find resistance seen from A-B; this is R_{th} .
4. Draw the Thevenin equivalent circuit: V_{th} in series with R_{th} , and reconnect R_L .
5. Load current $I_L = V_{th} / (R_{th} + R_L)$.

(Statement 1 M, steps 3 M)

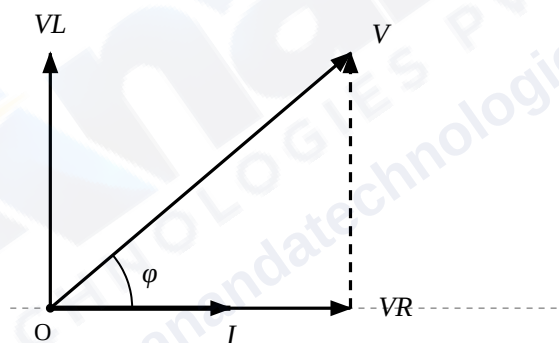
c) Series R-L circuit: circuit, phasor diagram, waveforms, voltage triangle.

4 M

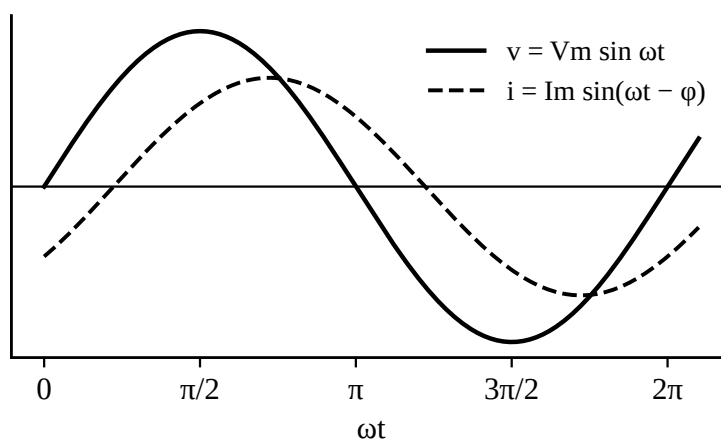


i) Series R-L circuit

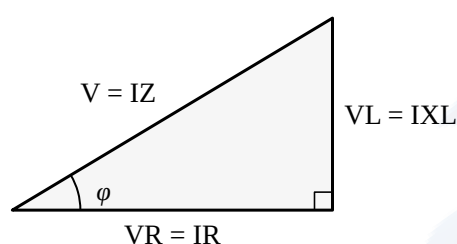
Current I is taken as reference. $V_R = IR$ is in phase with I , $V_L = IX_L$ leads I by 90° . Supply voltage $V = \sqrt{V_R^2 + V_L^2}$ leads the current by $\phi = \tan^{-1}(X_L/R)$, i.e. current lags voltage.



ii) Phasor diagram (I lags V by ϕ)



iii) Waveforms: i lags v by ϕ



iv) Voltage triangle

(Each part 1 M)

d) Series RC: 2.5 A from 220 V, 50 Hz, 300 W.

4 M

i) $P = I^2 R \Rightarrow R = P / I^2 = 300 / 2.5^2 = \mathbf{48 \, \Omega}$

$Z = V / I = 220 / 2.5 = 88 \, \Omega$

ii) $X_C = \sqrt{Z^2 - R^2} = \sqrt{88^2 - 48^2} = \mathbf{73.756 \, \Omega}$

iii) $C = 1 / (2\pi f X_C) = 1 / (2\pi \times 50 \times 73.756) = 43.157 \times 10^{-6} \text{ F} = \mathbf{43.16 \, \mu\text{F}}$

iv) $\text{pf} = \cos \phi = R / Z = 48 / 88 = \mathbf{0.5455 \text{ (leading)}}$ [check: $V I \cos \phi = 300 \text{ W}$]

(Each 1 M)

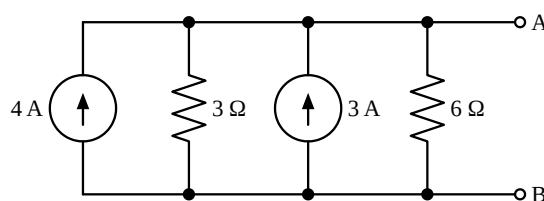
Q.3

a) Source conversion — reduce Fig. No. 1 to single voltage source.

