Certificate

Name: RITAV KASHYAP

Class: 3rd SEMESTER

Roll No: 20/237

Exam No:

Institution ASSAM ENGINEERING COLLEGE

This is certified to be the bonafide work of the student in the NETWORK THEORY *Laboratory during the academic year* 2021 / 2022 .

No. of practicals certified _____ *out of* _____ *in the subject of* _____

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Teacher In-charge

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Examiner's Signature

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Principal

Date: .....

Institution Rubber Stamp

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Expt. No. 1

Aim: Verification of principle of superposition with DC and AC sources.

Software required: NI Multisim

Theory: The superposition theorem states that in a linear circuit with several sources, the current and voltage for any element in the circuit is the sum of the current and voltages produced by each sources independently.

The voltage source is replaced with short circuit and current source is replaced with open circuit.

To apply superposition theorem, all the components must be linear. It is not applicable to power.

Teacher's Signature

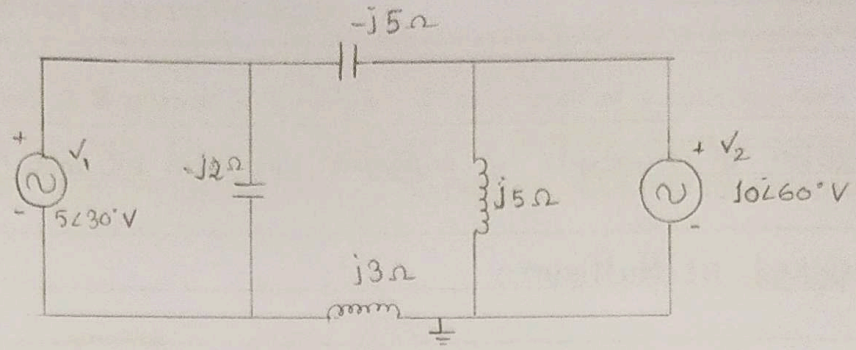


Fig1. Superposition in AC circuit

<u>Calculation</u>: Finding current through j3Ω inductor

<u>Sol^n</u>: <u>Step 1</u>– Consider only the left voltage source

$$I_2' = \frac{5\angle 30}{-j5+j3} = \frac{5\angle 30^\circ}{-j2} = 2.5\angle 30^\circ + 90^\circ$$

$$= 2.5\angle 120^\circ \text{ A}$$

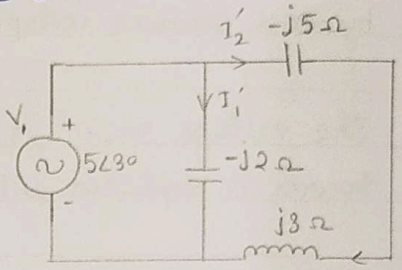


Fig1a: Short circuiting right voltage source.

<u>Step 2</u>– Consider only the right voltage source

$$I_2'' = \frac{10\angle 60^\circ}{-j5+j3} = \frac{10\angle 60^\circ}{-j2} = 5\angle 150^\circ \text{ A}$$

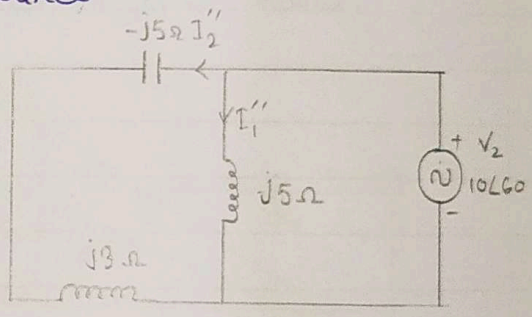


Fig1b: Short circuiting left voltage source.

<u>Step 3</u>– Calculate total current I_2

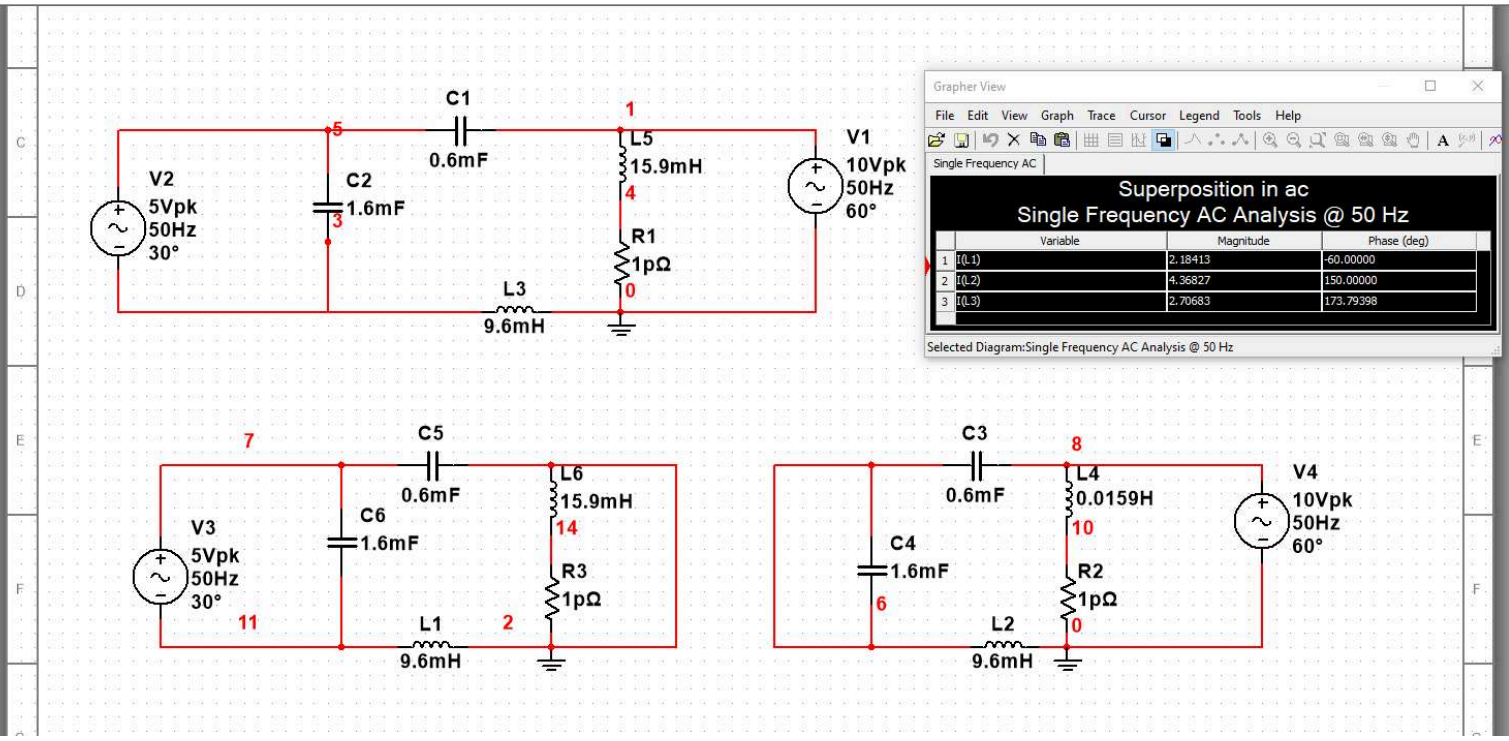
$$I_2 = I_2' - I_2''$$

$$= 2.5\angle 120^\circ - 5\angle 150^\circ$$

$$= -1.25 + j2.165 + 4.33 - j2.5$$

$$= 3.08 - j0.335$$

$$= 3.1\angle 6.2^\circ \text{A}$$


C1
0.6mF
1
5
L5
15.9mH
4
V1
10Vpk
50Hz
60°
V2
5Vpk
50Hz
30°
C2
1.6mF
3
R1
1pΩ
0
L3
9.6mH
Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
Single Frequency AC
Superposition in ac
Single Frequency AC Analysis @ 50 Hz
Variable Magnitude Phase (deg)
1 I(L1) 2.18413 -60.00000
2 I(L2) 4.36827 150.00000
3 I(L3) 2.70683 173.79398
Selected Diagram:Single Frequency AC Analysis @ 50 Hz
7
C5
0.6mF
L6
15.9mH
14
V3
5Vpk
50Hz
30°
C6
1.6mF
R3
1pΩ
11
L1
2
9.6mH
C3
0.6mF
8
L4
0.0159H
10
V4
10Vpk
50Hz
60°
C4
1.6mF
6
R2
1pΩ
0
L2
9.6mH

observation Table :

Table 1.1 - For AC circuit

Sources Present	Theoretical value of Voltage / current	Practical value of Voltage / current
Voltage (V_1)	$I_2' = 2.5 \angle 120^\circ$ A	$2.184 \angle -60^\circ$ A = I(L1)
Voltage (V_2)	$I_2'' = 5 \angle 150^\circ$ A	I(L2) = $4.368 \angle 150^\circ$ A
Both	$I_2 = 3.1 \angle 6.2^\circ$ A	I(L3) = $2.707 \angle 173.79$ A

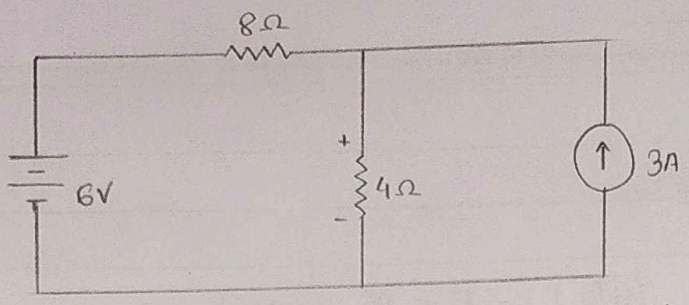


Fig 2: Superposition in DC circuit

<u>Calculation</u>: Finding current through 4Ω resistor

<u>Step 1</u>: Consider only voltage source

$$I_1 = \frac{6}{8+4} = \frac{6}{12} = 0.5\ A$$

$$\therefore V_1 = 0.5 \times 4 = \cancel{20A}\ 2V$$

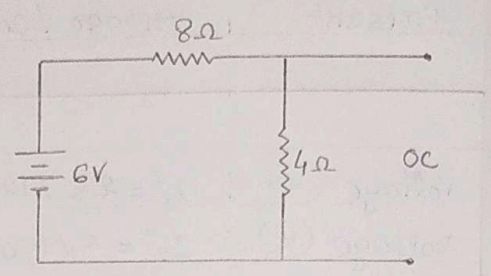


Fig 2.1: Open circuited left current source

<u>Step 2</u>: Consider only current source

$$I_2 = 3 \times \frac{8}{8+4} = 2A$$

$$\therefore V_2 = 2 \times 4 = 8V$$

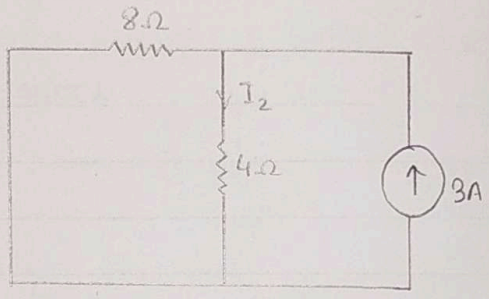
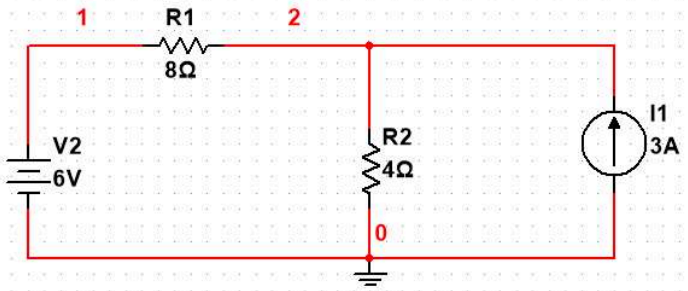


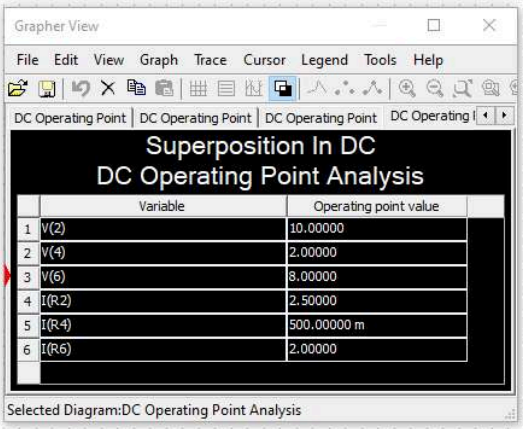
Fig 2.2: short circuited left voltage source.

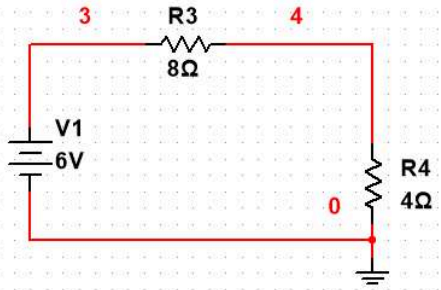
<u>Step 3</u>: Find total current using superposition

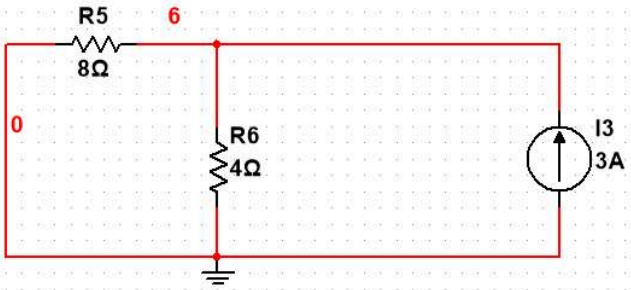
$$I_3 = I_1 + I_2 = 0.5 + 2 = 2.5\ A$$

$$V_3 = 2.5 \times 4 = 10V$$


1
R1
8Ω
2
V2
6V
R2
4Ω
0
I1
3A


Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
DC Operating Point
DC Operating Point
DC Operating Point
DC Operating
Superposition In DC
DC Operating Point Analysis
Variable
Operating point value
1 V(2) 10.00000
2 V(4) 2.00000
3 V(6) 8.00000
4 I(R2) 2.50000
5 I(R4) 500.00000 m
6 I(R6) 2.00000
Selected Diagram:DC Operating Point Analysis


3
R3
8Ω
4
V1
6V
0
R4
4Ω


R5
8Ω
6
0
R6
4Ω
I3
3A

Observation Table:

Table 1.2: For DC circuit

Sources Present	Theoretical value of current and voltage	Practical value of current and voltage
Voltage	$I_1 = 0.5A$ $V_1 = 2V$	$I(R4) = 500\ mA$, $V(4) = 2V$
Current	$I_2 = 2A$ $V_2 = 8V$	$I(R6) = 2A$, $V(6) = 8V$
Both	$I_3 = 2.5A$ $V_3 = 10V$	$I(R2) = 2.5A$, $V(2) = 10V$

Result: Principle of superposition theorem verified for both AC and DC sources.

Aim: Verification of Thevenin's, Norton's and Maximum Power Transfer Theorems.

Software required: NI Multisim

Theory: Thevenin's theorem: Any linear circuit containing several voltage and resistances can be replaced by just one single voltage in series with a single resistance connected across the load.

Norton's theorem: Any linear circuit containing several energy sources and resistances can be replaced by a single constant current generator in parallel with a single resistor.

Maximum power transfer theorem: It ensures that the maximum amount of power will be dissipited in the load resistance when the value of the load resistance is exactly equal to the resistance of the power source.

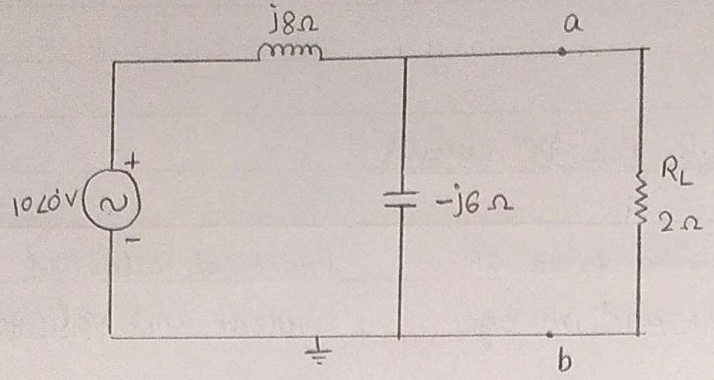


Fig 1: Circuit for verifying Theverin's theorem

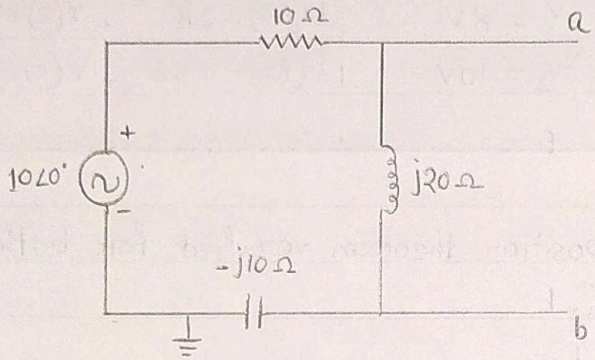


Fig 2: Circuit for verifying Norton's theorem

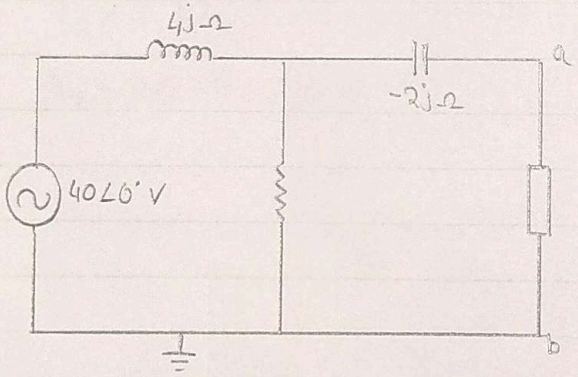


Fig 4: Circuit for verifying MPT in AC

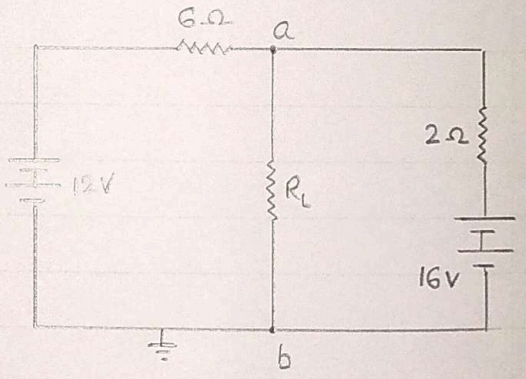


Fig 8: Circuit for verifying MPT in DC

Calculations for Thevenin's theorem:

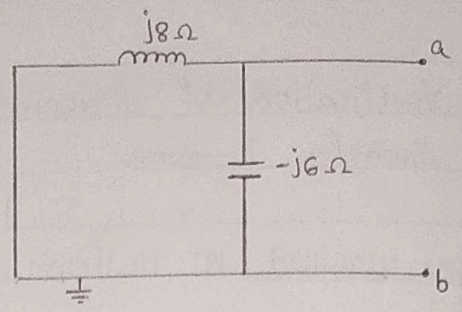


Fig 1.1 - Shorting the voltage source

Step 1: Remove the load resistance and ~~circuit~~ short circuited the voltage source. To find V_{Th} and Z_{Th}.

$Z_1 = jX_L = j8\,\Omega$ $\qquad$ $Z_2 = -jX_C = -j6\,\Omega$

$\Rightarrow Z_1 = 8\angle 90^\circ$ $\qquad$ $\Rightarrow Z_2 = 6\angle -90^\circ$

Z_1 and Z_2 are in Parallel

$$\therefore Z_{Th} = \frac{Z_1 Z_2}{Z_1 + Z_2} = \frac{(8\angle 90)(6\angle -90)}{2\angle 90} = \frac{48\angle 0}{2\angle 90} = 24\angle -90^\circ$$

Step 2: Calculation of V_{Th}

Applying KVL in mesh 1.

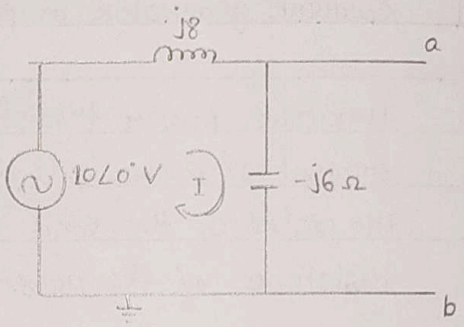


Fig 1.2: Calculation of V_{Th}

$$10\angle 0^\circ - j8I_1 + j6I_1 = 0$$

$$\Rightarrow 10\angle 0 = j2I_1$$

$$\Rightarrow I_1 = \frac{10\angle 0}{2\angle 90^\circ} = 5\angle -90^\circ\ A$$

$$\therefore V_{Th} = Z_2 I_1 = (-j6)(5\angle 90^\circ)$$

$$= 30\angle -180$$

Step 3: Drawing the equivalent circuit.

