

# Electronic Circuits & Networks (4331101) - Summer 2025 Solution

Milav Dabgar

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## Question 1(a) [3 marks]

Define following terms. (i) Active elements (ii) Bilateral elements (iii) Linear elements

### Solution

Term	Definition
Active elements	Electronic components that can supply energy or power to a circuit (like batteries, generators, op-amps)
Bilateral elements	Components that allow current flow equally in both directions with same characteristics (like resistors, capacitors, inductors)
Linear elements	Components whose current-voltage relationship follows a straight line and obeys the principle of superposition (like resistors following Ohm's law)

### Mnemonic

"ABL: Active powers Batteries, Bilateral flows Both ways, Linear stays Lawful"

## Question 1(b) [4 marks]

Capacitors of  $10\mu\text{F}$ ,  $20\mu\text{F}$  and  $30\mu\text{F}$  are connected in series and supply of 200V DC is given. Find voltage across each capacitor.

### Solution

For series-connected capacitors:

1. Find equivalent capacitance:  $1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3$

2. Voltage division:  $V_C = (C_{eq}/C_x) \times V$

**Calculation:**  $1/C_{eq} = 1/10 + 1/20 + 1/30 = 0.1 + 0.05 + 0.033 = 0.183$   $C_{eq} = 5.46\mu\text{F}$

Capacitor	Formula	Calculation	Voltage
$C_1 = 10\mu\text{F}$	$V_1 = (C_{eq}/C_1) \times V$	$(5.46/10) \times 200 = 109.2\text{V}$	109.2V
$C_2 = 20\mu\text{F}$	$V_2 = (C_{eq}/C_2) \times V$	$(5.46/20) \times 200 = 54.6\text{V}$	54.6V
$C_3 = 30\mu\text{F}$	$V_3 = (C_{eq}/C_3) \times V$	$(5.46/30) \times 200 = 36.4\text{V}$	36.4V

### Mnemonic

"Smaller Capacitors get Larger Voltages"

## Question 1(c) [7 marks]

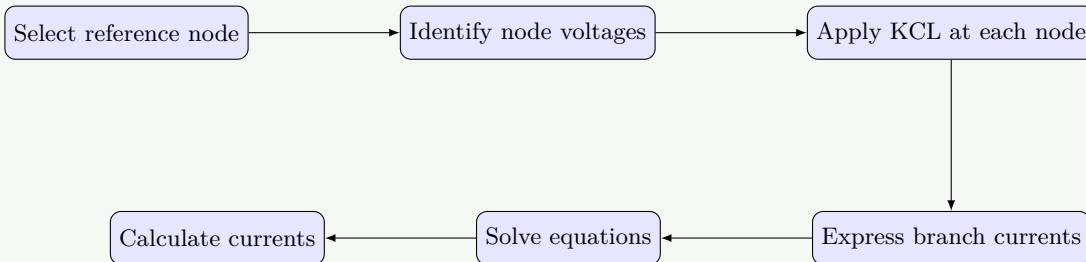
Explain Node pair voltage method for graph theory.

### Solution

Node pair voltage method is a systematic approach to analyze electrical networks.

#### Procedure:

1. Select a reference node (ground)
2. Identify the node voltages ( $N - 1$  unknowns for  $N$  nodes)
3. Apply KCL at each non-reference node
4. Express branch currents in terms of node voltages
5. Solve the equations for node voltages



**Figure 1.** Node Pair Voltage Method Procedure

#### Key advantages:

- **Fewer equations:** Only  $(n - 1)$  equations for  $n$  nodes
- **Computational efficiency:** Reduces system complexity
- **Direct voltage solutions:** Provides node voltages directly
- **Systematic approach:** Works for any network topology

### Mnemonic

“GARCS: Ground, Assign voltages, Relate with KCL, Calculate currents, Solve equations”

## Question 1(c) OR [7 marks]

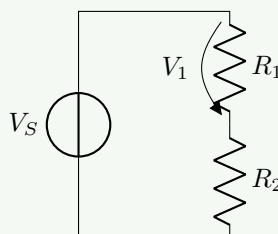
Explain voltage division method with necessary equations.

### Solution

Voltage division is a method to calculate how voltage distributes across series components.

**Principle:** In a series circuit, voltage divides proportionally to component resistances/impedances.

**Formula:** For a resistor  $R_1$  in a series circuit with total resistance  $R_T$ :  $V_1 = (R_1/R_T) \times V_S$



**Figure 2.** Voltage Divider Circuit

#### Mathematical explanation:

- For resistors:  $V_1 = (R_1/R_T) \times V_S$

- For capacitors:  $V_1 = (1/C_1)/(1/C_T) \times V_S = (C_T/C_1) \times V_S$
- For inductors:  $V_1 = (L_1/L_T) \times V_S$
- For complex impedances:  $V_1 = (Z_1/Z_T) \times V_S$

**Examples:**

- Voltage across a  $1\text{k}\Omega$  resistor in series with  $4\text{k}\Omega$  with  $5\text{V}$  source  $= (1/5) \times 5\text{V} = 1\text{V}$
- Voltage across a  $10\mu\text{F}$  capacitor in series with  $40\mu\text{F}$  with  $10\text{V}$  source  $= (1/10)/(1/8) \times 10\text{V} = 8\text{V}$

**Mnemonic**

“The BIGGER the RESISTANCE, the BIGGER the VOLTAGE drop”

**Question 2(a) [3 marks]**

Write open circuit impedance parameters of Two port network.

