Subject Name Solutions

4331101 – Winter 2023

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Explain Source transformation with appropriate diagram.

Solution

Source transformation is a technique to convert voltage source to current source or vice-versa without changing the external circuit behavior.

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    subgraph "Voltage Source Circuit"
    VS[V] {-{-}{-} RS[R]}
    end
    subgraph "Current Source Circuit"
    IS[I] {-.{-} RP[R]}
    end

    VS {-{-}{-} IS}

    class VS,IS fill:\#f96
{Highlighting}
{Shaded}
```

- **Voltage to Current Source**: I = V/R, same R in parallel
- **Current to Voltage Source**: V = I, same R in series

Mnemonic

"Value Stays, Resistance Shifts" (V=IR always applies)

Question 1(b) [4 marks]

Determine voltage, current and power relationship for two capacitor connected in series.

Solution

Table 1: Capacitors in Series

Parameter	Formula	Explanation
Total Capacitance	$1/CT = 1/C_1 + 1/C_2$	Reciprocal sum
Voltage Distribution	$V_1/V_2 = C_2/C_1$	Inverse to capacitance ratio
Current	$I = I_1 = I_2$	Same current flows through all
Charge	$Q = Q_1 = Q_2$	Same charge on each capacitor
Power	$P = VI = V^2/Xc$	Where Xc = 1/2 fC

- **Voltage division**: $V_1 = V \times C_2/(C_1 + C_2)$
- **Charge storage**: $Q = C_1 C_2 V/(C_1 + C_2)$

Mnemonic

"Capacitors in Series: Currents Same, Capacitance Shrinks"

Question 1(c) [7 marks]

State difference between Series and parallel connection of resistor and derive the equation of total resistance of parallel connection.

Solution

Table 2: Series vs Parallel Resistors

Parameter	Series Connection	Parallel Connection
Total Resistance	Increases (RT = $R_1 + R_2 + \ldots$)	Decreases (RT < smallest R)
Current	Same through all (I)	Divides (IT = $I_1 + I_2 + \ldots$)
Voltage	Divides (VT = $V_1 + V_2 + \ldots$)	Same across all (V)
Power	PT = $P_1 + P_2 + \ldots$	PT = $P_1 + P_2 + \ldots$

Derivation for Parallel Resistance:
By Kirchhoff's Current Law: IT = $I_1 + I_2 + \ldots + In$
Substituting
I = V/R: V/RT = V/$R_1 + V/R_2 + \ldots + V/Rn$
Dividing by V: 1/RT = 1/$R_1 + 1/R_2 + \ldots + 1/Rn$
For two resistors: 1/RT = 1/$R_1 + 1/R_2, whichgivesRT = R_1R_2/(R_1 + R_2)$

Mnemonic

"In Parallel, Reciprocals Add"

Question 1(c) OR [7 marks]

1) Define unilateral, bilateral network, Mesh and Loop. 2) Draw voltage division circuit and write equation.

Solution

Table 3: Network Definitions

Term	Definition	Example
Unilateral Network	Allows current in one direction only	Diode circuit
Bilateral Network	Allows current in both directions	RLC circuit
Mesh	Planar network path with no other path inside it	Single closed path
Loop	Any closed path in a network	Can contain other elements

Voltage Division Circuit:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Input] {-{-}{-} R1[R_{1}] {-}{-}{-} B[Output V_{0}] {-}{-}{-} R2[R_{2}] {-}{-}{-} C[Ground]}
{Highlighting}
{Shaded}
```

Voltage Division Equation: Vo = Vin $\times R_2/(R_1 + R_2)$

- **Proportional to**: Resistance across which voltage is measured
- **Inversely proportional to**: Total resistance

Mnemonic

"Voltage Output equals Input times Resistance Ratio"

Question 2(a) [3 marks]

Derive equations to convert T-type network into -type network

Solution

Diagram: T to Conversion

```
  A    Z_{1    B         A            B}
   o{-{-}{-}//{-}{-}o          o         o}
   |          |         {       /}
   |          |    ={          /}
   Z_{3         Z_{2}              /}
   |          |            Z_{1_{2} Z_{2}_{3}}
   o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}o             /}
   C                        o
                            C
```