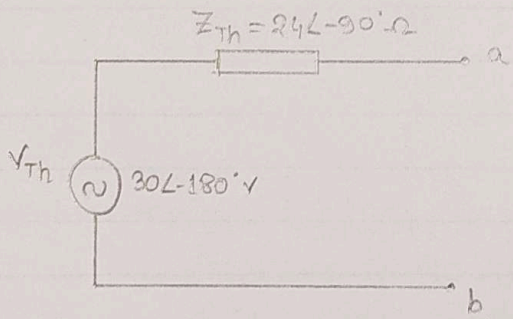
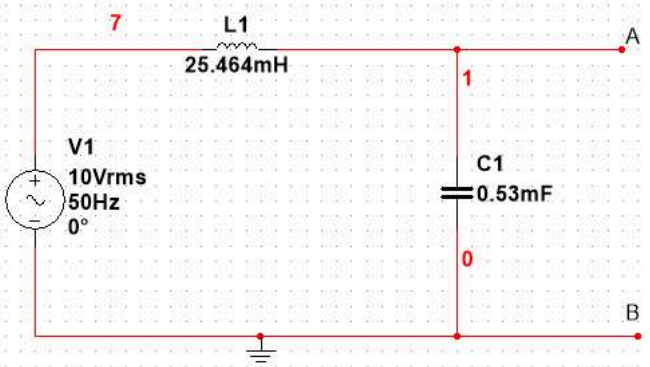
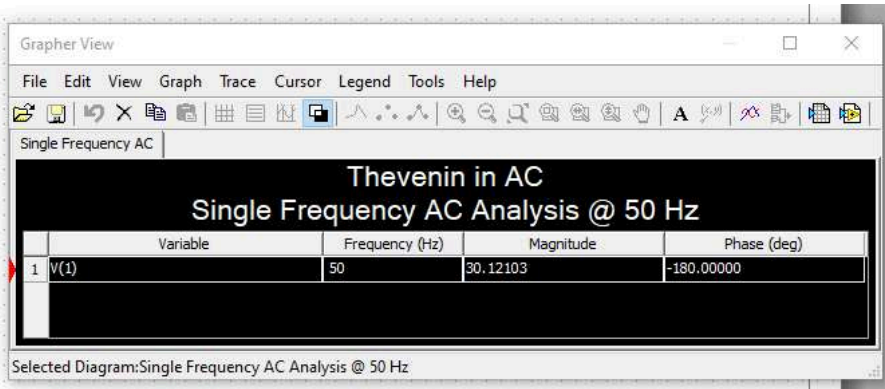
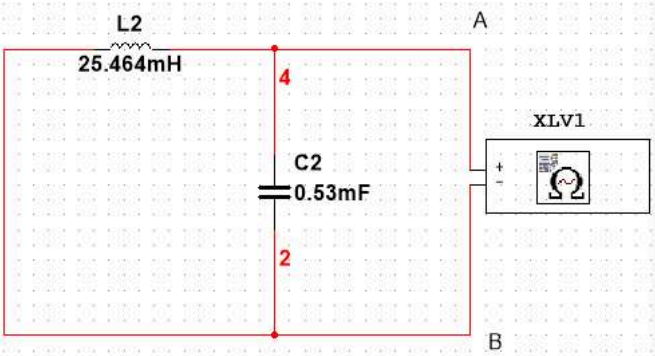
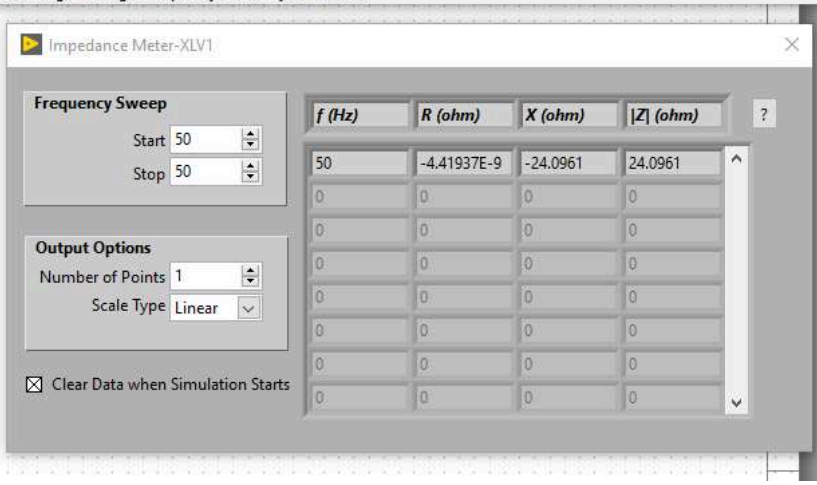


Fig 1.3: Thevenin's equivalent circuit


7
L1
25.464mH
A
1
V1
10Vrms
50Hz
0°
C1
0.53mF
0
B


Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
Single Frequency AC
Thevenin in AC
Single Frequency AC Analysis @ 50 Hz
Variable | Frequency (Hz) | Magnitude | Phase (deg)
1 | V(1) | 50 | 30.12103 | -180.00000
Selected Diagram:Single Frequency AC Analysis @ 50 Hz


L2
25.464mH
A
4
C2
0.53mF
2
XLV1
B


Impedance Meter-XLV1
Frequency Sweep
Start 50
Stop 50
Output Options
Number of Points 1
Scale Type Linear
Clear Data when Simulation Starts
f (Hz) | R (ohm) | X (ohm) | |Z| (ohm)
50 | -4.41937E-9 | -24.0961 | 24.0961

observation table :

Table 2.1 : For thevenin's theorem

Quantity	Theoretical value	Practical value
Thevenin's equivalent voltage (V_{Th})	$30\angle -180^\circ$ V	magnitude : 30.121 Phase : -180°
Thevenin's equivalent impedence (Z_{Th})	$24\angle -90^\circ$ V	magnitude : 24.096 Phase : -90°

Calculations for Norton's theorem:

Step 1: Calculation of Norton's current (I_N). Short circuiting the load resistance we found that j20 inductive resistance is also shorted.

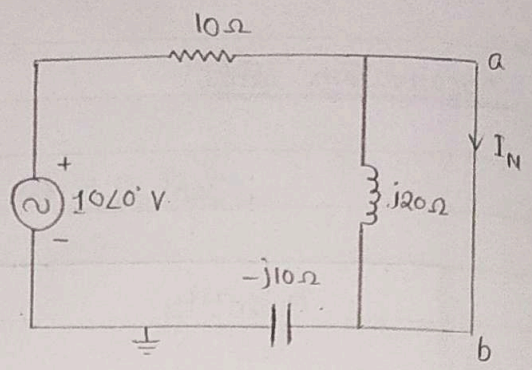


Fig 2.1: Finding I_N

Applying ohm's law,

$$I_N = \frac{10\angle 0^\circ}{10-j10} = \frac{1}{1-j1} = \frac{1}{\sqrt{2}}\angle 45^\circ A$$

$$\Rightarrow I_N = 0.707\angle 45^\circ A.$$

Step 2: Short circuiting voltage source and removing the load resistance to find Norton's equivalent resistance.

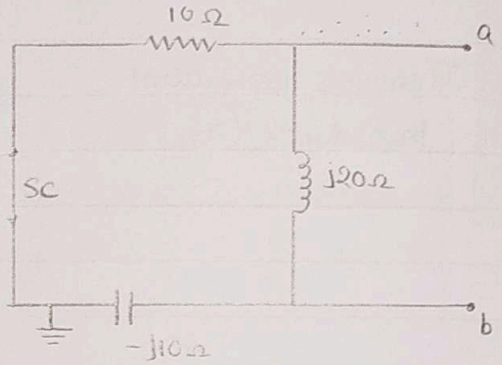


Fig 2.2: Finding R_N

Replacing $10\angle 0^\circ$ V with short circuit, we see that 10Ω and −j10Ω are in series and j20Ω is parallel to them.

$$\therefore Z_n = (10-j10) \parallel j20$$

$$= \frac{(10-j10)(j20)}{(10-j10)+j20} = 20\Omega$$

Step 3: Drawing the equivalent Norton's circuit.

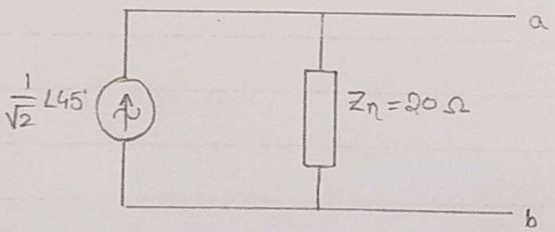
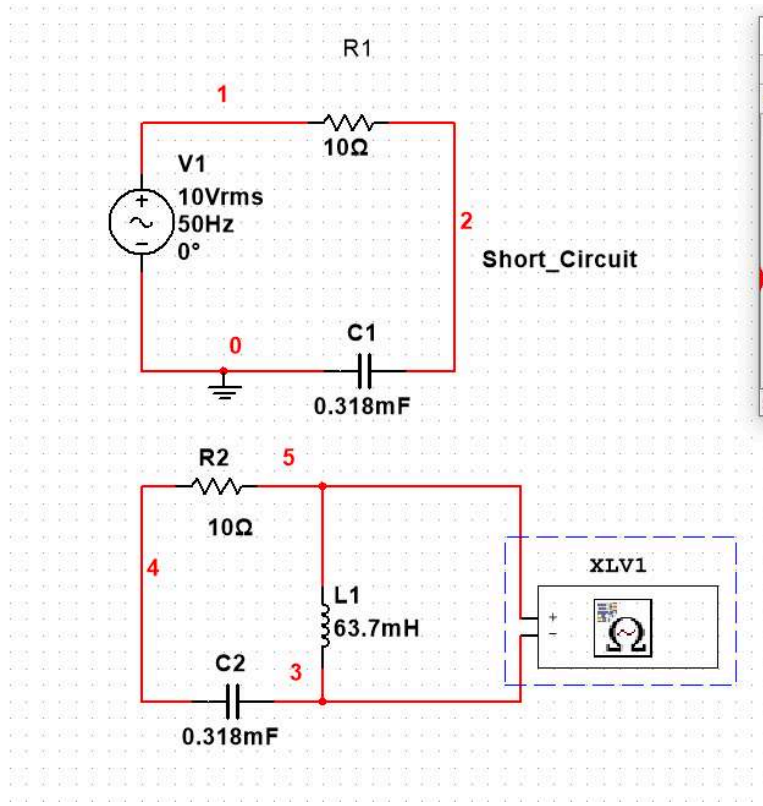
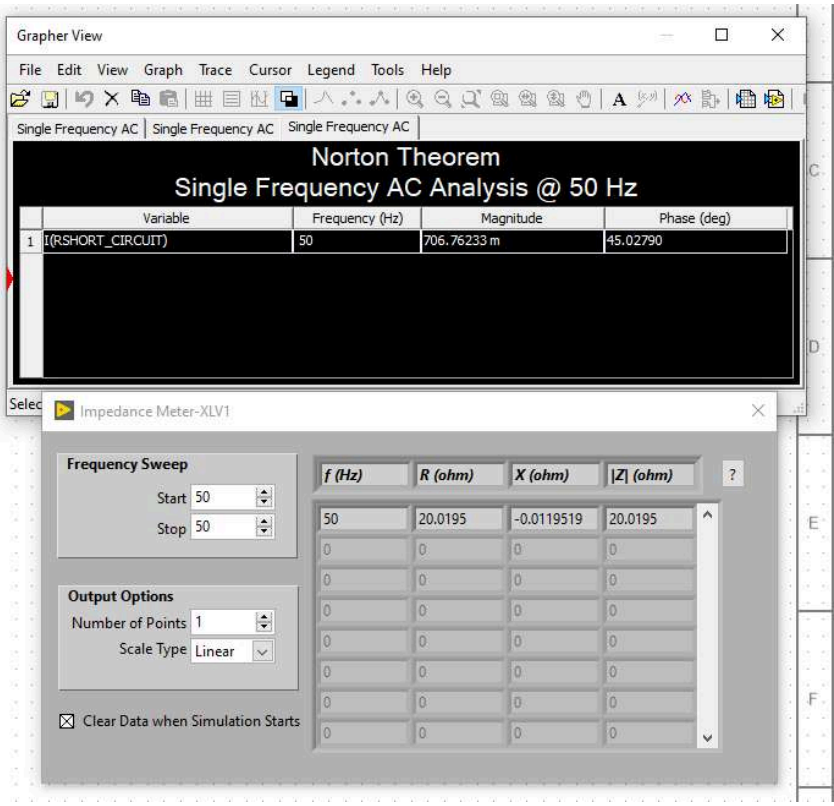


Fig 2.3: Norton's equivalent circuit.


R1
1
10Ω
V1
10Vrms
50Hz
0°
2
Short_Circuit
0
C1
0.318mF
R2
5
10Ω
4
L1
63.7mH
C2
3
0.318mF
XLV1


Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
Single Frequency AC
Single Frequency AC
Single Frequency AC
Norton Theorem
Single Frequency AC Analysis @ 50 Hz
Variable
Frequency (Hz)
Magnitude
Phase (deg)
1
I(RSHORT_CIRCUIT)
50
706.76233 m
45.02790
Impedance Meter-XLV1
Frequency Sweep
Start 50
Stop 50
Output Options
Number of Points 1
Scale Type Linear
Clear Data when Simulation Starts
f (Hz)
R (ohm)
X (ohm)
|Z| (ohm)
50
20.0195
-0.0119519
20.0195

Observation Table:

Table 2.2 : Norton's Theorem

Quantity	Theoretical value	Practical value
Norton's current (I_N)	$0.707\angle 45^\circ$ A	magnitude: 706.73 mA Phase: 45.028°
Norton's equivalent resistance	20 Ω	20.019 Ω

Calculations for Maximum power Transfer theorem in DC

Step 1: Remove the load resistance and find V_{Th}

Applying KVL, we get

$12 - 6I - 2I - 16 = 0$

$\Rightarrow I = -0.5A$

$\therefore$ The OC voltage across terminal A & B $\Rightarrow V_{AB} = 16 - 2 \times 0.5$

$= 15V$

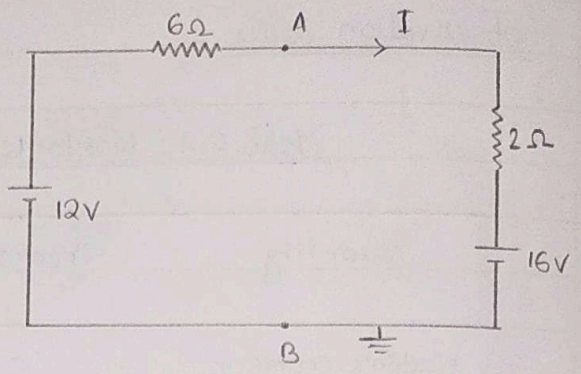


Fig 3.1 : Finding V_{Th}

Step 2: Short circuiting voltage sources to find R_{Th}

$$R_{Th} = \frac{6 \times 2}{6+2} = \frac{12}{8} = 1.5\,\Omega$$

$\therefore$ Maximum power will be transferred when $R_L = 1.5\,\Omega$

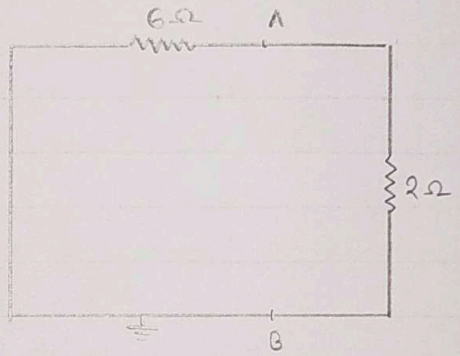


Fig 3.2 : Finding R_{Th}

Step 3: Finding maximum power

Current through the circuit

$$I' = \frac{15}{1.5 + 1.5} = 5A$$

$\therefore$ Maximum power $= I^2 R$

$= 5^2 \times 1.5$

$= 37.5\,W$

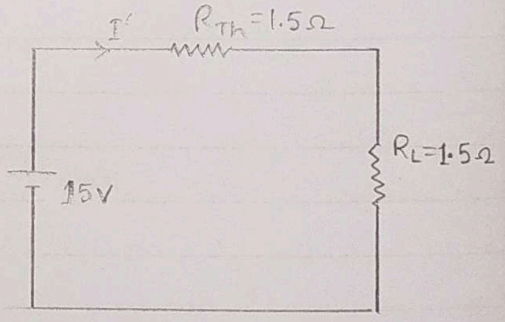
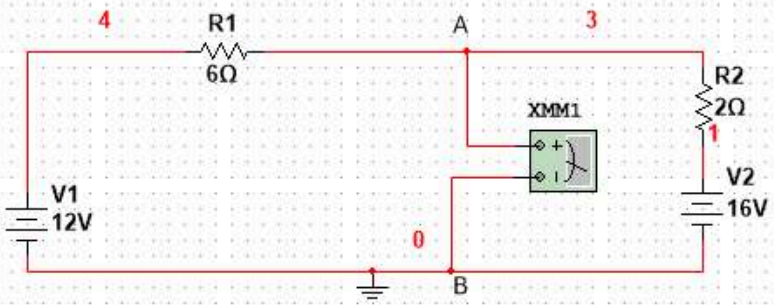
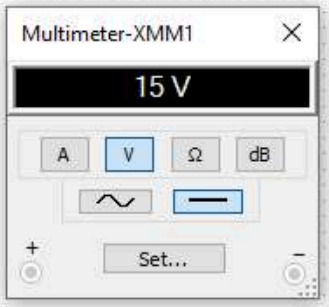
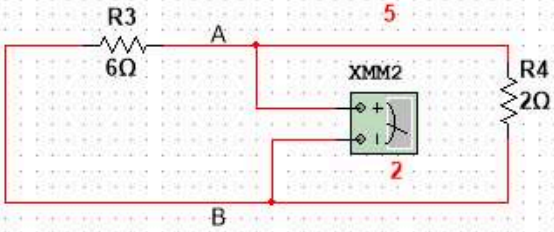
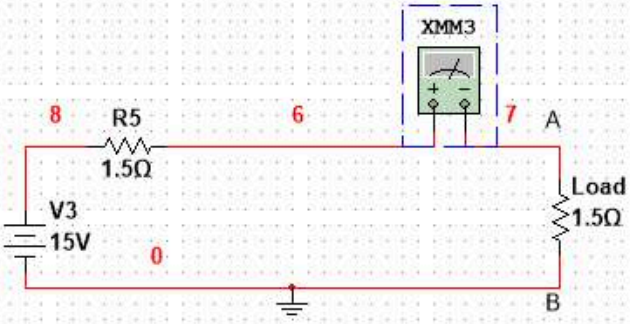


Fig 3.3: Equivalent ckt.









Therefore Max Power = I^2 x R(load) = 5^2 x 1.5 = 37.5W

Observation Table:

Table 2.3: For Maximum Power transfer theorem in DC

Quantity	Theoretical value	Practical value
Voltage (V_{Th})	15 V	15 V
Load (R_{Th})	1.5 Ω	1.5 Ω
Current (I)	5 A	5 A
Power (P_{max})	37.5 W	37.5 W

Calculation for Maximum Power Transfer theorem in AC circuit.

Step 1: Short circuit voltage source and remove load resistance to find Z_{Th}.

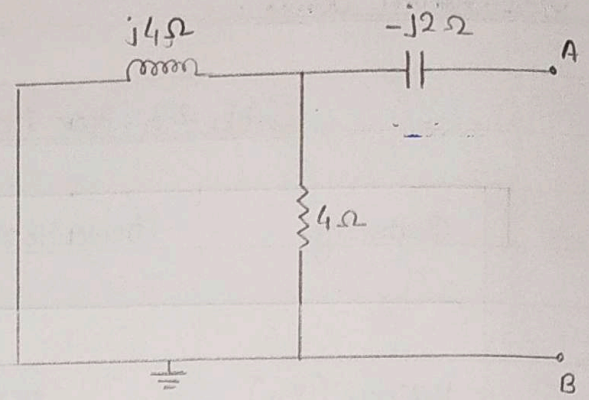


Fig 4.1: Finding Z_{Th}

From the circuit,

$$Z_{AB} = \frac{4 \times j4}{4+j4} - j2$$

$$= 2\Omega$$

∴ The condition for maximum power transfer is $Z_L = Z_{Th} = 2\Omega$

Step 2: Calculation of Thevenin's voltage.