**Solution****Open Circuit Impedance Parameters:**

Parameter	Equation	Physical Meaning
$Z_{11}$	$Z_{11} = V_1/I_1$ (when $I_2 = 0$ )	Input impedance with output open-circuited
$Z_{12}$	$Z_{12} = V_1/I_2$ (when $I_1 = 0$ )	Transfer impedance from port 2 to port 1
$Z_{21}$	$Z_{21} = V_2/I_1$ (when $I_2 = 0$ )	Transfer impedance from port 1 to port 2
$Z_{22}$	$Z_{22} = V_2/I_2$ (when $I_1 = 0$ )	Output impedance with input open-circuited

**Mnemonic**

“ZIPO: Z-parameters with Inputs and outputs, Ports Open where needed”

**Question 2(b) [4 marks]**

Derive conversion from T-type network to  $\Pi$ -type network.

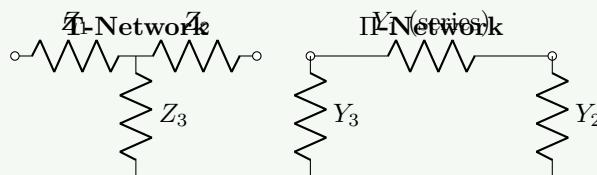
**Solution****T to  $\Pi$  Network Conversion:**

Figure 3. T and  $\Pi$  Network Conversion

**Conversion Equations:**

II-Parameter	Formula	Based on T-Parameters
$Y_1 = 1/Z_{\pi 1}$	$Y_1 = Z_2/(Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1)$	Reciprocal of $Z_1$ equivalent
$Y_2 = 1/Z_{\pi 2}$	$Y_2 = Z_1/(Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1)$	Reciprocal of $Z_2$ equivalent
$Y_3 = 1/Z_{\pi 3}$	$Y_3 = Z_3/(Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1)$	Reciprocal of $Z_3$ equivalent

**Derivation Steps:**

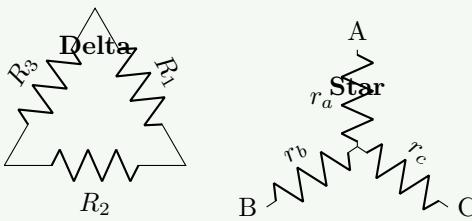
1. Define determinant  $\Delta = Z_1Z_2 + Z_2Z_3 + Z_3Z_1$
2. Use network theory to derive  $Y_1 = Z_2/\Delta$
3. Similarly,  $Y_2 = Z_1/\Delta$  and  $Y_3 = Z_3/\Delta$

**Mnemonic**

“Delta Divides: Y1 gets Z2, Y2 gets Z1, Y3 gets Z3”

**Question 2(c) [7 marks]**

Three resistances of 1, 1 and 1 ohms are connected in Delta. Find equivalent resistances in star connection.

**Solution****Delta to Star Conversion:**

**Figure 4.** Delta to Star Conversion

**Conversion Formulas:**

- $r_a = (R_1 \times R_3) / (R_1 + R_2 + R_3)$
- $r_b = (R_1 \times R_2) / (R_1 + R_2 + R_3)$
- $r_c = (R_2 \times R_3) / (R_1 + R_2 + R_3)$

**Calculation:** Given:  $R_1 = R_2 = R_3 = 1\Omega$  Sum of resistances:  $R_1 + R_2 + R_3 = 3\Omega$

Star Resistor	Formula	Calculation	Result
$r_a$	$(R_1 \times R_3) / \Sigma R$	$(1 \times 1) / 3$	$0.333\Omega$
$r_b$	$(R_1 \times R_2) / \Sigma R$	$(1 \times 1) / 3$	$0.333\Omega$
$r_c$	$(R_2 \times R_3) / \Sigma R$	$(1 \times 1) / 3$	$0.333\Omega$

**Mnemonic**

“Product Over Sum: Each star arm gets the product of adjacent delta sides divided by the sum of all”

**Question 2(a) OR [3 marks]**

Define. (i) Transfer Impedance (ii) Image Impedance (iii) Driving point Impedance

**Solution**

Term	Definition
<b>Transfer Impedance</b>	Ratio of output voltage at one port to input current at another port when all other ports are open-circuited ( $Z_{21} = V_2/I_1$ when $I_2 = 0$ )
<b>Image Impedance</b>	Input impedance at port when the output port is terminated with its own image impedance, creating infinite chain with same impedance at all points
<b>Driving point Impedance</b>	Input impedance seen when looking into a specified port or terminal pair ( $Z_{11} = V_1/I_1$ for port 1)

**Mnemonic**

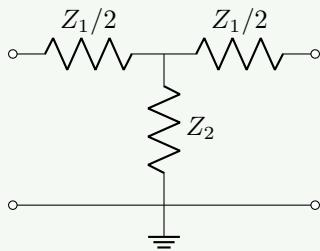
"TID: Transfer relates ports, Image creates reflections, Driving point looks inward"

**Question 2(b) OR [4 marks]**

Get the equation for characteristics impedance  $Z$  for a standard 'T' network.

**Solution**

Characteristic Impedance of 'T' network:



**Figure 5.** Symmetrical T-Network

**Derivation:** For a symmetrical T-network with series impedance  $Z_1$  (split as  $Z_1/2$  on each side) and shunt impedance  $Z_2$ :  $Z_0 = \sqrt{Z_1 Z_2 + Z_1^2/4}$

**Steps:**

1. ABCD parameters for T-network:

- $A = 1 + Z_1/2Z_2$
- $B = Z_1 + Z_1^2/4Z_2$
- $C = 1/Z_2$
- $D = 1 + Z_1/2Z_2$

2. From transmission line theory,  $Z_0 = \sqrt{B/C}$

3. Substituting:  $Z_0 = \sqrt{(Z_1 + Z_1^2/4Z_2)/(1/Z_2)}$

4. Simplifying:  $Z_0 = \sqrt{Z_1 Z_2 + Z_1^2/4}$

**Mnemonic**

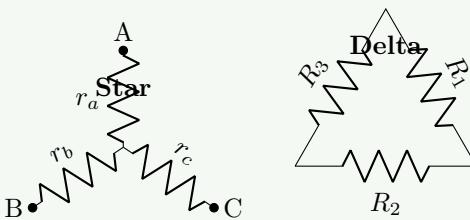
"Square root of Z-products plus quarter-square"

**Question 2(c) OR [7 marks]**

Three resistances of 6, 15 and 10 ohms are connected in star. Find equivalent resistances in delta connection.