4 M

Step 1: Convert each practical voltage source into a practical current source ($I = V/r$, r in parallel):

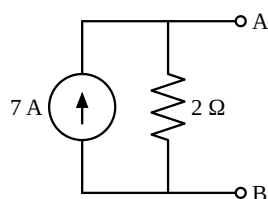
$12 \text{ V}, 3 \, \Omega \rightarrow I = 12/3 = 4 \text{ A}$ in parallel with $3 \, \Omega$; $18 \text{ V}, 6 \, \Omega \rightarrow I = 18/6 = 3 \text{ A}$ in parallel with $6 \, \Omega$



After conversion

Step 2: Parallel current sources (same direction) add; parallel resistances combine:

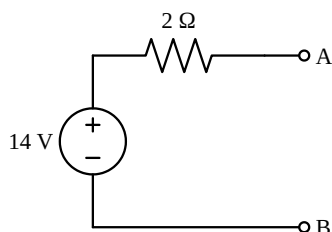
$$I = 4 + 3 = 7 \text{ A}; \quad R = 3 \parallel 6 = (3 \times 6)/(3 + 6) = 2 \Omega$$



Single current source

Step 3: Convert back into a voltage source: $V = I \times R$:

$$V = 7 \times 2 = \mathbf{14 \text{ V}}$$
 in series with $\mathbf{2 \Omega}$



Equivalent voltage source across A-B

(Each conversion step 1 M, final circuit 1 M)

b) Nodal analysis — current through 8Ω (Fig. No. 2).

4 M

Bottom node = reference. The node joined to the 20 V source is at 20 V, the node joined to the 10 V source is at 10 V. Unknowns: V_1 and V_2 . KCL (currents leaving = 0):

Node V_1 :

$$V_1/10 + (V_1 - 20)/4 + (V_1 - V_2)/5 = 0$$

$$\Rightarrow \text{(clearing fractions)} \quad 11V_1 - 4V_2 = 100 \quad \text{.....(1)}$$

Node V_2 :

$$V_2/8 + (V_2 - V_1)/5 + (V_2 - 10)/2 = 0$$

$$\Rightarrow -8V_1 + 33V_2 = 200 \quad \text{.....(2)}$$

Writing in matrix form:

$$\begin{bmatrix} 11 & -4 \\ -8 & 33 \end{bmatrix} \times \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 100 \\ 200 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 11 & -4 \\ -8 & 33 \end{vmatrix} = \mathbf{331}$$

$$\Delta_1 \text{ (replace column 1 by constants)} = \begin{vmatrix} 100 & -4 \\ 200 & 33 \end{vmatrix} = \mathbf{4100} \Rightarrow V_1 = \Delta_1/\Delta = 4100/331 = \mathbf{12.3867 \text{ V}}$$

$$\Delta_2 \text{ (replace column 2 by constants)} = \begin{vmatrix} 11 & 100 \\ -8 & 200 \end{vmatrix} = \mathbf{3000} \Rightarrow V_2 = \Delta_2/\Delta = 3000/331 = \mathbf{9.0634 \text{ V}}$$

$$\text{Current through } 8 \Omega = V_2 / 8 = 9.0634 / 8 = \mathbf{1.1329 \text{ A}} \text{ (downward)}$$

(Equations 2 M, solution 2 M)

c) Y-parameters, equivalent circuit, reciprocity and symmetry.

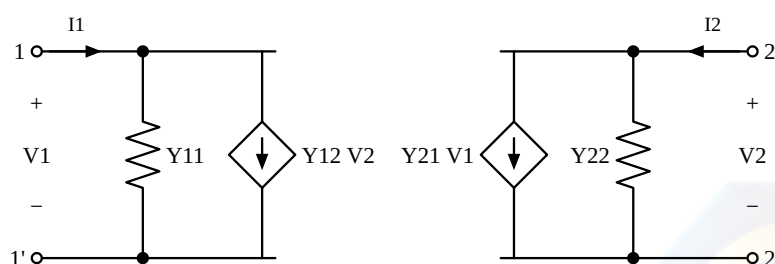
4 M

In Y-parameter representation the port currents are expressed in terms of port voltages:

$$I_1 = Y_{11}V_1 + Y_{12}V_2; \quad I_2 = Y_{21}V_1 + Y_{22}V_2$$

- $Y_{11} = I_1/V_1$ with $V_2 = 0$ — short-circuit input admittance
- $Y_{21} = I_2/V_1$ with $V_2 = 0$ — short-circuit forward transfer admittance
- $Y_{12} = I_1/V_2$ with $V_1 = 0$ — short-circuit reverse transfer admittance
- $Y_{22} = I_2/V_2$ with $V_1 = 0$ — short-circuit output admittance

They are called **short-circuit admittance parameters** because each is found by short-circuiting one port.



