Subject Name Solutions

4331101 – Winter 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Define (i) Node (ii) Branch and (iii) Loop for electronic network.

Solution

Node:

- **Junction point** where two or more branches meet in a network
- Points where elements are connected together
- Current sum of all branches at a node equals zero

Branch:

- **Single element** (R, L, or C) or path connecting two nodes
- Each branch has a specific current flowing through it
- Active branches contain sources; passive branches contain R, L, C

Loop:

- **Closed path** in a network formed by connected branches
- No node is encountered more than once
- Used in loop analysis for solving networks

Mnemonic

"NBL: Nodes join, Branches connect, Loops circle"

Question 1(b) [4 marks]

Three resistors of 200 Ω, 300 Ω and 500 Ω are connected in parallel across 100 V supply. Find (i) Current flowing through each resistor and Total current (ii) Equivalent Resistance

Solution

Table of Calculations:

Parameter	Formula	Calculation	Result
I_1(200)	I = V/R	100V/200Ω	0.5A
I_2(300)	I = V/R	100V/300Ω	0.333A
I_3(500)	I = V/R	100V/500Ω	0.2A
$I_{(total)}$	$I_1 + I_2 + I_3$	0.5+0.333+0.2	1.033A
$R_{(eq)}$	$1/R_{(eq)} = 1/R_1 + 1/R_2 + 1/R_3$	1/200+1/300+1/500	96.77Ω

Mnemonic

"Parallel paths divide current inversely with resistance"

Question 1(c) [7 marks]

Explain Series and Parallel connection for Capacitors

Solution

Capacitors in Series:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A["{+"] {-}{-}{-} B[C_{1}] {-}{-}{-} C[C_{2}] {-}{-}{-} D[C_{3}] {-}{-}{-} E["{}{-}"]}
{Highlighting}
{Shaded}
```

Table 1: Series Capacitors Properties

Property	Formula	Description
Equivalent Capacitance	$1/C_{(e}q) = 1/C_1 + 1/C_2 + 1/C_3$	Always smaller than smallest capacitor
Charge	$Q = Q_1 = Q_2 = Q_3$	Same on all capacitors
Voltage	$V = V_1 + V_2 + V_3$	Divides according to 1/C ratio
Energy	$E = CV^2/2$	Distributed across capacitors

Capacitors in Parallel:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A["{+"] {-}{-}{-} B["{}+"]}
    B {-{-}{-} C[C_{1}] {-}{-}{-} D["{}{-}"]}
    B {-{-}{-} E[C_{2}] {-}{-}{-} D}
    B {-{-}{-} F[C_{3}] {-}{-}{-} D}
    A {-{-}{-} D}
{Highlighting}
{Shaded}
```

Table 2: Parallel Capacitors Properties

Property	Formula	Description
Equivalent Capacitance	$C_{(e}q) = C_1 + C_2 + C_3$	Sum of individual capacitances
Charge	$Q = Q_1 + Q_2 + Q_3$	Distributes according to C value
Voltage	$V = V_1 = V_2 = V_3$	Same across all capacitors
Energy	$E = CV^2/2$	Sum of individual energies

Mnemonic

"Series caps add reciprocally, parallel caps add directly"

Question 1(c) OR [7 marks]

Explain Series and Parallel connection for Inductors.

Solution

Inductors in Series:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A["{+"] {-}{-}{-} B[L_{1}] {-}{-}{-} C[L_{2}] {-}{-}{-} D[L_{3}] {-}{-}{-} E["{}{-}"]}
{Highlighting}
{Shaded}
```

Table 3: Series Inductors Properties

Property	Formula	Description
Equivalent Inductance	$L_{(e}q) = L_1 + L_2 + L_3$	Sum of individual inductances

Current	$I = I_1 = I_2 = I_3$	Same through all inductors
Voltage	$V = V_1 + V_2 + V_3$	Divides according to L ratio
Energy	$E = LI^2/2$	Sum of individual energies

Inductors in Parallel:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A["{+"] {-}{-}{-} B["{}+"]}
    B {-{-}{-} C[L_{1}] {-}{-}{-} D["{}{-}"]}
    B {-{-}{-} E[L_{2}] {-}{-}{-} D}
    B {-{-}{-} F[L_{3}] {-}{-}{-} D}
    A {-{-}{-} D}
{Highlighting}
{Shaded}
```

Table 4: Parallel Inductors Properties

Property	Formula	Description
Equivalent Inductance	$1/L_{(eq)} = 1/L_1 + 1/L_2 + 1/L_3$	Always smaller than smallest inductor
Current	$I = I_1 + I_2 + I_3$	Divides according to 1/L ratio
Voltage	$V = V_1 = V_2 = V_3$	Same across all inductors
Energy	$E = LI^2/2$	Distributed across inductors

Mnemonic

"Series inductors add directly, parallel inductors add reciprocally"

Question 2(a) [3 marks]

Classify network elements.

