

National Institute of Technology, Durgapur

Department of Electrical Engineering

Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/01

Title: Transient Response of RC and RL Circuit. Transient Response of RC Circuit.

Objective: Study the transient response and understand the time constant concept of a series RC and RL circuit using pulse waveforms.

Theory: Transient Response of RC Circuit.

In this experiment, we apply a pulse waveform to the RC circuit to analyse the transient response of the circuit. The *pulse-width* relative to a circuit's *time constant* determines how it is affected by an RC circuit.

Time Constant (τ): A measure of time required for certain changes in voltages and currents in RC and RL circuits. Generally, when the elapsed time exceeds five-time constants (5τ) after switching has occurred, the currents and voltages have reached their final value, which is also called steady-state response.

The time constant of an RC circuit is the product of equivalent capacitance and the Thevenin resistance as viewed from the terminals of the equivalent capacitor.

$$\tau = RC \quad (1)$$

A *Pulse* is a voltage or current that changes from one level to the other and back again. If a waveform's high time equals its low time, as in figure, it is called a *square wave*. The length of each cycle of a pulse train is termed its *period* (T).

The *pulse width (t_p)* of an ideal square wave is equal to half the time period.

The relation between pulse width and frequency is then given by $f = \frac{1}{2t_p}$

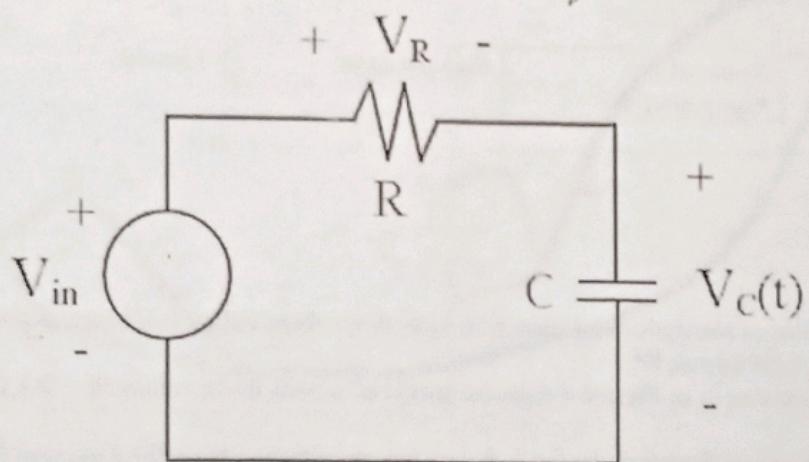


Figure 1: Series RC circuit.

From Kirchhoff's laws, it can be shown that the charging voltage $V_C(t)$ across the capacitor is given by: $V_C(t) = V(1 - e^{-t/RC})$ where, V is the applied source voltage to the circuit for $t \geq 0$. $RC = \tau$ is the time constant. The response curve is increasing and is shown in Figure 2.

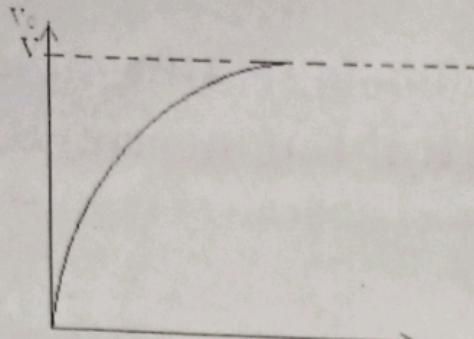


Fig -2 capacitor charging voltage

The discharge voltage for the capacitor is given by: $V_c(t) = V_0 e^{-t/RC}$ $t \geq 0$ ----- (4), Where V_0 is the initial voltage stored in capacitor at $t = 0$, and $RC = \tau$ is time constant. The response curve is a decaying exponential as shown in Figure 3.

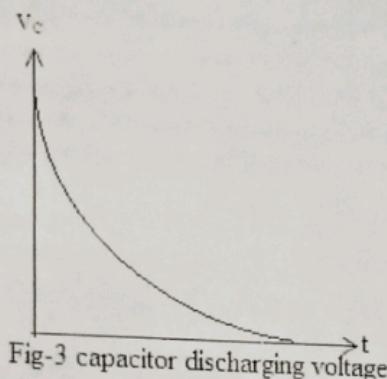


Fig-3 capacitor discharging voltage

Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

Procedure:

1. Measure the value of resistance and capacitor. Note down these values and hence determine the theoretical time constant of the circuit RC .
2. Set up the circuit shown in **Figure 4** with the component with those values ($R = 2 \text{ K}\Omega$ and $C = 1 \mu\text{F}$).
3. Connect the circuit as shown in the fig.5. Select the square wave from the Function Generator and apply a $5V_{\text{p-p}}$ square wave as input voltage to the circuit using the amplitude control.
4. Observe the transient response (exponentially rising) on DSO screen till the steady state (+5V DC level) is achieved.
5. Immediately press RUN/STOP Switch of DSO to hold the response shown on the DSO screen.
6. Observe and measure the time from DSO screen to reach the response from zero to steady state value.
7. Observe the response of the circuit for the following three cases and record the results.
 - a. $t_p \gg 5\tau$: Set the frequency such that the capacitor has enough time to fully charge and discharge during each cycle of the square wave. Determine the time constant from the waveforms obtained on the DSO screen.

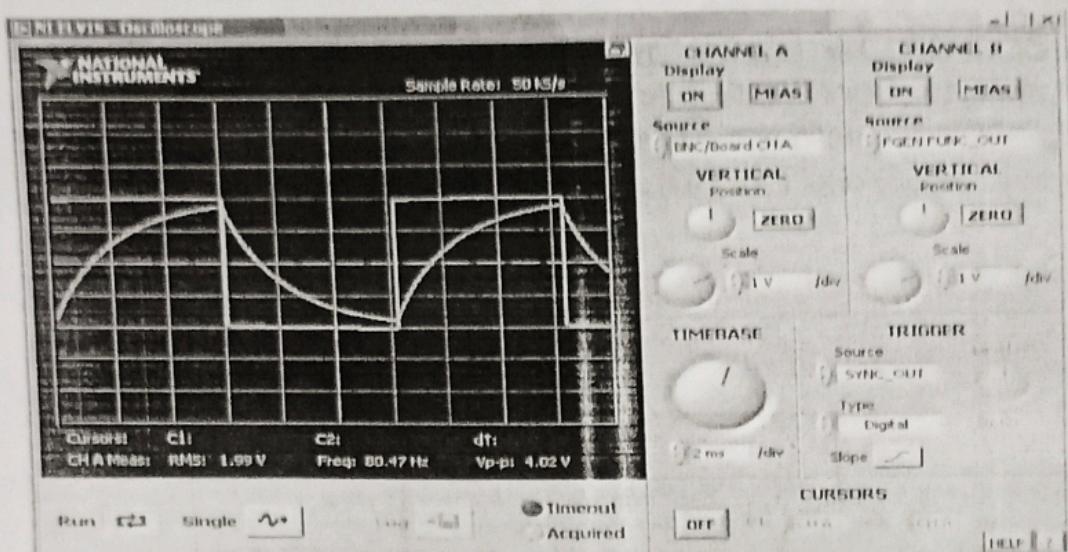
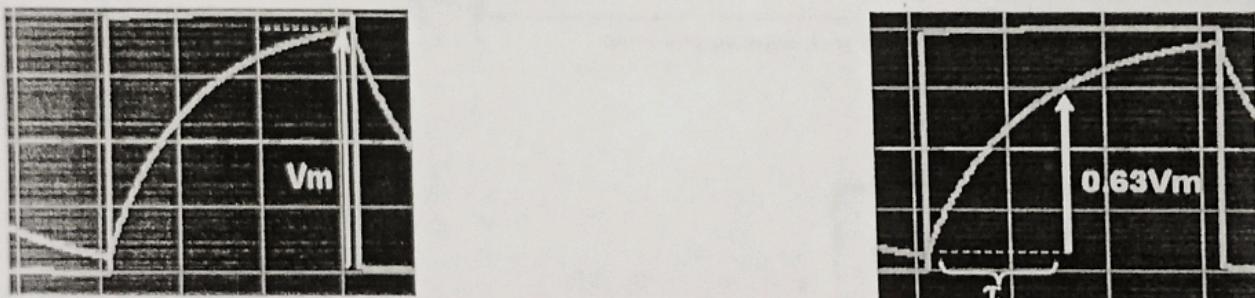


Figure 5: Oscilloscope Configuration

Figure 6: Measuring the time constant τ approximately by counting the number of squares.

Observation:

Charging of Capacitor			Discharging of Capacitor		
Time (sec)	Theoretical Charging Voltage (V)	Practical Charging Voltage (V)	Time (sec)	Theoretical Charging Voltage (V)	Practical Charging Voltage (V)

Table for time constant:

Time Constant, τ (sec)		
Theoretical	Practical	From graph

Report:

1. Plot the charging and discharging curves (V_s versus t)
2. Draw the tangent at $t=0$ on the discharging curve and note the time when it touches the X axis (τ). Compare this with the theoretical value Calculate the time constant and compare it to the measured value.
3. Repeat this for other set of R and C values.

