Electronic Circuits & Networks (4331101) - Summer 2024 Solution

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Question 1(a) [3 marks]

Define node, branch and loop with suitable diagram.

Solution

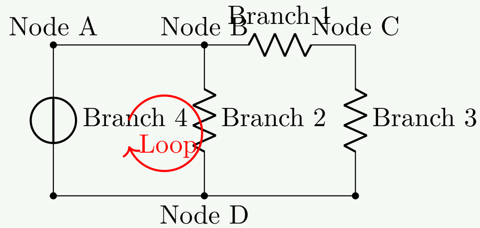


Figure 1. Circuit illustrating Node, Branch, and Loop

- **Node**: A point where two or more circuit elements join together. In the diagram, points A, B, C, and D are nodes.
- **Branch**: A single element connecting two nodes. The resistors and voltage source are branches connecting the nodes.
- **Loop**: Any closed path in a circuit where no node is encountered more than once. The path A-B-D-A is a loop.

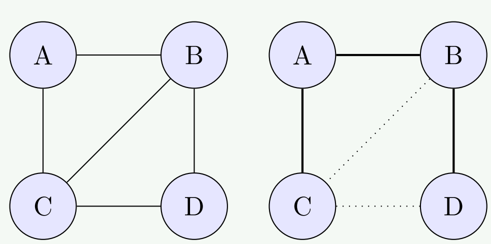
Mnemonic

"NBA circuit: Nodes are junctions, Branches are roads, Loops are Alternate paths"

Question 1(b) [4 marks]

Explain "Tree" and "Graph" of a network.

Solution



(a) Network Graph (b) Tree of Network

Figure 2. Graph and Tree of a Network

Feature	Graph	Tree
Definition	Complete topological representation of network	Connected subgraph containing all nodes but no loops
Elements	Contains all branches and nodes	Contains $N - 1$ branches where N is number of nodes
Loops	Contains loops	No loops
Application	Used for complete circuit analysis	Used for simplifying network calculations

Mnemonic

"GRAND Tree: Graph has Routes And Nodes with Detours, Tree has only single Routes"

Question 1(c) [7 marks]

Explain "Mesh current Method" using suitable diagram.

Solution

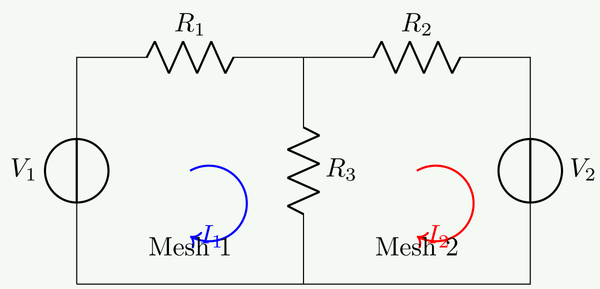


Figure 3. Mesh Analysis Circuit

Step	Description
1	Identify independent meshes in the circuit
2	Assign mesh currents (I_1, I_2, etc.) in clockwise direction
3	Apply KVL to each mesh
4	Form equations using: $\Sigma R \cdot I(\text{own}) - \Sigma R \cdot I(\text{adjacent}) = \Sigma V$
5	Solve the simultaneous equations

- **Advantage**: Fewer equations than branch current method
- **Application**: Best for planar networks
- **Limitation**: Less efficient for non-planar networks

Mnemonic

"MIAMI: Meshes Identified, Assign currents, Make equations, Intersection currents calculated, Solve"

Question 1(c) OR [7 marks]

Explain "Node pair voltage Method" using suitable diagram.

Solution

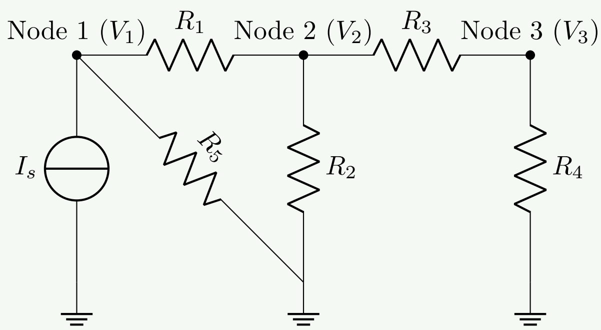


Figure 4. Nodal Analysis Circuit

Step	Description
1	Select a reference node (ground)
2	Assign node voltages (V_1, V_2, etc.) to remaining nodes
3	Apply KCL at each node (except reference)
4	Express currents in terms of node voltages using Ohm's Law
5	Solve the simultaneous equations

- **Advantage**: Fewer equations than mesh method for circuits with many meshes
- **Application**: Efficient for non-planar circuits
- **Key equation**: $\Sigma G \cdot V(\text{own}) - \Sigma G \cdot V(\text{adjacent}) = \Sigma I$

Mnemonic

"GRAND: Ground node fixed, Remaining nodes numbered, Apply KCL, Note voltage differences, Derive solutions"

Question 2(a) [3 marks]

Explain KCL with example.