Solution

Table 5: Classification of Network Elements

Category	Types	Examples
Active vs Passive	Active	Voltage/current sources, transistors
	Passive	Resistors, capacitors, inductors
Linear vs Non-linear	Linear	Resistors, ideal sources
	Non-linear	Diodes, transistors
Bilateral vs Unilateral	Bilateral	Resistors, capacitors, inductors
	Unilateral	Diodes, transistors
Lumped vs Distributed	Lumped	Discrete R, L, C components
	Distributed	Transmission lines

Mnemonic

"ALBU: Active/passive, Linear/non-linear, Bilateral/unilateral, lumped/distributed"

Question 2(b) [4 marks]

Three resistances of 10, 30 and 70 ohms are connected in star. Find equivalent resistances in delta connection.

Solution

Diagram: Star to Delta Conversion

```
graph TB
    subgraph Star Connection
        A((1)) {-{-}{-} R1[10Ω]}
        B((2)) {-{-}{-} R2[30Ω]}
        C((3)) {-{-}{-} R3[70Ω]}
        R1 {-{-}{-} D((0))}
        R2 {-{-}{-} D}
        R3 {-{-}{-} D}
    end

    subgraph Delta Connection
        A1((1)) {-{-}{-} R12[R_{1}_{2}]}
        A1 {-{-}{-} R31[R_{3}_{1}]}
        B1((2)) {-{-}{-} R12}
        B1 {-{-}{-} R23[R_{2}_{3}]}
        C1((3)) {-{-}{-} R23}
        C1 {-{-}{-} R31}
    end
```

Table 6: Star-Delta Conversion Formulas and Calculations

Delta Resistance	Formula	Calculation	Result
R_{12}	$(R_{12} + R_{23} + R_{31})/R_3$	$(10{\times}30 + 30 \times 70 + 70 \times 10)/70$	47.14Ω
R_{23}	$(R_{12} + R_{23} + R_{31})/R_1$	$(10{\times}30 + 30 \times 70 + 70 \times 10)/10$	330Ω
R_{31}	$(R_{12} + R_{23} + R_{31})/R_2$	$(10{\times}30 + 30 \times 70 + 70 \times 10)/30$	110Ω

Mnemonic

"Star-Delta: Product sum over opposite resistor"

Question 2(c) [7 marks]

Explain network.

Solution

Diagram: (Pi) Network

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input] {-{-}{-} B((Node 1))}
    B {-{-}{-} C[Z_{1}] {-}{-}{-} D((Node 2))}
    D {-{-}{-} E[Output]}
    B {-{-}{-} F[Z_{3}] {-}{-}{-} G((Ground))}
    D {-{-}{-} H[Z_{2}] {-}{-}{-} G}
{Highlighting}
{Shaded}
```

Table 7: Network Characteristics

Parameter	Description
Structure	Two shunt impedances $(Z_3, Z_2) and one series impedance (Z_1)$
Transmission Parameters	$A = 1 + Z_1/Z_2, B = Z_1, C = 1/Z_2 + 1/Z_3 + Z_1/(Z_{23}), D = 1 + Z_1/Z_3$
Impedance Parameters	$Z_{11} = Z_1 + Z_3, Z_{12} = Z_1, Z_{21} = Z_1, Z_{22} = Z_1 + Z_2$

Image Impedance	$Z_0 = \sqrt(Z_1 Z_2 Z_3/(Z_2 + Z_3))$
Applications	Matching networks, filters, attenuators
Conversion	Can be converted to T-network

Mnemonic

" has two legs down, one branch across"

Question 2(a) OR [3 marks]

List the types of network.

Solution

Table 8: Types of Networks

Category	Types
Based on Linearity	Linear Networks, Non-linear Networks
Based on Elements	Passive Networks, Active Networks
Based on Parameters	Time-variant, Time-invariant Networks
Based on Configuration	T-Network, -Network, Lattice Network
Based on Ports	One-port, Two-port, Multi-port Networks
Based on Symmetry	Symmetrical, Asymmetrical Networks
Based on Reciprocity	Reciprocal, Non-reciprocal Networks

Mnemonic

"LEPCPS: Linearity, Elements, Parameters, Configuration, Ports, Symmetry"

Question 2(b) OR [4 marks]

Three resistances of 20, 50 and 100 ohms are connected in delta. Find equivalent resistances in star connection.

Solution

Diagram: Delta to Star Conversion