Transient Response of an RL Circuit

Objective:

Study the transience due to inductors using a series RL circuit and understand the time constant concept.

Theory:

This lab is similar to the RC Circuit Lab except that the Capacitor is replaced by an Inductor. In this experiment, we apply a square waveform to the RL circuit to analyse the transient response of the circuit. The *pulse-width* relative to the circuit's *time constant* determines how it is affected by the RL circuit.

Time Constant (τ): It is a measure of time required for certain changes in voltages and currents in RC and RL circuits. Generally, when the elapsed time exceeds *five-time constants* (5τ) after switching has occurred, the currents and voltages have reached their final value, which is also called steady-state response.

The time constant of an RL circuit is the equivalent inductance divided by the Thevenin resistance as viewed from the terminals of the equivalent inductor.

$$\tau = L/R \quad (1)$$

A **Pulse** is a voltage or current that changes from one level to the other and back again. If a waveform's high time equals its low time, as in figure, it is called a *square wave*. The length of each cycle of a pulse train is termed its *period* (T). The *pulse width* (t_p) of an ideal square wave is equal to half the time period.

The relation between pulse width and frequency for the square wave is given by: $f = \frac{1}{2t_p}$

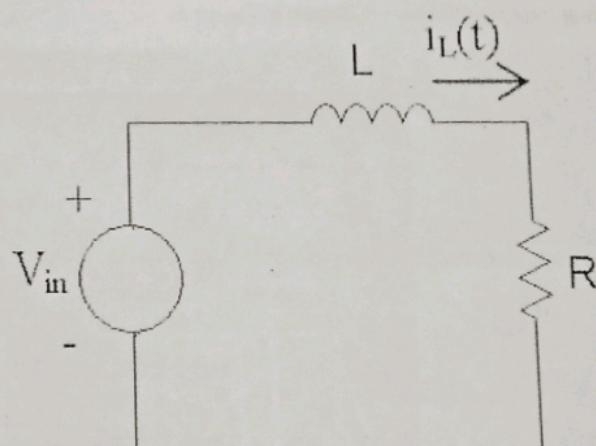


Fig-1, R-L series circuit

In an R-L circuit, voltage across the inductor decreases with time while in the *RC* circuit the voltage across the capacitor increased with time. Thus, *current* in an RL circuit has the same form as voltage in an RC circuit: they both rise to their final value exponentially according to $I - e^{-\frac{t}{\tau}}$.

The expression for the current build-up across the Inductor is given by

$$i_L(t) = RV(1 - e^{-\frac{t}{\tau}}) \quad t \geq 0 \quad (3), \text{ where, } V \text{ is the applied source voltage to the circuit}$$

for $t \geq 0$. The response curve is increasing and is shown in figure 2.

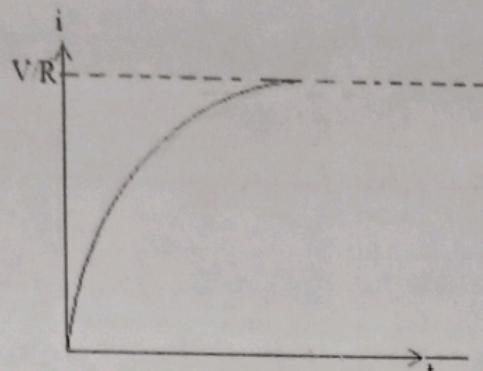


Fig-2, current build up across inductor

The expression for the current decay across the Inductor is given by:

$$i_L(t) = i_0 e^{-\frac{t}{L/R}} \quad t \geq 0 \quad \dots \dots \dots \quad (4)$$

where, i_0 is the initial current stored in the inductor at $t = 0$
 $L/R = \tau$ is time constant.

The response curve is a decaying exponential and is shown in figure 3.

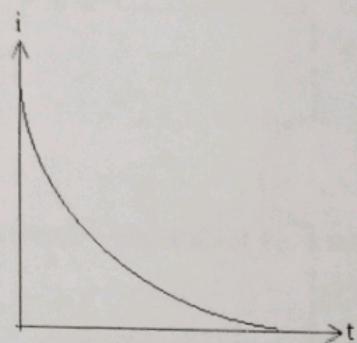


Fig-3, current decay across inductor

Since it is not possible to directly analyse the current through Inductor on a Scope, we will measure the output voltage across the Resistor. The resistor waveform should be similar to inductor current as $V_R = I_L R$. From the resistor voltage on the scope, we should be able to measure the time constant τ which should be equal to $\tau = L / R_{total}$.

Here, R_{total} is the total resistance and can be calculated from $R_{total} = R_{inductance} + R$.

$R_{inductance}$ is the measured value of inductor resistance and can be measured by connecting inductance to an ohmmeter prior to running the experiment.