Solution

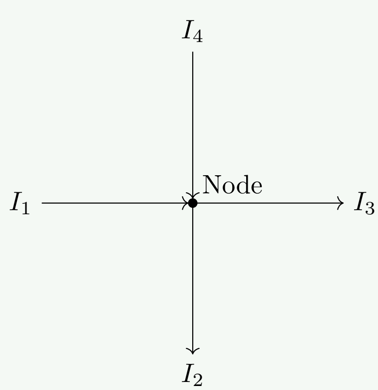


Figure 5. KCL at a Node

Kirchhoff's Current Law (KCL): The algebraic sum of all currents entering and leaving a node is zero.

Mathematical Form	Example Application
$\Sigma I = 0$	At node: $I_1 - I_2 - I_3 + I_4 = 0$
$\Sigma I_{in} = \Sigma I_{out}$	Currents entering = Currents leaving

Mnemonic

"ZINC: Zero Is Net Current at a node"

Question 2(b) [4 marks]

Explain Z-parameter, Y-parameter, h-parameter and ABCD-parameter using suitable network.

Solution

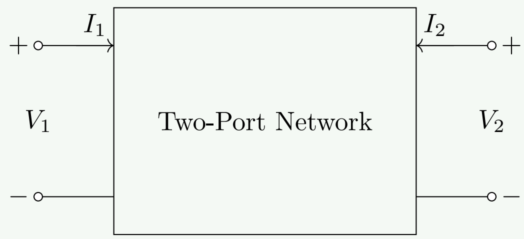


Figure 6. Two-Port Network

Param	Definition	Equations	Usage
Z	Impedance parameters	$V_1 = Z_{11}I_1 + Z_{12}I_2$ $V_2 = Z_{21}I_1 + Z_{22}I_2$	High impedance circuits
Y	Admittance parameters	$I_1 = Y_{11}V_1 + Y_{12}V_2$ $I_2 = Y_{21}V_1 + Y_{22}V_2$	Low impedance circuits
h	Hybrid parameters	$V_1 = h_{11}I_1 + h_{12}V_2$ $I_2 = h_{21}I_1 + h_{22}V_2$	Transistor circuits
ABCD	Transmission parameters	$V_1 = AV_2 - BI_2$ $I_1 = CV_2 - DI_2$	Cascaded networks

Mnemonic

"ZANY HAB: Z for high impedance, A for low, hy-brid for transistors, ABCD for Cascades"

Question 2(c) [7 marks]

Derive the equations to convert π-type network into T-type network and T-type network into π-type network.

Solution

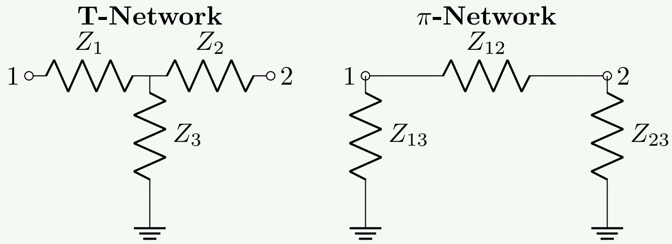


Figure 7. T and π Networks

Conversion	Formulas
π **to T**	$Z_1 = \frac{Z_{12}Z_{13}}{Z_{12}+Z_{23}+Z_{13}}$ $Z_2 = \frac{Z_{12}Z_{23}}{Z_{12}+Z_{23}+Z_{13}}$ $Z_3 = \frac{Z_{23}Z_{13}}{Z_{12}+Z_{23}+Z_{13}}$
T to π	$Z_{12} = \frac{Z_1Z_2+Z_2Z_3+Z_3Z_1}{Z_3}$ $Z_{23} = \frac{Z_1Z_2+Z_2Z_3+Z_3Z_1}{Z_1}$ $Z_{13} = \frac{Z_1Z_2+Z_2Z_3+Z_3Z_1}{Z_2}$

- **Application**: Network simplification and analysis
- **Condition**: Both networks must be equivalent at terminals
- **Limitation**: Only applies for linear networks

Mnemonic

"TRIP: T and $\pi networks Relate Impedances through Products and sums''$

Question 2(a) OR [3 marks]

Explain KVL with example.