```
graph TB
    subgraph Delta Connection
        A((1)) {-{-}{-} R12[20Ω]}
        A {-{-}{-} R31[100Ω]}
        B((2)) {-{-}{-} R12}
        B {-{-}{-} R23[50Ω]}
        C((3)) {-{-}{-} R23}
        C {-{-}{-} R31}
    end

    subgraph Star Connection
        A1((1)) {-{-}{-} R1[R_{1}]}
        B1((2)) {-{-}{-} R2[R_{2}]}
        C1((3)) {-{-}{-} R3[R_{3}]}
        R1 {-{-}{-} D((0))}
        R2 {-{-}{-} D}
        R3 {-{-}{-} D}
    end
```

Table 9: Delta-Star Conversion Formulas and Calculations

Star Resistance	Formula	Calculation	Result
R_1	$(R_{1231})/(R_{12} + R_{23} + R_{31})$	$(20\times100)/(20 + 50 + 100)$	11.76Ω

R_2	$(R_{1223})/(R_{12}+R_{23}+R_{31})$	$(20\times50)/(20+50+100)$	5.88Ω
R_3	$(R_{2331})/(R_{12}+R_{23}+R_{31})$	$(50\times100)/(20+50+100)$	29.41Ω

Mnemonic

"Delta-Star: Product of adjacent pairs over sum of all"

Question 2(c) OR [7 marks]

Explain T network.

Solution

Diagram: T Network

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input] {-{-}{-} B[Z_{1}] {-}{-}{-} C((Node))}
    C {-{-}{-} D[Z_{2}] {-}{-}{-} E[Output]}
    C {-{-}{-} F[Z_{3}] {-}{-}{-} G((Ground))}
{Highlighting}
{Shaded}
```

Table 10: T Network Characteristics

Parameter	Description
Structure	Two series impedances $(Z_1, Z_2) and one shunt impedance (Z_3)$
Transmission Parameters	$A = 1 + Z_1/Z_3, B = Z_1 + Z_2 + Z_1Z_2/Z_3, C = 1/Z_3,$ $D = 1 + Z_2/Z_3$
Impedance Parameters	$Z_{11} = Z_1 + Z_3, Z_{12} = Z_3, Z_{21} = Z_3, Z_{22} = Z_2 + Z_3$
Image Impedance	$Z_0T = \sqrt{(}Z_1Z_2 + Z_1Z_3 + Z_2Z_3)$
Applications	Matching networks, filters, attenuators
Conversion	Can be converted to -network

Mnemonic

"T has two arms across, one leg down"

Question 3(a) [3 marks]

Explain Kirchhoff's law.

Solution

Kirchhoff's Current Law (KCL):

- **Sum of currents** entering a node equals sum of currents leaving it
- Algebraic sum of currents at any node is zero
- = 0 (currents entering positive, leaving negative)

Kirchhoff's Voltage Law (KVL):

- **Sum of voltage drops** around any closed loop equals zero
- = 0 (voltage rises positive, drops negative)
- Based on conservation of energy

Diagram of Kirchhoff's Laws:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
```

```
graph TD
    subgraph KCL
        A((Node)) {-{-}{-} B[I_{1}]}
        A {-{-}{-} C[I_{2}]}
        A {-{-}{-} D[I_{3}]}
        A {-{-}{-} E[I_{4}]}
    end

    subgraph KVL
    direction LR
        F[V_{1}] {-}{-}{-} G[V_{2}] {-}{-}{-} H[V_{3}] {-}{-}{-} I[V_{4}] {-}{-}{-} F}
    end
{Highlighting}
{Shaded}
```

Mnemonic

"Current converges, Voltage voyages in a loop"

Question 3(b) [4 marks]

Explain Nodal analysis.

Solution

Diagram: Nodal Analysis Concept

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Step 1: Identify nodes] {-{-}{} B[Step 2: Select reference node]}
    B {-{-}{} C[Step 3: Assign node voltages]}
    C {-{-}{} D[Step 4: Apply KCL at each node]}
    D {-{-}{} E[Step 5: Solve equations]}
{Highlighting}
{Shaded}
```