Procedure: Same as RC circuit. Just consider L instead of C

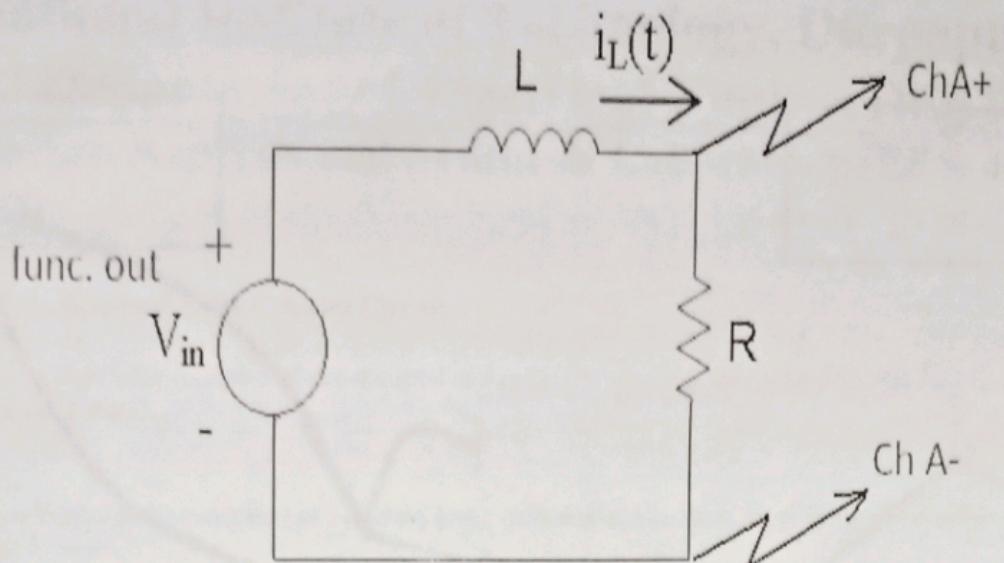


Fig-4, experimental setup

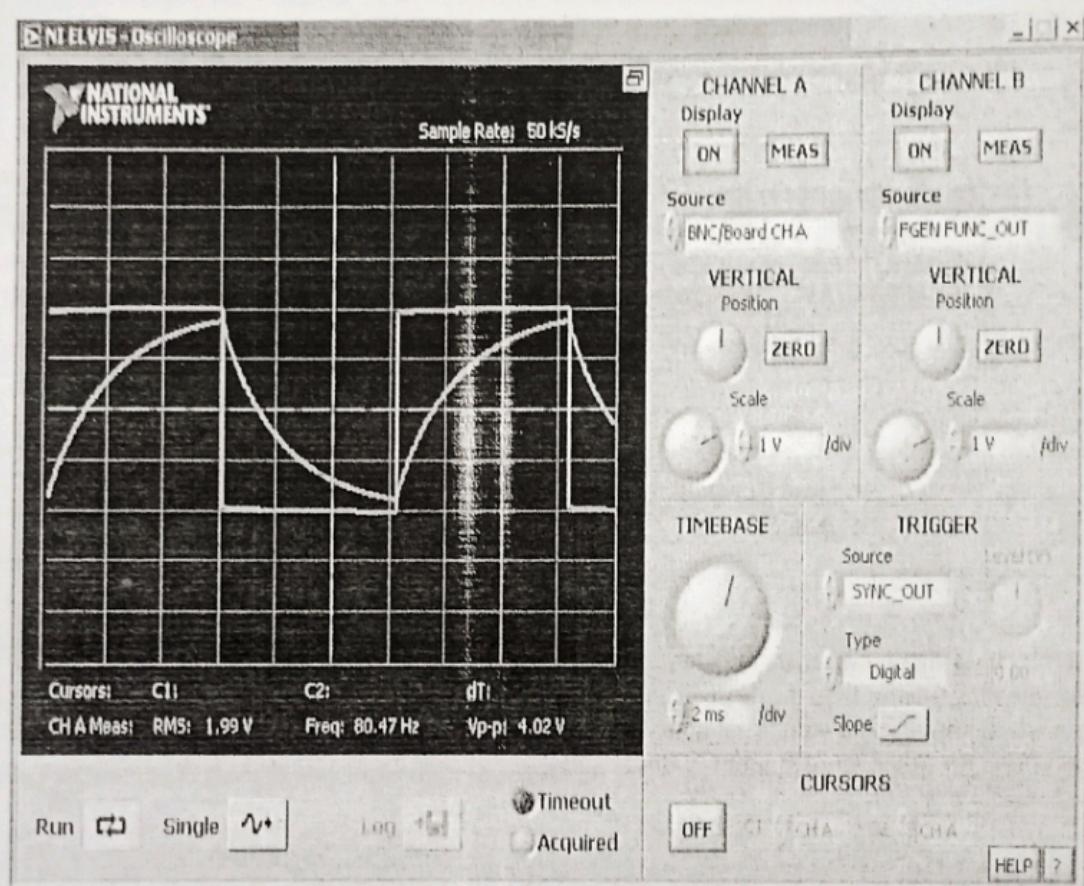


Figure 5: Oscilloscope Configuration

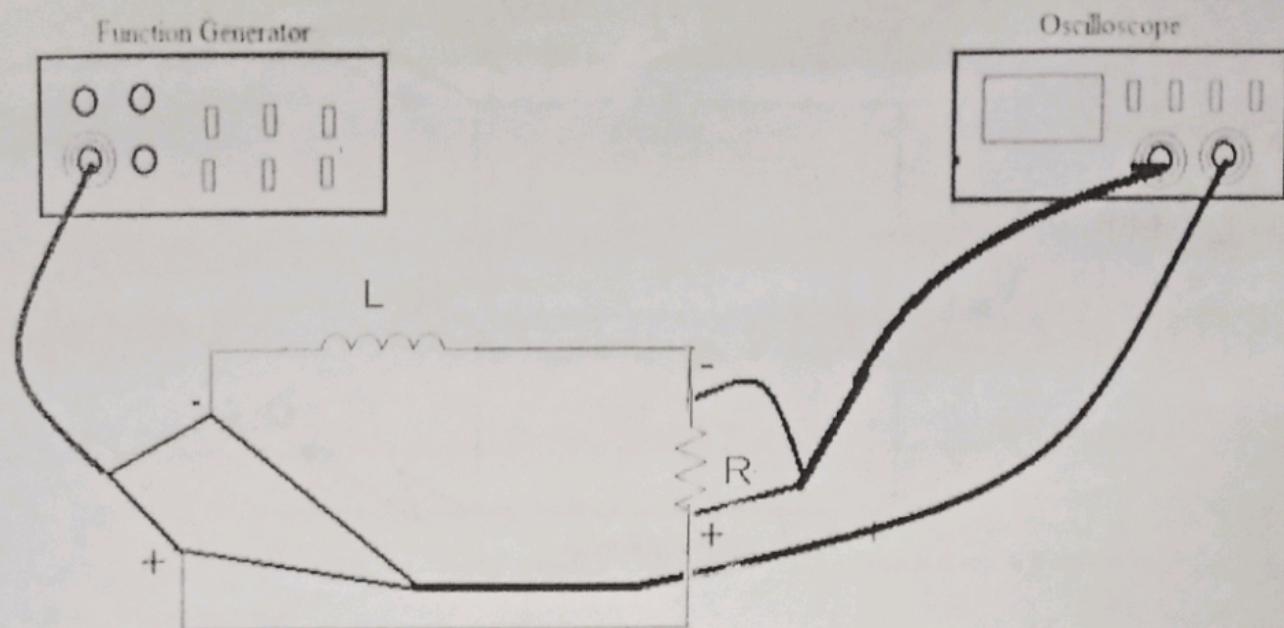


Fig 6. experimental circuit diagram

Observation:

During Charging of circuit			During Discharging of circuit		
Time (sec)	Theoretical current flow in the circuit (A)	Practical current flow in the circuit (A)	Time (sec)	Theoretical current flow in the circuit (A)	Practical current flow in the circuit (A)

Table for time constant:

Time Constant, τ (sec)		
Theoretical	Practical	From graph

Report:

1. Plot the charging and discharging curves (I_s versus t)
2. Draw the tangent at $t=0$ on the discharging curve and note the time when it touches the X axis (τ). Compare this with the theoretical value Calculate the time constant and compare it to the measured value.
3. Repeat this for other set of R and L values.

National Institute of Technology, Durgapur

Department of Electrical Engineering

Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/02

Title: Transient Response of RLC Series Circuit.

Objective: To design over-damped, under-damped and critically damped series *RLC circuit* and to observe their transient responses.

Theory:

A series RLC circuit can be modelled as a second order differential equation, having solution under the three conditions for its roots.

- When its roots are real and equal, the circuit response to a step input is called "Critically-damped".
- When its roots are real but unequal the circuit response is "Over-damped".
- When roots are a complex conjugate pair, the circuit response is labelled "Under-damped".

We will analyse the circuit shown in fig.1 in order to determine its transient characteristics.

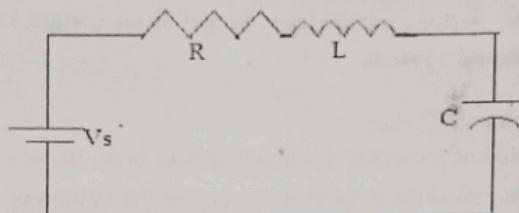


Fig-1

The equation that describes the response of the system is obtained by applying KVL around the mesh, i.e.
 $V_R + V_L + V_C = V_S \quad \dots \dots \dots (1)$

The current flowing in the circuit is $I = C \frac{dV_C}{dt} \quad \dots \dots \dots (2)$

And thus, the voltages V_R and V_L are given by $V_R = IR = RC \frac{dV_C}{dt} \quad \dots \dots \dots (3)$

$$\text{And } V_L = L \frac{dI}{dt} = LC \frac{d^2V_C}{dt^2} \quad \dots \dots \dots (4)$$

Substituting Equations (3) and (4) into Equation (1) we obtain

$$\frac{d^2V_C}{dt^2} + \frac{R}{L} \frac{dV_C}{dt} + \frac{1}{LC} V_C = \frac{1}{LC} V_S \quad \dots \dots \dots (5)$$

The solution to equation (5) is the linear combination of the homogeneous and the particular solution $V_C = V_{CP} + V_{CH}$

The particular solution is $V_{CP} = V_S \quad \dots \dots \dots (6)$

And the homogeneous solution satisfies the equation $\frac{d^2Vch}{dt^2} + \frac{R}{L} \frac{dVch}{dt} + \frac{1}{LC} Vch = 0$ ----- (7)

Assuming a homogeneous solution is of the form Ae^{st} and by substituting into Equation (7) we obtain the characteristic equation $S^2 + \frac{R}{L}S + \frac{1}{LC} = 0$ ----- (8)

By defining $\alpha = \frac{R}{2L}$ = Damping ratio----- (9) and $\omega_0 = \frac{1}{\sqrt{LC}}$ = natural frequency----- (10)

The characteristic equation becomes $S^2 + 2\alpha S + \omega_0^2 = 0$ ----- (11)

The roots of the characteristic equation are

$$S_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2} \quad (12) \text{ and } S_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2} \quad (13)$$

And the homogeneous solution becomes $V_{Ch} = A_1 e^{s_1 t} + A_2 e^{s_2 t}$ ----- (14)

The total solution now becomes $V_C = V_S + A_1 e^{s_1 t} + A_2 e^{s_2 t}$ ----- (15)

The parameters A_1 and A_2 are constants and can be determined by the application of the initial conditions of the system.

The value of the term $\sqrt{\alpha^2 - \omega_0^2}$ determines the behaviour of the response. Three types of responses are possible:

1. $\alpha = \omega_0$ then S_1 and S_2 are equal and real numbers: no oscillatory behaviour **Critically Damped System**.
2. $\alpha > \omega_0$ then S_1 and S_2 are real numbers but are unequal: no oscillatory behaviour **Over Damped System**
3. $\alpha < \omega_0$ $\sqrt{\alpha^2 - \omega_0^2} = j\sqrt{\omega_0^2 - \alpha^2}$ In this case the roots S_1 and S_2 are complex numbers: System exhibits oscillatory behaviour, **Under Damped System**.

Important observations for the series RLC circuit.

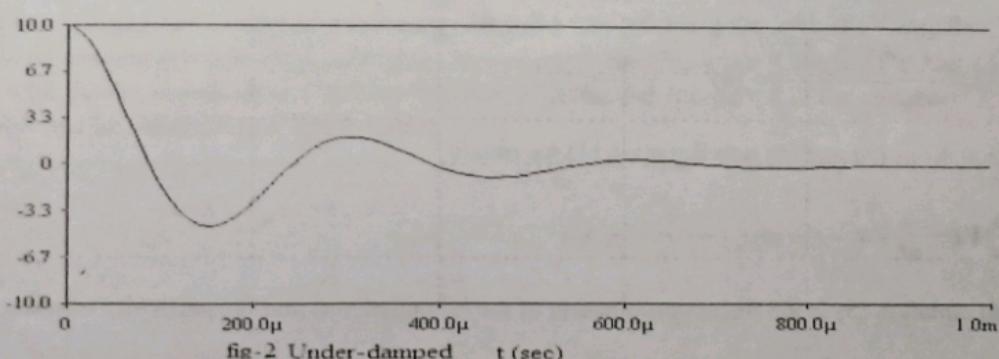
As the resistance increases the value of α increases and the system is driven towards an over damped response.