Conversion Equations:

- $Z_{12} = (Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1)/Z_3$
- $Z_{23} = (Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1)/Z_1$
- $Z_{31} = (Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1)/Z_2$

Where $Z_1, Z_2, Z_3 are T - network impedances and Z_{12}, Z_{23}, Z_{31} are - network impedances.$

Mnemonic

"Sum of all products divided by the opposite"

Question 2(b) [4 marks]

Explain Open circuit Impedance Parameter (Z Parameter)

Solution

Z-Parameters: Also called open-circuit impedance parameters because they're measured with output ports open.

Table 4: Z-Parameter Equations

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

Matrix Form: $[V_1] = [Z_{11} Z_{12}] \times [I_1][V_2][Z_{21} Z_{22}][I_2]$

- **Symmetrical Network**: $Z_{12} = Z_{21}$
- **Units**: Ohms (Ω)

Mnemonic

"Vs equal Zs times Is"

Question 2(c) [7 marks]

Derive the expressions for the characteristic impedance ($\mathbf{Z}_{0t}) for Symmetrical T Network.$

Solution

Diagram: Symmetrical T-Network

```
        Z_{1/2         Z_{1}/2}
    o{-{-}{-}{-}//{-}{-}{-}{-}o{-}{-}{-}//{-}{-}{-}{-}o}
    |            |           |
    |            |           |
   Z_{0_{t}          Z_{2}          Z_{0}_{t}}
    |            |           |
    |            |           |
    o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o}
```

Derivation:

1. **For symmetrical T-network,** $\mathbf{Z}_1 is split equally across two arms (Z_1/2 each)$
1. **For image impedance matching:** $\mathbf{Z}_{0t} = Z_{0t}'$

By voltage division: $\mathbf{V}_2/V_1 = Z_{0t}/(Z_1/2 + Z_{0t} + Z_2||Z_{0t})$
For matched condition: $\mathbf{Z}_{0t}^2 = (Z_1/2)(Z_1/2 + Z_2)$
Therefore: $\mathbf{Z}_{0t} = \sqrt[(Z_1/2)(Z_1/2+Z_2)]{Z}_{0t} = \sqrt[Z_1^2/4+Z_1Z_2/2]{Z}_{0t} =$

Mnemonic

"**The square root of** $\mathbf{Z}_1 times what Z_1 meets''$

Question 2(a) OR [3 marks]

Derive equations to convert -type network into T-type network.

Solution

Diagram: to T Conversion

```
  A            B         A    Z_{1    B}
  o          o           o{-{-}{-}//{-}{-}{-}o}
   {        /            |          |}
    {      /             |          |}
    Z_{1_{2}    Z_{2}_{3}      =    Z_{3}          Z_{2}}
     {    /              |          |}
      {  /               o{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o}
       o                  C
       C
```

Conversion Equations:

- $\mathbf{Z}_1 = (Z_{12}Z_{31})/(Z_{12} + Z_{23} + Z_{31})$
- $\mathbf{Z}_2 = (Z_{23}Z_{12})/(Z_{12} + Z_{23} + Z_{31})$
- $\mathbf{Z}_3 = (Z_{31}Z_{23})/(Z_{12} + Z_{23} + Z_{31})$

Where $\mathbf{Z}_{12}, Z_{23}, Z_{31} are - network impedances and Z_1, Z_2, Z_3 are T - network impedances.$

Mnemonic

"**Product of adjacent pairs divided by sum of all**"

Question 2(b) OR [4 marks]

Explain Admittance Parameter (Y Parameter).

Solution

Y-Parameters: Also called short-circuit admittance parameters because they're measured with output ports shorted.