Table 11: Nodal Analysis Method

Step	Description
1. Select reference node	Usually ground (0V)
2. Assign voltages	Label remaining node voltages ($V_1, V_2, etc.$)
3. Apply KCL	Write KCL equation at each non-reference node
4. Express currents	Use Ohm's Law to express branch currents
5. Solve equations	Find node voltages using simultaneous equations

Example: For nodes with voltages $V_1 and V_2$:

- **KCL at node 1: $(V_1 - 0)/R_1 + (V_1 - V_2)/R_2 + I_1 = 0$**
- **KCL at node 2: $(V_2 - V_1)/R_2 + (V_2 - 0)/R_3 + I_2 = 0$**

Mnemonic

"Nodal needs KCL to analyze voltage"

Question 3(c) [7 marks]

Use Thevenin's theorem to find current through the 5 Ω resistor for given circuit.

Solution

Diagram: Original Circuit and Thevenin Equivalent

```
+{-{-}+     +{-}{-}+}
|   |       |   |
12V 20Ω   8V  10Ω
|   |       |   |
+{-{-}+{-}{-}+{-}{-}+{-}{-}+}
    |       |
    +{-{-}+{-}{-}{-}+}
        |
        5Ω
        |
      {-{-}{-}}
        {-}
```

Steps to Find Thevenin Equivalent:

Table 12: Thevenin's Theorem Process and Calculations

Step	Process	Calculation	Result
1. Remove load (5Ω)	Calculate open-circuit voltage (Voc)	Voc = Voltage divider formula	Vth = 9.33V
2. Replace voltage sources with shorts	Calculate equivalent resistance (Req)	Req = 20Ω	
3. Draw Thevenin equivalent	Connect Vth and Rth in series with load		
4. Calculate load current	I = Vth/(Rth+RL)	I = 9.33/(6.67+5)	I = 0.8A

Mnemonic

"Thevenin transforms: Find Voc and Req, then calculate I"

Question 3(a) OR [3 marks]

State and explain Maximum Power Transfer Theorem.

Solution

Maximum Power Transfer Theorem:

- Maximum power is transferred from source to load when **load resistance equals source internal resistance** (RL = Rth)
- Only 50% efficiency is achieved at maximum power transfer
- Applies to DC and AC circuits (with complex impedances)

Diagram: Maximum Power Transfer

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Source Circuit] {-{-}{-} B[Rth]}
    B {-{-}{-} C[RL]}
    A {-{-}{-} D[Vth]}
    D {-{-}{-} C}
    E[Power Transfer Curve] {-{-}{-} F[Peak at RL = Rth]}
{Highlighting}
{Shaded}
```

Formula: P = $(\mathbf{Vth}^2)/(Rth + RL)^2$

Mnemonic

"Match the load to the source for maximum power transfer"

Question 3(b) OR [4 marks]

Explain method of drawing dual network using any circuit.

Solution

Diagram: Original and Dual Network Example

```
Original:        Dual:
R1               C1
o{-{-}{-}www{-}{-}{-}o     o{-}{-}{-}||{-}{-}{-}o}
|          |      |         |
C1         R2     L1        L2
|          |      |         |
o{-{-}{-}||{-}{-}{-}o      o{-}{-}{-}www{-}{-}o}
    L1                R1
```

Table 13: Dual Network Conversion Rules

Original Element	Dual Element	Example
Series connection	Parallel connection	Series R $\rightarrow ParallelC$
Parallel connection	Series connection	Parallel C $\rightarrow SeriesL$
Voltage source	Current source	V source $\rightarrow Isource$
Current source	Voltage source	I source $\rightarrow Vsource$
Resistor (R)	Conductance (1/R)	R $\rightarrow G(1/R)$
Inductor (L)	Capacitor (1/L)	L $\rightarrow C(1/L)$
Capacitor (C)	Inductor (1/C)	C $\rightarrow L(1/C)$

Duality Process:

1. Redraw network with meshes as nodes and nodes as meshes
2. Replace elements with their duals
3. Interchange series and parallel connections

Mnemonic

"Duality swaps: Series, V, R, L"

Question 3(c) OR [7 marks]

Find out Norton's equivalent circuit for the given network. Find out load current if (i) R$_(L_) = 3K(ii)R_(L_) = 1.5$

Solution

Diagram: Original Circuit and Norton Equivalent

```
    +{-{-}+}
    |  |
    6V 9KΩ
    |  |
+{-{-}{-}+{-}{-}+{-}{-}{-}{-}+}
|            |
3KΩ         6KΩ
|            |
+{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
      |
      RL
      |
```