Y-parameter equivalent circuit

Reciprocity: $Y_{12} = Y_{21}$ **Symmetry:** $Y_{11} = Y_{22}$

(Equations 1 M, equivalent circuit 2 M, conditions 1 M)

d) Quality factor and bandwidth of series resonant circuit.

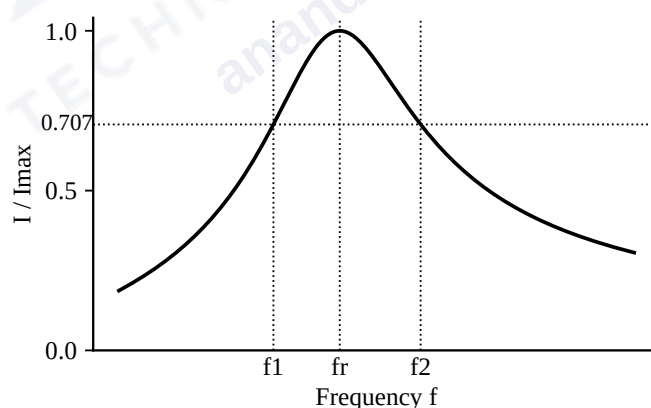
4 M

Quality factor (Q): It is the voltage magnification of the series resonant circuit, i.e. the ratio of voltage across L (or C) at resonance to the supply voltage. It also shows the selectivity of the circuit.

$$Q = V_L/V = \omega_r L/R = 1/(\omega_r CR) = (1/R)\sqrt{L/C}$$

Bandwidth (BW): The range of frequencies between the two half-power frequencies f_1 and f_2 , at which the current falls to $0.707 I_{\max}$.

$$BW = f_2 - f_1 = R/(2\pi L) \text{ Hz} = f_r/Q$$



Resonance curve showing f_1 , f_r , f_2 and bandwidth

(Q definition and expression 2 M, BW definition and expression 2 M)

Q.4

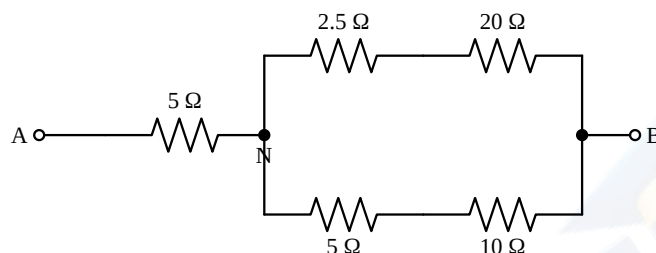
a) Equivalent resistance between A and B using star-delta (Fig. No. 3).

4 M

Let the top node be C and bottom node be D. The bridge is not balanced ($10/20 \neq 20/10$), so convert the delta formed by A, C and D ($R_{AC} = 10 \Omega$, $R_{CD} = 10 \Omega$, $R_{AD} = 20 \Omega$) into an equivalent star:

$$\text{Sum} = 10 + 10 + 20 = 40 \Omega$$

$$R_A = R_{AC}R_{AD}/40 = (10 \times 20)/40 = 5 \Omega; \quad R_C = R_{AC}R_{CD}/40 = (10 \times 10)/40 = 2.5 \Omega; \quad R_D = R_{AD}R_{CD}/40 = (20 \times 10)/40 = 5 \Omega$$



Network after delta-to-star conversion

Upper path: $2.5 + 20 = 22.5 \Omega$; lower path: $5 + 10 = 15 \Omega$

These are in parallel: $(22.5 \times 15)/(22.5 + 15) = 9 \Omega$

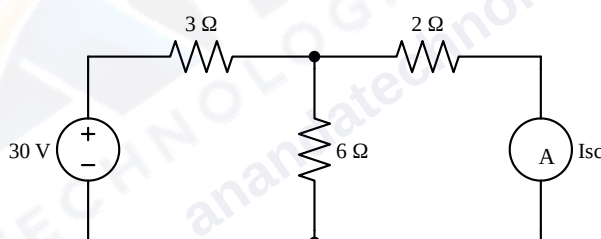
$$R_{AB} = 5 + 9 = \mathbf{14 \Omega}$$

(Conversion 2 M, reduction 1 M, answer 1 M)

b) Norton's theorem — current through $R_L = 4 \Omega$ (Fig. No. 4).