The frequency $\omega_0 = \frac{1}{\sqrt{LC}}$ (rad/sec) is called the natural frequency of the system or the resonant frequency.

The parameter $\alpha = \frac{R}{2L}$ is called the damping rate and its value in relation to ω_0 determines the behaviour of the response.

The quantity $\sqrt{\frac{L}{C}}$ has units of resistance

Figure 2 shows the response of the series RLC circuit and for three different values of R corresponding to the under damped, critically damped and over damped case. We will construct this circuit in the laboratory and examine its behaviour in more detail.



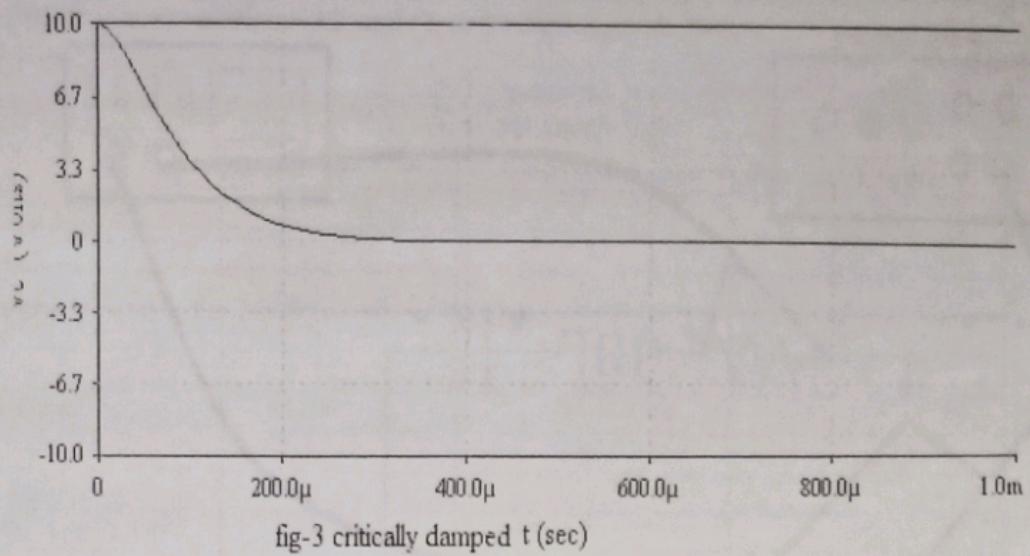


fig-3 critically damped t (sec)

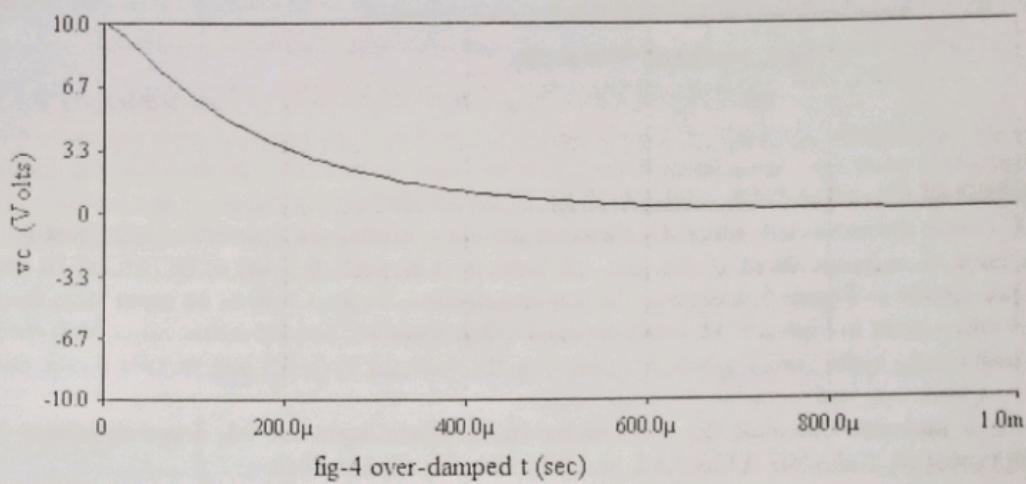


fig-4 over-damped t (sec)

Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

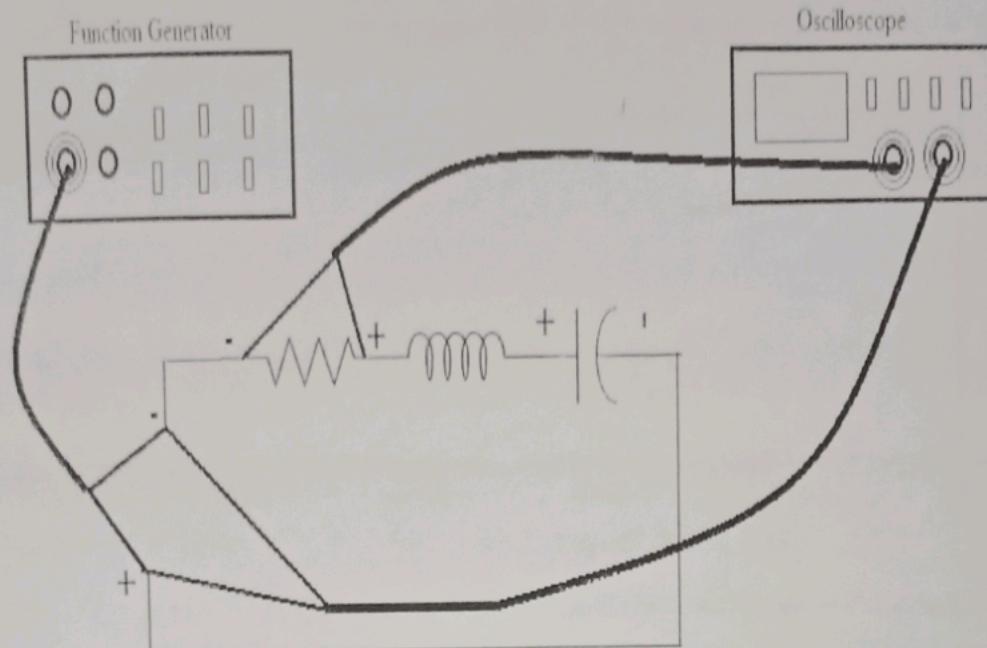


Fig-5, experimental circuit diagram

Procedure:

OVER-DAMPED RLC CAPACITOR VOLTAGE SETP RESPONSE:

With the RLC circuit disconnected, adjust the function generator to produce a repetitive pulse that is -5 volts for about 10 ms, then +5 volts for about 10 ms. (i.e., 10 Volts peak-to-peak, 0 Volts of DC offset, 20 ms Period or 50 Hz). For the circuit in Figure 5, calculate the output response, $V_C(t)$, $t > 0$, to an input step, from -5 to +5 Volts. Connect the circuit in Figure 5. Measure the final value, $V_C(t=\infty)$, and the initial value, $V_C(t=0^+)$, from the oscilloscope and record in the Data section. Also measure the voltages $V_C(t=0.5 \text{ ms})$, $V_C(t=1.0 \text{ ms})$, and $V_C(t=2.0 \text{ ms})$ from the oscilloscope and record in the Data section.

First determine α and ω_0 . Calculate the roots of the characteristic equation, $S1, 2$ and determine $V_C(0)$, and $V_C(\infty)$, and $d[V_C(0)]/dt$. Calculate $A1$ and $A2$, and fill in the Data Table-I below:

Table-I
OVERDAMPED RLC

SI No	Quantity	Calculated Value	Measured Value
R			
α			
ω_0			
$S1, 2$			
$V_C(0)$			
$d[V_C(0)]/dt$			
$V_C(\infty)$			
$A1$ and $A2$,			
Equation for $V_C(t)$			
$V_C(0.5\text{ms})$			
$V_C(1\text{ms})$			
$V_C(2\text{ms})$			

UNDER-DAMPED RLC CAPACITOR VOLTAGE SETP RESPONSE:

Keep the function generator settings used in Part I. For the circuit in Figure 5, change the resistor value for under-damped case and calculate the output response, $V_C(t)$, $t > 0$, to an input step, from -5 to +5 Volts.

First determine α and ω_0 . Calculate the roots of the characteristic equation, S_1, S_2 and determine $V_c(0)$, and $V_c(\infty)$, and $d[V_c(0)]/dt$. Calculate A_1 and A_2 , and fill in the Data Table II below:

Table-II
UNDERDAMPED RLC

SI No	Quantity	Calculated Value	Measured Value
R			
α			
ω_0			
S_1, S_2			
$V_c(0)$			
$d[V_c(0)]/dt$			
$V_c(\infty)$			
A_1 and A_2 ,			
Equation for $V_c(t)$			
$V_c(0.5ms)$			
$V_c(1ms)$			
$V_c(2ms)$			

CRITICALLY DAMPED RLC CAPACITOR VOLTAGE SETP RESPONSE:

Keep the function generator settings used in Part 1. For the circuit in Figure 5, change the resistor value for critical-damped case and calculate the output response, $V_C(t)$, $t > 0$, to an input step, from -5 to +5 Volts.