```
{-{-}{-}}
 {-}
```

Table 14: Norton's Theorem Process and Calculations

Step	Process	Calculation	Result
1. Calculate short-circuit current (Isc)	Short load terminals and find current	Isc = Source current through short	In = 0.5mA
2. Calculate Norton resistance (Rn)	Replace sources with internal resistance	Rn = 9KΩ	
3. Draw Norton equivalent	Connect In and Rn in parallel		
4. Calculate load current (RL = 3KΩ)	I = In $\times Rn/(Rn + RL)$	I = 0.5mA $\times 3K/(3K + 3K)$	I = 0.25mA
5. Calculate load current (RL = 1.5Ω)	I = In $\times Rn/(Rn + RL)$	I = 0.5mA $\times 3K/(3K + 1.5)$	I = 0.33mA

Mnemonic

"Norton needs Isc and Req to make a current source"

Question 4(a) [3 marks]

Derive the equation of Quality factor Q for a coil.

Solution

Diagram: Coil Equivalent Circuit

```
     R       L
o{-{-}{-}www{-}{-}{-}000000{-}{-}{-}o}
```

Derivation of Q factor for a coil:

Table 15: Q Factor Derivation for Coil

Step	Expression	Explanation
1. Impedance	Z = R + j L	Complex impedance of coil
2. Reactive power	PX = (L)I^2	Power stored in inductor
3. Real power	PR = RI^2	Power dissipated in resistance
4. Quality factor	Q = PX/PR	Ratio of stored to dissipated power
5. Substitution	Q = (L)I$^2/RI^2$	Substitute expressions
6. Final equation	Q = L/R	Simplify to get Q factor

Mnemonic

"Quality coils: L/R shows energy saving ability"

Question 4(b) [4 marks]

A series RLC circuit has R = 50 Ω, L = 0.2 H and C = 10 F. Calculate (i) Q factor, (ii) BW, (iii) Upper cut off and lower cut off frequencies.

Solution

Diagram: Series RLC Circuit

```
R=50Ω

L=0.2H

o{-{-}{-}{-}www{-}{-}{-}{-}{-}{-}OOOOOO{-}{-}{-}{-}+}
                           |
                           |
                         {-{-}{-}}
                         {-{-}{-} C=10 F}
                           |
                           |
o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Table 16: Calculations for Series RLC Circuit

Parameter	Formula	Calculation	Result
Resonant frequency (fr)	**fr = 1/(2)**	**1/(2** $\sqrt{(}0.2 \times 10 \times 10^{-6}))$	**112.5 Hz**
Quality factor (Q)	**Q = (1/R)**$\sqrt{(}L/C)$	**(1/50)**$\sqrt{(}0.2/10 \times 10^{-6})$	**28.28**
Bandwidth (BW)	**BW = fr/Q**	**112.5/28.28**	**3.98 Hz**
Lower cutoff (f_1)	$f_1 = fr - BW/2$	**112.5 - 3.98/2**	**110.51 Hz**
Upper cutoff (f_2)	$f_2 = fr + BW/2$	**112.5 + 3.98/2**	**114.49 Hz**

Mnemonic

"Q defines BW, which sets cutoff frequencies"

Question 4(c) [7 marks]

Explain Mutual Inductance along with Co-efficient of mutual inductance. Also derive the equation of K.

Solution

Diagram: Mutual Inductance Between Two Coils

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input] {-{-}{-} B[L_{1}]}
    B {-{-}{-} C[Output 1]}
    D[Input] {-{-}{-} E[L_{2}]}
    E {-{-}{-} F[Output 2]}
    B {-.{-} E}
    linkStyle 4 stroke{-width:2px,stroke{-}dasharray: 5 5}
{Highlighting}
{Shaded}
```

Mutual Inductance (M):

- **When current in one coil induces voltage in nearby coil**
- **Coupling between coils depends on position, orientation, and medium**
- **Mutual inductance M in henries (H)**

Table 17: Mutual Inductance Equations

Parameter	Formula	Description
Induced voltage	$v_2 = M(di_1/dt)$	**Voltage induced in coil 2 due to current in coil 1**

Mutual inductance	**M** $= k\sqrt{(L_1 L_2)}$	**Mutual inductance related to self-inductances**
Coupling coefficient (k)	$k = M/\sqrt{(L_1 L_2)}$	**Measure of coupling between coils** ($0 \leq k \leq 1$)
Total inductance	$Lt = L_1 + L_2 \pm 2M$	**Total inductance depends on direction of coupling**

Derivation of Coupling Coefficient (k):

- **From** $M = k\sqrt{(L_1 L_2)}$
- **Rearranging:** $k = M/\sqrt{(L_1 L_2)}$
- **k = 1 for perfect coupling**
- **k = 0 for no coupling**
- **Typically 0.1 to 0.9 for real circuits**

Mnemonic

"M measures magnetic linkage, k shows coupling quality"

Question 4(a) OR [3 marks]

Explain the types of coupling for coupled circuit.

Solution

Diagram: Types of Coupling