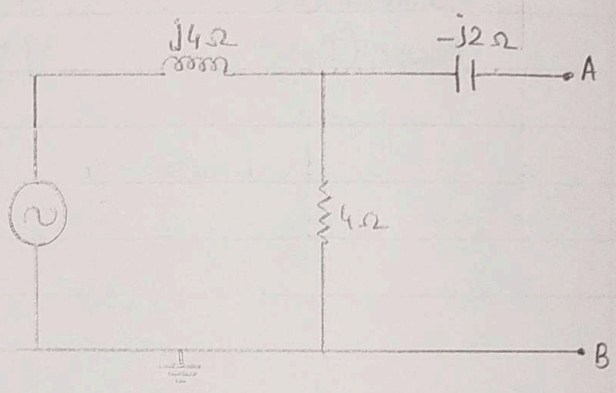


Fig 4.2: Finding V_{Th}

using voltage divider rule,

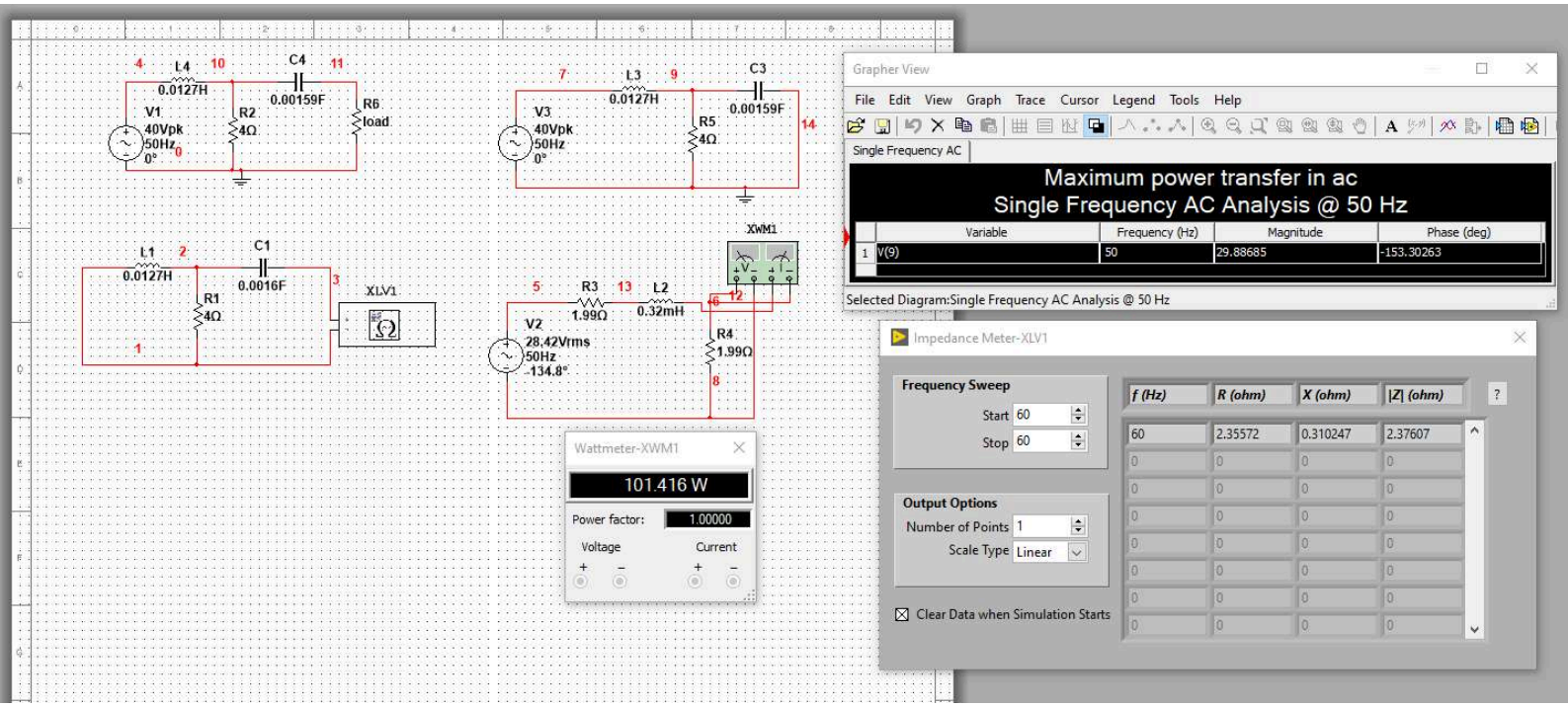
$$V_{Th} = V_{AB} = \frac{40}{4(1+j)} \times 4$$

$$= 28.29\angle -45^\circ$$

Step 3: Finding maximum power

The maximum power, $P_{max} = \frac{V_{Th}^2}{4R_{Th}}$

$$= \frac{800}{4 \times 2} = 100W$$


L4
0.0127H
C4
0.00159F
V1
40Vpk
50Hz
0°
R2
4Ω
R6
load
L3
0.0127H
C3
0.00159F
V3
40Vpk
50Hz
0°
R5
4Ω
L1
0.0127H
C1
0.0016F
R1
4Ω
XLV1
XWM1
R3
1.99Ω
L2
0.32mH
V2
28.42Vrms
50Hz
-134.8°
R4
1.99Ω
Wattmeter-XWM1
101.416 W
Power factor:
1.00000
Voltage
Current
Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
Single Frequency AC
Maximum power transfer in ac
Single Frequency AC Analysis @ 50 Hz
Variable
Frequency (Hz)
Magnitude
Phase (deg)
V(9)
50
29.88685
-153.30263
Selected Diagram:Single Frequency AC Analysis @ 50 Hz
Impedance Meter-XLV1
Frequency Sweep
Start 60
Stop 60
Output Options
Number of Points 1
Scale Type Linear
Clear Data when Simulation Starts
f (Hz)
R (ohm)
X (ohm)
|Z| (ohm)
60
2.35572
0.310247
2.37607

Observation Table:

Table 2.4: For Maximum Power transfer theorem in AC

Quantity	Theoretical value	Practical value
V_{Th}	$28.29\angle -45°$ V	$29.89\angle -153.3°$ V
R_{Th}	2Ω	2.38Ω
P_{max}	100 W	101.416 W

Result: Thevenin's, Norton's and Maximum power transfer theorem have been verified.

Aim: Verification of Tellegen's theorem for two networks of the same topology.

Software required: NI Multisim

Theory: Tellegen's theorem states that the summation of power delivered is zero for each branch of any electrical network at any instant of time.

$\therefore$ For K^{th} branch $\sum_{K=1}^{n} V_K i_K = 0$

+ve $\Rightarrow$ absorbing

-ve $\Rightarrow$ Delivering

where, n = no of branches

V_K = Voltage in the branch

i_K = Current flowing through the branch.

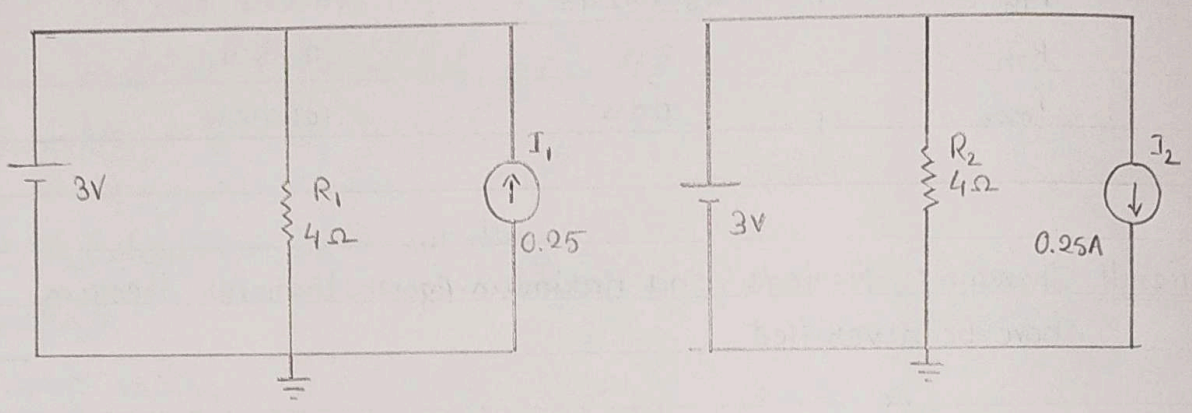
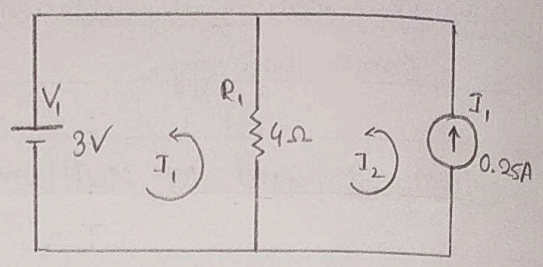


Fig 1: Circuits to prove Tellegen's theorem

Calculations:

From the 1st circuit

Applying KVL in loop 1



$$-3 = 4I_1 - 4I_2$$

$$\Rightarrow -3 = 4I_1 - 4 \times 0.25 \quad (\because I_2 = 0.25A)$$

$$\Rightarrow I_1 = -0.5\,A$$

$$\therefore P(V_1) = -0.5 \times 3 = -1.5\,W$$

Now, current through 4Ω is $I = I_1 - I_2 = -0.5 - 0.25 = -0.75\,A$

$$\therefore P(R_1) = I^2R = 0.75^2 \times 4 = 2.25\,W$$

and $P(I_1) = 3 \times (-0.25) = -0.75\,W$

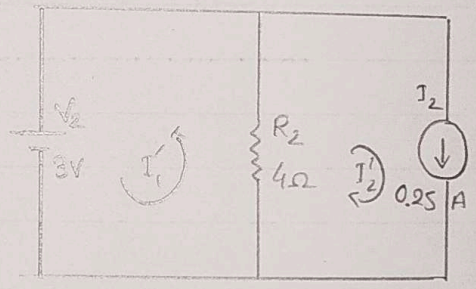
According to Tellegen's theorem

$$P(V_1) + P(R_1) + P(I_1) = 0$$

$$\Rightarrow -1.5\,W + 2.25\,W + (-0.75)\,W = 0$$

From the 2nd circuit

Applying KVL in loop 1



$$-3 = 4I_1' + 4I_2'$$

$$\Rightarrow -3 = 4I_1' + 4 \times 0.25 \quad (\because I_2' = 0.25A)$$

$$\Rightarrow I_1' = \cancel{0.5A} - 1\,A$$

$$\therefore P(V_2) = -1 \times 3 = -3\,W$$

Now, current through 4Ω is

$$I' = I_1' + I_2' = -1 + 0.25 = -0.75\,A$$

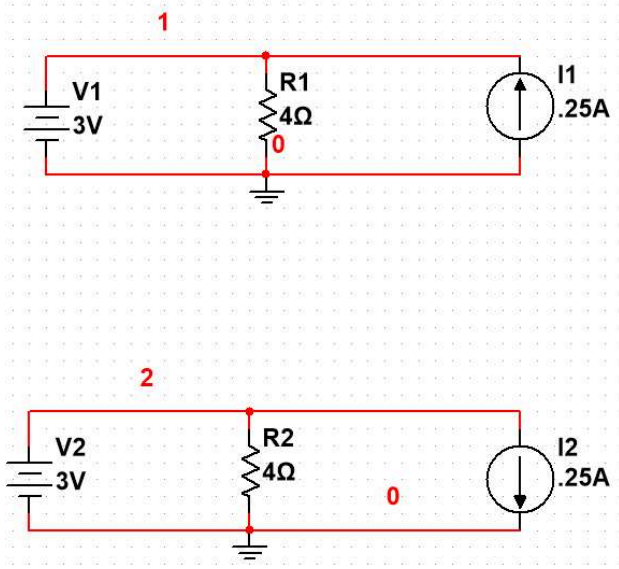
$$\therefore P(R_2) = I'^2 R_2 = (-0.75)^2 \times 4 = 2.25\,W$$

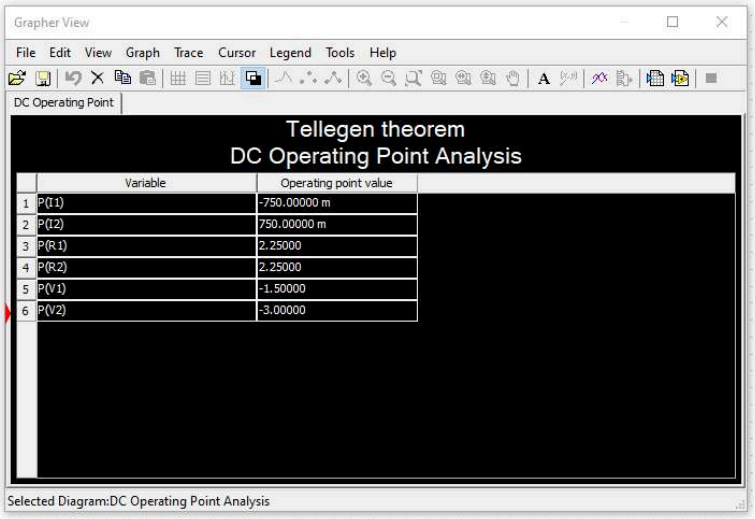
$$P(I_2) = +3 \times 0.25 = +0.75$$

According to Tellegen's theorem

$$P(V_2) + P(I_2) + P(R_2) = 0$$

$$\Rightarrow -3 + 2.25 + 0.75 = 0$$





	Variable	Operating point value
1	P(I1)	-750.00000 m
2	P(I2)	750.00000 m
3	P(R1)	2.25000
4	P(R2)	2.25000
5	P(V1)	-1.50000
6	P(V2)	-3.00000

Observation Table:

Table 3.1: For the 1st circuit

Quantity	Theoretical value	Practical value
Voltage source	-1.5 W	-1.5 W
Current source	-0.75 W	-750 mW
Resistor	2.25 W	2.25 W

Table 3.2: For the 2nd circuit

Quantity	Theoretical value	Practical value
Voltage source	-3 W	-3 W
Current source	0.75 W	750 mW
Resistor	2.25 W	2.25 W

Result: Tellegen's theorem have been verified.

Aim: Determination of transient response of current and voltage in RL and RC circuit with step voltage input.

Software required: NI Multisim.

Theory: Just after a change, a capacitor or inductor takes sometimes to charge or discharge and eventually settled on its new steady state. The response of a circuit immediately after a sudden change is called transient response.

With reference to fig 1, we can see that with a full analysis of transience, steady state comes two times.

- Past ie $t<0$
- In Present $t=\infty$

At steady state, the capacitor acts as open circuit and ~~an~~ the inductor acts as ~~op~~ short circuit.

Time constant τ:

It has units of seconds. It governs speed of transient response, higher than τ. The longer it will take to get the steady state.

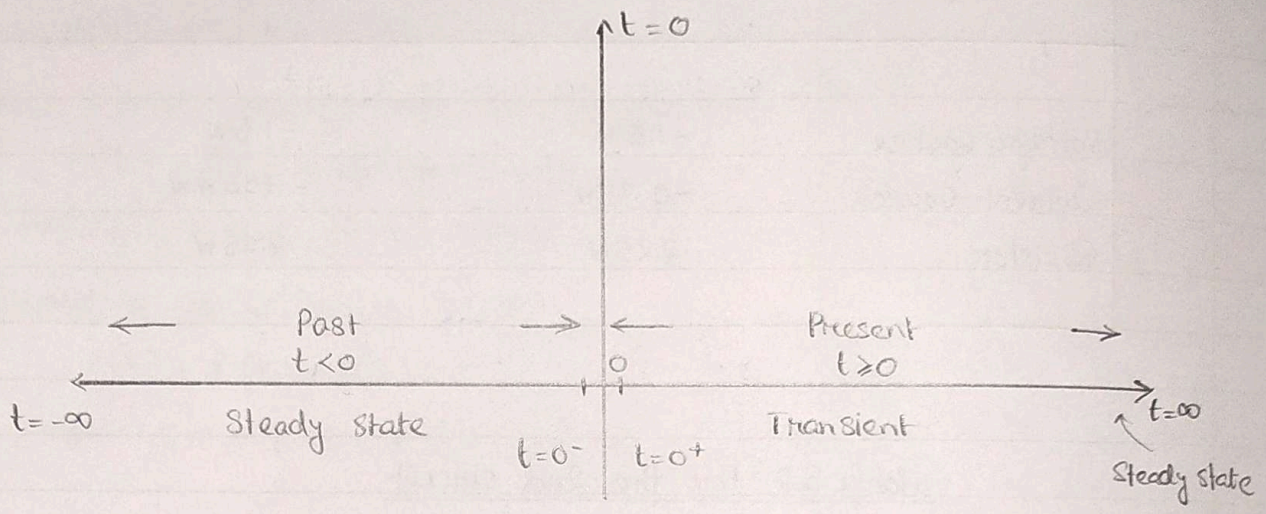


Fig 1: Time frame for transient analysis

Transient response in RC circuit:

Lets consider the following circuit, whose voltage source provide $v_i(t) = 0$ volts for $t<0$, $v(t) = V$ volts for $t \geq 0$ (Refer to fig 2.82b)

Step 1: For $t<0$

$V\,u(t) = 0$

$\therefore V_c(0^-) = 0\,V$, ie capacitor is uncharged

From properties of capacitor

$V_c(0^-) = V_c(0^+) = 0\,V$

Step 2: For $t \geq 0$

Just before step voltage from 0 volts to V volts at $t=0$, $V_c(0^-) = 0$ volts.

$\therefore$ Just after the step $V_c(0^+)$ is also 0 volts

If we wait long enough, the circuit will reach steady state

$\therefore V_c(\infty) = V$ volts

using KCL at top right node

$$\frac{V - V_c}{R} = \frac{C\,dV_s}{dt}$$

Solving this differential equation, we get

$$V_c(t) = V_c(\infty) + [V_c(0^+) - V_c(\infty)]\,e^{-t/\tau} \quad \text{— (I)}$$

We know, from initial condition $V_c(0^+) = 0\,V$, from final condition $V_c(\infty) = V$ volts and $\tau = R.C$ sec for single R & C. (I) $\Rightarrow V_c(t) = V(1 - e^{-t/RC})$

Immediately, after the step current $i(t) = i_c(t) = C\frac{dV_c}{dt}$ — (II) will start flowing which cause rising V_c, which in turn reduces i_c to 0 at $t=\infty$

Solving (II), we get $i_c(t) = \frac{V}{R}e^{-t/RC}$

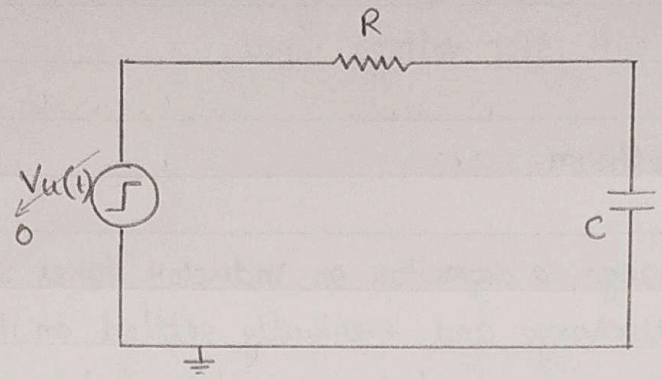


Fig 2a: Transient response in RC circuit (at $t<0$)

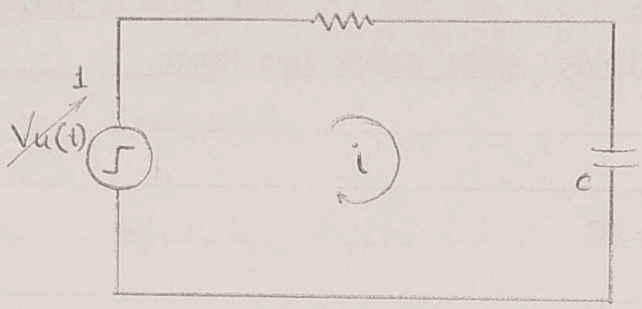


Fig 2b: Transient response in RL circuit (at $t \geq 0$)

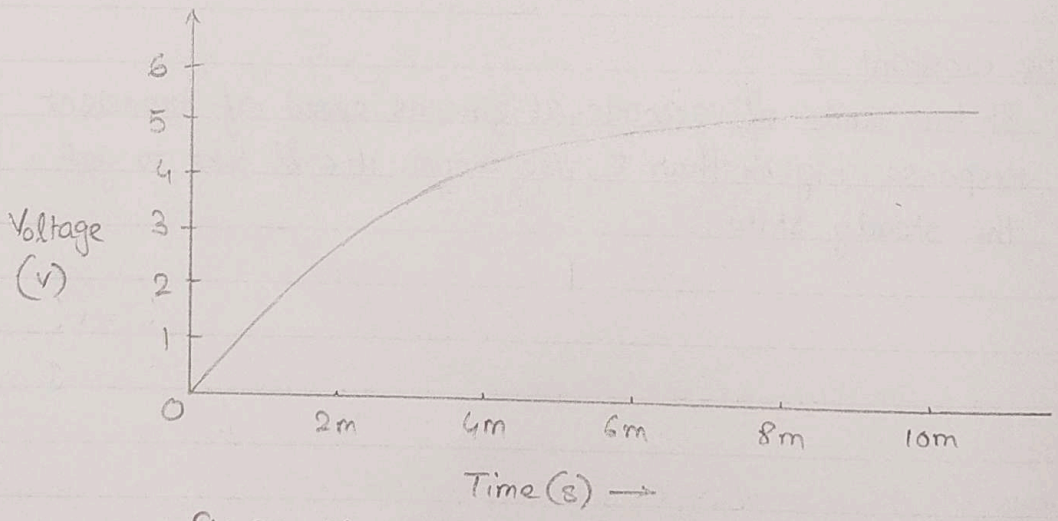


Fig 2c: V_c curve of RC circuit

Transient response in RL circuit

Let's consider the following circuit whose voltage source provided $V_1(t) = 0$ volts for $t<0$ & $V(t) = V$ volts for $t \geq 0$ (Refers to 3a & 3b)

Step 1: For $t<0$

$V_L(t) = 0$ volts

$\therefore V_L(0^-) = V_L(0^+) = 0$ volts

Step 2: For $t \geq 0$

Inductor current cannot change instantaneously. When power is 1st applied, the circulating current must remain zero. So, no voltage drop is produced across the resistor and by KVL, the voltage across the inductor must be = V.

As current starts to increase, voltage drop across the resistor increase. This reduces voltage variable for the inductor, thus, showing the rate of change of current.