Table 5: Y-Parameter Equations

Parameter	Definition	Calculation
$\mathbf{Y}_{11}$	Input admittance with output shorted	$\mathbf{Y}_{11} = I_1/V_1 (when V_2 = 0)$
$\mathbf{Y}_{12}$	Transfer admittance from port 2 to port 1	$\mathbf{Y}_{12} = I_1/V_2 (when V_1 = 0)$
$\mathbf{Y}_{21}$	Transfer admittance from port 1 to port 2	$\mathbf{Y}_{21} = I_2/V_1 (when V_2 = 0)$
$\mathbf{Y}_{22}$	Output admittance with input shorted	$\mathbf{Y}_{22} = I_2/V_2 (when V_1 = 0)$

Matrix Form: $[\mathbf{I}_1] = [Y_{11} Y_{12}] \times [V_1][I_2][Y_{21} Y_{22}][V_2]$

- **Symmetrical Network:** $\mathbf{Y}_{12} = Y_{21}$
- **Units: Siemens (S)**

Mnemonic

"Is equal Ys times Vs"

Question 2(c) OR [7 marks]

Derive the expressions for the characteristic impedance $(\mathbf{Z}_0) for Symmetrical Network.$

Solution

Diagram: Symmetrical -Network

```
o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o}
 |            |           |
 |            |           |
2Z_{3         Z_{1}         2Z_{3}}
 |            |           |
 |            |           |
o{-{-}{-}{-}Z_{0} {-}{-}{-}{-}o{-}{-}{-}{-}Z_{0} {-}{-}{-}o}
```

Derivation:

1. **For symmetrical -network, admittance** $\mathbf{Y}_1 in shunt arms is split into 2 equal parts (Y_3 = Y_1/2)$
1. **For image impedance matching:** $\mathbf{Z}_0 = Z_0'$

By current division: $\mathbf{I}_2/I_1 = Z_0/(Z_0 + Z_1 + Z_0||2Z_3)$
For matched condition: $\mathbf{Z}_0{}^2 = Z_1(2Z_3)/(Z_1 + 2Z_3)$
Simplifying: $\mathbf{Z}_0 = \sqrt[Z_1(2Z_3)/(Z_1+2Z_3)]{Z}_0 =$

Mnemonic

"Pi's impedance equals the geometric mean of what it sees"

Question 3(a) [3 marks]

Explain principal of duality.

Solution

Principle of Duality: For every electrical network, there exists a dual network with similar behavior but with interchanged elements.

Table 6: Dual Element Pairs

Original Circuit	Dual Circuit
Voltage (V)	Current (I)
Current (I)	Voltage (V)
Resistance (R)	Conductance (G)
Inductance (L)	Capacitance (C)
Series Connection	Parallel Connection
KVL	KCL
Mesh Analysis	Nodal Analysis

- Network Transformation: Replace each element with its dual
- Topology Transformation: Replace each node with a loop and each loop with a node

Mnemonic

"Series to Parallel, Source turns dual, V becomes I and I becomes V"

Question 3(b) [4 marks]

State and Explain Thevenin's Theorem.

Solution

Thevenin's Theorem: Any linear two-terminal network can be replaced by an equivalent circuit consisting of a voltage source (Vth) in series with a resistance (Rth).

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph "Original Network"
    direction LR
    A[Complex Network] {-{-}{-} R1[Load]}
    end
    subgraph "Thevenin Equivalent"
    direction LR
    VTH[Vth] {-{-}{-} RTH[Rth] {-}{-}{-} RL[Load]}
    end
{Highlighting}
{Shaded}
```

Finding Thevenin Equivalent:

1. Remove the load resistance
2. Calculate open-circuit voltage (Vth)
3. Find Rth by:
   - Deactivating all sources (V=0, I=0)
   - Calculate resistance between terminals

Mnemonic

"Open for Voltage, Dead for Resistance"

Question 3(c) [7 marks]

State and explain KCL and KVL with example.

Solution

Table 7: Kirchhoff's Laws

Law	Statement	Mathematical Form	Application
KCL	**Sum of currents entering a node equals sum of currents leaving it**	=	**Node Analysis**
KVL	**Sum of voltage drops around any closed loop equals zero**	= 0	**Mesh Analysis**

KCL Example:

```
        I_{1}
        ↓
        o
       / {}
      /   {}
     I_{2    I_{3}}
    /       {}
   o         o
```

```
At node: I_{1 = I_{2} + I_{3}}
```

KVL Example:

```
    +    R_{1     +}
    o{-{-}{-}///{-}{-}o}
    |           |
   V_{1           R_{2}}
    |           |
    o{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o}
    {-            {-}}
```

```
Around loop: V_{1 {-} I_{1} {-} I_{2} = 0}
```

Mnemonic

"Currents at nodes sum to zero, Voltages round loops also do"

Question 3(a) OR [3 marks]

Explain the solution of a network by Mesh Analysis.

Solution

Mesh Analysis: A circuit analysis method that uses mesh currents as variables to solve for unknown currents and voltages.
Diagram: Simple Two-Mesh Circuit

```
    +   R_{1    +   R_{3}   +}
    o{-{-}//{-}{-}o{-}{-}//{-}{-}o}
    |         |         |
   V_{1        R_{2}        V_{2}}
    |         |         |
    o{-{-}{-}{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}{-}{-}{-}{-}o}
    {-          {-}         {-}}
     Mesh 1     Mesh 2
```

Steps:

1. Identify meshes (closed loops)
2. Assign clockwise mesh currents (I_1, I_2)
2. Apply KVL to each mesh
3. Solve the resulting simultaneous equations

Example Equations:

- Mesh 1: $V_1 = I_1(R_1 + R_2) - I_2R_2$
- Mesh 2: $-V_2 = -I_1R_2 + I_2(R_2 + R_3)$

Mnemonic

"Assign, Apply KVL, Arrange, and Solve"

Question 3(b) OR [4 marks]

State and Explain Norton's Theorem.

Solution

Norton's Theorem: Any linear two-terminal network can be replaced by an equivalent circuit consisting of a current source (IN) in parallel with a resistance (RN).

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph "Original Network"
    direction LR
    A[Complex Network] {-{-}{-} R1[Load]}
    end
    subgraph "Norton Equivalent"
    direction LR
    IN[In] {-.{-} RN[Rn] {-}{-}{-} RL[Load]}
    end
{Highlighting}
{Shaded}
```

Finding Norton Equivalent:

1. Remove the load resistance
2. Calculate short-circuit current (IN)
3. Find RN by:
    - Deactivating all sources (V=0, I=0)
    - Calculate resistance between terminals (RN = Rth)

Mnemonic

"Short for Current, Dead for Resistance"

Question 3(c) OR [7 marks]

State and explain Maximum power transfer theorem. Derive condition for maximum power transfer.

Solution

Maximum Power Transfer Theorem: A load receives maximum power when its resistance equals the Thevenin equivalent resistance of the network.

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Vth] {-{-}{-} B[Rth] {-}{-}{-} C[RL]}
{Highlighting}
{Shaded}
```

Derivation:

1. **Power delivered to load: P = $I^2 RL$**
1. **Current through circuit: I = Vth/(Rth + RL)**
2. **Substituting: P = $Vth^2 RL/(Rth + RL)^2$**
2. **Differentiating with respect to RL and setting to zero: dP/dRL = 0**
3. **This gives: RL = Rth**
4. **Maximum power: Pmax = $Vth^2/(4Rth)$**

Mnemonic

"Match to maximize"

Question 4(a) [3 marks]

Derive equation of Q factor for coil.

Solution

Q Factor (Quality Factor) for a coil represents the ratio of inductive reactance to resistance.
Diagram: Coil with Resistance

```
    o{-{-}{-}{-}///{-}{-}{-}{-}uuuu{-}{-}{-}{-}o}
         R          L
```

Derivation:

1. **For an inductor with resistance, impedance Z = R + j L**
2. **Q factor is defined as: Q = Reactive Power / Active Power**
3. **Q = L/R**

Where:

- **L = Inductance in Henries**
- **R = Series resistance in Ohms**
- ** = 2 f, Angular frequency**

Mnemonic

"Quality equals Reactance over Resistance"

Question 4(b) [4 marks]

Derive the formula for resonant frequency for a parallel RLC circuit.

Solution

Diagram: Parallel RLC Circuit