First determine α and ω_0 . Calculate the roots of the characteristic equation, S_1, S_2 and determine $V_c(0)$, and $V_c(\infty)$, and $d[V_c(0)]/dt$. Calculate A_1 and A_2 , and fill in the Data Table III below:

Table-III
CRITICALLY DAMPED RLC

SI No	Quantity	Calculated Value	Measured Value
R			
α			
ω_0			
S_1, S_2			
$V_c(0)$			
$d[V_c(0)]/dt$			
$V_c(\infty)$			
A_1 and A_2 ,			
Equation for $V_c(t)$			
$V_c(0.5ms)$			
$V_c(1ms)$			
$V_c(2ms)$			

Report:

1. Compare the theoretical and practical results of this experiment.
2. What is natural and damped frequency?

National Institute of Technology, Durgapur

Department of Electrical Engineering

Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/03

Title: Determination of frequency response of current in RLC circuit with sinusoidal ac input.

Objective: To observe amplitude and phase change in an RLC circuit under a sinusoidal forcing function.

Theory: A resonant circuit, also called a tuned circuit consists of an inductor and a capacitor together with a voltage or current source. It is one of the most important circuits used in electronics. For example, a resonant circuit, in one of its many forms, allows us to select a desired radio or television signal from the vast number of signals that are around us at any time. A network is in resonance when the voltage and current at the network input terminals are in phase and the input impedance of the network is purely resistive.

Series Resonant Circuit: In a series RLC circuit there becomes a frequency point where the inductive reactance of the inductor becomes equal in value to the capacitive reactance of the capacitor. The point at which this occurs is called the **Resonant Frequency**, (f_r) and as we are analysing a series RLC circuit this resonance frequency produces a **Series Resonance** circuit.

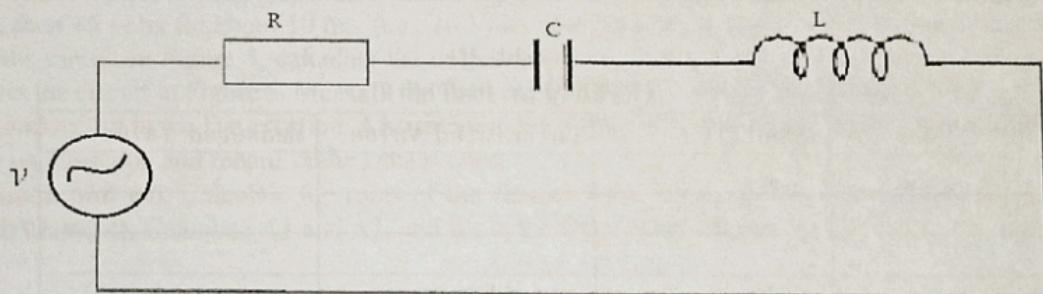


Fig-1 Series RLC Circuit

For the above circuit,

$$I = \frac{V}{R + j\omega L + \frac{1}{j\omega C}}, \text{ If we let } V = V_m \angle 0^\circ, \text{ we get the following characteristics: the amplitude of the current}$$

depends on several variables:

1. It is directly related to the amplitude of the forcing signal V_m .
2. It is inversely related to the value of the **resistor R**.
3. It is inversely related to the value of the **inductor L**.
4. It is directly related to the value of the **capacitor C**.

In a series resonant circuit, the resonant frequency, f_r point can be calculated $f_r = \frac{1}{2\pi\sqrt{LC}}$

As starts ω from a value of zero, the current starts to increase from zero up to the point where, $\omega = \frac{1}{\sqrt{LC}}$, At this point, the current will have maximum amplitude of $\frac{V_m}{R}$. As ω is increased further, the current will decrease towards zero as goes to ω infinity (∞).

The phase angle of the current:

1. The source voltage will be leading by 90° at a frequency very close to zero. As the frequency is increased, this leading angle will start to decrease up to the point $\omega = \frac{1}{\sqrt{LC}}$ at which there will be no phase shift. As the frequency is increased further, the angle of the current starts to lag the source voltage. It will approach 90° lagging as the frequency ω approaches infinity.
2. A decrease in the value of R serves to increase the sharpness of the curve and compress it at the point of inversion.
3. A change in the value of L or C will move the point of inversion along the frequency axis.

Parallel Resonant Circuit: A parallel circuit containing a resistance, R, an inductance, L and a capacitance, C will produce a parallel resonance (also called anti-resonance) circuit when the resultant current through the parallel combination is in phase with the supply voltage. At resonance there will be a large circulating current between the inductor and the capacitor due to the energy of the oscillations. A parallel resonant circuit stores the circuit energy in the magnetic field of the inductor and the electric field of the capacitor. This energy is constantly being transferred back and forth between the inductor and the capacitor which results in zero current and energy being drawn from the supply. This is because the corresponding instantaneous values of I_L and I_C will always be equal and opposite and therefore the current drawn from the supply is the vector addition of these two currents and the current flowing in I_R .

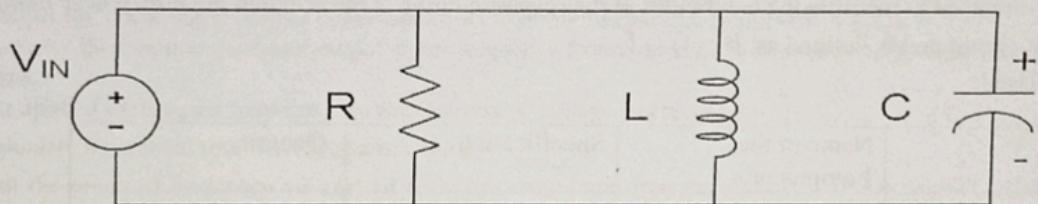


Fig. 2, parallel RLC circuit

Consider the Parallel RLC circuit of figure 2. The steady-state admittance offered by the circuit is $Y = 1/R + j(\omega C - 1/\omega L)$. Resonance occurs when the voltage and current at the input terminals are in phase. This corresponds to a purely real admittance, so that the necessary condition is given by $\omega C - 1/\omega L = 0$. The resonant condition may be achieved by adjusting L, C, or ω . Keeping L and C constant, the resonant frequency ω_0 is given by: $\omega_0 = \frac{1}{\sqrt{LC}}$

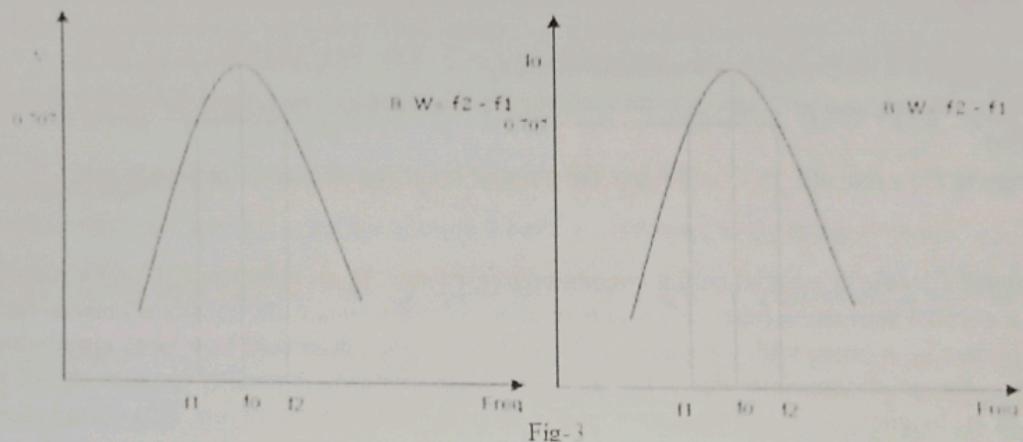
The forced response of a parallel RCL circuit is given by the form: $I = \left(\frac{1}{R} + j\omega C + \frac{1}{j\omega L} \right) V$. If we let $V = V_m \angle 0^\circ$, we get the following characteristics: the amplitude of the current depends on several variables:

1. It is directly related to the amplitude of the forcing signal V_m and value of the capacitor C.
 2. It is inversely related to the value of the resistor R and inductor L.
- As far as is concerned, we note that as ω starts from a value of zero the current will start to decrease from ∞ up to the point where $\omega = \frac{1}{\sqrt{LC}}$ at which the current will have minimum amplitude of $\frac{V_m}{R}$, as ω is increased further, the current will increase back to ∞ as ω goes to infinity.