4 M

Step 1 — Norton current I_N : Short-circuit the load terminals (replace R_L by a short):



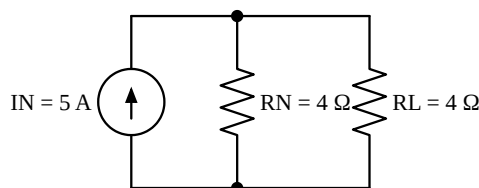
$$R_T = 3 + (6 \parallel 2) = 3 + 1.5 = 4.5 \Omega; \quad I_T = 30 / 4.5 = 6.6667 \text{ A}$$

$$I_N = I_{sc} = I_T \times 6/(6 + 2) = \mathbf{5 \text{ A}}$$

Step 2 — R_N : Remove R_L , short the 30 V source:

$$R_N = (3 \parallel 6) + 2 = 2 + 2 = \mathbf{4 \Omega}$$

Step 3 — Norton equivalent and load current:



Norton's equivalent circuit

$$I_L = I_N \times R_N / (R_N + R_L) = 5 \times 4 / (4 + 4) = 2.5 \text{ A}$$

(IN 1.5 M, RN 1 M, circuit and IL 1.5 M)

c) Series resonance: R = 10 Ω, L = 0.2 H, C = 50 μF, 100 V.

4 M

i) $f_r = 1 / (2\pi\sqrt{LC}) = 1 / (2\pi\sqrt{0.2 \times 50 \times 10^{-6}}) = 50.33 \text{ Hz}$

ii) At resonance $Z = R$, $I_0 = V/R = 100/10 = 10 \text{ A}$

iii) $Q = (1/R)\sqrt{L/C} = (1/10)\sqrt{0.2 / 50 \times 10^{-6}} = 6.325$ ($= \omega_r L / R = 6.325$)

iv) $BW = R / (2\pi L) = 10 / (2\pi \times 0.2) = 7.958 \text{ Hz}$ ($= f_r / Q$)

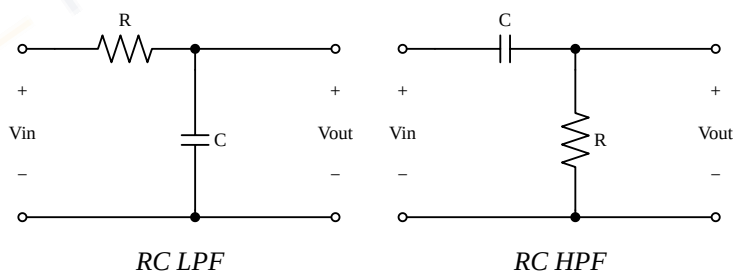
(Voltage across C at resonance = $Q \times V = 632.5 \text{ V}$.)

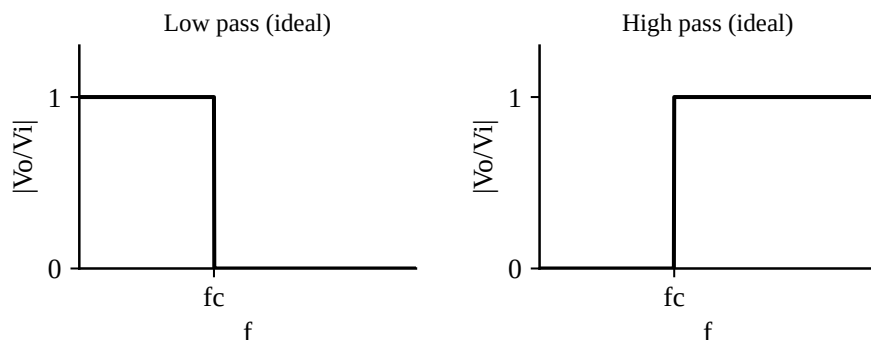
(Each 1 M)

d) Low pass filter vs high pass filter.

4 M

Point	Low pass filter (LPF)	High pass filter (HPF)
Pass band	Passes frequencies from 0 to f_c .	Passes frequencies above f_c (f_c to ∞).
Stop band	Attenuates frequencies above f_c .	Attenuates frequencies below f_c .
RC circuit	R in series arm, C in shunt arm (output across C).	C in series arm, R in shunt arm (output across R).
LC (constant-k)	Series arm: inductor; shunt arm: capacitor.	Series arm: capacitor; shunt arm: inductor.
Applications	Removing high-frequency noise, power supply ripple filter, audio bass (woofer) circuits.	Removing dc / hum, treble (tweeter) circuits, coupling circuits.





(Any four points 1 M each)

e) ABCD parameters of L-network (Fig. No. 5).

4 M

ABCD equations: $V_1 = A V_2 - B I_2$; $I_1 = C V_2 - D I_2$ (I_2 taken entering port 2).