### Solution

**Star to Delta Conversion:**



**Figure 6.** Star to Delta Conversion

**Conversion Formulas:**

- $R_1 = (r_a r_b + r_b r_c + r_c r_a) / r_a$
- $R_2 = (r_a r_b + r_b r_c + r_c r_a) / r_b$
- $R_3 = (r_a r_b + r_b r_c + r_c r_a) / r_c$

**Calculation:** Given:  $r_a = 6\Omega$ ,  $r_b = 15\Omega$ ,  $r_c = 10\Omega$  Sum of products =  $(6 \times 15) + (15 \times 10) + (10 \times 6) = 90 + 150 + 60 = 300$

Delta Resistor	Formula	Calculation	Result
$R_1$	Sum of Products/ $r_a$	$300/6$	$50\Omega$
$R_2$	Sum of Products/ $r_b$	$300/15$	$20\Omega$
$R_3$	Sum of Products/ $r_c$	$300/10$	$30\Omega$

### Mnemonic

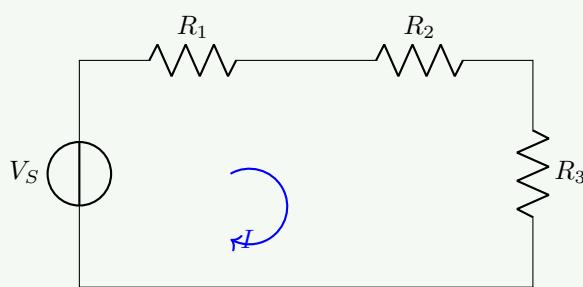
“Sum of Products Over Each: Delta side gets all products divided by opposite star arm”

## Question 3(a) [3 marks]

Analyze the circuit ( $R_1$ ,  $R_2$  and  $R_3$  Connected in series with dc supply) to calculate loop current using KVL.

### Solution

**KVL for Series Circuit:**



**Figure 7.** Series Circuit for KVL

**KVL Equation:**  $V_S - IR_1 - IR_2 - IR_3 = 0$

**Loop Current:**  $I = V_S / (R_1 + R_2 + R_3)$

**Steps:**

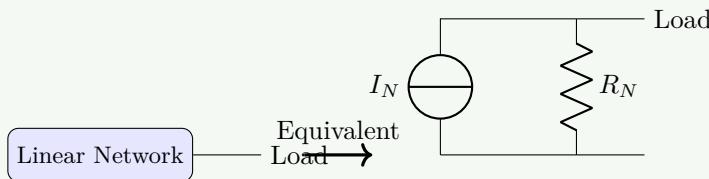
1. Identify all elements in the loop:  $V_S, R_1, R_2, R_3$
2. Apply KVL: Sum of voltage rises = Sum of voltage drops
3. Solve for  $I$ :  $I = V_S / R_{eq}$  where  $R_{eq} = R_1 + R_2 + R_3$

**Mnemonic**

"KVL: Kirchhoff's Voltage Loop requires total resistance"

**Question 3(b) [4 marks]****State Norton's theorem****Solution**

**Norton's Theorem:** Any linear electrical network consisting of voltage sources, current sources, and resistances can be replaced by an equivalent circuit consisting of a current source  $I_N$  in parallel with a resistance  $R_N$ .



**Figure 8.** Norton's Equivalent Circuit

**How to find Norton equivalent:**

1. **Norton Current ( $I_N$ ):** Short-circuit current flowing through the load terminals
2. **Norton Resistance ( $R_N$ ):** Input resistance seen at the terminals with all sources replaced by their internal resistances

**Mnemonic**

"SCIP: Short-Circuit current In Parallel with equivalent resistance"

**Question 3(c) [7 marks]**

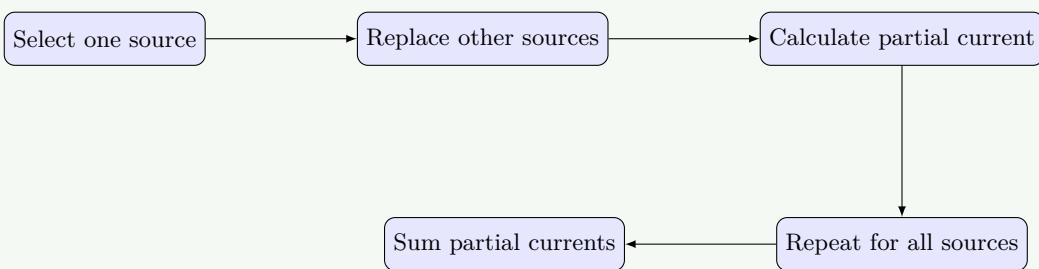
Explain the steps to calculate the current in any branch of the ckt using superposition theorem

**Solution****Superposition Theorem Application:**

**Principle:** In a linear circuit with multiple sources, the response in any element equals the sum of responses caused by each source acting alone.