```
        o{-{-}{-}{-}{-}o}
        |     |
        R     |
        |     |
        o     |
        |     |
        C     L
        |     |
        o{-{-}{-}{-}{-}o}
```

Derivation:

1. **Admittance of parallel RLC:**
   Y = 1/R + j C + 1/j L = 1/R + j(C - 1/ L)
2. **At resonance, imaginary part is zero: C - 1/ L = 0**
3. **Solving for :** $^2 = 1/LC$
3. **Therefore:** **= 1/**$\sqrt(LC)$
3. **Resonance frequency: fr = 1/(2** $\sqrt(LC))$

Note: R affects bandwidth but not resonance frequency.

Mnemonic

"One over Two Pi times Square Root of LC"

Question 4(c) [7 marks]

Write types of coupled circuits with necessary diagram and explain iron core transformer.

Solution

Table 8: Types of Coupled Circuits

Type	Coupling Medium	Application
Direct Coupling	Conductively connected	DC amplifiers
Capacitive Coupling	Capacitor	AC signal coupling
Inductive Coupling	Magnetic field	Transformers
Resistive Coupling	Resistor	Low-frequency signals

Diagram: Iron Core Transformer

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    subgraph "Primary"
    V1[V_{1} {-}{-}{-} L1[uuuu]}
    end

    subgraph "Iron Core"
    Core[" "]
    end

    subgraph "Secondary"
    L2[uuuu] {-{-}{-} V2[V_{2}]}
    end

    L1 {-{-}{-} Core {-}{-}{-} L2}
{Highlighting}
{Shaded}
```

Iron Core Transformer:

- **Principle: Mutual inductance through iron core**
- **Function: Transfers energy between circuits by electromagnetic induction**
- **Coupling Coefficient: k** $\approx 1(nearperfectcoupling)$
- **Turns Ratio: V**$_2/V_1 = N_2/N_1$
- **Advantages: High efficiency, good coupling**

Mnemonic

"Primary excites, Core conducts, Secondary delivers"

Question 4(a) OR [3 marks]

Derive equation of Q factor for capacitor.

Solution

Q Factor (Quality Factor) for a capacitor represents the ratio of capacitive reactance to resistance.
Diagram: Capacitor with Resistance

```
o{-{-}{-}{-}///{-}{-}{-}{-}||{-}{-}{-}{-}o}
     R          C
```

Derivation:

1. **For a capacitor with series resistance, impedance Z = R - j/(C)**
2. **Q factor is defined as: Q = Reactive Power / Active Power**
3. **Q = 1/(CR)**

Where:

- **C = Capacitance in Farads**
- **R = Series resistance in Ohms**
- **= 2 f, Angular frequency**

Mnemonic

"Quality equals One over Resistance times Reactance"

Question 4(b) OR [4 marks]

Derive the equation of resonance frequency for a series resonance circuit.

Solution

Diagram: Series RLC Circuit

```
o{-{-}{-}{-}///{-}{-}{-}{-}uuuu{-}{-}{-}{-}||{-}{-}{-}{-}o}
     R          L       C
```

Derivation:

1. **Impedance of series RLC:**
   Z = R + j L - j/(C) = R + j(L - 1/ C)
2. **At resonance, imaginary part is zero: L - 1/ C = 0**
3. **Solving for :** $^2 = 1/LC$
3. **Therefore: = 1/**$\sqrt(LC)$
3. **Resonance frequency: fr = 1/(2** $\sqrt(LC))$

Key Points:

- **At resonance, impedance is purely resistive: Z = R**
- **Circuit appears as a resistor**
- **Current is maximum at resonance**

Mnemonic

"One over Two Pi times Square Root of LC"

Question 4(c) OR [7 marks]

Derive the Expression for coefficient coupling between pair of magnetically coupled coils.