(i) Port 2 open ($I_2 = 0$): I_1 flows through $5\ \Omega$ and $20\ \Omega$.

$$V_1 = I_1(5 + 20) = 25 I_1, \quad V_2 = 20 I_1$$

$$A = V_1/V_2 = 25/20 = \mathbf{1.25}; \quad C = I_1/V_2 = 1/20 = \mathbf{0.05\ S}$$

(ii) Port 2 short-circuited ($V_2 = 0$): $20\ \Omega$ is shorted, so $I_1 = -I_2$ and $V_1 = 5 I_1$.

$$B = V_1/(-I_2) = 5 I_1/I_1 = \mathbf{5\ \Omega}; \quad D = I_1/(-I_2) = \mathbf{1}$$

Reciprocity check: $AD - BC = 1.25 \times 1 - 5 \times 0.05 = 1 \Rightarrow \mathbf{\text{reciprocal}}$

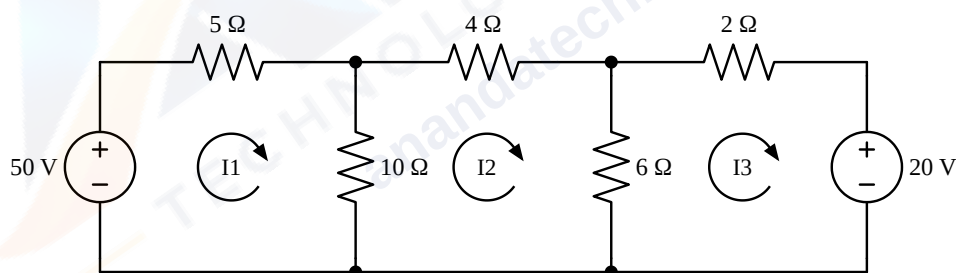
Symmetry check: $A = 1.25 \neq D = 1 \Rightarrow \mathbf{\text{not symmetrical}}$

(A, C 1.5 M; B, D 1.5 M; checks 1 M)

Q.5

a) Three-mesh analysis (Fig. No. 6).

6 M



Assume clockwise mesh currents I_1, I_2, I_3 . Applying KVL ($\sum IR \text{ drops} = \sum \text{emfs}$):

Mesh 1: $5I_1 + 10(I_1 - I_2) = 50 \Rightarrow 15I_1 - 10I_2 = 50 \dots\dots(1)$

Mesh 2: $10(I_2 - I_1) + 4I_2 + 6(I_2 - I_3) = 0 \Rightarrow -10I_1 + 20I_2 - 6I_3 = 0 \dots\dots(2)$

Mesh 3: $6(I_3 - I_2) + 2I_3 = -20 \Rightarrow -6I_2 + 8I_3 = -20 \dots\dots(3)$

Writing in matrix form:

$$\begin{bmatrix} 15 & -10 & 0 \\ -10 & 20 & -6 \\ 0 & -6 & 8 \end{bmatrix} \times \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 50 \\ 0 \\ -20 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 15 & -10 & 0 \\ -10 & 20 & -6 \\ 0 & -6 & 8 \end{vmatrix} = \mathbf{1060}$$

$$\Delta_1 \text{ (replace column 1 by constants)} = \begin{vmatrix} 50 & -10 & 0 \\ 0 & 20 & -6 \\ -20 & -6 & 8 \end{vmatrix} = \mathbf{5000} \Rightarrow I_1 = \Delta_1/\Delta = 5000/1060 = \mathbf{4.717 \text{ A}}$$

$$\Delta_2 \text{ (replace column 2 by constants)} = \begin{vmatrix} 15 & 50 & 0 \\ -10 & 0 & -6 \\ 0 & -20 & 8 \end{vmatrix} = \mathbf{2200} \Rightarrow I_2 = \Delta_2/\Delta = 2200/1060 = \mathbf{2.0755 \text{ A}}$$

$$\Delta_3 \text{ (replace column 3 by constants)} = \begin{vmatrix} 15 & -10 & 50 \\ -10 & 20 & 0 \\ 0 & -6 & -20 \end{vmatrix} = \mathbf{-1000} \Rightarrow I_3 = \Delta_3/\Delta = -1000/1060 = \mathbf{-0.9434 \text{ A}}$$

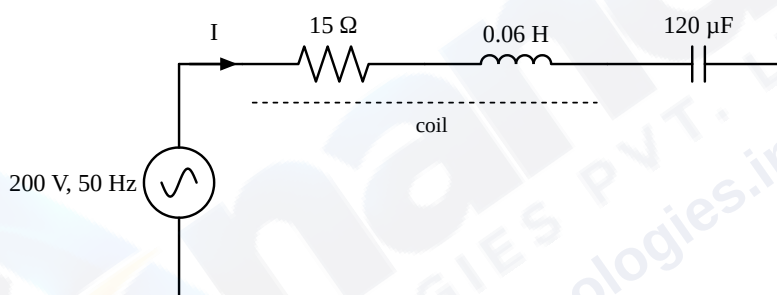
Resistor	Current	Value (A)
5 Ω	I ₁	4.717
10 Ω	I ₁ - I ₂	2.6415
4 Ω	I ₂	2.0755
6 Ω	I ₂ - I ₃	3.0189
2 Ω	I ₃	-0.9434 (opposite to assumed)

(Directions: series resistors in direction of mesh current; shunt resistors downward.)