**Steps:**

1. Consider only one source at a time
2. Replace other voltage sources with short circuits
3. Replace other current sources with open circuits
4. Calculate partial current for each source
5. Add all partial currents (algebraically) for final current

**Figure 9.** Superposition Process

**Mathematical Expression:**  $I = I_1 + I_2 + I_3 + \dots + I_n$  where  $I_1, I_2$ , etc. are partial currents due to individual sources

**Example calculation:** For a branch with current contributions:  $I_1 = 2A$  (from source 1)  $I_2 = -1A$  (from source 2)  $I_3 = 0.5A$  (from source 3) Total current =  $2A + (-1A) + 0.5A = 1.5A$

#### Mnemonic

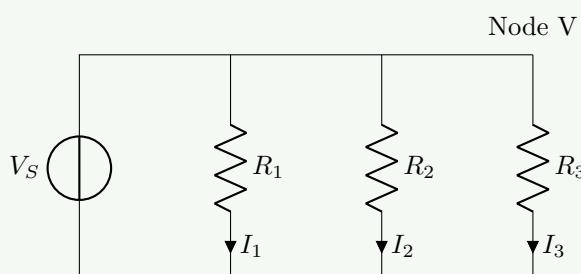
“OSACI: One Source Active, Calculate and Integrate”

## Question 3(a) OR [3 marks]

Analyze the circuit ( $R_1, R_2$  and  $R_3$  Connected in parallel with dc supply) to calculate node voltage using KCL.

#### Solution

**KCL for Parallel Circuit:**

**Figure 10.** Parallel Circuit for KCL

**KCL Equation:**  $I_1 + I_2 + I_3 = I_{total}$  (if current source) or simply sum of currents from node is zero. Here connected to DC supply  $V_S$ : Since parallel, Voltage across each  $R$  is  $V_S$ . Node Voltage  $V = V_S$ .

#### Steps:

1. Identify node voltage  $V$
2. Express branch currents:  $I_1 = V/R_1, I_2 = V/R_2, I_3 = V/R_3$
3. Apply KCL if there was a current source. For Voltage source,  $V$  is known.
4. If  $V_S$  connected via series resistor, then  $V/R_1 + V/R_2 + V/R_3 = (V_S - V)/R_{series}$ .

#### Mnemonic

“KCL: Kirchhoff’s Current Law means parallel voltage equals source”

## Question 3(b) OR [4 marks]

State Maximum power transfer theorem.

### Solution

**Maximum Power Transfer Theorem:** For a source with internal resistance, maximum power is transferred to the load when the load resistance equals the source's internal resistance.

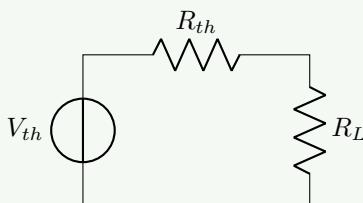


Figure 11. Maximum Power Transfer Circuit

#### Mathematical expression:

- Maximum power transfer occurs when  $R_L = R_{source}$  (or  $R_{th}$ )
- Maximum power:  $P_{max} = V_{th}^2 / (4 \times R_{th})$

#### Key points:

- **Efficiency:** Only 50% at maximum power transfer
- **AC Circuits:** Load impedance must be complex conjugate of source impedance ( $Z_L = Z_S^*$ )
- **Applications:** Signal transmission, audio systems, RF circuits

#### Mnemonic

“MEET: Maximum Efficiency Equals when Thevenin-matched”

## Question 3(c) OR [7 marks]

Explain the steps to calculate  $V_{th}$ ,  $R_{th}$  and load current in the ckt using Thevenin's theorem

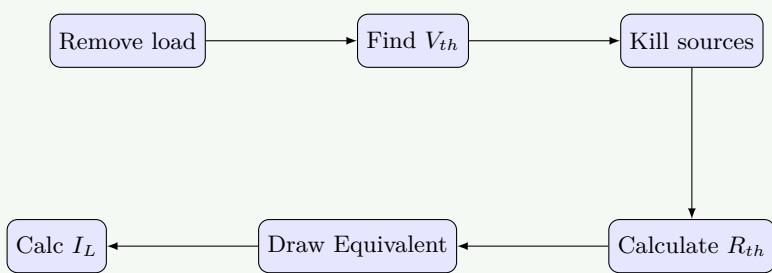
### Solution

#### Thevenin's Theorem Application:

**Principle:** Any linear electrical network with voltage and current sources can be replaced by an equivalent circuit with a single voltage source  $V_{th}$  and a series resistance  $R_{th}$ .

#### Steps:

1. Remove the load resistance from the circuit
2. Calculate open-circuit voltage ( $V_{th}$ ) across the load terminals
3. Replace all sources with their internal resistances (voltage sources as short circuits, current sources as open circuits)
4. Calculate equivalent resistance ( $R_{th}$ ) seen from the load terminals
5. Draw the Thevenin equivalent circuit with  $V_{th}$  and  $R_{th}$
6. Reconnect the load and calculate load current:  $I_L = V_{th} / (R_{th} + R_L)$

**Figure 12.** Thevenin's Procedure**Example calculation:**

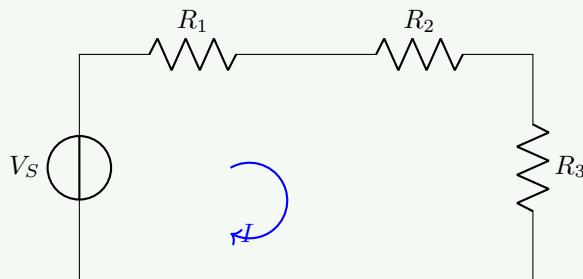
- If  $V_{th} = 12V$
- $R_{th} = 3\Omega$
- $R_L = 6\Omega$
- Then  $I_L = 12V/(3\Omega + 6\Omega) = 12V/9\Omega = 1.33A$

**Mnemonic**

“VORTE: Voltage Open, Resistance with sources Transformed, Equivalent circuit”

**Question 3(a) [3 marks]**

Analyze the circuit ( $R_1$ ,  $R_2$  and  $R_3$  Connected in series with dc supply) to calculate loop current using KVL.