The relevent equivalent for RL circuit is shown below

$\tau = L/R$ for single R and L in series

$V_L(t) = Ve^{-t/\tau}$

$I(t) = V/R\,(1-e^{-t/\tau})$

$V_L(t)$ = Inductor voltage at time t

$I(t)$ = Current at time t

V = Voltage source

R = Series resistance

t = time of interest

τ = time constant

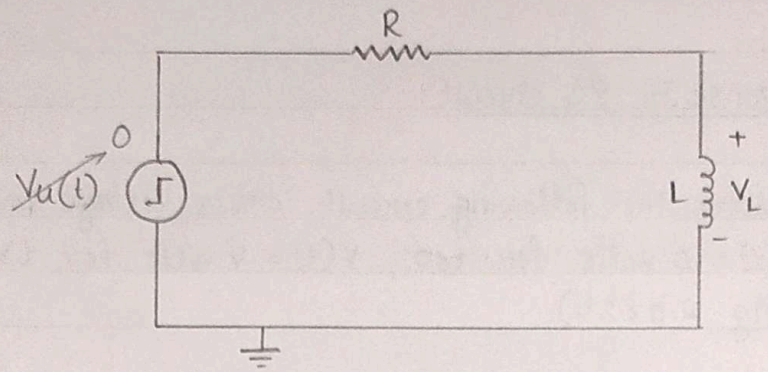


Fig 3a: Series RL circuit at $t<0$

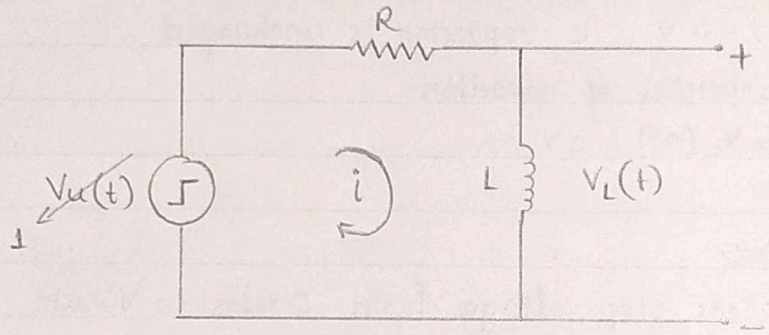


Fig 3b: Series RL circuit at $t \geq 0$

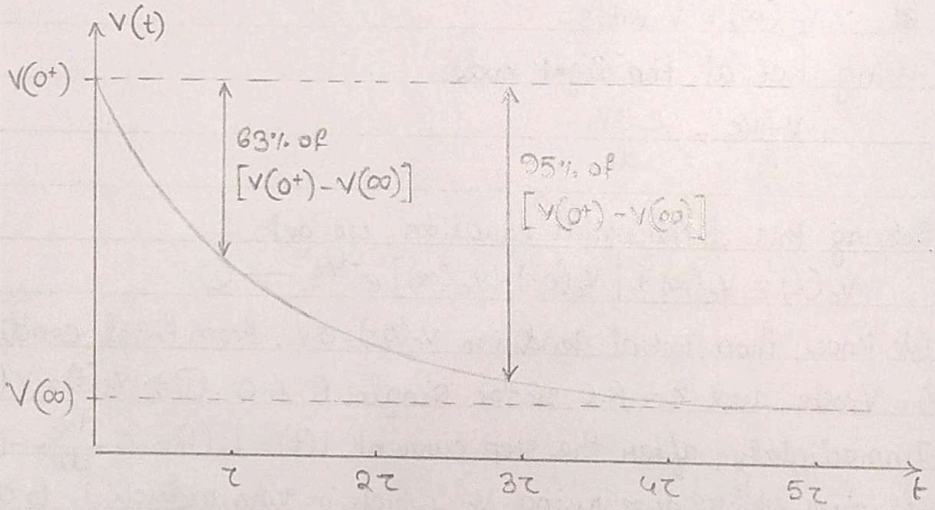


Fig 3c: Time constant of a RL circuit.

Calculations for series RC circuit in step response

Here $\tau = RC$

$= 1\times10^{-3}\,\Omega \times 10\times10^{-6}\,F$

$= 10\,ms = 10^{-2}\,s$

$\tau_{settle} = 5\tau = 50\,ms$

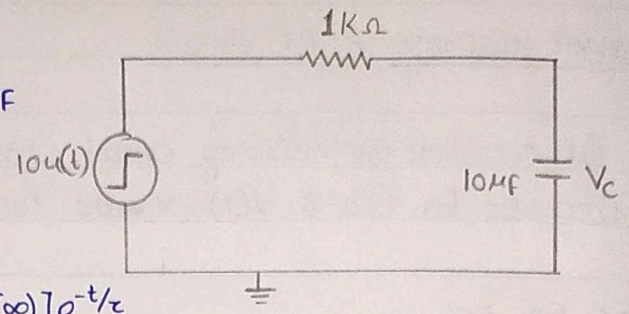


Fig 4 - Example RC circuit

& $V_c(t) = V_c(\infty) + [V_c(0^+) - V_c(\infty)]e^{-t/\tau}$

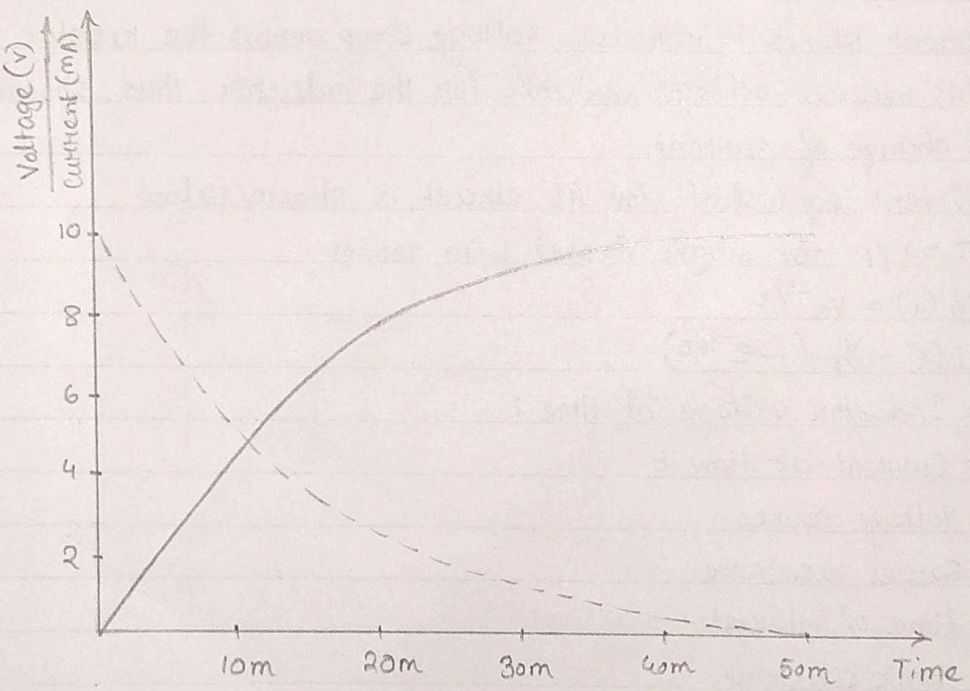
$= 10 + (0-10)e^{-t/10^{-2}}$

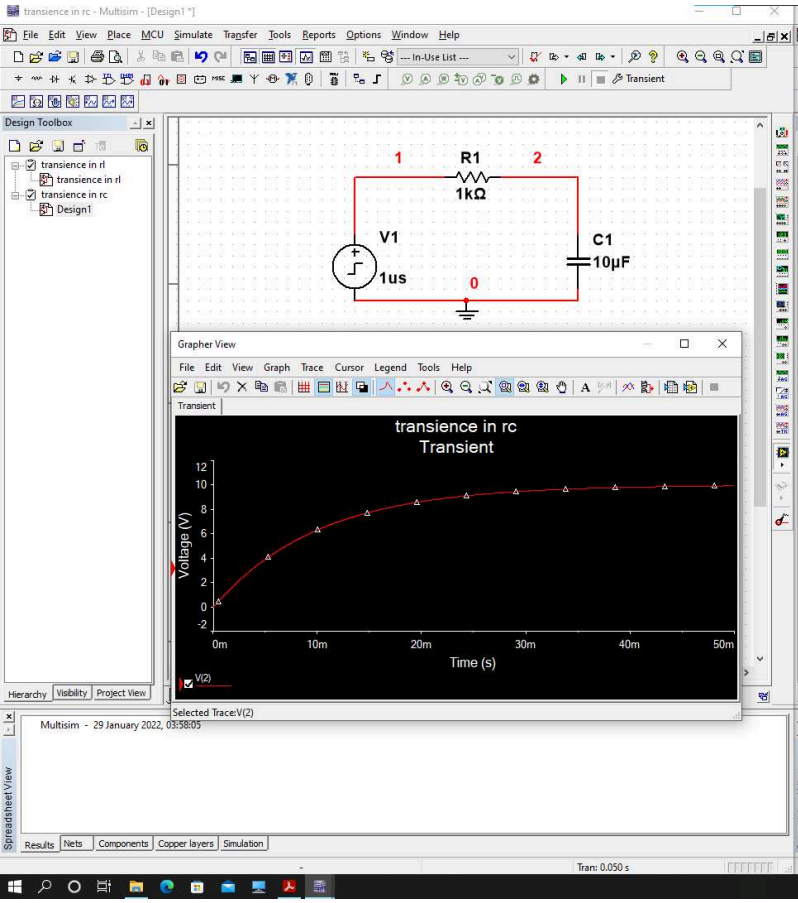
$= 10\left(1 - e^{-t/10^{-2}}\right)$ volts

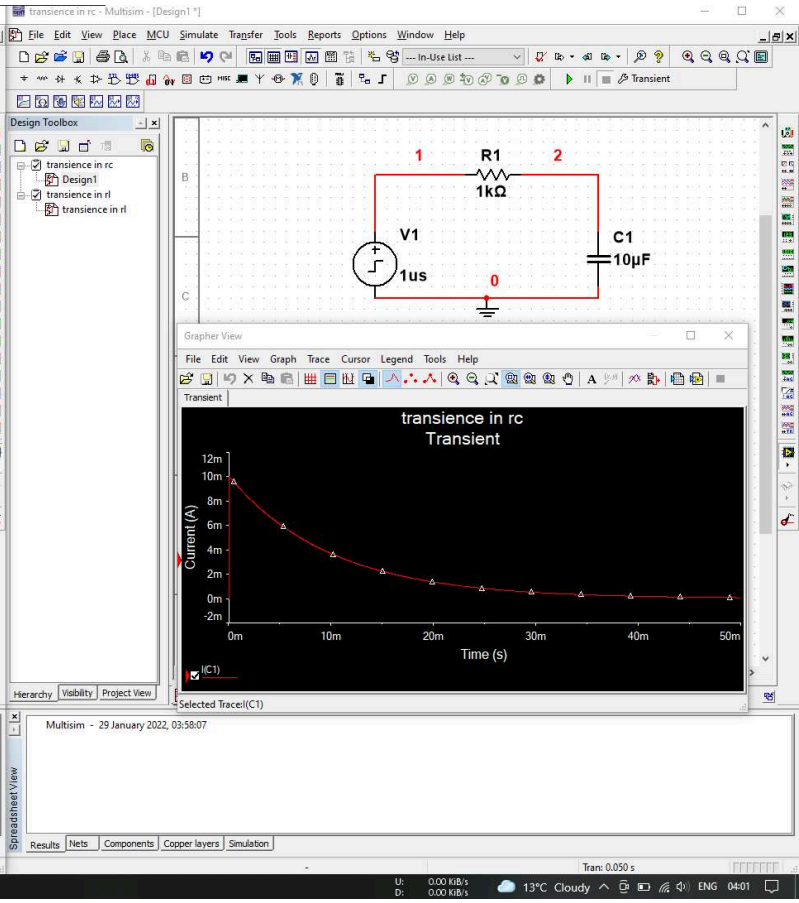
at $t = 10\,ms$, we get $V_c = 6.3V$

& $i_c(t) = Ve^{-t/RC} = 10e^{-t/10^{-2}}\,A = 3.68\,mA$

Output waveform -




transience in rc - Multisim - [Design1 *]
File Edit View Place MCU Simulate Transfer Tools Reports Options Window Help
Design Toolbox
transience in rl
transience in rl
transience in rc
Design1
1
R1
2
1kΩ
V1
1us
C1
10µF
0
Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
Transient
transience in rc
Transient
Voltage (V)
Time (s)
V(2)
Selected Trace:V(2)
Multisim - 29 January 2022, 03:58:05
Results Nets Components Copper layers Simulation
Tran: 0.050 s


transience in rc - Multisim - [Design1 *]
File Edit View Place MCU Simulate Transfer Tools Reports Options Window Help
Design Toolbox
transience in rc
Design1
transience in rl
transience in rl
1
R1
2
1kΩ
V1
1us
C1
10µF
0
Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
Transient
transience in rc
Transient
Current (A)
Time (s)
I(C1)
Selected Trace:I(C1)
Multisim - 29 January 2022, 03:58:07
Results Nets Components Copper layers Simulation
Tran: 0.050 s

observation table:

Table 4.1: Transient response in RC circuit

Type of circuit	Quantity	Expression
RC	$v(t)$	$10\left(1-e^{-t/10^{-2}}\right)$ V
	$I(t)$	$\left(10e^{-t/10^{-2}}\right)$ A

Calculation for series RL circuit in step response:

Here $\tau = L/R$

$= \frac{400\ \mu H}{150\ \Omega}$

$= 2.667\ \mu s = 2.667 \times 10^{-6}\ s$

Now, $V_L(t) = Ve^{-t/\tau}$

$= 9e^{-t/2.667 \times 10^{-6}}$

At $t = 2\mu s$ $\quad V_L(t) = 4.2\ V$

Also, $I_L(t) = V/R\,(1 - e^{-t/\tau})$

$= \frac{9}{150}\left(1 - e^{-t/2.667 \times 10^{-6}}\right) A$

At $t = 2\mu s$, $I_L = 60 \times \left(1 - e^{-\frac{2 \times 10^{-6}}{2.66 \times 10^{-6}}}\right) mA$

$= 31.66\ mA$

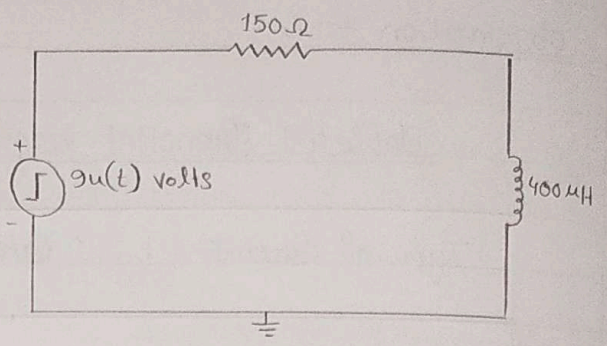
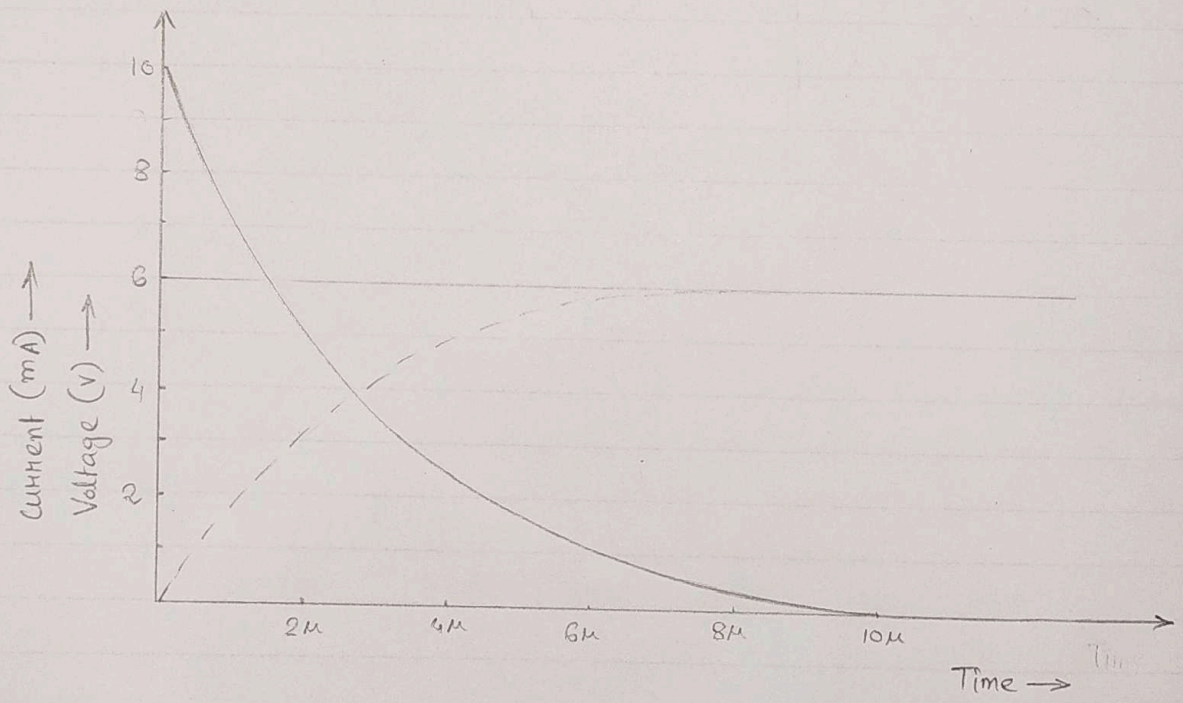
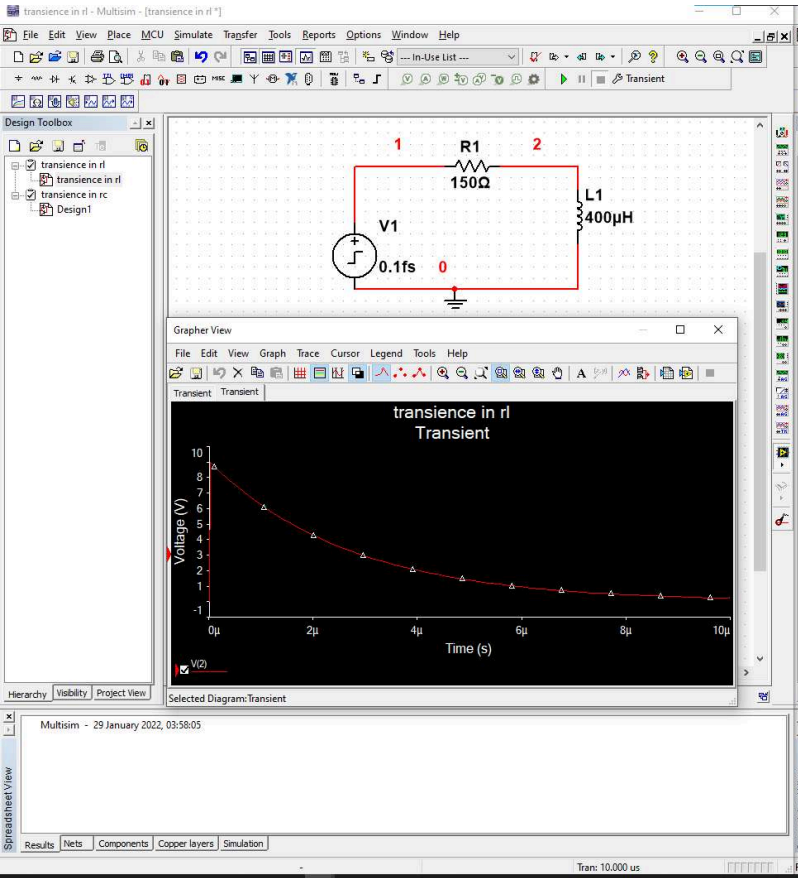
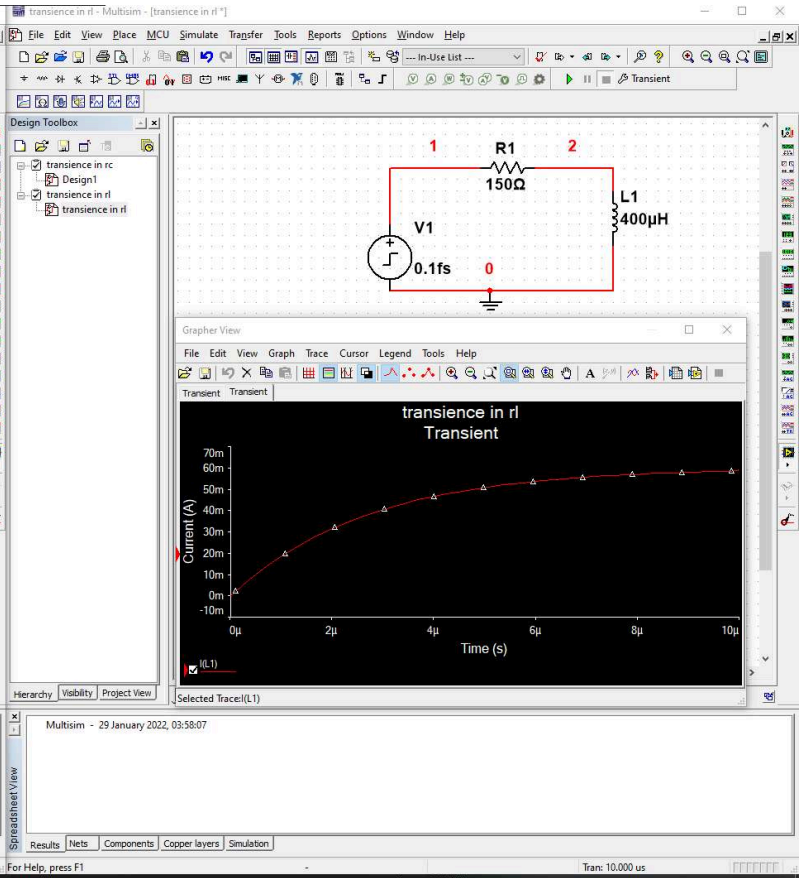


Fig: Example RL circuit

output waveform -




transience in rl - Multisim - [transience in rl *]
1
R1
2
150Ω
L1
400µH
V1
0.1fs
0
Grapher View
transience in rl
Transient
Voltage (V)
Time (s)
V(2)
Selected Diagram:Transient
Multisim - 29 January 2022, 03:58:05


transience in rl - Multisim - [transience in rl *]
1
R1
2
150Ω
L1
400µH
V1
0.1fs
0
Grapher View
transience in rl
Transient
Current (A)
Time (s)
I(L1)
Selected Trace:I(L1)
Multisim - 29 January 2022, 03:58:07

Observation table:

Table 4.2: Transient response in RL circuit

Type of circuit	Quantity	Expression
RL	$v(t)$	$(9e^{-t/2.667\times10^{-6}})$ V
	$I(t)$	$0.6(1-e^{-t/2.667\times10^{-6}})$ A

Result: Transient response of RL and RC circuits have been studied.