Solution

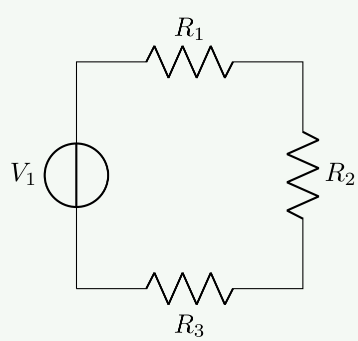


Figure 8. KVL Loop

Kirchhoff's Voltage Law (KVL): The algebraic sum of all voltages around any closed loop is zero.

Mathematical Form	Example Application
$\Sigma V = 0$	In loop: $V_1 - IR_1 - IR_2 - IR_3 = 0$
$\Sigma V_{rises} = \Sigma V_{drops}$	Voltage rises = Voltage drops

Mnemonic

"ZERO: Zero is Every voltage Round a loop's Output"

Question 2(b) OR [4 marks]

Classify and explain various Electronics network.

Solution

Network Type	Description	Example
Linear vs Non-linear	Follows/doesn't follow proportionality principle	Resistors vs Diodes
Passive vs Active	Don't/do supply energy	RC circuit vs Amplifier
Bilateral vs Unilateral	Same/different properties in either direction	Resistors vs Diodes
Lumped vs Distributed	Parameters concentrated/spread	RC circuit vs Transmission line
Time variant vs Invariant	Parameters change/don't change with time	Electronic switch vs Fixed resistor

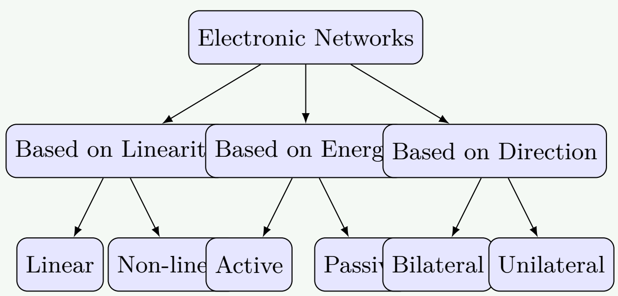


Figure 9. Classification of Electronic Networks

Mnemonic

"PLANT: Proportionality for Linear, Lively for Active, All directions for bilateral, Near for lumped, Time-fixed for invariant"

Question 2(c) OR [7 marks]

Derive the equation of characteristic impedance for T-network and π-network.

Solution

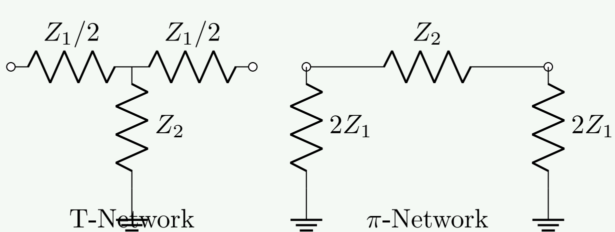


Figure 10. Symmetrical T and π Networks

Network	Characteristic Impedance Equation	Derivation Steps
T-Network	$Z_{0T} = \sqrt{Z_1(Z_1/4 + Z_2)}$	1. Apply symmetrical load Z_0 2. Find input impedance 3. For impedance matching, $Z_{in} = Z_0$ 4. Solve for Z_0
π-Network	$Z_{0\pi} = \sqrt{\frac{Z_1 Z_2}{1+Z_1/4Z_2}}$	1. Apply symmetrical load Z_0 2. Find input impedance 3. For impedance matching, $Z_{in} = Z_0$ 4. Solve for Z_0

- **Relation**: $Z_{0T} \times Z_{0\pi} = Z_1 \cdot Z_2$ (using simplified model elements)
- **Application**: Impedance matching and filters
- **Limitation**: Valid only for symmetrical networks

Mnemonic

"TIPSZ: T-networks and $\pi - networksImpedancesareProductsandSquarerootsofZvalues''$

Question 3(a) [3 marks]

Explain the principle of duality with example.