```
graph TB
    A[Types of Coupling] {-{-} B[Tight Coupling]}
    A {-{-} C[Loose Coupling]}
    A {-{-} D[Critical Coupling]}
    A {-{-} E[Direct Coupling]}
    A {-{-} F[Inductive Coupling]}
    A {-{-} G[Capacitive Coupling]}
```

Table 18: Types of Coupling

Coupling Type	Characteristics	Applications
Tight Coupling	k > 0.5, high energy transfer	Transformers
Loose Coupling	k < 0.5, selective frequency response	RF tuning circuits
Critical Coupling	k adjusted for optimal bandwidth	RF filters
Direct Coupling	Components directly connected	Audio amplifiers
Inductive Coupling	Magnetic field transfers energy	Transformers, wireless charging
Capacitive Coupling	Electric field transfers energy	Signal coupling between stages

Mnemonic

"TLCLIC: Tight, Loose, Critical, Direct, Inductive, Capacitive"

Question 4(b) OR [4 marks]

Q = 100, resonant frequency Fr = 50 KHz. Find out (i)

Required capacitance C, (ii) Resistance R of the coil, (iii) BW.A parallel resonant circuit having inductance of 10 mH with quality factor

Q = 100, resonant frequency Fr = 50 KHz. Find out (i)

Required capacitance C, (ii) Resistance R of the coil, (iii) BW.

Solution

Diagram: Parallel Resonant Circuit

```
        L=10mH
o{-{-}{-}{-}{-}{-}{-}OOOOOO{-}{-}{-}{-}{-}{-}{-}+}
|                     |
|        R            |
|       WWW           |
|                     |
|                    {-{-}{-}}
|                    {-{-}{-} C=?}
|                     |
o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Table 19: Calculations for Parallel Resonant Circuit

Parameter	Formula	Calculation	Result
Resonant frequency	fr = 1/(2)	50 kHz = $1/(2\ \sqrt{(}10 \times 10^{-3}))$	
Capacitance (C)	C = $1/(4\ ^{2}fr^{2}L)$	C = $1/(4\ ^{2} \times (50 \times 10^{3})^{2} \times 10 \times 10^{-3})$	C = 1.01 nF
Resistance (R)	Q = L/R	100 = 2 $\times 50 \times 10^{3} \times 10 \times 10^{-3}/R$	R = 31.4 Ω
Bandwidth (BW)	BW = fr/Q	BW = $50{\times}10^{3}/100$	BW = 500 Hz

Mnemonic

"Parallel resonance parameters: C from fr, R from Q, BW from fr/Q"

Question 4(c) OR [7 marks]

Explain Band width and Selectivity of a series RLC circuit. Also establish the relation between Q factor and BW for series resonance circuit.

Solution

Diagram: Frequency Response of Series RLC Circuit

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Frequency f] {-{-}{} B[Impedance Z]}
    B {-{-}{} C[Resonance at fr]}
    B {-{-}{} D[f1: Lower cutoff]}
    B {-{-}{} E[f2: Upper cutoff]}
    F[BW = f2 {- f1] {-}{-}{} G[Q = fr/BW]}
{Highlighting}
{Shaded}
```

Bandwidth (BW):

- **Frequency range** between half-power points
- At half-power points, impedance is $\sqrt{2} times minimum value$
- BW = $f_2 - f_1, where f_1 and f_2 are lower and upper cutoff frequencies$

Selectivity:

- **Ability to reject** frequencies outside the bandwidth
- Higher Q means higher selectivity and narrower bandwidth
- Measured by steepness of response curve

Table 20: Series RLC Bandwidth Parameters

Parameter	Formula	Description
Bandwidth (BW)	BW = $f_2 - f_1$	Difference between upper and lower cutoff points
Half-power points	Z = $\sqrt{2} \times Z_{mn}$	Points where power drops to half of maximum
Resonant frequency	fr = 1/(2)	Center frequency
Quality factor	Q = $_oL/R$	Energy storage vs. dissipation ratio

Derivation of Q-BW Relationship:

- At resonance, impedance Z = R
- At cutoff frequencies, Z = $\sqrt{2}R$
- This occurs when reactance XL - XC =
- At $f_1 : L - 1/C = -R$
- At $f_2 : L - 1/C = +R$
- Solving these equations: BW = R/2 L = fr/Q
- Therefore, Q = fr/BW

Mnemonic

"Quality inversely proportional to bandwidth"

Question 5(a) [3 marks]

Design a symmetrical T type attenuator to give attenuation of 60 dB and work in to the load of 500 Ω resistance.

Solution

Diagram: Symmetrical T-type Attenuator