The phase angle of the current:

1. The source voltage will be lagging by 90° at a frequency very close to zero. As the frequency is increased, this lagging angle will start to decrease up to the point $\omega = \frac{1}{\sqrt{LC}}$ at which there will be no phase shift. As the frequency is increased further, the angle of the current starts to lead the source voltage. It will approach 90° leading as the frequency ω approaches infinity.
2. A decrease in the value of R serves to decrease the sharpness of the curve and expands the point of inversion.
3. A change in the value of L or C will move the point of inversion along the frequency axis.

Frequency Response: It is a plot of the magnitude of output Voltage of a resonance circuit as function of frequency. The response of course starts at zero, reaches a maximum value in the vicinity of the natural resonant frequency, and then drops again to zero as ω becomes infinite. The frequency response is shown in figure 3.



The two additional frequencies f_1 and f_2 are also indicated which are called *half-power frequencies*. These frequencies locate those points on the curve at which the voltage response is $1/\sqrt{2}$ or 0.707 times the maximum value. They are used to measure the bandwidth of the response curve. This is called the *half-power bandwidth* of the resonant circuit and is defined as: $\beta = f_2 - f_1$

Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

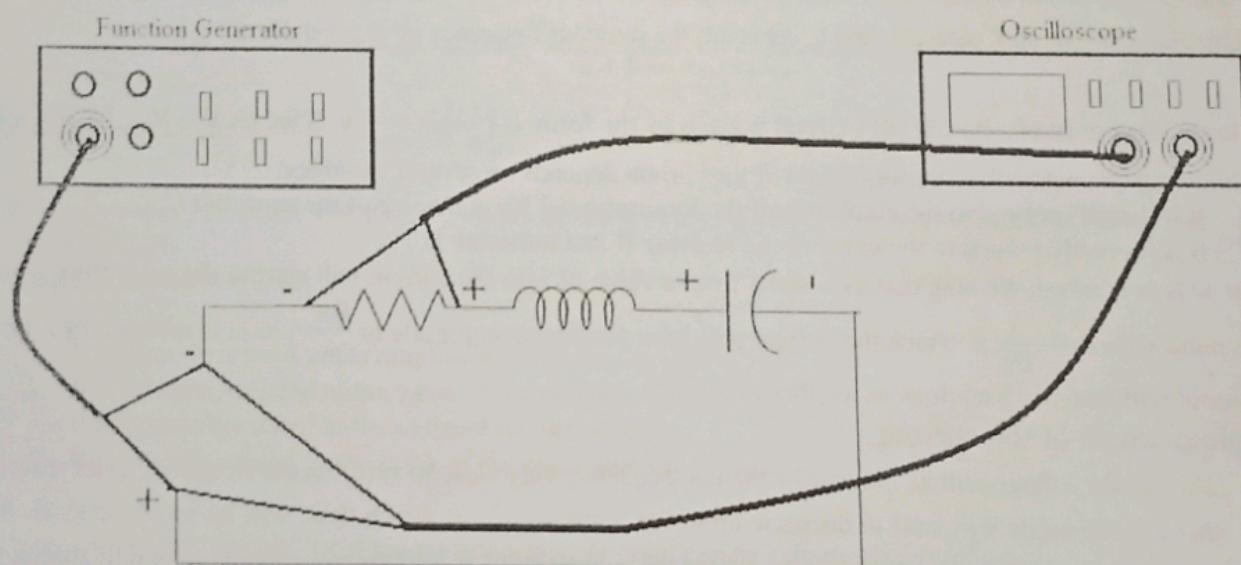


Fig-4, experimental circuit diagram for series circuit

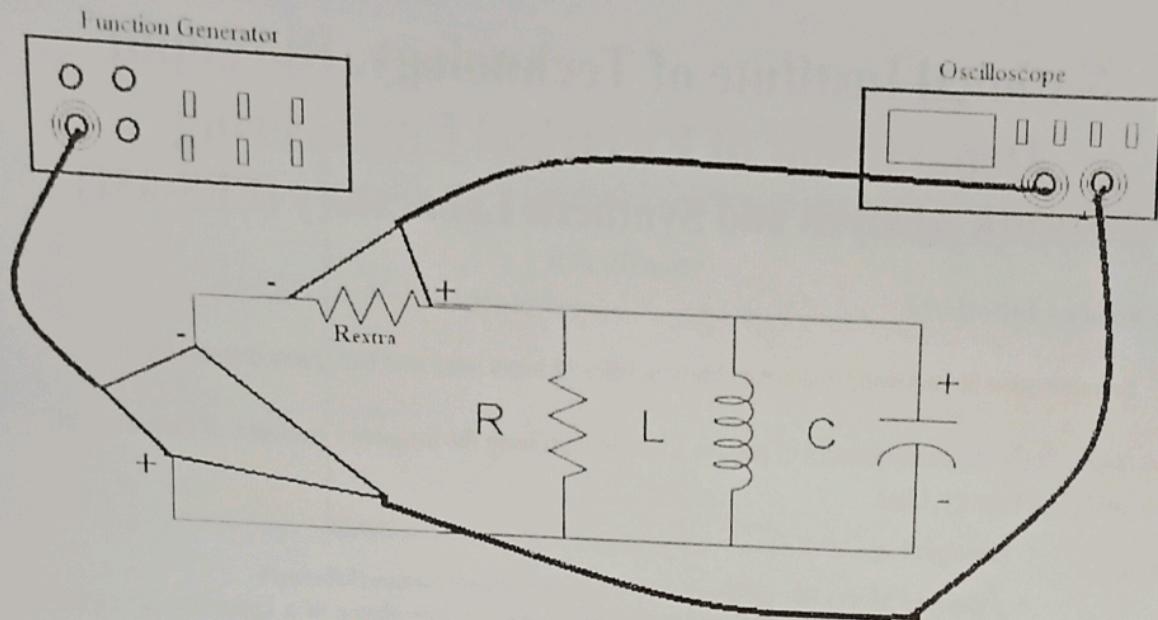


Fig-5, experimental circuit diagram for parallel circuit

Procedure:

1. Measure the value of resistance, inductor, and capacitor. Note down these values.
2. Connect the circuit as shown in fig 4.
3. Set the function generator output voltage to a particular value.
4. Check the phase angle current behaviour for RLC series and parallel circuit both separately.
5. Increase the function generator output signal frequency from minimum to a maximum signal frequency in decade steps.
6. For applied each signal frequency measure current or voltage and record it.
7. Calculate theoretical resonance frequency using $f_r = \frac{1}{2\pi\sqrt{LC}}$.
8. Plot the graph of frequency v/s current for series circuit and frequency v/s voltage for parallel circuit, find the frequency on the graph at which Current and voltage is maximum, this frequency is known as Resonant frequency, and this should be approximately to the theoretical frequency calculated in previous step.

Observation Table:

Table-I: for series circuit

Sl No	Frequency	Voltage drops across R (V_R)	Current

Table-II: for parallel circuit

Sl No	Frequency	Voltage drops across R_{extra} (V_R)	Current

Table-III

	Series Resonance		Parallel Resonance	
	Theoretical Practical	Theoretical Practical	Theoretical Practical	Theoretical Practical
Resonant frequency				
Bandwidth				
Q-factor				

Report:

1. What is the effect of changing resistance on Q?
2. Are f_1 and f_2 spaced symmetrically around f_0 ?
3. In practical terms, what sets the limit on how high Q may be?

National Institute of Technology, Durgapur

Department of Electrical Engineering

Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/04

Title: Determination of frequency response characteristics of a low pass and high pass passive filters.

Objectives: Study the characteristics of passive filters by obtaining the frequency response of Low Pass RC filter and High Pass RL filter.

Theory:

The impedance of an inductor is proportional to frequency and the impedance of a capacitor is inversely proportional to frequency. These characteristics can be used to select or reject certain frequencies of an input signal. This selection and rejection of frequencies is called filtering, and a circuit which does this is called a *filter*. If a filter passes high frequencies and rejects low frequencies, then it is a high-pass filter. Conversely, if it passes low frequencies and rejects high ones, it is a low-pass filter. Filters, like most things, aren't perfect. They don't absolutely pass some frequencies and absolutely reject others. A frequency is considered passed if its magnitude (voltage amplitude) is within 70% (or $1/\sqrt{2}$) of the maximum amplitude passed and rejected otherwise. The 70% frequency is called corner frequency, roll-off frequency or half-power frequency.