Solution

Diagram: Magnetically Coupled Coils

```
   uuuu    k    uuuu
o{-{-}WWWW{-}{-}{-}{-}{-}{-}{-}WWWW{-}{-}o}
```

```
L_{1          L_{2}    }
```

Derivation:

1. Mutual inductance (M) relates to individual inductances by: M = k$\sqrt{(L_1 L_2)}$
1. Solving for k: k = M/$\sqrt{(L_1 L_2)}$

Where:

- k = Coefficient of coupling (0 $\leq k \leq 1$)
- M = Mutual inductance in Henries
- L$_1, L_2 = Self - inductances of coils in Henries$

Table 9: Coupling Coefficient Values

Value of k	Coupling Type	Application
k = 0	No coupling	Separate circuits
0 < k < 0.5	Loose coupling	RF transformers
0.5 < k < 1	Tight coupling	Power transformers
k = 1	Perfect coupling	Ideal transformer

Mnemonic

"Mutual over square root of product"

Question 5(a) [3 marks]

Define Neper and dB. Establish relationship between Neper and dB.

Solution

Table 10: Neper and dB Definitions

Unit	Definition	Formula	Usage
Neper (Np)	Natural logarithmic ratio	N = ln(V$_1/V_2) or ln(I_1/I_2)$	Power system analysis
Decibel (dB)	Common logarithmic ratio	dB = 20log$_{10}(V_1/V_2) or 10 log_{10}(P_1/P_2)$	Signal level measurement

Relationship:

1. N = ln(V$_1/V_2$)
1. dB = 20log$_{10}(V_1/V_2)$
1. Since ln(x) = 2.303 $\times log_{10}(x)$
1. Therefore:
   N = 2.303 $\times dB/20 = 0.1152 \times dB$

2. Conversely: dB = 8.686 $\times N$

Mnemonic

"A Neper is 8.686 dB"

Question 5(b) [4 marks]

Classify various types of Attenuators.

Solution

Table 11: Types of Attenuators

Type	Structure	Characteristics	Applications
T-type	Three resistors in T formation	Fixed impedance, good balance	Signal level control

-type (Pi)	Three resistors in formation	Better isolation, more common	RF signal attenuation
L-type	Two resistors in L formation	Simple, unbalanced	Basic level adjustment
Bridged T	T with bridging resistor	Constant impedance	Audio applications
Balanced	Symmetrical design	Good CMRR	Balanced transmission
Lattice	Diamond-shaped	Balanced, symmetrical	Telephone systems

Diagram: Basic Attenuator Types

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph "T{-type"}
    direction LR
    T1[o]{-{-}{-}TR1[R_{1}]{-}{-}{-}T2[o]}
    TR2[R_{2]}
    T2{-{-}{-}TR2{-}{-}{-}T3[o]}
    end

    subgraph " {-type"}
    direction LR
    P1[o]{-{-}{-}PR1[R_{1}]{-}{-}{-}P2[o]}
    PR2[R_{2]}
    P1{-{-}{-}PR2}
    PR3[R_{3]}
    PR2{-{-}{-}P2}
    end
{Highlighting}
{Shaded}
```

Mnemonic

"Tees, Pies and Ells attenuate the signals well"

Question 5(c) [7 marks]

Determine the cut-off frequency and the nominal impedance of each of the low-pass filter sections shown below.

Solution

Diagram: Low-Pass Filter Sections

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

For T-section:

- **Cut-off frequency: fc = 1/(** $\sqrt(LC))$
- **Nominal impedance: R**$_0 = \sqrt(L/C)$
- **Where**
  L = 10 mH,
  C = 0.1 F

Calculation: fc = 1/($\sqrt(10 \times 10^{-3} \times 0.1 \times 10^{-6})) = 1/(\sqrt(10^{-9})) = 1/(\times 10^{-45}) = 3.18 kHz R_0 = \sqrt(10 \times 10^{-3}/0.1 \times 10^{-6}) = \sqrt(10^5) = 316.23$

For -section:

- Cut-off frequency: fc = 1/($\sqrt{(LC)}$)
- Nominal impedance: R$_0 = \sqrt{(L/C)}$
- Same values as T-section

Mnemonic

"Cut-off frequency is inverse to the square root of LC"

Question 5(a) OR [3 marks]

Explain the limitation of constant k type filters.

Solution

Table 12: Limitations of Constant-k Filters

Limitation	Description	Effect
Impedance Matching	Impedance varies with frequency	Signal reflection, power loss
Attenuation Band	Gradual transition at cut-off	Poor frequency selectivity
Phase Response	Non-linear phase characteristic	Signal distortion
Passband Ripple	Non-uniform response in passband	Signal amplitude variation
Roll-off Rate	Slow roll-off (20 dB/decade)	Poor stop-band rejection

- Main issue: Poor transition from pass to stop band
- Improvement: Using m-derived filters

Mnemonic

"Poor Matching And Transition Results In Distortion"

Question 5(b) OR [4 marks]

Derive equation of cut-off frequency for T-type Constant-k high Pass filter.

Solution

Diagram: T-type Constant-k High Pass Filter