**Solution****KVL for Series Circuit:****Figure 13.** Series Circuit for KVL

**KVL Equation:**  $V_S - IR_1 - IR_2 - IR_3 = 0$

**Loop Current:**  $I = V_S/(R_1 + R_2 + R_3)$

**Steps:**

1. Identify all elements in the loop:  $V_S, R_1, R_2, R_3$
2. Apply KVL: Sum of voltage rises = Sum of voltage drops
3. Solve for  $I$ :  $I = V_S/R_{eq}$  where  $R_{eq} = R_1 + R_2 + R_3$

**Mnemonic**

“KVL: Kirchhoff’s Voltage Loop requires total resistance”

## Question 3(b) [4 marks]

State Norton's theorem

### Solution

**Norton's Theorem:** Any linear electrical network consisting of voltage sources, current sources, and resistances can be replaced by an equivalent circuit consisting of a current source  $I_N$  in parallel with a resistance  $R_N$ .

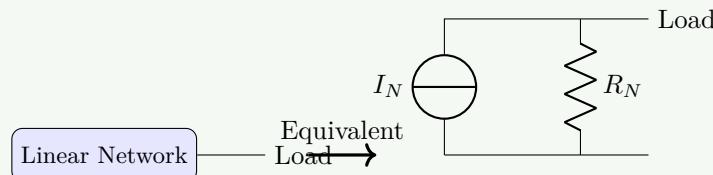


Figure 14. Norton's Equivalent Circuit

How to find Norton equivalent:

1. **Norton Current ( $I_N$ ):** Short-circuit current flowing through the load terminals
2. **Norton Resistance ( $R_N$ ):** Input resistance seen at the terminals with all sources replaced by their internal resistances

### Mnemonic

"SCIP: Short-Circuit current In Parallel with equivalent resistance"

## Question 3(c) [7 marks]

Explain the steps to calculate the current in any branch of the ckt using superposition theorem

### Solution

**Superposition Theorem Application:**

**Principle:** In a linear circuit with multiple sources, the response in any element equals the sum of responses caused by each source acting alone.

**Steps:**

1. Consider only one source at a time
2. Replace other voltage sources with short circuits
3. Replace other current sources with open circuits
4. Calculate partial current for each source
5. Add all partial currents (algebraically) for final current

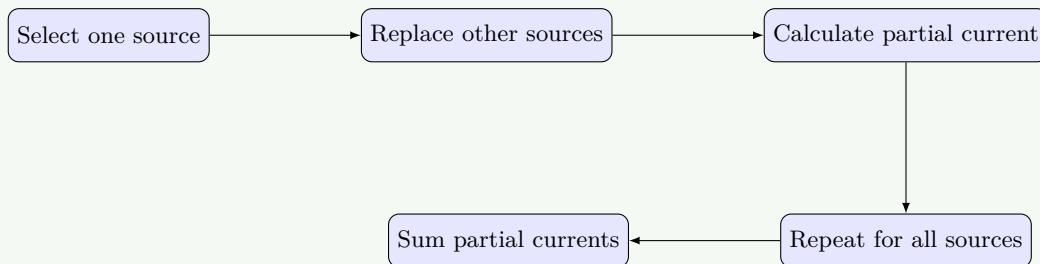


Figure 15. Superposition Process

**Mathematical Expression:**  $I = I_1 + I_2 + I_3 + \dots + I_n$  where  $I_1, I_2$ , etc. are partial currents due to individual sources

**Example calculation:** For a branch with current contributions:  $I_1 = 2A$  (from source 1)  $I_2 = -1A$  (from source 2)  $I_3 = 0.5A$  (from source 3) Total current =  $2A + (-1A) + 0.5A = 1.5A$

#### Mnemonic

“OSACI: One Source Active, Calculate and Integrate”

## Question 3(a) OR [3 marks]

Analyze the circuit ( $R_1$ ,  $R_2$  and  $R_3$  Connected in parallel with dc supply) to calculate node voltage using KCL.

#### Solution

KCL for Parallel Circuit:

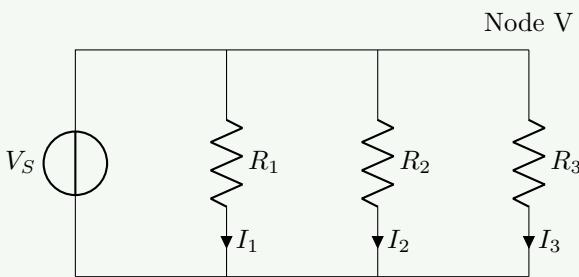


Figure 16. Parallel Circuit for KCL

**KCL Equation:**  $I_1 + I_2 + I_3 = I_{total}$  (if current source) or simply sum of currents from node is zero. Here connected to DC supply  $V_S$ : Since parallel, Voltage across each  $R$  is  $V_S$ . Node Voltage  $V = V_S$ .

#### Steps:

1. Identify node voltage  $V$
2. Express branch currents:  $I_1 = V/R_1$ ,  $I_2 = V/R_2$ ,  $I_3 = V/R_3$
3. Apply KCL if there was a current source. For Voltage source,  $V$  is known.
4. If  $V_S$  connected via series resistor, then  $V/R_1 + V/R_2 + V/R_3 = (V_S - V)/R_{series}$ .

#### Mnemonic

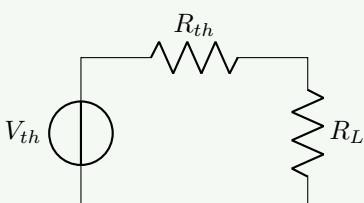
“KCL: Kirchhoff’s Current Law means parallel voltage equals source”

## Question 3(b) OR [4 marks]

State Maximum power transfer theorem.