```
     R1/2          R1/2
 o{-{-}{-}{-}www{-}{-}{-}{-}{-}o{-}{-}{-}{-}www{-}{-}{-}{-}o}
 |             |           |
 |             |           |
 |            R2           |
 |             |           |
 |             |           |
IN           {-{-}{-}        OUT}
              {-}
```

Table 21: Attenuator Design

Parameter	Formula	Calculation	Result
Attenuation (N)	N = 10^(dB/20)	10^(60/20)	N = 1000
Z_0	Given	500 Ω	500 Ω
R_1	$R_1 = 2Z_0(N-1)/(N+1)$	$2{\times}500 \times (1000-1)/(1000+1)$	$R_1 = 998$
R_2	$R_2 = Z_0(N+1)/(N-1)$	$500{\times}(1000+1)/(1000-1)$	$R_2 = 0.5$

Mnemonic

"T attenuator: $R_1 seriesdivides, R_2 shunts''$

Question 5(b) [4 marks]

Compare Band pass and Band stop filters.

Solution

Diagram: Band Pass vs Band Stop Response

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Frequency] {-{-}{} B[Gain]}
    B {-{-}{}|Band Pass| C[Pass in middle band]}
    B {-{-}{}|Band Stop| D[Reject in middle band]}
{Highlighting}
{Shaded}
```

Table 22: Comparison of Band Pass and Band Stop Filters

Parameter	Band Pass Filter	Band Stop Filter
Frequency Response	Passes frequencies within specific band	Rejects frequencies within specific band
Circuit Structure	Series & parallel resonant circuits	Series & parallel resonant circuits
Cut-off Frequencies	Has lower (f_1)$andupper(f_2)cut-offs$	Has lower (f_1)$andupper(f_2)cut-offs$
Bandwidth	BW = $f_2 - f_1$	BW = $f_2 - f_1$
Applications	Radio tuning, audio equalization	Noise elimination, harmonic suppression
Implementation	Series/parallel combination of HPF & LPF	Parallel/series combination of HPF & LPF
Phase Response	$0°atresonance$	$180°atresonance$

Mnemonic

"Pass the middle or Stop the middle"

Question 5(c) [7 marks]

Explain constant K Low Pass Filter.

Solution

Diagram: Constant K Low Pass Filter T and Sections

```
T{-section:                       {-}section:}
    L/2         L/2                 L
o{-{-}{-}OOOO{-}{-}{-}{-}o{-}{-}{-}OOOO{-}{-}{-}{-}{-}{-}o  o{-}{-}{-}OOOO{-}{-}{-}o}
            |                  |      |
            C                 C/2    C/2
            |                  |      |
            |                  |      |
o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o  o{-}{-}{-}{-}{-}{-}{-}{-
```

Constant K Low Pass Filter:

- **Passes frequencies** below cutoff frequency (fc)
- Attenuates frequencies above fc
- "Constant K" means product of series and shunt impedances is constant at all frequencies ($Z_1 Z_2 = K^2$)

Table 23: T and Section Parameters

Parameter	T-section	-section
Series arm	L/2 at each end	L in center
Shunt arm	C in center	C/2 at each end
Cutoff frequency	fc = 1/( )	fc = 1/( )
Characteristic impedance	$Z_0 = \sqrt(L/C)$	$Z_0 = \sqrt(L/C)$
Design equation for L	L = Z_0/fc	L = Z_0/fc
Design equation for C	C = 1/(fcZ_0)	C = 1/(fcZ_0)

Frequency Response:

- Passes DC and low frequencies with minimal attenuation
- Attenuation increases rapidly above cutoff frequency
- Phase shift increases with frequency

Mnemonic

"Constant K LPF: L series blocks high, C shunt shorts high"

Question 5(a) OR [3 marks]

Design a high pass filter with T section having a cut-off frequency of 2 KHz with a load resistance of 500 Ω.