(Three equations 3 M, solution 2 M, branch currents 1 M)

b) Coil (15 Ω , 0.06 H) in series with 120 μF on 200 V, 50 Hz.

6 M



$$X_L = 2\pi \times 50 \times 0.06 = 18.85 \Omega; \quad X_C = 1/(2\pi \times 50 \times 120 \times 10^{-6}) = 26.526 \Omega; \quad X = X_L - X_C = -7.676 \Omega \text{ (capacitive)}$$

$$\text{i) } Z = \sqrt{(15^2 + (-7.676)^2)} = \mathbf{16.85 \Omega}$$

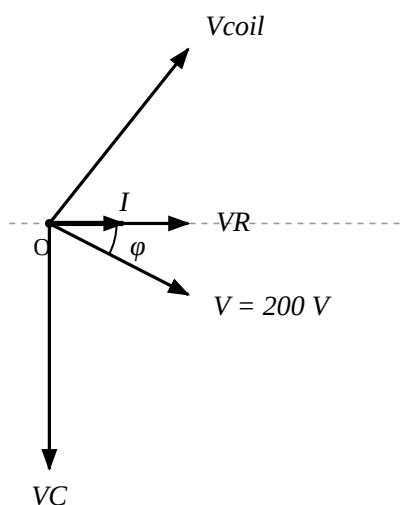
$$\text{ii) } I = 200 / 16.85 = \mathbf{11.869 \text{ A}}$$

$$\text{iii) } \text{pf} = R/Z = 15/16.85 = \mathbf{0.8902 \text{ leading}}, \quad \phi = 27.1^\circ$$

$$\text{iv) Active power } P = VI \cos \phi = 200 \times 11.869 \times 0.8902 = \mathbf{2113.23 \text{ W}}$$

$$\text{Reactive power } Q = VI \sin \phi = 200 \times 11.869 \times 0.4556 = \mathbf{1081.45 \text{ VAR}} \text{ (capacitive)}$$

$$\text{Apparent power } S = VI = 200 \times 11.869 = \mathbf{2373.88 \text{ VA}} \quad (\text{check } \sqrt{(P^2 + Q^2)} = 2373.88)$$



Phasor diagram (I leads V by ϕ)

$$V_{\text{coil}} = I \times 24.09 = 285.93 \text{ V}, V_C = I \times X_C = 314.85 \text{ V}.$$

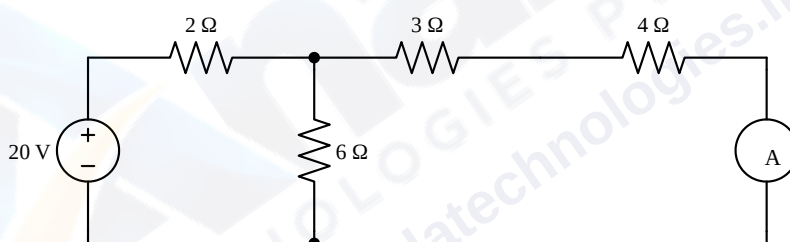
(Z, I, pf 3 M; powers 1.5 M; phasor 1.5 M)

c) Reciprocity theorem — statement and verification (Fig. No. 7).

6 M

Statement: In any linear, bilateral, passive network, if a voltage source V in one branch produces a current I in another branch, then the same voltage source V placed in the second branch will produce the same current I in the first branch. The ratio V/I (transfer resistance) remains the same.