#### Solution

**Maximum Power Transfer Theorem:** For a source with internal resistance, maximum power is transferred to the load when the load resistance equals the source’s internal resistance.



**Figure 17.** Maximum Power Transfer Circuit**Mathematical expression:**

- Maximum power transfer occurs when  $R_L = R_{source}$  (or  $R_{th}$ )
- Maximum power:  $P_{max} = V_{th}^2 / (4 \times R_{th})$

**Key points:**

- **Efficiency:** Only 50% at maximum power transfer
- **AC Circuits:** Load impedance must be complex conjugate of source impedance ( $Z_L = Z_S^*$ )
- **Applications:** Signal transmission, audio systems, RF circuits

**Mnemonic**

“MEET: Maximum Efficiency Equals when Thevenin-matched”

**Question 3(c) OR [7 marks]**

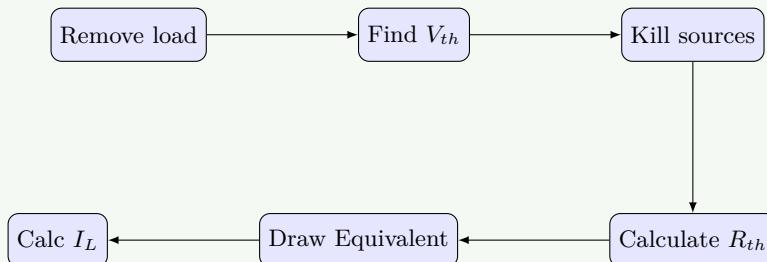
Explain the steps to calculate  $V_{th}$ ,  $R_{th}$  and load current in the ckt using Thevenin’s theorem

**Solution****Thevenin’s Theorem Application:**

**Principle:** Any linear electrical network with voltage and current sources can be replaced by an equivalent circuit with a single voltage source  $V_{th}$  and a series resistance  $R_{th}$ .

**Steps:**

1. Remove the load resistance from the circuit
2. Calculate open-circuit voltage ( $V_{th}$ ) across the load terminals
3. Replace all sources with their internal resistances (voltage sources as short circuits, current sources as open circuits)
4. Calculate equivalent resistance ( $R_{th}$ ) seen from the load terminals
5. Draw the Thevenin equivalent circuit with  $V_{th}$  and  $R_{th}$
6. Reconnect the load and calculate load current:  $I_L = V_{th} / (R_{th} + R_L)$

**Figure 18.** Thevenin’s Procedure**Example calculation:**

- If  $V_{th} = 12V$
- $R_{th} = 3\Omega$
- $R_L = 6\Omega$
- Then  $I_L = 12V / (3\Omega + 6\Omega) = 12V / 9\Omega = 1.33A$

**Mnemonic**

“VORTE: Voltage Open, Resistance with sources Transformed, Equivalent circuit”

## Question 4(a) [3 marks]

Draw a coupled circuit. Mark L1, L2 and M.

### Solution

Coupled Circuit Diagram:

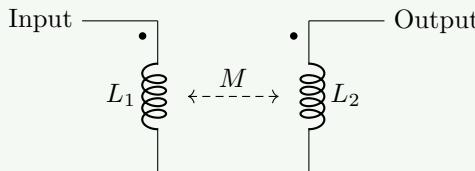


Figure 19. Magnetically Coupled Circuit

### Components:

- $L_1$ : Self-inductance of coil 1
- $L_2$ : Self-inductance of coil 2
- $M$ : Mutual inductance between coils
- Dots indicate polarity of induced voltage

### Mnemonic

"M-Link: Mutual inductance links two coils together"

## Question 4(b) [4 marks]

Define coefficient of coupling. State the relation K, M, L1, L2.

### Solution

**Coefficient of Coupling (K):** The fraction of magnetic flux produced by one coil that links with the other coil. It represents the extent of magnetic coupling between two coils.

**Relation:**  $M = K\sqrt{L_1 L_2}$  or  $K = M/\sqrt{L_1 L_2}$

### Key properties:

- Range:  $0 \leq K \leq 1$
- $K = 1$ : Perfectly coupled (tight coupling)
- $K = 0$ : No coupling (magnetically isolated)
- $K < 0.5$ : Loosely coupled

### Mnemonic

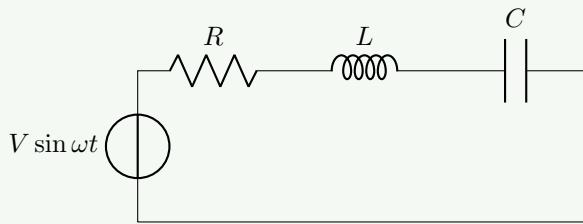
"K defines the Link: Ratio of Mutual to Geometric Mean of Selfs"

## Question 4(c) [7 marks]

Derive equation for resonant frequency of series resonance circuit. A series RLC circuit has  $R=10$  ohm,  $L=0.1H$  and  $C=10\mu F$ . Calculate resonant frequency.

### Solution

Series Resonance Derivation:

**Figure 20.** Series RLC Circuit

**Condition for Resonance:** Resonance occurs when inductive reactance equals capacitive reactance ( $X_L = X_C$ ), making the circuit purely resistive.

**Derivation:**

1.  $X_L = 2\pi f L$  and  $X_C = 1/(2\pi f C)$
2. At resonance ( $f_r$ ):  $X_L = X_C$
3.  $2\pi f_r L = 1/(2\pi f_r C)$
4.  $(2\pi f_r)^2 = 1/(LC)$
5.  $f_r = 1/(2\pi\sqrt{LC})$

**Calculation:** Given:  $R = 10\Omega$ ,  $L = 0.1\text{H}$ ,  $C = 10\mu\text{F}$  ( $10 \times 10^{-6}\text{F}$ )

$$f_r = 1/(2\pi\sqrt{0.1 \times 10 \times 10^{-6}}) = 1/(2\pi\sqrt{10^{-6}}) = 1/(2\pi \times 10^{-3}) = 1000/2\pi = 159.15 \text{ Hz}$$

#### Mnemonic

“Formula is inverse of 2-pi-root-LC”

## Question 4(a) OR [3 marks]

Define Quality factor.