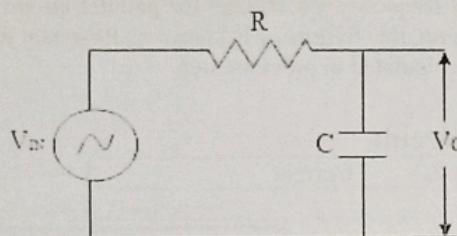


Fig-1, low pass RC filter

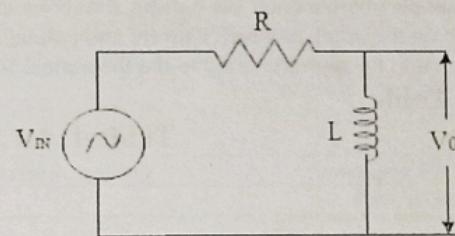


Fig-2, high pass RL filter

The corner frequencies for RC filter and RL filter are as follows:

$$\text{For RC filter, } f_c = \frac{1}{2\pi RC} \text{ and for RL filter, } f_c = \frac{R}{2\pi L}$$

Frequency Response: It is a graph of magnitude of the output voltage of the filter as a function of the frequency. It is generally used to characterize the range of frequencies in which the filter is designed to operate within

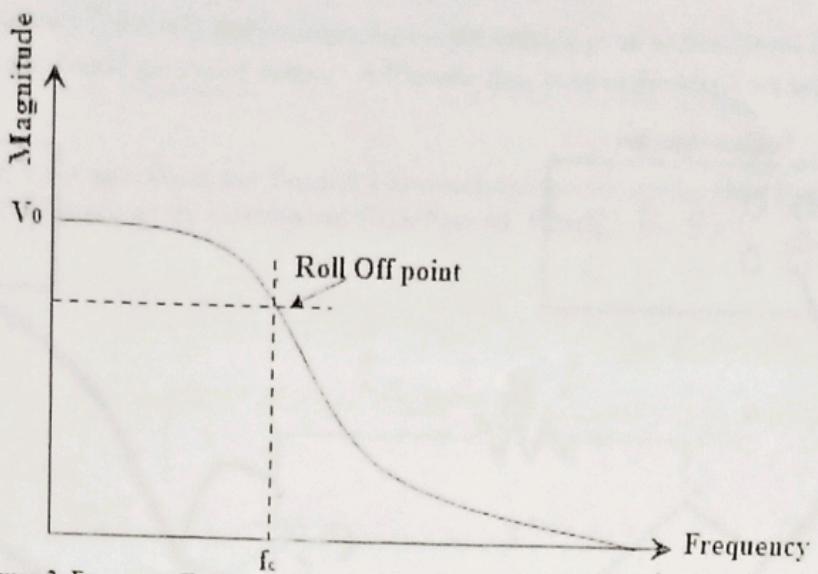


Figure 3: Frequency Response of a typical Low Pass Filter with a cut-off frequency f_c

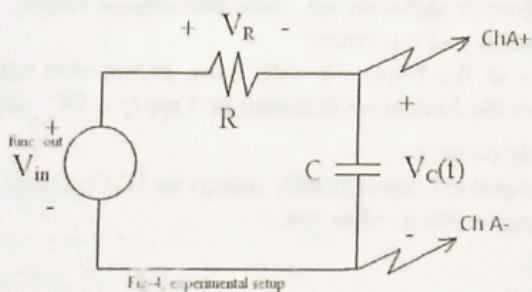
Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

Procedure:

A. Low Pass RC Filter:

1. Measure the value of resistance, inductor, and capacitor. Note down these values.
2. Calculate the cut-off frequency of RC and RL circuit
3. Set up the circuit shown in the **Figure 5** with those component values R and C.
4. Select the sine wave from the Function Generator and apply a $5V_{pp}$ sine wave as input voltage to the circuit using the amplitude control.
5. Observe the frequency response (exponentially rising) on DSO screen. Change the frequency and check that the frequency response is observed or not.
6. Start with a low frequency i.e., 50 Hz and measure output voltage peak to peak from the scope screen. It should be same as the signal generator output. Vary the frequency until you see very very less peak to peak value.
7. Compute the 70 % of V_{pp} and obtain the frequency at which this occurs on the Oscilloscope. This gives the cut-off (roll-off) frequency for the constructed Low Pass RC filter.



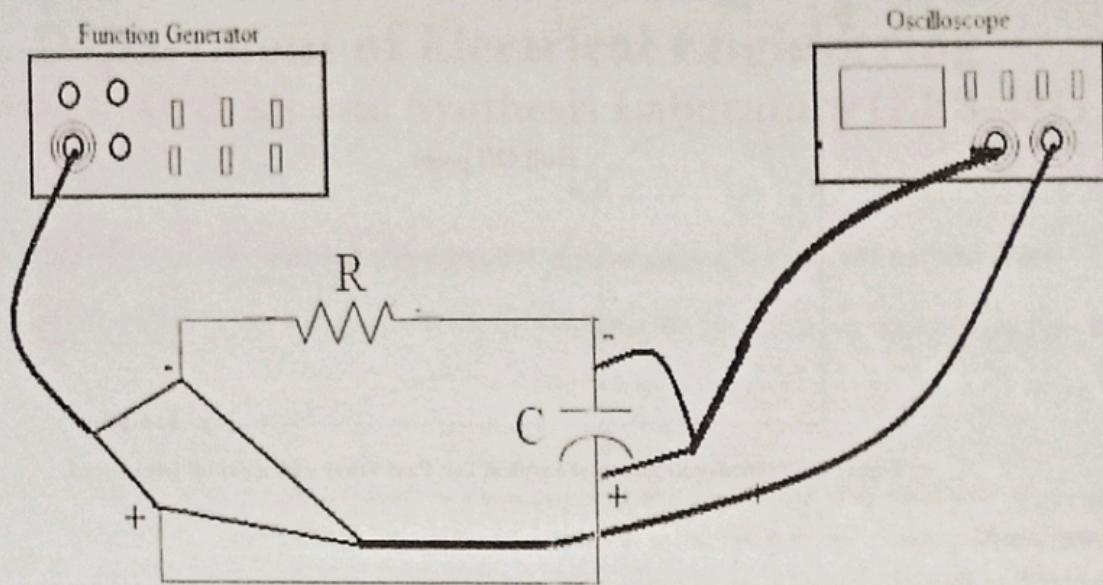


Fig-5. experimental circuit diagram

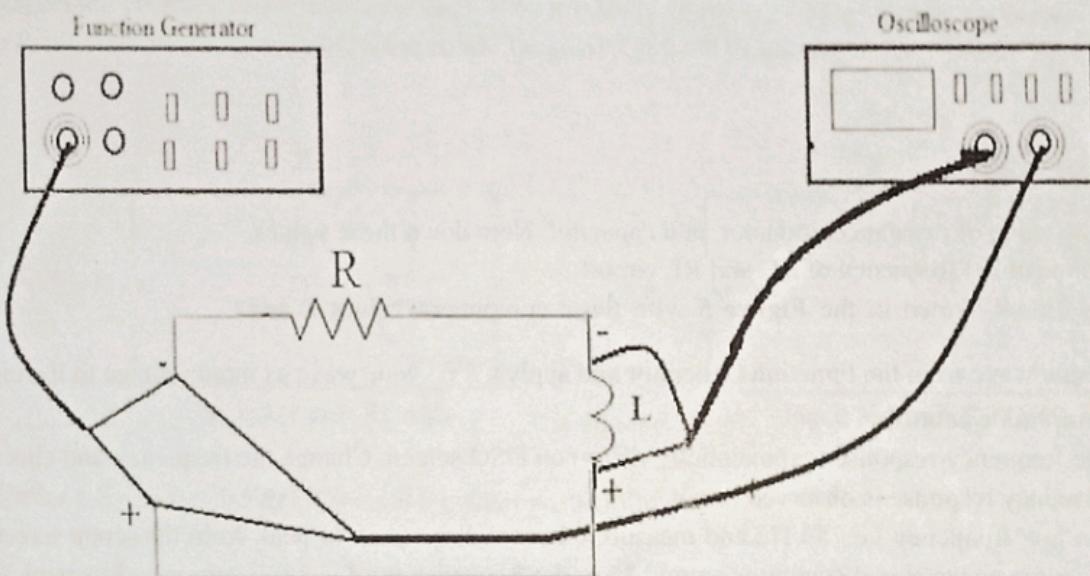


Fig-6. experimental circuit diagram

B. High Pass RL Filter:

1. Measure the value of resistance and inductor. Note down these values.
2. Calculate the cut-off frequency of RL circuit.
3. Set up the circuit shown in the **Figure 6** with those component values R and L.
4. Select the sine wave from the Function Generator and apply a $5V_{p-p}$ sine wave as input voltage to the circuit using the amplitude control.
5. Observe the frequency response (exponentially rising) on DSO screen. Change the frequency and check that the frequency response is observed or not.

- Start with a high frequency (20 KHz) and measure the output voltage peak to peak from the scope screen. It should be same as the signal generator output. Adjust the time base of the scope accordingly to observe this.
- Compute the 70 % of V_{p-p} and obtain the frequency at which this occurs on the Oscilloscope. This gives the cut-off (roll-off) frequency for the constructed High Pass RL filter.