Solution

Diagram: High Pass T-section Filter

```
     C/2          C/2
  o{-{-}{-}||{-}{-}{-}{-}o{-}{-}{-}||{-}{-}{-}o}
  |         |        |
  |         L        |
  |        OOO       |
  |         |        |
 IN        {-{-}{-}      OUT}
            {-}
```

Table 24: High Pass Filter Design

Parameter	Formula	Calculation	Result
Cutoff frequency (fc)	Given	2 kHz	2 kHz
Load resistance (R_0)	Given	500 Ω	500 Ω
Series capacitance (C/2)	C = 1/(fcR_0)	C = 1/($\times 2 \times 10^3 \times 500$)	C = 0.318 F
Total capacitance (C)	2 $\times (C/2)$	2 $\times 0.159F$	C = 0.318 F
Shunt inductance (L)	L = $R_0/(fc)$	L = 500/($\times 2 \times 10^3$)	L = 79.6 mH

Mnemonic

"High pass T: C blocks DC in series, L passes high in shunt"

Question 5(b) OR [4 marks]

Give classification of filters.

Solution

Diagram: Filter Classification

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Filters] {-{-}{} B[By Function]}
    A {-{-}{} C[By Design]}
    A {-{-}{} D[By Implementation]}
    B {-{-}{} B1[Low Pass]}
    B {-{-}{} B2[High Pass]}
    B {-{-}{} B3[Band Pass]}
    B {-{-}{} B4[Band Stop]}
```

```
    B {-{-}{} B5[All Pass]}
    C {-{-}{} C1[Passive]}
    C {-{-}{} C2[Active]}
    C1 {-{-}{} C11[Constant{-}k]}
    C1 {-{-}{} C12[m{-}derived]}
    C1 {-{-}{} C13[Composite]}
    D {-{-}{} D1[Analog]}
    D {-{-}{} D2[Digital]}
{Highlighting}
{Shaded}
```

Table 25: Classification of Filters

Classification By	Types	Characteristics
Function	Low Pass	Passes frequencies below cutoff
	High Pass	Passes frequencies above cutoff
	Band Pass	Passes frequencies within a band
	Band Stop	Rejects frequencies within a band
	All Pass	Passes all frequencies but modifies phase
Design	Passive	Uses passive elements (R, L, C)
	Active	Uses active components (op-amps)
Response	Butterworth	Maximally flat response
	Chebyshev	Ripple in passband, steeper rolloff
	Bessel	Linear phase response
	Elliptic	Ripple in both passband and stopband
Implementation	Passive Filter Types	Constant-k, m-derived, composite

Mnemonic

"FLHBA: Function (Low/High/Band/All-pass), Design, Response, Implementation"

Question 5(c) OR [7 marks]

Explain constant K High Pass Filter.

Solution

Diagram: Constant K High Pass Filter T and Sections

```
T{-section:                        {-}section:}
     C/2          C/2                  C
o{-{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}{-}o   o{-}{-}{-}{-}||{-}{-}{-}{-}o}
             |                   |      |
             L                   L/2    L/2
             |                   |      |
             |                   |      |
o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o  o{-}{-}{-}{-}{-}{-}{-
```

Constant K High Pass Filter:

- **Passes frequencies** above cutoff frequency (fc)
- Attenuates frequencies below fc
- "Constant K" means product of series and shunt impedances is constant at all frequencies ($Z_1 Z_2 = K^2$)

Table 26: T and Section Parameters

Parameter	T-section	-section
Series arm	C/2 at each end	C in center
Shunt arm	L in center	L/2 at each end
Cutoff frequency	fc = 1/( )	fc = 1/( )
Characteristic impedance	$Z_0 = \sqrt{(L/C)}$	$Z_0 = \sqrt{(L/C)}$
Design equation for L	$L = Z_0/(fc)$	$L = Z_0/(fc)$
Design equation for C	$C = 1/(\ fcZ_0)$	$C = 1/(\ fcZ_0)$

Frequency Response:

- Blocks DC and low frequencies
- Passes high frequencies with minimal attenuation
- Attenuation increases as frequency decreases below cutoff
- Phase shift approaches $0^\circ atveryhighfrequencies$

Mnemonic

"Constant K HPF: C series blocks low, L shunt passes high"