#### Solution

**Quality Factor (Q-factor):** It is a figure of merit acting as a measure of the sharpness of resonance or the selectivity of a resonant circuit.

**Definitions:**

1. Ratio of voltage across L or C to applied voltage at resonance (Voltage Magnification).
2. Ratio of reactive power to active power ( $Q = \text{Reactive Power}/\text{Active Power}$ ).
3. Ratio of energy stored to energy dissipated per cycle ( $Q = 2\pi \times (\text{Max Energy Stored}/\text{Energy Dissipated per cycle})$ ).

**Formula:** For Series RLC:  $Q = (1/R)\sqrt{L/C} = \omega_r L/R$

#### Mnemonic

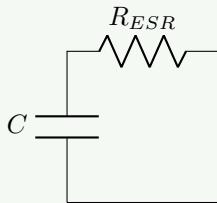
“Quality magnifies Voltage and selects Frequencies”

## Question 4(b) OR [4 marks]

Explain Quality factor of a capacitor.

#### Solution

**Quality Factor of Capacitor:** It represents the efficiency of a capacitor, comparing its stored energy to its energy losses. A real capacitor has some leakage resistance or equivalent series resistance (ESR).



Real Capacitor Model

Figure 21. Real Capacitor Model

**Expression:**  $Q_C = X_C / R_{ESR} = 1 / (\omega C R_{ESR})$

**Significance:**

- High Q means low losses (closer to ideal capacitor).
- Important in RF circuits for sharp tuning.
- Dissipation Factor ( $D$ ) is reciprocal of Q ( $D = 1/Q$ ).

#### Mnemonic

“Q is Reactance over Resistance implies Low Loss”

## Question 4(c) OR [7 marks]

Explain parallel resonance with necessary diagrams and Analysis.

#### Solution

**Parallel Resonance (Tank Circuit):**

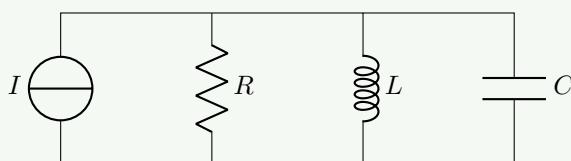


Figure 22. Ideal Parallel RLC Circuit

**Analysis:**

1. Admittance  $Y = 1/R + j(\omega C - 1/\omega L)$
2. Resonance occurs when imaginary part of admittance is zero (Susceptance  $B = 0$ ).
3. Condition:  $\omega C - 1/\omega L = 0 \implies \omega C = 1/\omega L$
4. Resonant Frequency:  $f_r = 1/(2\pi\sqrt{LC})$  (same as series for ideal case)

**Characteristics at Resonance:**

- **Impedance:** Maximum ( $Z = R$  purely resistive). In practical tank (L with series internal r),  $Z_{dynamic} = L/(Cr)$ .
- **Current:** Minimum from source (at voltage source), but circulating current between L and C is magnified (Current Magnification).
- **Power Factor:** Unity.

#### Mnemonic

“Parallel Resonance: Max Impedance, Min Source Current, Current Magnification”

## Question 5(a) [3 marks]

List types of Attenuators.

### Solution

**Types of Attenuators:**

Type	Configuration	Characteristics
<b>T-type</b>	Series-shunt-series	Symmetric, good for matching, widely used
<b>II-type</b>	Shunt-series-shunt	Symmetric, alternative to T-type
<b>Lattice</b>	Balanced bridge	Symmetrical, used in balanced lines
<b>L-type</b>	Series-shunt	Asymmetric, simpler design
<b>Bridged-T</b>	T with bridged shunt	Better frequency response, complex
<b>O-type</b>	Series-shunt-series-shunt	Improved rejection characteristics

### Mnemonic

“TLΠBO: Top attenuators Let II signals Balance Output”

## Question 5(b) [4 marks]

Derive relation between Decibel and Neper

### Solution

**Decibel to Neper Conversion:**

**Definitions:**

- **Decibel (dB):** Power ratio logarithm using base 10 (common logarithm)
- **Neper (Np):** Voltage/current ratio logarithm using base e (natural logarithm)

**Derivation:**

1. Power ratio in dB:  $\text{Loss(dB)} = 10 \log_{10}(P_1/P_2)$
2. Voltage ratio in dB:  $\text{Loss(dB)} = 20 \log_{10}(V_1/V_2)$
3. Voltage ratio in Nepers:  $\text{Loss(Np)} = \ln(V_1/V_2)$
4. Converting between logarithm bases:  $\log_{10}(x) = \ln(x)/\ln(10)$
5. Substitute:  $\text{Loss(dB)} = 20 \ln(V_1/V_2)/\ln(10) = 20\text{Loss(Np)}/\ln(10)$

**Final Relation:**

- 1 Neper =  $(\ln(10)/20) \times 10 \text{ dB} \approx 20/2.303 \approx 8.686 \text{ dB}$
- 1 dB = 0.115 Neper

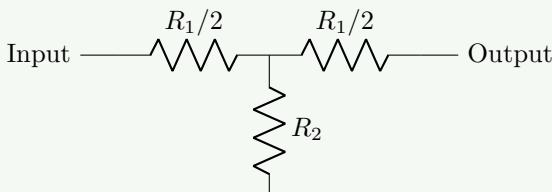
Conversion	Formula	Value
Neper to dB	$1 \text{ Np} = (20/\ln 10) \text{ dB}$	$1 \text{ Np} = 8.686 \text{ dB}$
dB to Neper	$1 \text{ dB} = (\ln 10/20) \text{ Np}$	$1 \text{ dB} = 0.115 \text{ Np}$

### Mnemonic

“8.686: Eight Point Six Nepers Buy Ten decibels”

## Question 5(c) [7 marks]

Design T type attenuator which provides 20 dB attenuation and having characteristics Impedance of 600 ohm.