Transient response of ~~circuit~~ current in RL is found to be increasing and that in RC circuit is found to be decreasing with step voltage input.

Aim: Determination of transient response of current in RLC circuit with step voltage input for underdamp, critically damp and overdamped cases.

Software Required: NI Multisim

Theory: For $t > 0$, using the transformed network of fig-1,

Applying KVL, $V/s - RI(s) - LsI(s) - 1/Cs\, I(s) = 0$

$$\Rightarrow (R + Ls + 1/Cs)\, I(s) = V/s$$

$$\Rightarrow \left(\frac{LCs^2 + RCs + 1}{Cs}\right) I(s) = V/s$$

$$I(s) = \frac{V/s}{\frac{LCs^2 + RCs + 1}{Cs}} = \frac{V/L}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \frac{V/L}{(s - s_1)(s - s_2)}$$

where s_1 and s_2 are the roots of the equation $s^2 + \left(\frac{R}{L}\right)s + \left(\frac{1}{LC}\right) = 0$

$$s_1 = \frac{-R}{2L} + \sqrt{(R/2L)^2 - 1/LC} = -\alpha + \sqrt{\alpha^2 - \omega_0^2} = -\alpha + \beta$$

$$s_2 = \frac{-R}{2L} - \sqrt{(R/2L)^2 - 1/LC} = -\alpha - \sqrt{\alpha^2 - \omega_0^2} = -\alpha - \beta$$

where, $\alpha = R/2L$

$\omega_0 = 1/\sqrt{LC}$

$\beta = \sqrt{\alpha^2 - \omega_0^2}$

By partial - faction expansion of $I(s)$

$$I(s) = \frac{A}{s - s_1} + \frac{B}{s - s_2}$$

$$A = (s - s_1)\, I(s) \Big|_{s - s_1} = \frac{V/L}{s - s_2}$$

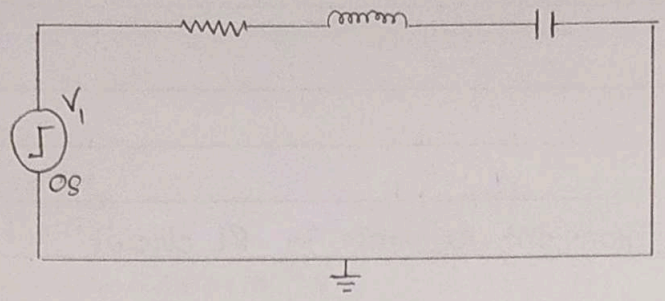


Fig 1: RLC circuit with step voltage input.

Calculations:

Case I: $R = 40\,\Omega$

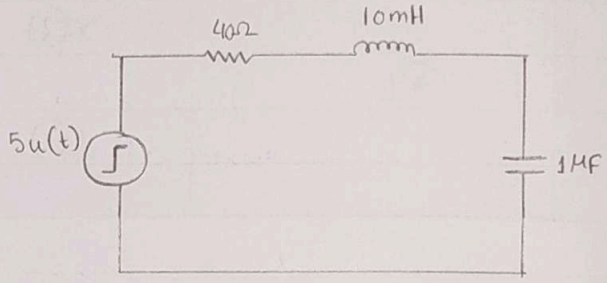


Fig 1: Underdamped response

For $t < 0$

$i(0^-) = i(0^+) = 0\,A$

$v(0^-) = v(0^+) = 0\,V$

$$\alpha = R/2L = \frac{40}{2\times10\times10^{-3}} = 2\times10^3$$

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10\times10^{-3}\times1\times10^{-6}}} = 10^{+4}$$

$\because \alpha < \omega_0$, therefore it is an underdamped condition

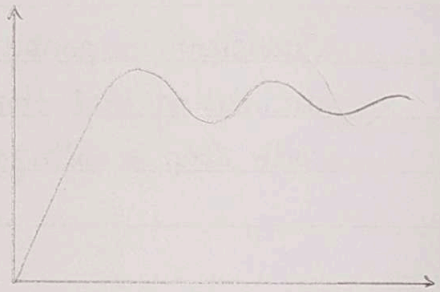


Fig: Underdamped condition waveform

$$S_{12} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} = -2\times10^3 \pm \sqrt{(2\times10^3)^2 - (10^4)^2}$$

$$= -2\times10^3 \pm j9797.95$$

Total response,

$$v(t) = V_{ss} + (A_1 \cos\omega_d t + A_2 \sin\omega_d t)e^{-\alpha t}$$

$$= 5 + (A_1 \cos 9797.95t + A_2 \sin 9797.95t)e^{-2\times10^3 t}$$

Now, $v(0) = 5 + A_1 = 0 \Rightarrow A_1 = -5$

$$i(0) = C\frac{dv(0)}{dt} \Rightarrow \frac{dv(0)}{dt} = \frac{i(0)}{C} = 0$$

$$\frac{dv(t)}{dt} = e^{-2\times10^3 t}(-9797.95A_1 \sin 9797.95 A_2 \cos 9797.95t) - 2\times10^3 e^{-2\times10^3}(A_1 \cos 9797.95 + A_2 \sin 9797.95t)$$

$$B = (s-s_2)\, I(s)\Big|_{s-s_2} = \frac{V/L}{s_2-s_1} = \frac{-V/L}{s_1-s_2}$$

$$I(s) = \frac{V}{L(s-s_1)}\left[\frac{1}{s-s_1} - \frac{1}{s-s_2}\right]$$

Taking inverse Laplace transforms

$$i(t) = \frac{V}{L(s-s_i)}\left[e^{s_1 t} - e^{s_2 t}\right] = k_1 e^{s_1 t} + k_2 e^{s_2 t}$$

<u>Case I</u>: When the roots are real and unequal, it given an overdamped

$$\frac{R}{2L} > \frac{1}{\sqrt{LC}}$$

$$\alpha > \omega_0$$

In this case, the sol^n is given by

$$i(t) = e^{-\alpha t}(k_1 e^{\beta t} + k_2 e^{-\beta t}$$

$$i(t) = k_1 e^{s_1 t} + k_2 e^{s_2 t} \quad \text{for } t>0$$

<u>Case II</u>: When the roots are equal and real, it gives critically damped response.

$$\frac{R}{2L} = \frac{1}{\sqrt{LC}}$$

$$\alpha = \omega_0$$

In this case, the sol^n is given by $i(t) = e^{-\alpha t}(k_1 + k_2 t)$ for $t>0$

<u>Case III</u>: When the roots are complex conjugate, it gives a critically underdamped response

$$\frac{R}{2L} < \frac{1}{\sqrt{LC}}$$

$$\alpha < \omega_0$$

Therefore $\frac{dv(0)}{dt} = 9797.95\,A_2 - 2\times10^3(-5) = 0 \Rightarrow A_2 = \frac{-10^4}{9797.95} = -1.02$

$$v(t) = 5 - (5\cos 9797.95t + 1.02\sin 9797.95t)\,e^{-2\times10^3 t}\ V$$

At $t = 0$ $\quad v(t) = 0\,V$ $\qquad$ ~~t(∞)~~ $t = \infty$ $\quad v(t) = 5\,V$

$t = 1ms$ $\quad v(t) = 5.68\,V$ $\qquad$ $t = 2ms$ $\quad v(t) = 4.91\,V$

<u>Case II</u> $\quad R = 200\,\Omega$

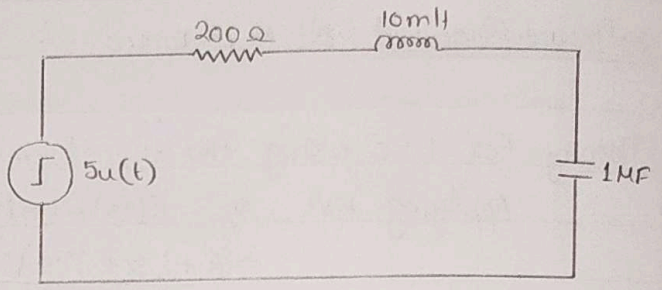


Fig: Critically damped RLC circuit

For $t < 0$

$i(0^-) = i(0^+) = 0A$

$v(0^-) = v(0^+) = 0V$

$$\alpha = \frac{R}{2L} = \frac{200}{2\times10\times10^{-3}} = 10^4$$

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10\times10^{-3}\times1\times10^{-6}}} = 10^4$$

$\because \alpha = \omega_0$, therefore it is the critically dumped condition

$$S_{12} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} = -10^4, -10^4$$

$\therefore$ Total response

$$v(t) = V_{ss} + (A_1 + A_2 t)\,e^{-\alpha t} = 5 + (A_1 + A_2 t)\,e^{-10^4 t}$$

Now, $v(0) = 5 + A_1 = 0 \Rightarrow A_1 = -5$

$$i(0) = C\frac{dv(0)}{dt} \Rightarrow \frac{dv(0)}{dt} = \frac{i(0)}{C} = 0$$

$$\frac{dv(0)}{dt} = -10^4(A_1 + A_2 t)e^{-10^4 t} + A_2 e^{-10^4 t}$$

Therefore $\frac{dv(0)}{dt} = -10^4(-5) + A_2 = 0 \Rightarrow A_2 = -5\times10^4$

$$v(t) = 5 + (-5 - 5\times10^4 t)\,e^{-10^4 t}$$

At $t = 0$ $\quad v(t) = 0\,V$

$t = \infty$ $\quad v(t) = 5\,V$

$t = 0.5\,ms$ $\quad v(t) = 4.79\,V$

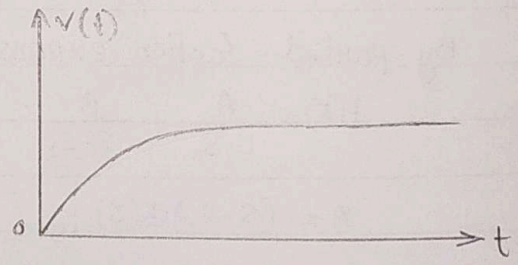


Fig: Critically damped waveform

Case III : $R = 1\,K\Omega$

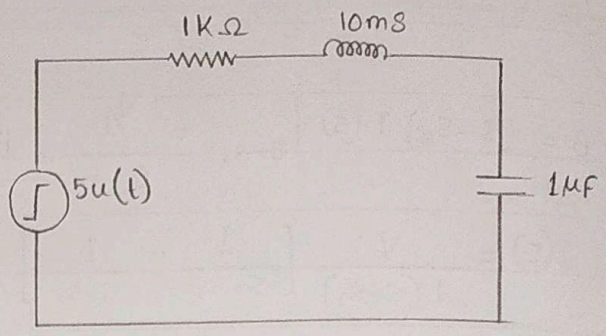


Fig: Overdamped response RLC circuit.

For $t < 0$

$$i(0^-) = i(0^+) = 0\,A$$

$$v(0^-) = v(0^+) = 0\,V$$

$$\alpha = \frac{R}{2L} = \frac{10^3}{2 \times 10 \times 10^{-3}} = 5 \times 10^4$$

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10 \times 10^{-3} \times 1 \times 10^{-6}}} = 10^4$$

$\because \alpha > \omega_0$, therefore it is an overdamped response.

$$S_{12} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2} = -5 \times 10^4 \pm \sqrt{(5 \times 10^4)^2 - (10^4)^2}$$

$$= -5 \times 10^4 \pm 48989.79$$

$$= -98989.79,\ -1010.21$$

$\therefore$ Total response

$$v(t) = V_{ss} + A_1 e^{s_1 t} + A_2 e^{s_2 t} = 5 + A_1 e^{-98989.79t} + A_2 e^{-1010.21t}$$

Now, $v(0) = 5 + A_1 + A_2 = 0 \Rightarrow A_1 + A_2 = -5$ — (I)

$$i(0) = C\frac{dv(0)}{dt} \Rightarrow \frac{dv(0)}{dt} = \frac{i(0)}{C} = 0$$

$$\frac{dv(0)}{dt} = -98989.79 A_1 e^{-98989.79t} - 1010.21 A_2 e^{-1010.21t}$$

$$\therefore \frac{dv(0)}{dt} = -98989.79 A_1 - 1010.21 A_2 = 0 \quad \text{— (II)}$$

Solving (I) & (II) we get, $A_1 = 0.051$, $A_2 = -5.051$

$$v(t) = 5 + 0.051 e^{-98989.79t} - 5.051 e^{-1010.21t}$$

At $t = 0$ $\quad v(t) = 0\,V$

$t = \infty$ $\quad v(t) = 5\,V$

$t = 1\,ms$ $\quad v(t) = 3.16\,V$

$t = 3\,ms$ $\quad v(t) = 4.75\,V$

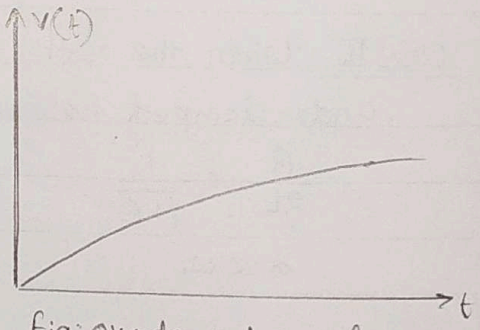
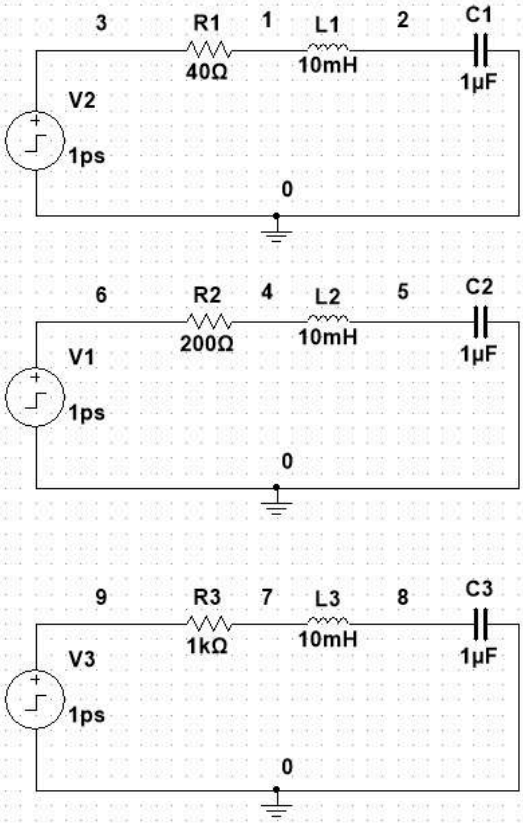
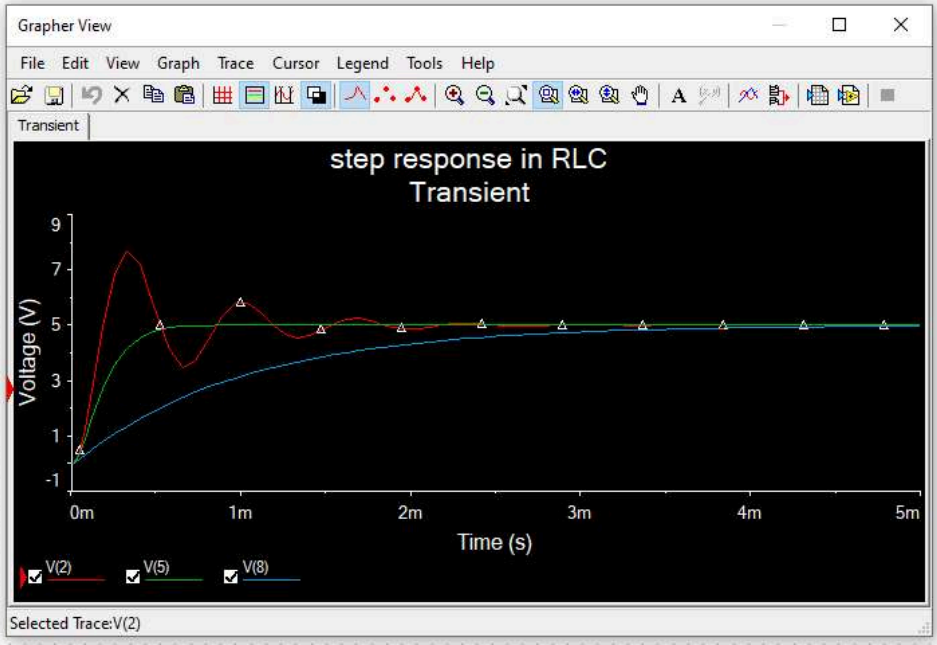


Fig: Overdamped waveform


3
R1
1
L1
2
C1
40Ω
10mH
1µF
V2
1ps
0
6
R2
4
L2
5
C2
200Ω
10mH
1µF
V1
1ps
0
9
R3
7
L3
8
C3
1kΩ
10mH
1µF
V3
1ps
0


Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
Transient
step response in RLC
Transient
Voltage (V)
9
7
5
3
1
-1
0m
1m
2m
3m
4m
5m
Time (s)
V(2)
V(5)
V(8)
Selected Trace:V(2)

In this case, the sol^n is given by $i(t) = K_1 e^{S_1 t} + K_2 e^{S_2 t}$

where, $S_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$

Let $\sqrt{\alpha^2 - \omega_0^2} = \sqrt{-1}\sqrt{\omega_0^2 - \alpha^2} = j\omega_d$

where $j = \sqrt{-1}$ and $\omega_d = \sqrt{\omega_0^2 - \alpha^2}$

Hence, $i(t) = e^{-\alpha t}\left(K_1 e^{j\omega t} + K_2 e^{-j\omega_d t}\right)$

$$= e^{-\alpha t}\left[(K_1 + K_2)\left\{\frac{e^{j\omega_d t} + e^{-j\omega_d t}}{2}\right\} + j(K_1 - K_2)\left\{\frac{e^{j\omega_d t} - e^{-j\omega_d t}}{j2}\right\}\right]$$

$$= e^{-\alpha t}\left[(K_1 + K_2)\cos\omega_d t + j(K_1 - K_2)\sin\omega_d t\right] \text{ for } t > 0$$

<u>Result</u>: Transient response of current in RLC circuit with step voltage input for underdamp, critical and overdamped cases are studied.

Aim: Determination of frequency response of current in RLC circuit with sinusoidal AC input.

Software required: NI Multisim

Theory: The current response of the series RLC circuit is found via Laplace transform as $I(s) = Y(s)V(s)$.
where $I(s)$ and $V(s)$ are laplace transform of $i(t)$ and $u(t)$.
s is complex frequency and $Y(s)$ = complex admittance.

$$Y(s) = \frac{1}{Z(s)} = \frac{1}{R + sL + L/sC} = \frac{sC}{s^2LC + sRC + 1}$$

This function is usually expressed in standard form

$$Y(s) = 1/R \times \frac{2\zeta(s/\omega_0)}{(s/\omega_0)^2 + 2\zeta(s/\omega_0) + 1}$$

where, $\omega_0 = 1/\sqrt{LC}$ $\quad \zeta = R/2\sqrt{C/L}$

Here, ω_0 is the undamped natural frequency in rad/s
ζ is the damping ratio, dimensionless

The value of s for which denominator of $Y(s)$ becomes zero are called poles of $Y(s)$ and zeros of $Z(s)$.

$$s_{12} = \omega_0\left(-\zeta \pm \sqrt{\zeta^2 - 1}\right)$$

For $\zeta > 1$, the poles are real and distinct and the system is overdamped

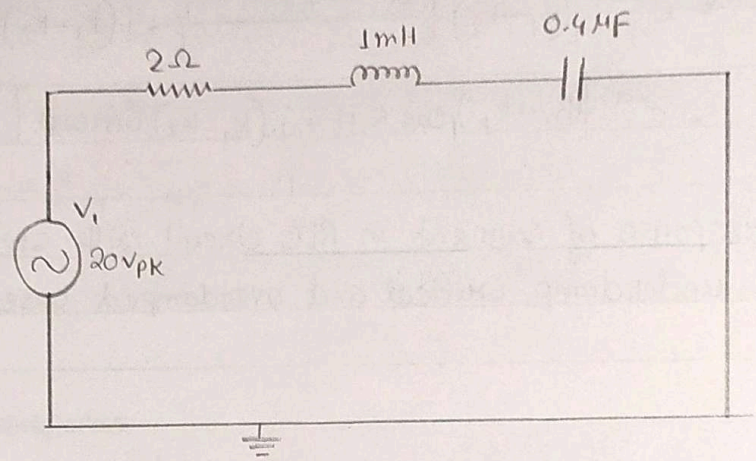


Fig 1: RLC circuit with sinusoidal AC input

For $\zeta = 1$, the poles are real and coincident, the system is critically damped.

For $0 < \zeta < 1$, the poles are complex conjugate or

$$s_{1,2} = \omega_0 (\zeta \pm j\sqrt{1-\zeta^2}) \quad \text{where } j^2 = -1$$

The system is underdamped.