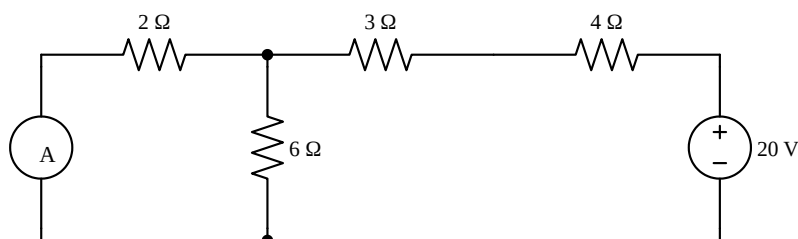
Case 1 — source in branch 1, ammeter in branch 2 (Fig. No. 7):



$$\text{Right branch} = 3 + 4 = 7 \Omega; R_T = 2 + (6 \parallel 7) = 2 + 3.2308 = 5.2308 \Omega$$

$$I_T = 20 / 5.2308 = 3.8235 \text{ A}; I (\text{ammeter}) = I_T \times 6 / (6 + 7) = \mathbf{1.7647 \text{ A}}$$

Case 2 — source and ammeter interchanged:



$$\text{Left branch} = 2 \Omega (\text{ammeter ideal}); R_T = 3 + 4 + (6 \parallel 2) = 7 + 1.5 = 8.5 \Omega$$

$$I_T = 20 / 8.5 = 2.3529 \text{ A}; I' (\text{ammeter}) = I_T \times 6 / (6 + 2) = \mathbf{1.7647 \text{ A}}$$

Since $I = I' = 1.7647 \text{ A}$, i.e. $V/I = V/I' = 11.333 \Omega$, the **reciprocity theorem is verified**.

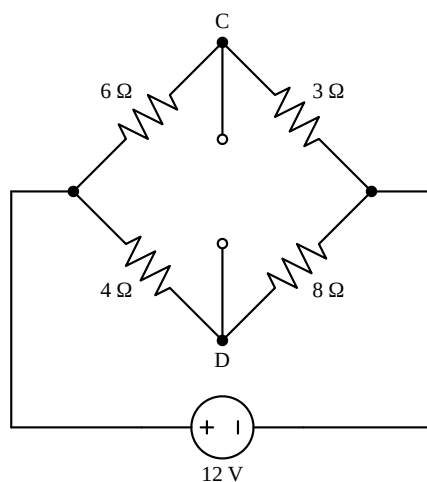
(Statement 1 M, case 1 2 M, case 2 2 M, conclusion 1 M)

Q.6

a) Thevenin's theorem — bridge network (Fig. No. 8).

6 M

Let the left node be P (+ of 12 V), right node S (– of 12 V, taken as 0 V), top node C and bottom node D. Remove the 5 Ω resistor between C and D.



5 Ω removed (C-D open)

Step 1 — V_{th} : Two independent voltage dividers across 12 V:

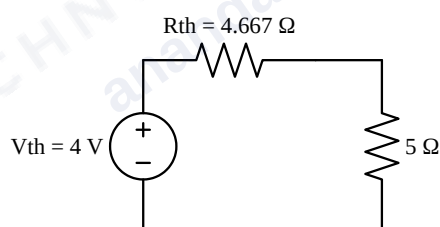
$$V_C = 12 \times 3 / (6 + 3) = 4 \text{ V}; \quad V_D = 12 \times 8 / (4 + 8) = 8 \text{ V}$$

$$V_{th} = V_D - V_C = 8 - 4 = 4 \text{ V (D is positive w.r.t. C)}$$

Step 2 — R_{th} : Short the 12 V source; P and S become one node. Seen from C-D: (6 $\parallel$ 3) in series with (4 $\parallel$ 8):

$$R_{th} = (6 \times 3) / (6 + 3) + (4 \times 8) / (4 + 8) = 2 + 2.6667 = 4.6667 \text{ } \Omega$$

Step 3:



Thevenin equivalent circuit

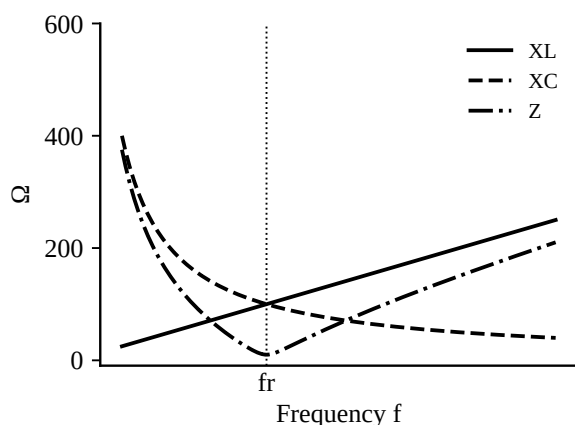
$$I_{5\Omega} = V_{th} / (R_{th} + 5) = 4 / (4.6667 + 5) = 0.4138 \text{ A, flowing from D to C}$$

(Vth 2 M, Rth 2 M, circuit and current 2 M)