**Solution****T-Type Attenuator Design:**

$R_1$  is total series, split into  $R_1/2$

**Figure 23.** T-Type Attenuator

**Design Steps:**

1. Calculate attenuation ratio  $N$  from dB:  $N = 10^{(dB/20)}$

2. Calculate  $R_1$  (Series) and  $R_2$  (Shunt) using formulas:  $R_1 = R_0 \times [(N^2 - 1)/(N^2 + 1)]$   $R_2 = R_0 \times [2N/(N^2 - 1)]$

**Calculation:** Given: Attenuation = 20 dB,  $Z_0 = 600\Omega$

Parameter	Formula	Calculation	Result
$N$	$10^{(dB/20)}$	$10^{(20/20)}$	10
$R_1$ (total)	$R_0[(N^2 - 1)/(N^2 + 1)]$	$600[(99)/(101)]$	$588.1\Omega$
$R_1/2$ (each arm)	$R_1/2$	$588.1/2$	$294.05\Omega$
$R_2$ (shunt)	$R_0[2N/(N^2 - 1)]$	$600[20/99]$	$121.2\Omega$

**Final Values:** Each series arm =  $294.05\Omega$ , Shunt arm =  $121.2\Omega$ .

**Mnemonic**

“N-squared minus ONE over N-squared plus ONE for series resistance”

**Question 5(a) OR [3 marks]****State limitations of constant K low pass filters****Solution****Limitations of Constant-K Low Pass Filters:**

Limitation	Description
<b>Poor cutoff transition</b>	Gradual transition from pass band to stop band instead of sharp cutoff
<b>Uneven impedance</b>	Impedance varies with frequency, causing matching problems ( $Z_0$ is not constant)
<b>Attenuation ripple</b>	Non-uniform attenuation in both pass band and stop band
<b>Phase distortion</b>	Non-linear phase response causing signal distortion
<b>Fixed termination</b>	Designed for specific load impedance ( $R_0$ ); performance deteriorates with other loads
<b>Limited selectivity</b>	Poor selectivity compared to modern filter designs (m-derived filters are better)

**Mnemonic**

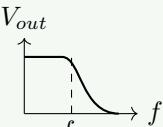
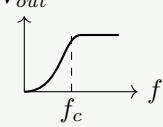
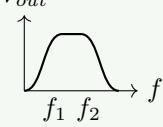
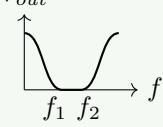
“PUAPFL: Poor transition, Uneven impedance, Attenuation ripple, Phase distortion, Fixed termination, Limited selectivity”

## Question 5(b) OR [4 marks]

Give classification of filters showing frequency response curves For each of them

### Solution

#### Classification of Filters:

Filter Type	Response Curve	Characteristics
Low Pass		Passes frequencies below cutoff $f_c$ , blocks higher
High Pass		Blocks frequencies below cutoff $f_c$ , passes higher
Band Pass		Passes frequencies between $f_1$ and $f_2$
Band Stop		Blocks frequencies between $f_1$ and $f_2$

### Mnemonic

"LHBS: Low lets low tones, High lets high tones, Band-pass selects middle, Band-Stop rejects middle"

## Question 5(c) OR [7 marks]

Derive equation for designing a constant K low pass filters.

### Solution

#### Constant-K Low Pass Filter Design:

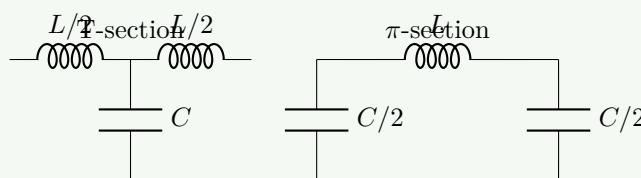


Figure 24. Constant-K Low Pass Filter Sections

**Design Theory:** A constant-K filter has impedance product  $Z_1 Z_2 = R_0^2$  (constant) at all frequencies.

#### Derivation Steps:

- For a T-section low-pass filter: Series impedance  $Z_1 = j\omega L$ , Shunt impedance  $Z_2 = 1/j\omega C$
- Product  $Z_1 Z_2 = L/C = R_0^2$  (constant  $k^2$ )
- Characteristic impedance at zero frequency:  $R_0 = \sqrt{L/C}$

4. Cut-off frequency occurs when  $Z_1/4 + Z_2 = 0$  or  $Z_1 = -4Z_2$  (Pass band condition in filter theory  $-1 < Z_1/4Z_2 < 0$ , cutoff at limit). More simply, cutoff  $\omega_c$  is where  $X_L = 2X_C$  for full section? Standard formula:  $\omega_c = 2/\sqrt{LC}$
5. From  $R_0 = \sqrt{L/C}$  and  $\omega_c = 2/\sqrt{LC}$ :  $L = R_0/\pi f_c$   $C = 1/(\pi f_c R_0)$

**Final Design Equations:**

- Inductance:  $L = R_0/(\pi f_c)$
- Capacitance:  $C = 1/(\pi f_c R_0)$
- Cutoff Frequency:  $f_c = 1/(\pi\sqrt{LC})$

**Mnemonic**

“One over Pi-Root-LC: The frequency where we Cut”