Frequency response:

System theory indicates that the frequency response of a circuit is found by letting $s \rightarrow j\omega$ in the transfer function, we use $Q = 1/2\zeta$

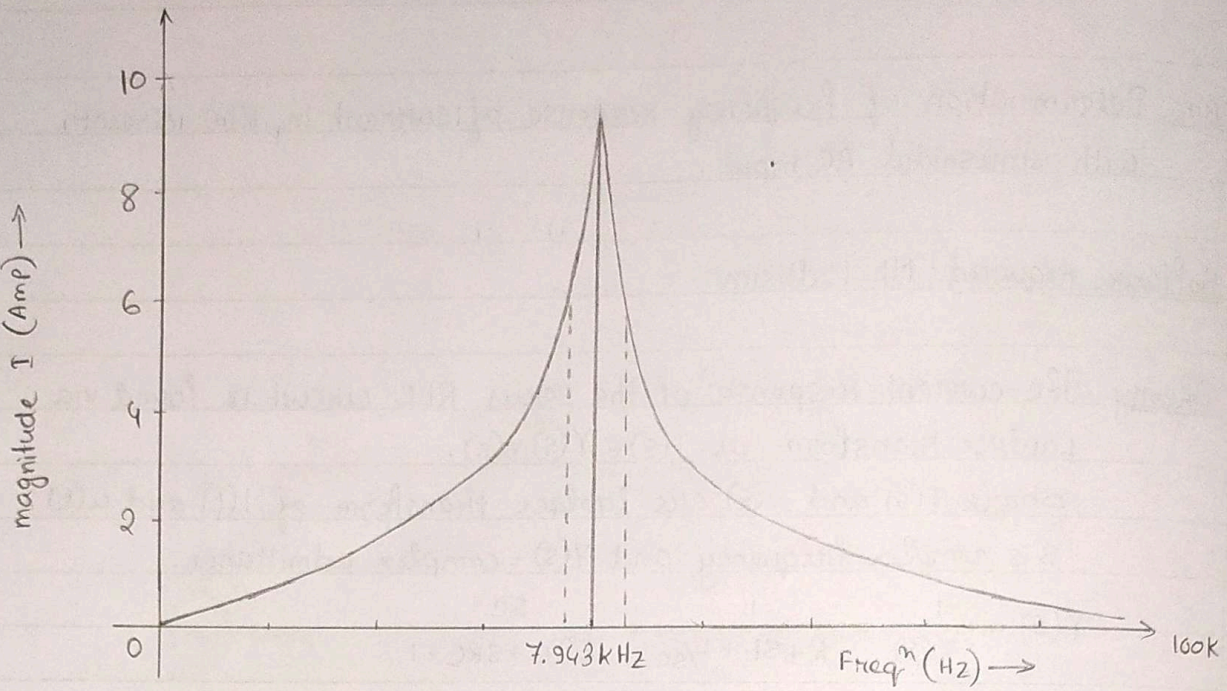
$$\therefore \cancel{Y(s)}\ Y(j\omega) = \frac{1}{R} \times H_{BP}(j\omega)$$

where $H_{BP}(j\omega) = \dfrac{j(\omega/\omega_0)}{1-(\omega/\omega_0)^2 + j(\omega/\omega_0)/Q}$ [Standard 2nd order band pass function]

$$\omega_0 = 1/\sqrt{LC} \qquad Q = 1/R\sqrt{L/C}$$

To investigate the frequency response of the circuit, we apply an AC voltage of $v_1(t) = V_{im}\cos\omega t$ and we observe the response $v_0(t) = R_i(t)$ across the resistor, which is an AC voltage of the type, $v_0(t) = V_{om}\cos(\omega t + \phi)$

$$V_{om} = |H_{BP}| \times V_{im} \qquad \phi = \angle H_{BP}$$

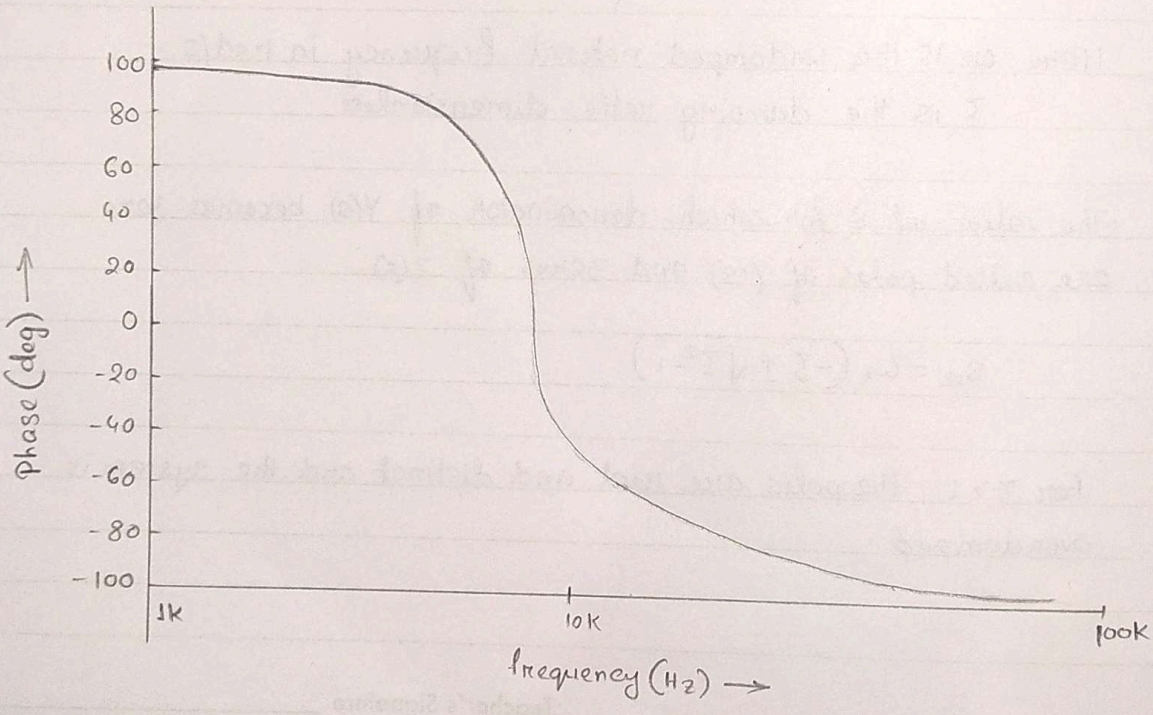


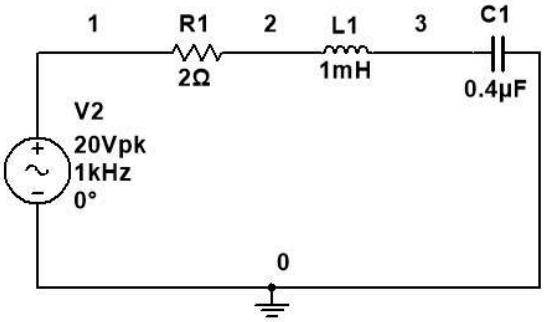
$I_{max} = 9.9589\,A$

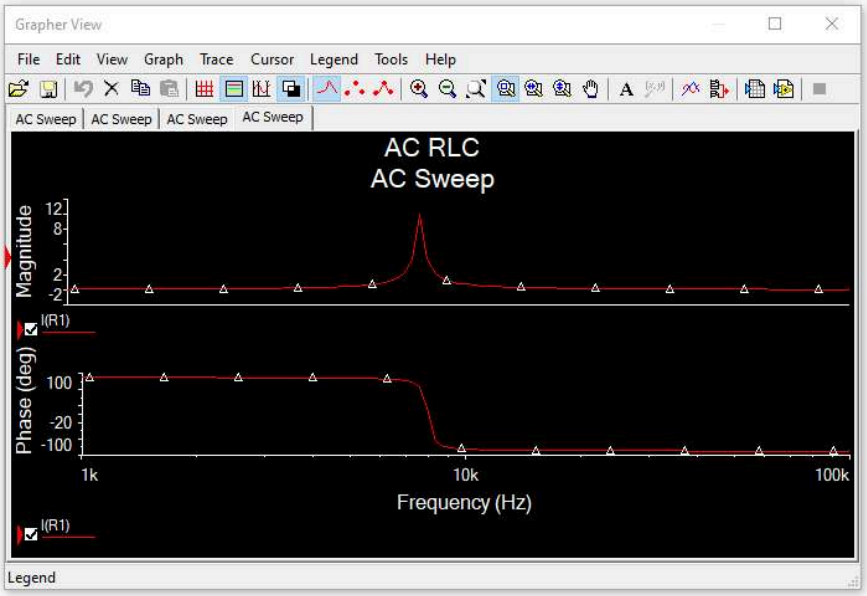
$\therefore 0.707\, I_{max} = 0.707 \times 9.9589 = 7.0409$

Corresponding frequencies $f_1 = 7.763\,Hz$ and $f_2 = 8.1\,KHz$

$f_0 = 7.943\,KHz$




1
R1
2
L1
3
C1
2Ω
1mH
0.4µF
V2
20Vpk
1kHz
0°
0


Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
AC Sweep
AC Sweep
AC Sweep
AC Sweep
AC RLC
AC Sweep
Magnitude
12
8
2
-2
I(R1)
Phase (deg)
100
-20
-100
1k
10k
100k
Frequency (Hz)
I(R1)
Legend

Calculations:

Resonant frequency, $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Here, $L = 1mH = 10^{-3} H$

$C = 0.4 \mu F = 4 \times 10^{-7} F$

$\therefore f_0 = \frac{1}{2 \times 3.14 \sqrt{10^{-3} \times 4 \times 10^{-7}}}$

$= 7957.74 Hz$

and maximum current $= \frac{V_m}{R} = \frac{20}{2} = 10A$

observation Table:

Table 6: Frequency response

Theoretical value	Practical value
$I_{max} = V_m/R$ $= 20/2 = 10A$	$I_{max} = 9.959A$
Resonant frequency $f_0 = 1/2\pi \sqrt{LC}$ $= 1/2\pi \sqrt{1mH \times 0.4\mu F}$ $= 7957\ Hz$	$f_0 = 7.943\ KHz$

Result: The frequency response of current in RLC circuit with sinusoidal AC input is studied.

Aim: Determination of Z and h parameters (DC only) for a network and computation of Y and ABCD parameters.

Software required: NI Multisim

Theory: Z parameter:

Also known as impedence parameters. The voltages are represented as a function of currents.

So,

$$V_1 = f_1(I_1, I_2) \text{ and } V_2 = f_2(I_1, I_2)$$

The Z-Parameters are

Z_{11} = input impedence keeping output open $\frac{V_1}{I_1}\Big|_{I_2=0}$

Z_{22} = ~~in~~ output impedence keeping input open $\frac{V_2}{I_2}\Big|_{I_1=0}$

Z_{12} = Reverse transfer impedence keeping input open $\frac{V_1}{I_2}\Big|_{I_1=0}$

Z_{21} = ~~Reverse~~ Forward transfer impedence keeping ~~imp~~ output open $\frac{V_2}{I_1}\Big|_{I_2=0}$

The voltage are represented as

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$
$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

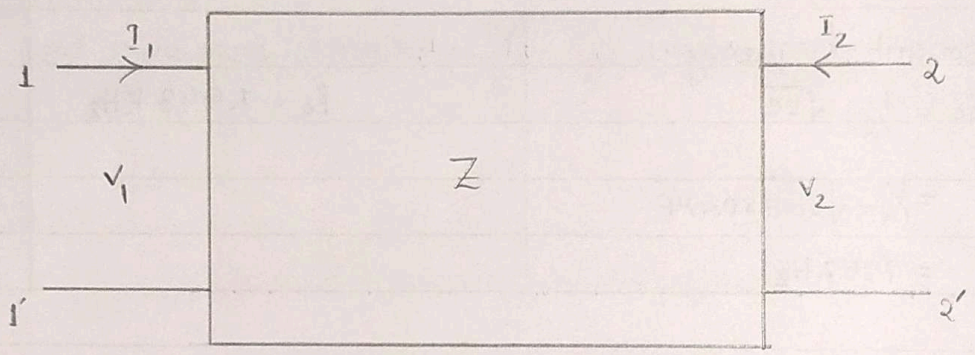


Fig: A two port network

Calculation

1) Z Parameters

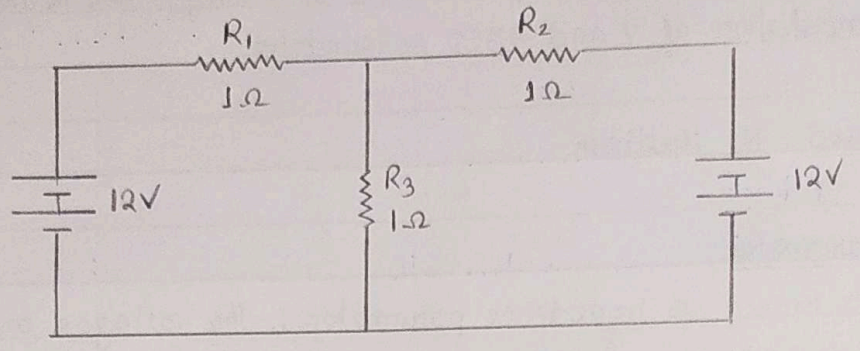


Fig: T network for finding Z parameters.

The Z-parameters for the T network are given by

$Z_{11} = R_1 + R_3 = 1\Omega + 1\Omega = 2\Omega$

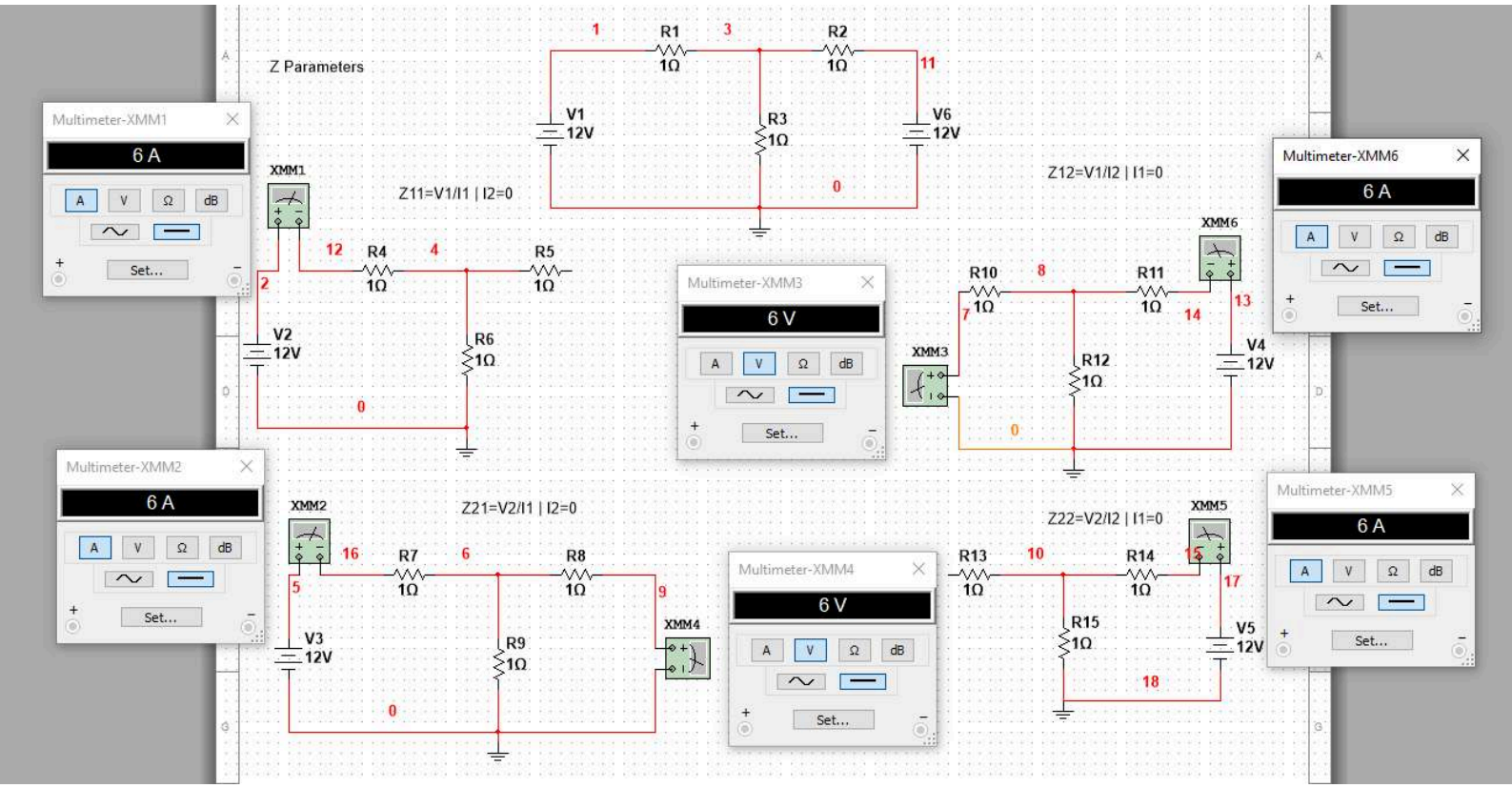
$Z_{12} = R_3 = 1\Omega$

$Z_{21} = R_3 = 1\Omega$

$Z_{22} = R_3 + R_2 = 1 + 1 = 2\Omega$

The Z-parameter matrix is

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} 2\Omega & 1\Omega \\ 1\Omega & 2\Omega \end{bmatrix}$$


Z Parameters
Z11=V1/I1 | I2=0
Z12=V1/I2 | I1=0
Z21=V2/I1 | I2=0
Z22=V2/I2 | I1=0
Multimeter-XMM1
6 A
Multimeter-XMM2
6 A
Multimeter-XMM3
6 V
Multimeter-XMM4
6 V
Multimeter-XMM5
6 A
Multimeter-XMM6
6 A
XMM1
XMM2
XMM3
XMM4
XMM5
XMM6
V1 12V
V2 12V
V3 12V
V4 12V
V5 12V
V6 12V
R1 1Ω
R2 1Ω
R3 1Ω
R4 1Ω
R5 1Ω
R6 1Ω
R7 1Ω
R8 1Ω
R9 1Ω
R10 1Ω
R11 1Ω
R12 1Ω
R13 1Ω
R14 1Ω
R15 1Ω

Y Parameter :

Y parameter is a dual of Z-parameter

~~Y_{11} = Input impedence~~

Y_{11} = input admittance keeping output short-circuited $\frac{I_1}{V_1}\Big|_{V_2=0}$

Y_{22} = output admittance keeping input short circuited $\frac{I_2}{V_2}\Big|_{V_1=0}$

Y_{12} = Reverse transfer admittance keeping output short circuited $\frac{I_1}{V_2}\Big|_{V_1=0}$

Y_{21} = Forward transfer admittance keeping input ~~open~~ short circuited $\frac{I_2}{V_1}\Big|_{V_2=0}$

In the two port network represented by admittance, the current and voltage is related by the following equations.