Solution

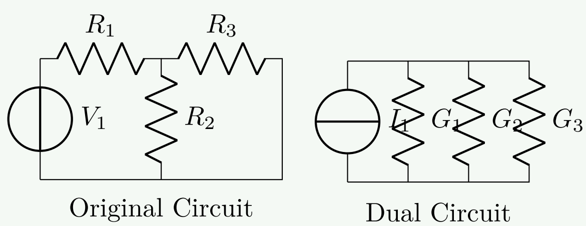


Figure 11. Principle of Duality

Principle of Duality: For every electrical network, there exists a dual network where:

Original	Dual	Example
Voltage (V)	Current (I)	10V source $\rightarrow$ 10A source
Current (I)	Voltage (V)	5A $\rightarrow$ 5V
Resistance (R)	Conductance (G)	100Ω $\rightarrow$ 100S
Series connection	Parallel connection	Series resistors $\rightarrow$ Parallel conductors
KVL	KCL	$\Sigma V = 0 \rightarrow \Sigma I = 0$

Mnemonic

"VIGOR: Voltage to current, Impedance to admittance, Graph remains, Open to closed, Resistors to conductors"

Question 3(b) [4 marks]

Explain the steps to calculate the load current in the circuit using Thevenin's Theorem.

Solution

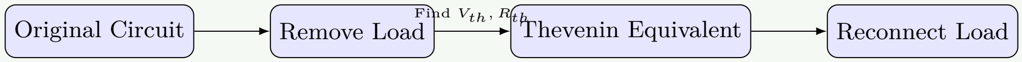


Figure 12. Thevenin's Theorem Procedure

Step	Description
1	Remove the load resistor from the circuit
2	Find open-circuit voltage (V_{th}) across load terminals
3	Calculate Thevenin resistance (R_{th}) looking back into circuit
4	Draw Thevenin equivalent circuit (V_{th} in series with R_{th})
5	Reconnect load resistor (R_L) to Thevenin circuit
6	Calculate load current: $I_L = V_{th}/(R_{th} + R_L)$

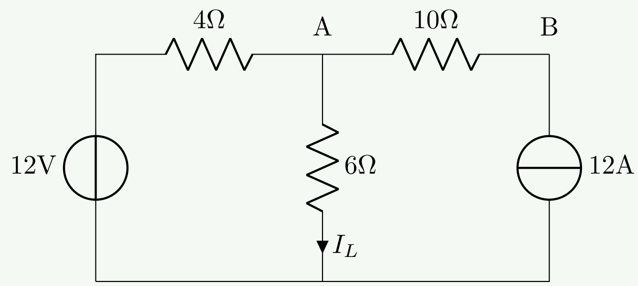
Mnemonic

"REVOLT: Remove load, Evaluate Voc, Obtain Rth, Look at Thevenin circuit, Use I = V/R formula"

Question 3(c) [7 marks]

Find the current through load resistor using superposition theorem.

Solution



Given Circuit

Figure 13. Superposition Problem

Table: Step-by-Step Solution:

Step	Description	Calculation
1	Consider 12V source only (replace 12A with open)	$I_1 = 12/(4 + 6 + 10) = 0.6A$ (10)
2	Consider 12A source only (replace 12V with short)	$I_2 = -12 \times 4/(4 + 10 + 6) = -2.4A$ ( )
3	Apply superposition	$I_L = I_1 + I_2 = 0.6 + (-2.4) = -1.8A$

Answer: $I_L = -1.8A$ (current flowing upward through 6Ω load resistor)

Mnemonic

"SONAR: Sources Only one at a time, Neutralize others, Add Results"

Question 3(a) OR [3 marks]

Write Maximum Power Transfer Theorem statement. What are the conditions for maximum power transfer for AC and DC networks?

Solution

Maximum Power Transfer Theorem: Maximum power is transferred from source to load when the load impedance is equal to the complex conjugate of the source internal impedance.

Network Type	Condition for Maximum Power Transfer
DC Networks	$R_L = R_{th}$ (Load resistance equals Thevenin resistance)
AC Networks	$Z_L = Z_{th}^*$ (Load impedance equals complex conjugate of Thevenin impedance) $R_L = R_{th}$ and $X_L = -X_{th}$

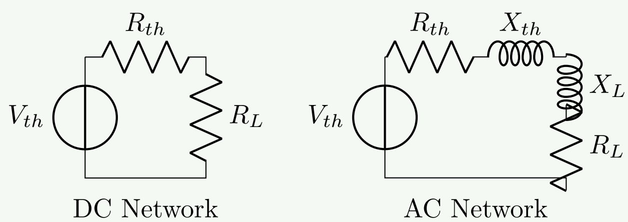


Figure 14. Maximum Power Transfer Circuits

Mnemonic

"MATCH: Maximum power At Terminals when Conjugate impedances are Honored"

Question 3(b) OR [4 marks]

Explain the steps to calculate the load current in the circuit using Norton's Theorem.