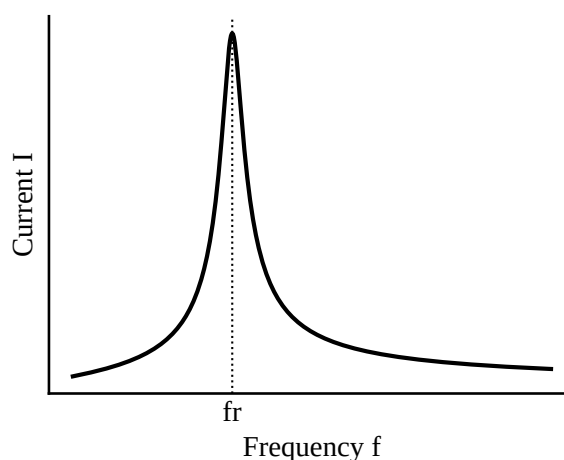
b) Resonance curve and variation of X_L , X_C , Z and I with frequency.

6 M

Curves below are plotted (computed) for $R = 10 \text{ } \Omega$, $L = 0.1 \text{ H}$, $C = 10 \text{ } \mu\text{F}$, $f_r = 159.2 \text{ Hz}$.



(a) X_L , X_C and Z vs f



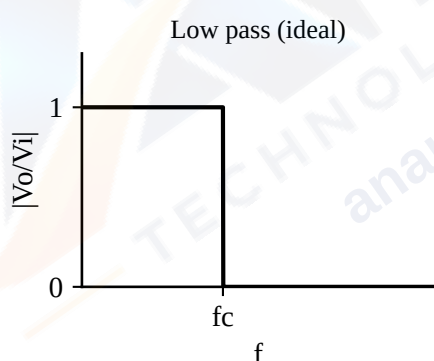
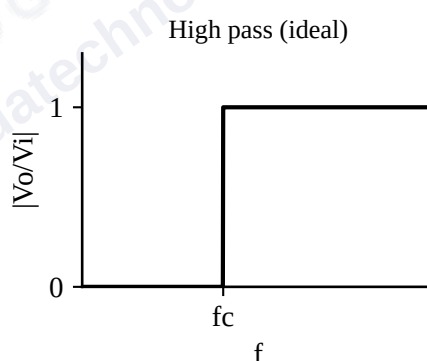
(b) Resonance curve (I vs f)

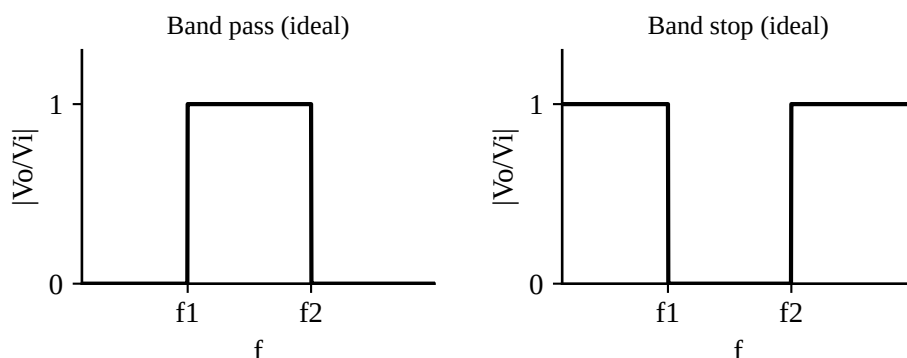
- $X_L = 2\pi fL$ increases linearly with frequency (straight line through origin).
- $X_C = 1/(2\pi fC)$ decreases with frequency (rectangular hyperbola).
- Below f_r : $X_C > X_L$, circuit is capacitive (current leads). Above f_r : $X_L > X_C$, circuit is inductive (current lags).
- Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$ is very high at low and high frequencies and **minimum (= R) at f_r** .
- Current $I = V/Z$ is small at low and high frequencies and **maximum (= V/R) at f_r** ; power factor is unity at f_r . The I - f curve is the resonance curve; a smaller R gives a sharper (more selective) curve.

(Graphs 3 M, explanation 3 M)

c) Ideal responses of LPF, HPF, BPF, BSF and applications.

6 M





Filter	Pass band	Applications (any two)
Low pass	0 to f_c	Ripple filter in power supply; removing high-frequency noise; bass (woofer) speaker circuit
High pass	f_c to ∞	Removing dc and low-frequency hum; treble (tweeter) speaker circuit; coupling in amplifiers
Band pass	f_1 to f_2	Tuning (station selection) in radio/TV receivers; IF amplifiers; communication channels
Band stop (band reject / notch)	0 to f_1 and f_2 to ∞	Removing 50 Hz mains hum; rejecting an unwanted interfering frequency; wave trap

(Four responses 4 M, applications 2 M)

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