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

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

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

Calculations

Y parameters -

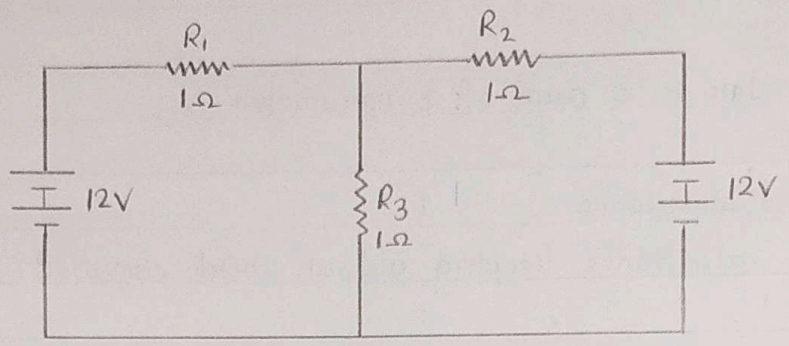


Fig: T-network for finding Y parameters

We have obtained the Z parameters for the given circuit as,

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} 2\Omega & 1\Omega \\ 1\Omega & 2\Omega \end{bmatrix}$$

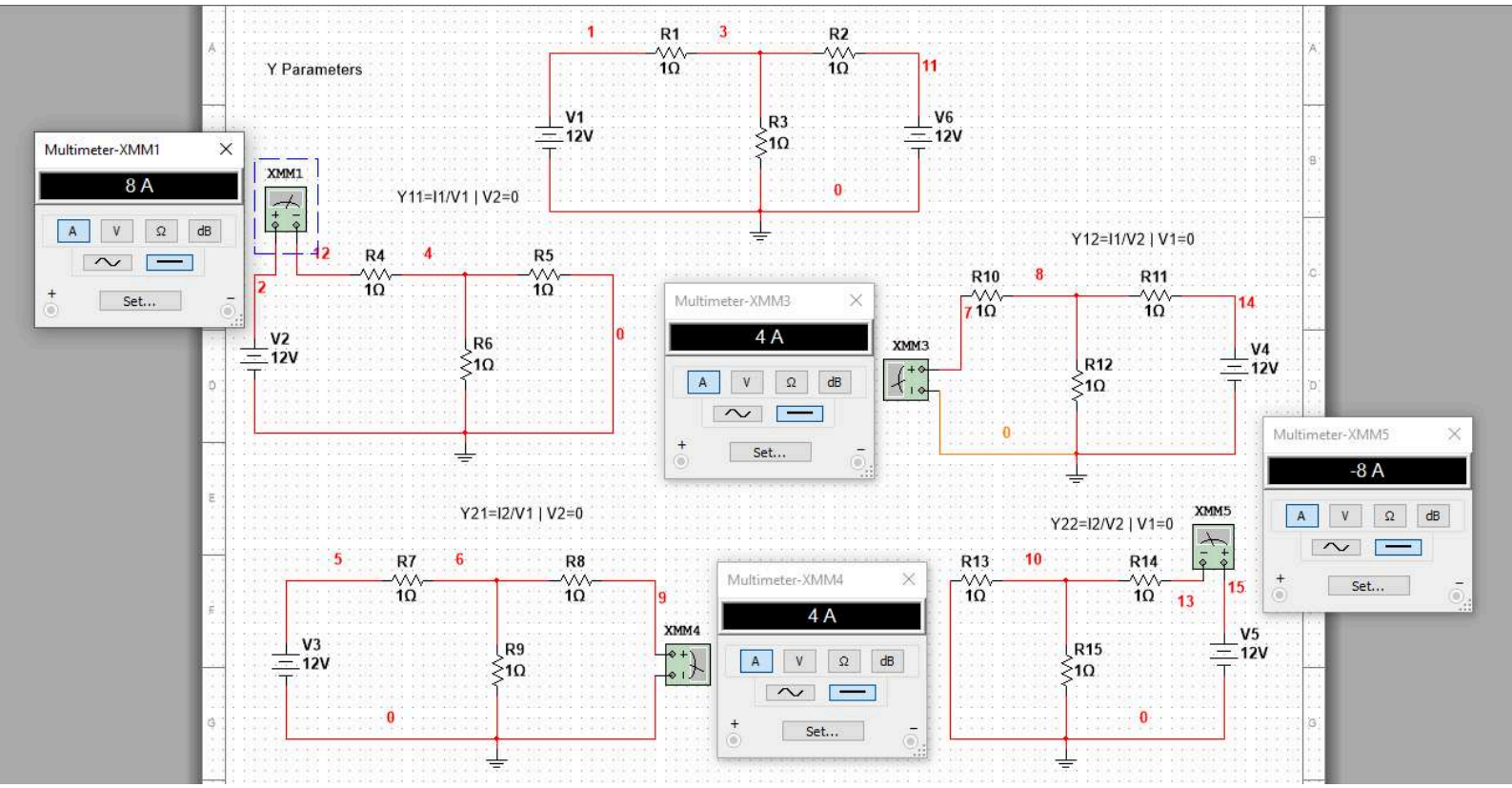
∴ The Y parameters are given by

$$\frac{1}{|Z|}\begin{bmatrix} Z_{22} & -Z_{12} \\ -Z_{21} & Z_{11} \end{bmatrix}$$

$$= \frac{1}{3}\begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix}$$

$$= \begin{bmatrix} 2/3 & -1/3 \\ -1/3 & 2/3 \end{bmatrix}$$

$$\therefore \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} 2/3\,\mho & -1/3\,\mho \\ -1/3\,\mho & 2/3\,\mho \end{bmatrix}$$


Y Parameters
Y11=I1/V1 | V2=0
Y12=I1/V2 | V1=0
Y21=I2/V1 | V2=0
Y22=I2/V2 | V1=0
R1 1Ω
R2 1Ω
R3 1Ω
R4 1Ω
R5 1Ω
R6 1Ω
R7 1Ω
R8 1Ω
R9 1Ω
R10 1Ω
R11 1Ω
R12 1Ω
R13 1Ω
R14 1Ω
R15 1Ω
V1 12V
V2 12V
V3 12V
V4 12V
V5 12V
V6 12V
XMM1
XMM3
XMM4
XMM5
Multimeter-XMM1
8 A
Multimeter-XMM3
4 A
Multimeter-XMM4
4 A
Multimeter-XMM5
-8 A
A
V
Ω
dB
Set...

h - parameter

Also known as hybrid parameters

$V_1 = f_1(I_1, V_2) \Rightarrow V_1 = h_{11} I_1 + h_{12} V_2$

$I_2 = f_2(I_1, V_2) \Rightarrow I_2 = h_{21} I_1 + h_{22} V_2$

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

In hybrid parameter circuit, voltage gain, ~~circuit~~ ~~ga~~ current gain, impedence and admittance are used to determine the relation between current & voltage of two port network.

Hence,

h_{11} = input impedence keeping the output short circuited $= \frac{V_1}{I_1}\Big|_{V_2=0}$

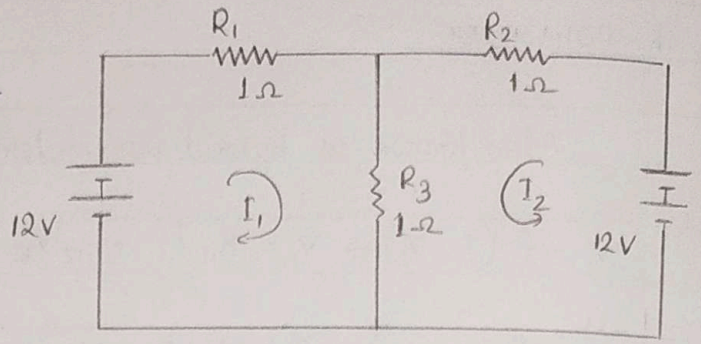
h_{12} = Reverse voltage gain keeping input open $= \frac{V_1}{V_2}\Big|_{I_1=0}$

h_{21} = Forward current gain keeping output short circuited $= \frac{I_2}{I_1}\Big|_{V_2=0}$

h_{22} = Output admittance keeping input open $= \frac{I_2}{V_2}\Big|_{I_1=0}$

Calculation

h-parameters



Fig; T-network finding h-parameter

Applying KVL in output port

$V_2 = I_2 + (I_1 + I_2)$

$\Rightarrow V_2 = 2I_2 + I_1$

$\Rightarrow 2I_2 = V_2 - I_1$

$\Rightarrow I_2 = -\frac{1}{2} I_1 + \frac{1}{2} V_2$ — (I)

We know, $I_2 = h_{21} I_1 + h_{22} V_2$ — (II)

From (I) & (II)

$h_{21} = -\frac{1}{2}$ ℧ , $h_{22} = \frac{1}{2}$ ℧

Again applying KVL in input port

$V_1 = I_1 + (I_1 + I_2)$

$\Rightarrow V_1 = 2I_1 + I_2$

$\Rightarrow V_1 = 2I_1 + (-\frac{1}{2}) I_1 + \frac{1}{2} V_2$

$\Rightarrow V_1 = \frac{3}{2} I_1 + \frac{1}{2} V_2$ — (III)

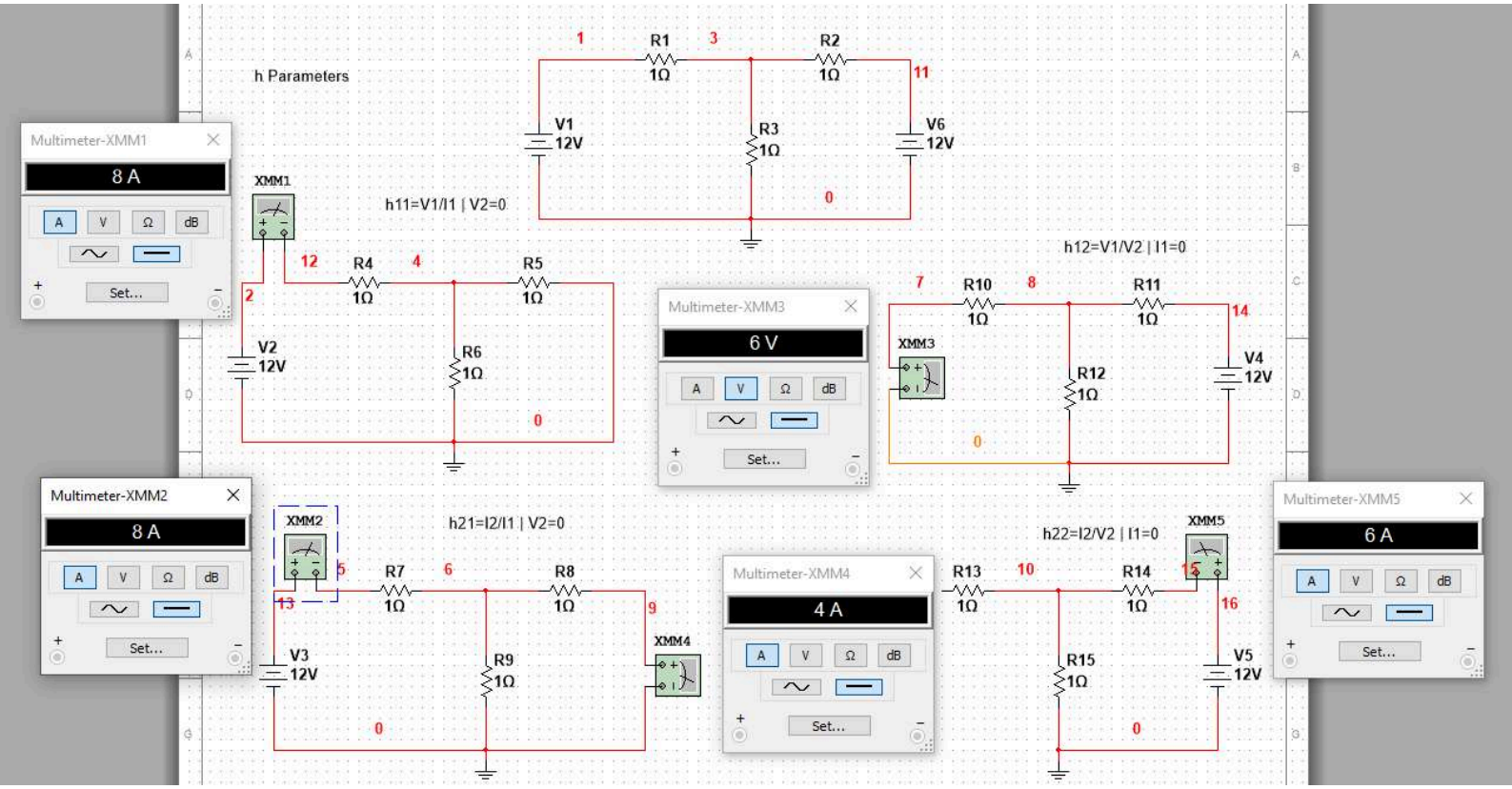
We know, $V_1 = h_{11} I_1 + h_{12} V_2$ — (IV)

From (III) & (IV),

$h_{11} = \frac{3}{2}\Omega$, $h_{12} = \frac{1}{2}$

Therefore,

$$\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} = \begin{bmatrix} \frac{3}{2}\Omega & \frac{1}{2} \\ -\frac{1}{2} & \frac{1}{2}℧ \end{bmatrix}$$


h Parameters
h11=V1/I1 | V2=0
h12=V1/V2 | I1=0
h21=I2/I1 | V2=0
h22=I2/V2 | I1=0
Multimeter-XMM1
8 A
Multimeter-XMM2
8 A
Multimeter-XMM3
6 V
Multimeter-XMM4
4 A
Multimeter-XMM5
6 A
XMM1
XMM2
XMM3
XMM4
XMM5
V1 12V
V2 12V
V3 12V
V4 12V
V5 12V
V6 12V
R1 1Ω
R2 1Ω
R3 1Ω
R4 1Ω
R5 1Ω
R6 1Ω
R7 1Ω
R8 1Ω
R9 1Ω
R10 1Ω
R11 1Ω
R12 1Ω
R13 1Ω
R14 1Ω
R15 1Ω
Set...

ABCD Parameter

These are also called transmission parameters. Here, voltage and current of input port are expressed in terms of output port.

Here, $V_1 = AV_2 - BI_2$

$I_1 = CV_2 - DI_2$

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

A = Reverse voltage gain keeping output open circuited $\frac{V_1}{V_2}\Big|_{I_2=0}$

B = Reverse transfer impedence keeping output short circuited = $\frac{V_1}{I_2}\Big|_{V_2=0}$

C = Reverse transfer admittance keeping output open circuited = $\frac{I_1}{V_2}\Big|_{I_2=0}$

D = Reverse current gain keeping output short circuited $\frac{I_1}{I_2}\Big|_{V_2=0}$

Calculations

ABCD Parameters

Applying KVL in output port

$V_2 = I_2 + (I_1 + I_2)$

$\Rightarrow V_2 = 2I_2 - I_1$

$\Rightarrow I_1 = V_2 - 2I_1$ —— (1)

$\Rightarrow I_1 = 1V_2 + \cancel{2(-I_2)}\ 2(-I_2)$

We know, $I_1 = CV_2 + D(-I_2)$

$\therefore C = 1\mho$, $D = 2$

Applying KVL in input port

$V_1 = I_1 + (I_1 + I_2)$

$\Rightarrow V_1 = 2I_1 + I_2$

$\Rightarrow V_1 = I_2 + 2(V_2 - 2I_2)$

$\Rightarrow V_1 = 2V_2 - 3I_2$

We know, $V_1 = AV_2 + B(-I_2)$

$\therefore A = 2$, $B = 3\Omega$

Therefor,

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 2 & 3\Omega \\ 1\mho & 2 \end{bmatrix}$$

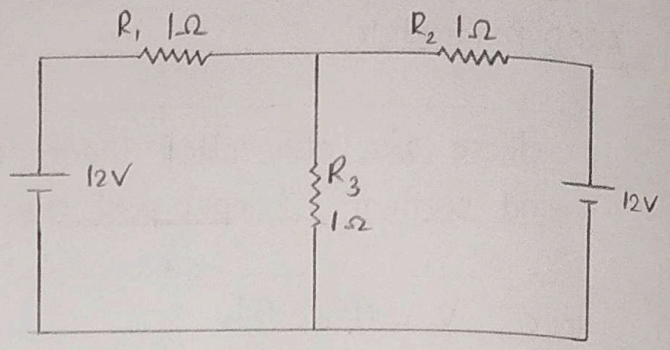
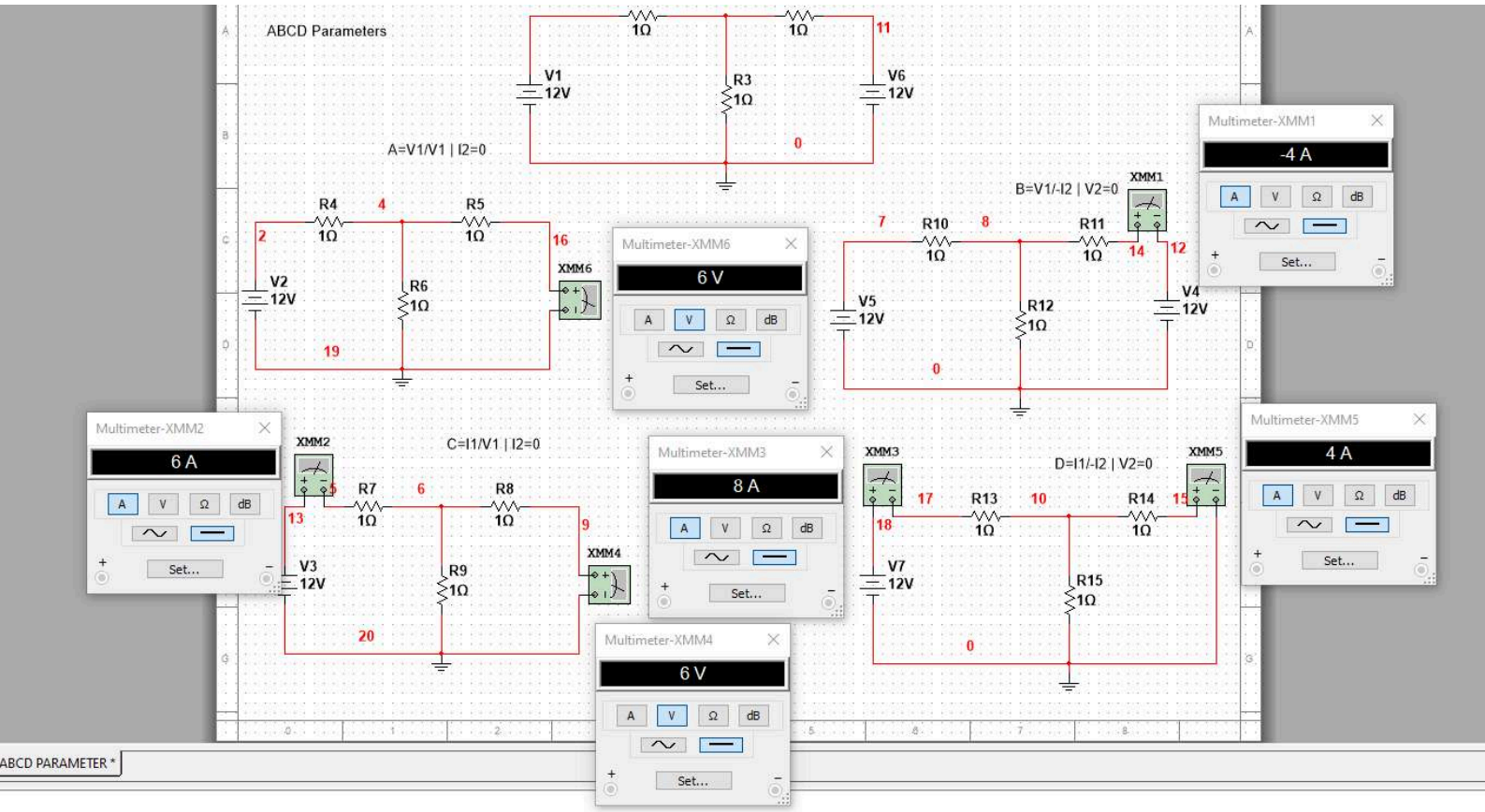


Fig: T-network finding ABCD Parameters


ABCD Parameters
A=V1/V1 | I2=0
B=V1/-I2 | V2=0
C=I1/V1 | I2=0
D=I1/-I2 | V2=0
V1 12V
V2 12V
V3 12V
V4 12V
V5 12V
V6 12V
V7 12V
R3 1Ω
R4 1Ω
R5 1Ω
R6 1Ω
R7 1Ω
R8 1Ω
R9 1Ω
R10 1Ω
R11 1Ω
R12 1Ω
R13 1Ω
R14 1Ω
R15 1Ω
XMM1
XMM2
XMM3
XMM4
XMM5
XMM6
Multimeter-XMM1
-4 A
Multimeter-XMM2
6 A
Multimeter-XMM3
8 A
Multimeter-XMM4
6 V
Multimeter-XMM5
4 A
Multimeter-XMM6
6 V
A V Ω dB
Set...
ABCD PARAMETER *

Observation Table :

Table: Various two port parameters

Parameters	Theoretical values		Practical values	
1) Z-Parameters	$Z_{11} = 2\Omega$	$Z_{12} = 1\Omega$	$Z_{11} = 2\Omega$	$Z_{12} = 1\Omega$
	$Z_{21} = 1\Omega$	$Z_{22} = 2\Omega$	$Z_{21} = 1\Omega$	$Z_{22} = 2\Omega$
2) Y- Parameters	$Y_{11} = 3/2\,\mho$	$Y_{12} = -1/3\,\mho$	$Y_{11} = 3/2\,\mho$	$Y_{12} = -1/3\,\mho$
	$Y_{21} = -1/3\,\mho$	$Y_{22} = 2/3\,\mho$	$Y_{21} = -1/3\,\mho$	$Y_{22} = 2/3\,\mho$
3) h-Parameters	$h_{11} = 3/2\,\Omega$	$h_{12} = 1/2$	$h_{11} = 3/2\,\Omega$	$h_{12} = 1/2$
	$h_{21} = -1/2$	$h_{22} = 1/2\,\mho$	$h_{21} = -1/2$	$h_{22} = 1/2\,\mho$
4) ABCD-Parameters	$A = 2$	$B = 3\,\Omega$	$A = 2$	$B = 3\,\Omega$
	$C = 1\,\mho$	$D = 2$	$C = 1\,\mho$	$D = 2$

Result: Z, Y, h and ABCD parameters are successfully computed.

Aim: Determination of driving point and transfer function of a two-port ladder network and verify with theoretical values.