Solution

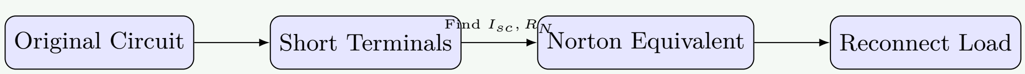


Figure 15. Norton's Theorem Steps

Step	Description
1	Remove the load resistor from the circuit
2	Find short-circuit current (I_{sc} or I_N) across load terminals
3	Calculate Norton resistance (R_N) looking back into circuit
4	Draw Norton equivalent circuit (I_N in parallel with R_N)
5	Reconnect load resistor (R_L) to Norton circuit
6	Calculate load current: $I_L = I_N \times R_N/(R_N + R_L)$

Mnemonic

"SENIOR: Short terminals, Evaluate Isc, Notice Rn value, Implement Norton circuit, Obtain result"

Question 3(c) OR [7 marks]

Demonstrate how the reciprocity theorem is applied to a given network.

Solution

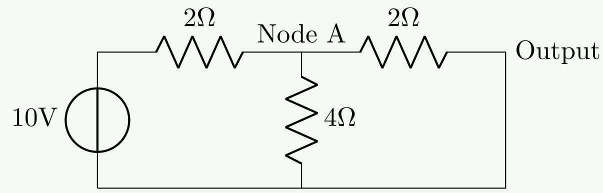


Figure 16. Reciprocity Theorem Example

Table: Applying Reciprocity Theorem:

Step	Circuit 1	Circuit 2	Verification
1	10V source at left, Find I_1 at right	10V source at right, Find I_2 at left	$I_1 = I_2$ confirms reciprocity
2	Create mesh equations using KVL	Create new mesh equations for swapped source	Solve both systems
3	$I_1 = \frac{10\times2}{2\times4+2\times2+4\times2} = 0.625A$	$I_2 = \frac{10\times2}{2\times4+2\times2+4\times2} = 0.625A$	$I_1 = I_2 = 0.625A$ ✓

Principle: In a passive network containing only bilateral elements, if voltage source E in branch 1 produces current I in branch 2, then the same voltage source E placed in branch 2 will produce the same current I in branch 1.

Mnemonic

"RESPECT: Rewire sources, Exchange positions, See if currents Preserve Equality when Circuit Transformed"

Question 4(a) [3 marks]

Explain coupled circuit.

Solution

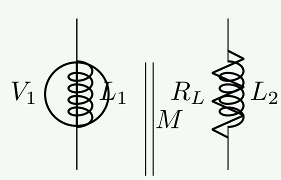


Figure 17. Coupled Circuit

Coupled Circuit: A circuit where energy is transferred between inductors through mutual inductance.

Parameter	Description
Mutual Inductance (M)	Measure of magnetic coupling between coils
Coupling Coefficient (k)	$k = M/\sqrt{L_1L_2}$, ranges from 0 (no coupling) to 1 (perfect coupling)
Applications	Transformers, filters, tuned circuits

Mnemonic

"MICE: Mutual Inductance Creates Energy transfer"

Question 4(b) [4 marks]

Derive the equation of co-efficient of coupling for coupled circuit.

Solution

Figure 18. Derivation Logic

Step	Description	Equation
1	Define mutual inductance	$M = N_2 \cdot \phi_{12}/I_1$
2	Define self-inductances	$L_1 = N_1 \cdot \phi_{11}/I_1$, $L_2 = N_2 \cdot \phi_{22}/I_2$
3	Maximum possible M	$M_{max} = \sqrt{L_1 L_2}$
4	Define coupling coefficient	$k = M/\sqrt{L_1 L_2}$

- **Range**: $0 \leq k \leq 1$
- **Physical meaning**: Fraction of flux from one coil linking with the other coil
- **Perfect coupling**: $k = 1$, when all flux links both coils

Mnemonic

"MASK: Mutual inductance And Self inductances create K"

Question 4(c) [7 marks]

Derive equation of resonance frequency for series resonance. Calculate resonant frequency, Q factor and bandwidth of series RLC circuit with R=20Ω, L=1H, C=1μF.