```
o{-{-}{-}C/2{-}{-}{-}o{-}{-}{-}{-}C/2{-}{-}{-}{-}{-}{-}o}
          |
          L
          |
o{-{-}{-}{-}{-}{-}{-}{-}{-}o{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}o}
```

Derivation:

1. For high-pass filter, series elements are capacitors and shunt elements are inductors
2. Transfer function: H(j) = Z$_2/(Z_1 + Z_2)$
2. Where Z$_1 = 1/(jC)andZ_2 = jL$
2. Impedance condition for cut-off: Z$_1/Z_2 = 4orZ_1/4Z_2 = 1$
2. Substituting: 1/(j C) = 4j L
3. Solving for : $^2 = 1/(4LC)$
3. Cut-off frequency: fc = 1/(4 $\sqrt{(LC)}$)

Mnemonic

"High Pass cuts frequencies below one over four pi L-C"

Question 5(c) OR [7 marks]

Give classification of filters using definitions and characteristics graphs for each.

Solution

Table 13: Filter Classification

Filter Type	Passes	Blocks	Applications
Low-Pass	Frequencies below fc	Frequencies above fc	Audio amplifiers, power supplies
High-Pass	Frequencies above fc	Frequencies below fc	Noise elimination, treble control
Band-Pass	Range between fL and fH	Frequencies outside range	Radio tuning, equalizers
Band-Stop	Frequencies outside range	Range between fL and fH	Noise elimination, notch filters
All-Pass	All frequencies with unity gain	None (changes only phase)	Phase correction, time delay

Characteristic Response Graphs:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    subgraph "Low{-Pass"}
    LP[High{br/{} {}br/{}Gain{}br/{} {}br/{}Low] {-}{-}{-} LPf[Frequency ]}

    style LP stroke{-width:0, fill:\#fff}
    style LPf stroke{-width:0, fill:\#fff}
    end

    subgraph "High{-Pass"}
    HP[High{br/{} {}br/{}Gain{}br/{} {}br/{}Low] {-}{-}{-} HPf[Frequency ]}

    style HP stroke{-width:0, fill:\#fff}
    style HPf stroke{-width:0, fill:\#fff}
    end

    subgraph "Band{-Pass"}
    BP[High{br/{} {}br/{}Gain{}br/{} {}br/{}Low] {-}{-}{-} BPf[Frequency ]}

    style BP stroke{-width:0, fill:\#fff}
    style BPf stroke{-width:0, fill:\#fff}
    end

    subgraph "Band{-Stop"}
    BS[High{br/{} {}br/{}Gain{}br/{} {}br/{}Low] {-}{-}{-} BSf[Frequency ]}

    style BS stroke{-width:0, fill:\#fff}
    style BSf stroke{-width:0, fill:\#fff}
    end
{Highlighting}
{Shaded}
```

Filter Implementations:

- **Passive: Uses R, L, C components**
- **Active: Uses op-amps with RC networks**
- **Digital: Uses DSP algorithms**

Mnemonic

"Low-High-Band-Stop makes Signals Perfect"