Software required: NI Multisim

Theory: An application of two-port network is the synthesis of ladder network in order to design low pass filter. Fig 1. shows an ~~ladder~~ LC ladder network with an odd no of elements. When either network is terminated by the load impedence Z_L and the source impedence Z_S, we obtain the structure in fig 2. We assume $Z_S = 0$

To synthesize the LC ladder network, we begin with the ladder network characterisation by it's admittance parameter, namely

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

At the input port $V_1 = V_S$, $Z_S = 0$

At the output port $V_2 = V_o$, $I_2 = -V_2/Z_L = V_o Y_L$

$\therefore$ The above eq^n becomes $-V_o Y_L = Y_{21} V_S + Y_{22} V_o$

$$H(S) = V_o/V_S$$
$$= \frac{-Y_{21}}{Y_L + Y_{22}}$$
$$= \frac{-Y_{21}/Y_L}{1 + Y_{22}/Y_L}$$

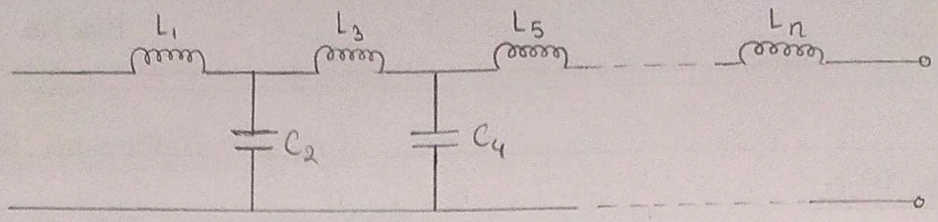


Fig 1: odd order

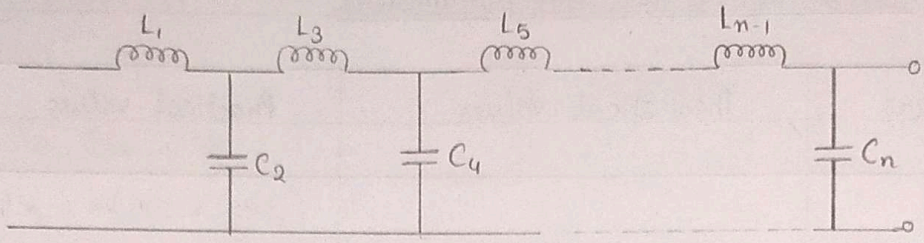


Fig 2: Even order

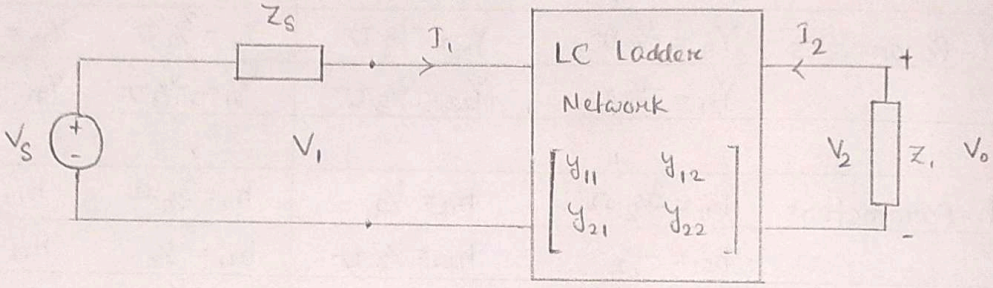


Fig 3: LC ladder n/w with terminating impedances

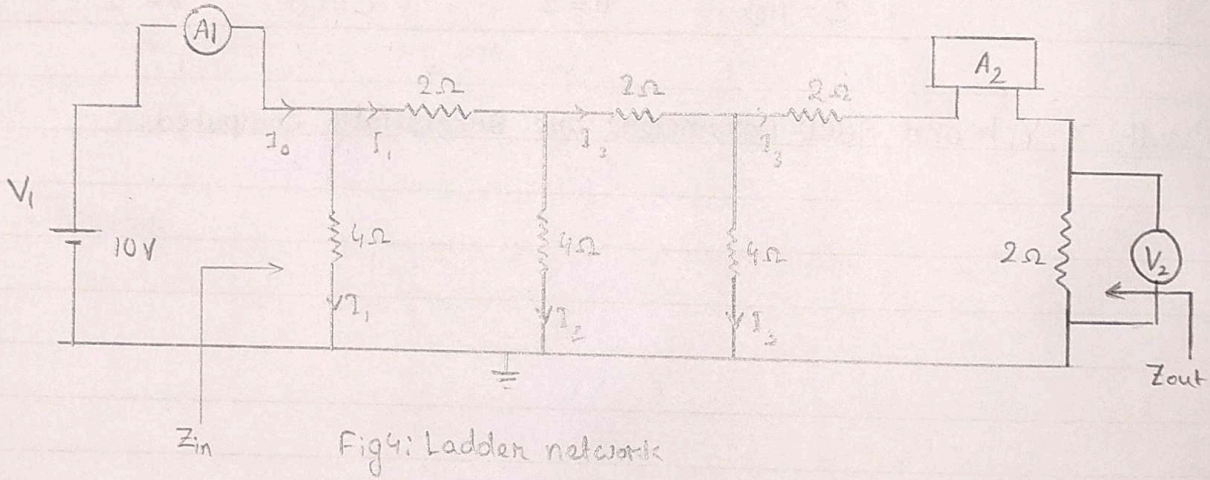
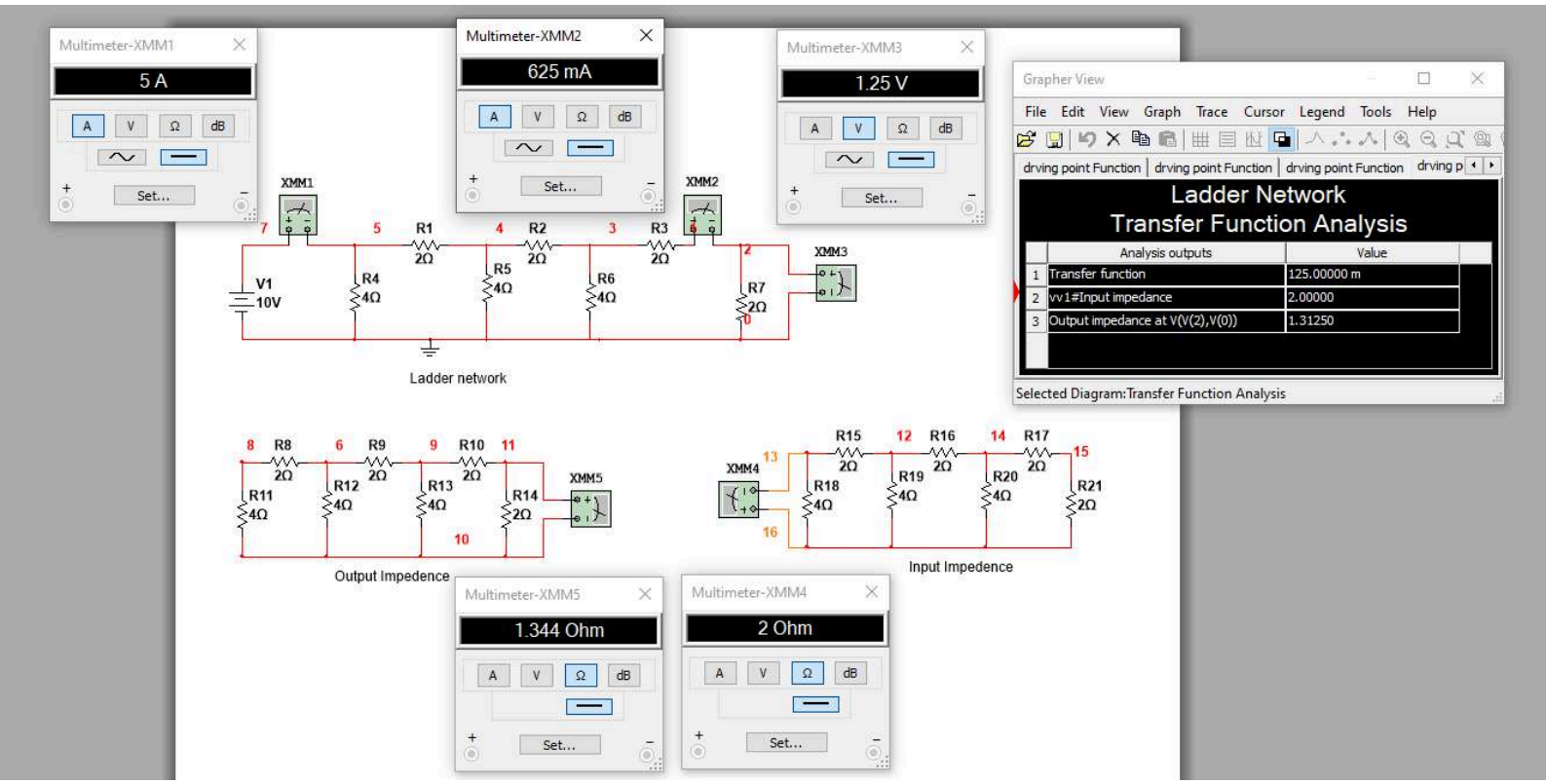


Fig 4: Ladder network


Multimeter-XMM1
5 A
Multimeter-XMM2
625 mA
Multimeter-XMM3
1.25 V
Grapher View
File Edit View Graph Trace Cursor Legend Tools Help
drving point Function
drving point Function
drving point Function
Ladder Network
Transfer Function Analysis
Analysis outputs
Value
1 Transfer function 125.00000 m
2 vv1#Input impedance 2.00000
3 Output impedance at V(V(2),V(0)) 1.31250
Selected Diagram:Transfer Function Analysis
XMM1
XMM2
XMM3
XMM4
XMM5
V1
10V
R1 2Ω
R2 2Ω
R3 2Ω
R4 4Ω
R5 4Ω
R6 4Ω
R7 2Ω
Ladder network
R8 2Ω
R9 2Ω
R10 2Ω
R11 4Ω
R12 4Ω
R13 4Ω
R14 2Ω
Output Impedence
R15 2Ω
R16 2Ω
R17 2Ω
R18 4Ω
R19 4Ω
R20 4Ω
R21 2Ω
Input Impedence
Multimeter-XMM5
1.344 Ohm
Multimeter-XMM4
2 Ohm

Calculations:

Input impedence as seen from left side

$$= \left[\left\{\left[\left\{\left[(2+2)\|4\right]+2\right\}\|4\right]+2\right\}\|4\right] = 2\Omega$$

$\therefore$ Input current $= \frac{10V}{2\Omega} = 5A = I_0$ [Reading in A_1 ammeter]

We can see from the network, as equivalent resistances are same for each part of the ladder, same current will flow between each resistance of each mesh and applying KVL, we see that

$I_1 = \frac{I_0}{2} = 2.5A$, $I_2 = \frac{I_1}{2} = 1.25A$, $I_3 = \frac{I_2}{2} = 0.625A$

$\therefore$ output current (Reading in A_2 ammeter) $= I_3 = 0.625A$

$\therefore$ output voltage $V_2 = 2\Omega \times 0.625A = 1.25V$.

And output impedence $= \left[\left\{\left[\left\{\left[(4+2)\|4\right]+2\right\}\|4\right]+2\right\}\|4\right] = 1.345\Omega$

Now, Transfer voltage function $= V_2/V_1 = 1.25/10 = 0.125$

Transfer current function $= I_3/I_0 = 0.625/5 = 0.125$

Transimpedence $= V_2/I_0 = 1.25/5 = 0.25\Omega$

Transadmittance $= I_3/V_1 = 0.625/10 = 0.0625\,\mho$

Driving point voltage $= V_1/V_2 = 10/1.25 = 8$

Driving point current $= I_0/I_3 = \frac{5}{0.625} = 8$

Driving point impedence $= V_1/I_0 = 10/5 = 2\Omega$

Driving point admittance $= I_0/V_1 = 5/10 = 0.5\,\mho$

Observation Table:

Table: Driving point function and transfer function

Quantity	Theoretical value	Practical value
Input voltage	10V	10V
Output voltage	1.25 V	1.25 V
Input current	5A	5A
Output current	0.625 A	625mA
Input impedence	2 Ω	2 Ω
Output impedence	1.345 Ω	1.344 Ω
Transfer voltage ratio	125×10^{-3}	125 m
Transfer current ratio	125×10^{-3}	0.125
Transimpedence	0.25 Ω	2.00 Ω
Trans admittance	0.0625 ℧	1.3125 ℧
Driving point voltage ratio	8	8
Driving point current ratio	8	8
Driving point impedence	2 Ω	2 Ω
Driving point admittance	0.5 ℧	0.5 ℧

Result: The driving point and transfer function of a two port ladder network is determined.

Aim: To study frequency response of passive Filter ~~account~~ circuit.

Software required: NI Multisim

Theory: It is made up of R, L and C. It allows or block signal.

The low pass filter: It only allows low frequency signal from 0Hz to its cut off frequency and block higher frequencies.

The high pass filter: It only allows high frequency signals from its cut off frequency to infinity and block lower frequencies.

The band pass filter: It passes only a particular range of signal while blocking all the higher and lower frequencies on either side of the band

Cut off frequency is given by $f_c = \frac{1}{2\pi RC}$ or $\frac{R}{2\pi L}$

Phase shift $\phi = \tan^{-1}(1/2\pi fRC)$

Band width, $BW = f_H - f_L$ (For Band Pass filter)

Point of maximum output gain = GM of two - 3DB values
= Centre frequency.

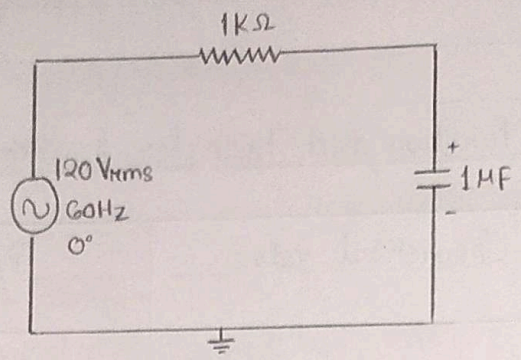


Fig1: Low pass filter

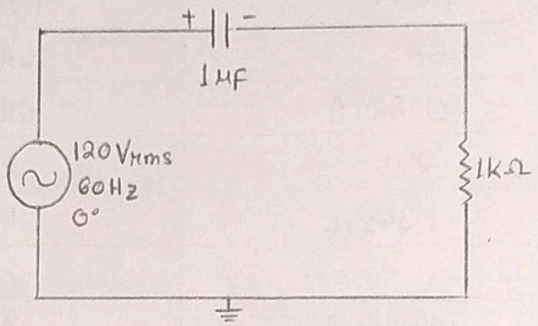


Fig2: High pass filter

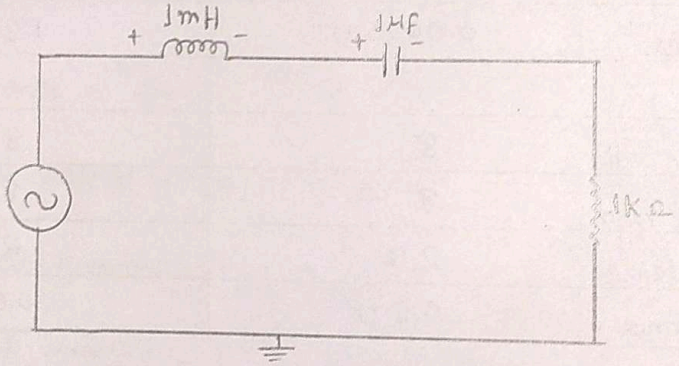
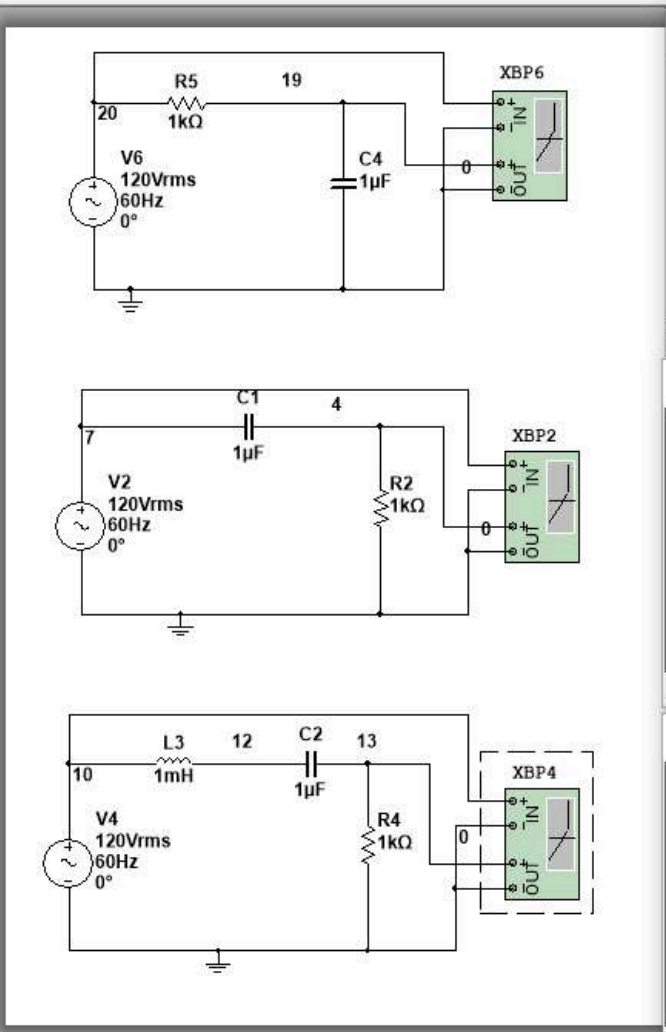
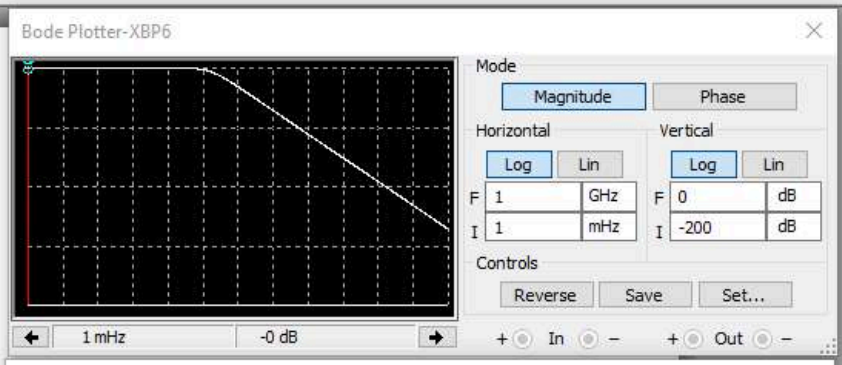
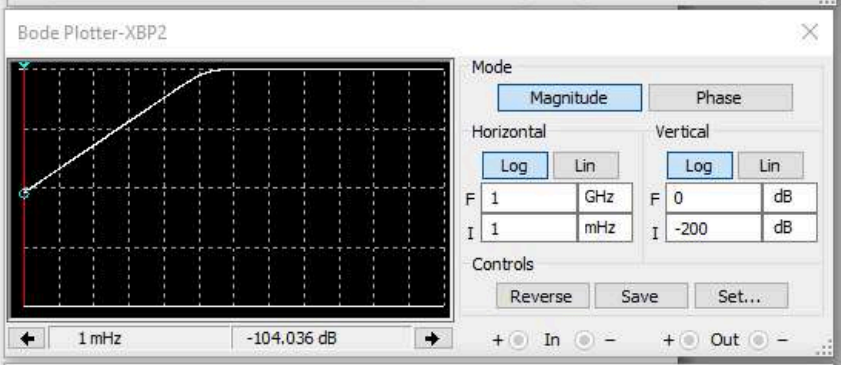
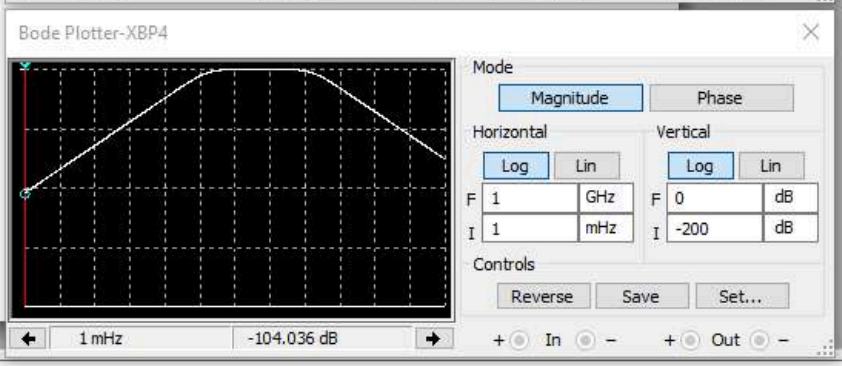


Fig3: Band pass filter


R5
1kΩ
19
20
V6
120Vrms
60Hz
0°
C4
1µF
0
XBP6
IN
OUT
C1
1µF
4
7
V2
120Vrms
60Hz
0°
R2
1kΩ
0
XBP2
IN
OUT
L3
1mH
12
C2
1µF
13
10
V4
120Vrms
60Hz
0°
R4
1kΩ
0
XBP4
IN
OUT


Bode Plotter-XBP6
Mode
Magnitude
Phase
Horizontal
Vertical
Log
Lin
Log
Lin
F 1 GHz
I 1 mHz
F 0 dB
I -200 dB
Controls
Reverse
Save
Set...
1 mHz
-0 dB
In
Out


Bode Plotter-XBP2
Mode
Magnitude
Phase
Horizontal
Vertical
Log
Lin
Log
Lin
F 1 GHz
I 1 mHz
F 0 dB
I -200 dB
Controls
Reverse
Save
Set...
1 mHz
-104.036 dB
In
Out


Bode Plotter-XBP4
Mode
Magnitude
Phase
Horizontal
Vertical
Log
Lin
Log
Lin
F 1 GHz
I 1 mHz
F 0 dB
I -200 dB
Controls
Reverse
Save
Set...
1 mHz
-104.036 dB
In
Out

observation table:

Table: Cutoff frequency for various filter

Type of filter	Theoretical value	Practical value
1) LPF (Fig-1)	$f_c = \frac{1}{2\pi \times 1K\Omega \times 1MF}$ $= 159\ Hz$	158.77 Hz
2) HPF (Fig-2)	$f_c = \frac{1}{2\pi \times 1K\Omega \times 1MF}$ $= 159\ Hz$	159.551 Hz
3) BPF (Fig-3)	$f_c = \frac{1}{2\pi\sqrt{10^{-9}}}$ $= 5\ KHz$	4.798 KHz

Result: Frequency response of Passive filter circuits has been studied.