Solution

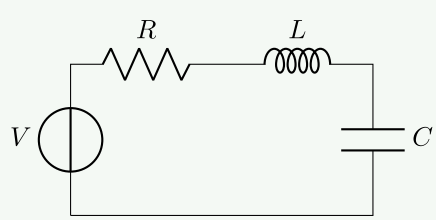


Figure 19. Series RLC Circuit

Derivation:

1. Impedance of series RLC: $Z = R + j(\omega L - 1/\omega C)$
2. At resonance, Imaginary part is zero: $\omega L - 1/\omega C = 0$
3. Solve for resonant frequency: $\omega_0 = 1/\sqrt{LC}$ or $f_0 = 1/(2\pi\sqrt{LC})$

Calculations:

Parameter	Formula	Calculation	Result
Resonant frequency	$f_0 = 1/(2\pi\sqrt{LC})$	$f_0 = 1/(2\pi\sqrt{1 \times 10^{-6}})$	159.15 Hz
Q factor	$Q = \omega_0 L/R$	$Q = 2\pi \times 159.15 \times 1/20$	50
Bandwidth	$BW = f_0/Q$	$BW = 159.15/50$	3.18 Hz

Mnemonic

"FQBR: Frequency from reactances, Q from resistance ratio, Bandwidth from Resonance divided by Q"

Question 4(a) OR [3 marks]

Explain Quality factor.

Solution

Quality Factor (Q): A dimensionless parameter that indicates how under-damped a resonator is, or alternatively, characterizes a resonator's bandwidth relative to its center frequency.

Definition	Mathematical Expression
Energy perspective	$Q = 2\pi \times \frac{\text{Energy stored}}{\text{Energy dissipated per cycle}}$
Circuit perspective	$Q = X/R$ (where X is reactance, R is resistance)
Frequency perspective	$Q = f_0/BW$ (where f_0 is resonant frequency, BW is bandwidth)

Mnemonic

"QSEL: Quality shows Energy vs. Loss and Selectivity"

Question 4(b) OR [4 marks]

Derive the equation of quality factor for a capacitor.

Solution

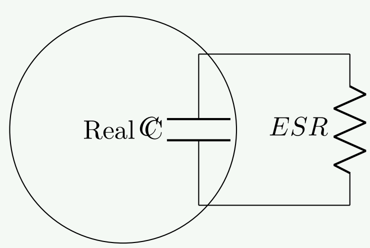


Figure 20. Real Capacitor Model

Derivation:

Step	Description	Equation
1	Define energy stored	$E_{stored} = CV^2/2$
2	Define energy loss per cycle	$E_{loss} = \pi CV^2/\omega CR = \pi V^2/\omega R$
3	Define Q factor	$Q = 2\pi \times E_{stored}/E_{loss}$
4	Substitute and simplify	$Q = 2\pi \times (CV^2/2) \div (\pi V^2/\omega R) = \omega CR$

Final equation: $Q = \omega CR = 1/(\omega RC) = 1/\tan\delta$
Where:
- ω = Angular frequency ($2\pi f$)
- R = Equivalent series resistance (ESR)
- C = Capacitance
- $\tan\delta$ = Dissipation factor

Mnemonic

"CORE: Capacitors' Quality equals One over Resistance times Capacitance"

Question 4(c) OR [7 marks]

Derive equation of resonance frequency for parallel resonance. Calculate resonant frequency, Q factor and bandwidth of parallel RLC circuit with R=30Ω, L=1H, C=1μF.

Solution

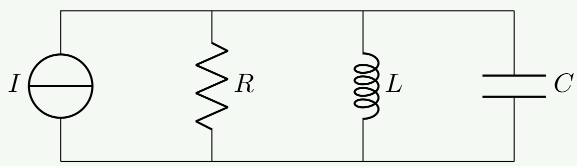


Figure 21. Parallel RLC Circuit

Derivation:
1. Admittance of parallel RLC: $Y = 1/R + 1/j\omega L + j\omega C$
2. At resonance, Imaginary part is zero: $1/j\omega L + j\omega C = 0 \Rightarrow j(\omega C - 1/\omega L) = 0$
3. Solve for resonant frequency: $\omega_0 = 1/\sqrt{LC}$ or $f_0 = 1/(2\pi\sqrt{LC})$

Calculations:

Parameter	**Formula**	**Calculation**	**Result**
Resonant frequency	$f_0 = 1/(2\pi\sqrt{LC})$	$f_0 = 1/(2\pi\sqrt{1 \times 10^{-6}})$	159.15 Hz
Q factor	$Q = R/\omega_0 L$	$Q = 30/(2\pi \times 159.15 \times 1)$	0.03
Bandwidth	$BW = f_0/Q$	$BW = 159.15/0.03$	5305 Hz

Mnemonic

"FPQB: Frequency from Parallel elements, Q from Resistance divided by reactance, Bandwidth from division"

Question 5(a) [3 marks]

Explain the T type attenuator.

Solution

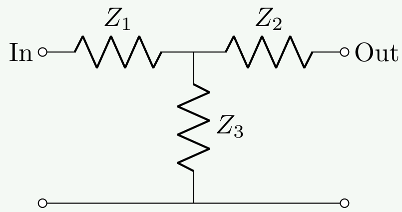


Figure 22. T-type Attenuator

T-type Attenuator: A passive network in T configuration used to reduce signal amplitude.

Component	Description	Formula
Z_1, Z_2	Series arms	$Z_1 = Z_2 = Z_0(N-1)/(N+1)$
Z_3	Shunt arm	$Z_3 = 2Z_0/(N^2-1)$
N	Attenuation ratio	$N = 10^{(dB/20)}$

- **Characteristic**: Symmetrical for matched source and load
- **Applications**: Signal level control, impedance matching
- **Advantage**: Maintains impedance matching with proper design

Mnemonic

"TSAR: T-shape with Series Arms and Resistance in middle"

Question 5(b) [4 marks]

Classify the various passive filter circuits.

Solution

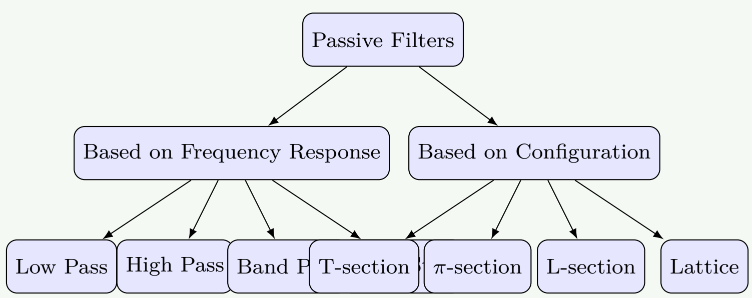


Figure 23. Classification of Passive Filters

Filter Type	Function	Typical Circuit	Applications
Low Pass	Passes low frequencies	RC, RL circuits	Audio filters, Power supplies
High Pass	Passes high frequencies	CR, LR circuits	Noise filtering, Signal conditioning
Band Pass	Passes a band of frequencies	RLC circuits	Radio tuning, Signal selection
Band Stop	Blocks a band of frequencies	Parallel RLC	Interference rejection

Mnemonic

"LHBB: Low High Band Band filters for Pass and Block"

Question 5(c) [7 marks]

Design constant-k type low pass and High pass filter with T-section having cutoff frequency= 1000Hz & load of 500Ω.

Solution

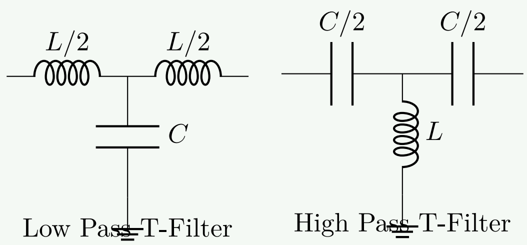


Figure 24. Constant-k Type T-Filters

Design Calculations:
For Constant-k T-type low pass filter:

Parameter	**Formula**	**Calculation**	**Value**
Cut-off frequency	$f_c = 1000$ Hz	Given	1000 Hz
Load impedance	$R_0 = 500\Omega$	Given	500 Ω
Series inductor	$L = R_0/\pi f_c$	$L = 500/(\pi \times 1000)$	159.15 mH
Half sections	$L/2$	159.15/2	79.58 mH
Shunt capacitor	$C = 1/(\pi f_c R_0)$	$C = 1/(\pi \times 1000 \times 500)$	0.636 μF

For Constant-k T-type high pass filter:

Parameter	**Formula**	**Calculation**	**Value**
Series capacitor	$C = 1/(4\pi f_c R_0)$	$C = 1/(4\pi \times 1000 \times 500)$	0.159 μF
Half sections	$C/2$	0.159/2	0.0795 μF
Shunt inductor	$L = R_0/(4\pi f_c)$	$L = 500/(4\pi \times 1000)$	39.79 mH

Mnemonic

"FRED: Frequency Ratio determines Element Dimensions"

Question 5(a) OR [3 marks]

Explain the π type attenuator.

Solution

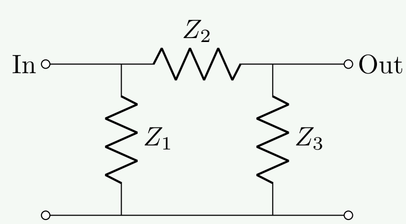


Figure 25. π-type Attenuator

π-type Attenuator: A passive network in π configuration used to reduce signal amplitude.

Component	Description	Formula
Z_2	Series arm	$Z_2 = 2Z_0/(N^2 - 1)$
Z_1, Z_3	Shunt arms	$Z_1 = Z_3 = Z_0(N + 1)/(N - 1)$
N	Attenuation ratio	$N = 10^{(dB/20)}$

- **Characteristic**: Symmetrical for matched source and load
- **Applications**: Signal level control, impedance matching
- **Advantage**: Good isolation between input and output

Mnemonic

"PASS: Pi-Attenuator has Series in middle and Shunt arms outside"

Question 5(b) OR [4 marks]

Classify various types of attenuators.

Solution

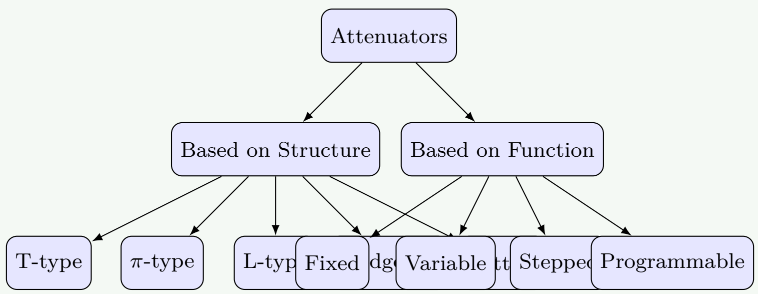


Figure 26. Classification of Attenuators

Table 1. Classification of Attenuators

Attenuator Type	Characteristics	Applications	Advantages
T-type	Series-Shunt-Series	Audio systems	Simple design
π-type	Shunt-Series-Shunt	RF circuits	Better isolation
L-type	Series-Shunt	Simple matching	Impedance transformation
Bridged-T	Balanced structure	Test equipment	Minimal distortion
Balanced	Symmetric dual paths	Differential signals	Common mode rejection

Mnemonic

"TPLBV: T, Pi, L, Bridged-T, and Variable attenuators"

Question 5(c) OR [7 marks]

Design a symmetrical T type attenuator and π type attenuator to give attenuation of 40dB and to work into the load of 500Ω.

Solution

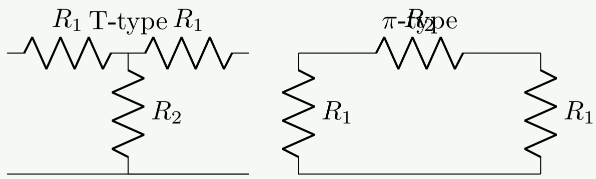


Figure 27. Designed Attenuators

Design Calculations:

Table 2. Calculation Steps

Step	Formula	Calculation	Value
Given	Attenuation = 40 dB	-	40 dB
Step 1	$N = 10^{(dB/20)}$	$10^{(40/20)}$	100
Step 2	$K = (N-1)/(N+1)$	$(100-1)/(100+1)$	0.98

For T-type attenuator:

Table 3. T-type Attenuator Values

Component	Formula	Calculation	Value
R_1 (series)	$Z_0 \cdot K$	500×0.98	490 Ω
R_2 (shunt)	$Z_0/(K \cdot (N-K))$	$500/(0.98 \times (100-0.98))$	5.15 Ω

For π-type attenuator:

Table 4. π-type Attenuator Values

Component	Formula	Calculation	Value
R_1 (shunt)	Z_0/K	$500/0.98$	510.2 Ω
R_2 (series)	$Z_0 \cdot K \cdot (N-K)$	$500 \times 0.98 \times (100-0.98)$	48,541 Ω

Mnemonic

"DANK: dB Attenuation is Number K, which determines resistor values"