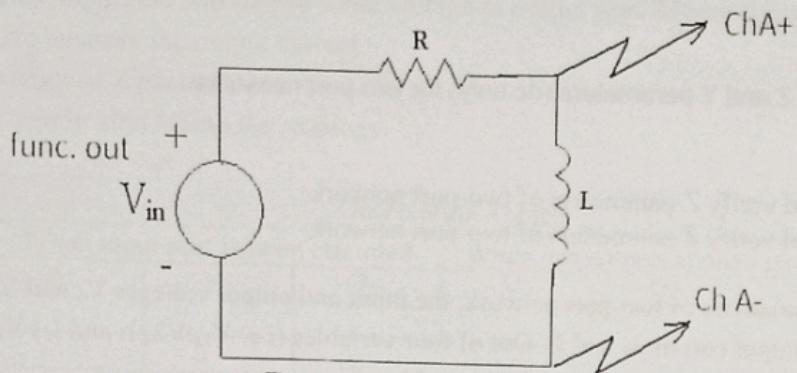


Fig-4, experimental setup

Observation:

For RC Low pass filter:

SI No	Frequency (Hz)	Output (V)

For RL High pass filter:

SI No	Frequency (Hz)	Output (V)

Questions for Lab Report:

- Plot the graph of Gain in dB Vs Frequency.
- Compute the Cut-off frequencies for the RC and RL filter using the formulae in equations (1) and (2). Compare these theoretical values to the ones obtained from the experiment and provide suitable explanation for any differences

National Institute of Technology, Durgapur

Department of Electrical Engineering

Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/05

Title: Determination of Z and Y parameters (dc only) for two port networks.

Objective:

1. To calculate and verify Z parameters of two-port network.
2. To calculate and verify Y parameters of two-port network.

Brief Theory: In a Z parameter of two-port network, the input and output voltages V_1 and V_2 can be expressed in terms of input and output current I_1 and I_2 . Out of four variables (i.e. V_1 , V_2 , I_1 and I_2) V_1 and V_2 are dependent variables and I_1 and I_2 are independent variables. Thus

$$V_1 = Z_{11} I_1 + Z_{12} I_2 \quad \text{--- (i)}$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2 \quad \text{--- (ii)}$$

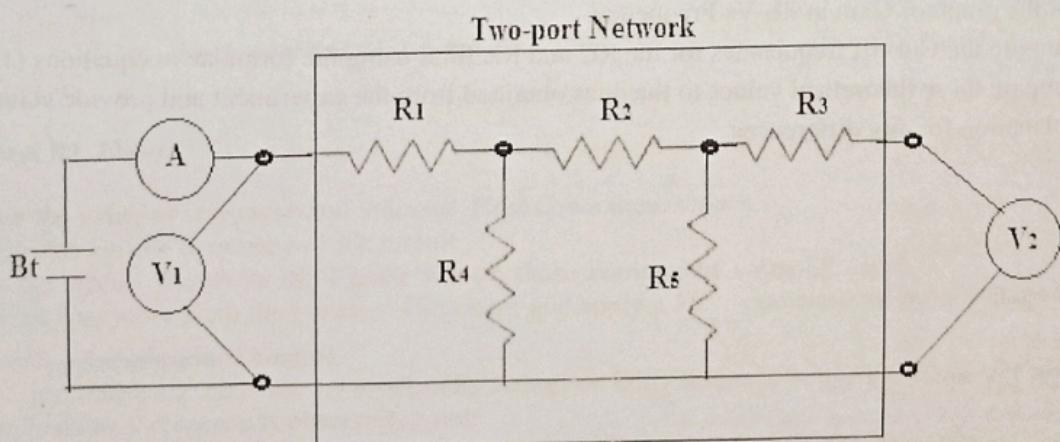
Here Z_{11} and Z_{22} are the input and output driving point impedances while Z_{12} and Z_{21} are the reverse and forward transfer impedances.

Now, $Z_{11} = \frac{V_1}{I_1}$ at $I_2=0$; $Z_{21} = \frac{V_2}{I_1}$ at $I_2=0$ and $Z_{12} = \frac{V_1}{I_2}$ at $I_1=0$; $Z_{22} = \frac{V_2}{I_2}$ at $I_1=0$.

Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

Circuit Diagram:



Procedure:

1. Measure the value of each and every resistance. Note down these values.
2. Connect the circuit as shown in the above figure.
3. First open the output port and supply some voltage to input port. Measure the input and output voltages and also measure the input current.
4. Secondly open the input port and supply some voltage to output port. Measure the input and output voltages and also measure the output current.
5. Calculate the values of Z parameters.
6. Switch off the supply after taking the readings.

Observation Table:

SI No	When input port is open circuited			When output port is open circuited		
	V ₁	V ₂	I ₂	V ₁	V ₂	I ₁

Verification Table:

Parameters	Practical Values	Theoretical Values
Z ₁₁		
Z ₁₂		
Z ₂₁		
Z ₂₂		

Brief Theory: In a Y parameter of two-port network, the input and output currents I₁ and I₂ can be expressed in terms of input and output voltages V₁ and V₂. Out of four variables (i.e. V₁, V₂, I₁ and I₂) I₁ and I₂ are dependent variables and V₁ and V₂ are independent variables. Thus

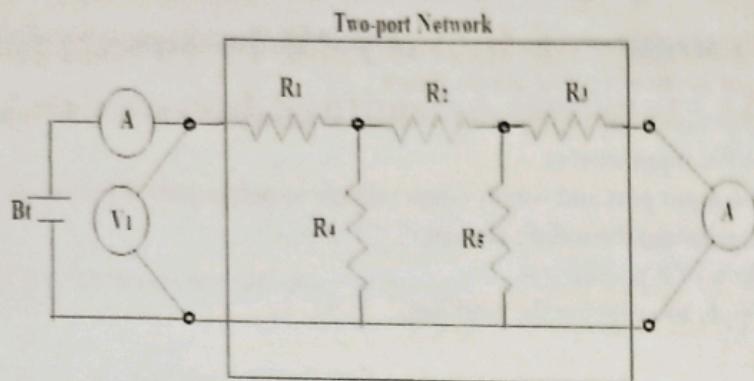
$$I_1 = Y_{11} V_1 + Y_{12} V_2 \quad \text{--- (i)}$$

$$I_2 = Y_{21} I_1 + Y_{22} V_2 \quad \text{--- (ii)}$$

Here Y₁₁ and Y₂₂ are the input and output driving point admittances while Y₁₂ and Y₂₁ are the reverse and forward transfer admittances.

Now, $Y_{11} = \frac{I_1}{V_1}$ at $V_2=0$; $Y_{21} = \frac{I_2}{V_1}$ at $V_2=0$ and $Y_{12} = \frac{I_1}{V_2}$ at $V_1=0$; $Y_{22} = \frac{I_2}{V_2}$ at $V_1=0$.

Circuit Diagram:



Procedure:

1. Connect the circuit as shown in the above figure.
2. First short the output port through ammeter and supply some voltage to input port. Measure the input and output current and also measure the input voltage.
3. Secondly short the output port through ammeter and supply some voltage to output port. Measure the input and output currents and also measure the output voltages.
4. Calculate the values of Z parameters.
5. Switch off the supply after taking the readings.

Observation Table:

SI No	When input port is short circuited			When output port is short circuited		
	V ₂	I ₁	I ₂	V ₁	I ₁	I ₂

Verification Table:

Parameters	Practical Values	Theoretical Values
Y ₁₁		
Y ₁₂		
Y ₂₁		
Y ₂₂		

Report:

1. Calculate the Z and Y Parameters and check them with experimental values.
2. What is the condition of symmetry and reciprocity. Justify that your network is symmetry and reciprocity?

National Institute of Technology, Durgapur

Department of Electrical Engineering

Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/06

Title: Magnetically coupled circuit.

Objective:

1. Determination of self-inductance, mutual-inductance, and coefficient of coupling for a magnetic coupled circuit.
2. Determination of driving point and transfer impedance of a coupled circuit.

Brief Theory:

Self-Inductance: Consider a single coil wound around a magnetic core as shown in fig.1 below.

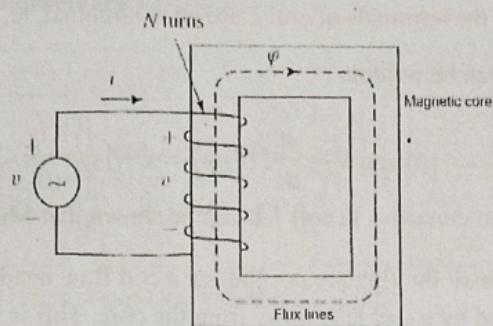


Fig. 1: A single coil wound around a magnetic core.

A current i flowing in the coil will produce a magnetic flux ϕ in the magnetic core. If the current is varying with time, the produced flux is also varying with time and then according to Faraday's law of electro-magnetic

induction, an induced voltage v will be generated across the coil terminals. V is given by the relation, $v = N \frac{d\phi}{dt}$

(1). The self-inductance of the coil is defined as the ratio between the flux linkage, $N \phi$, linking the coil and the current, I , producing the flux. So, $L = \frac{N\phi}{i}$

(2). Substituting from equation (2) into (1) gives $v = L \frac{di}{dt}$ (3).

Mutual inductance: If a second coil is wound around the magnetic core of fig.1 as shown in fig.2, the two coils become magnetically coupled. The flux produced by the first links the second. The mutual inductance, M_{12} , between coils 1 & 2 is defined as the ratio between the flux linkage, $N_2 \phi$, linking the coil 2 and the current i_1 producing this flux.

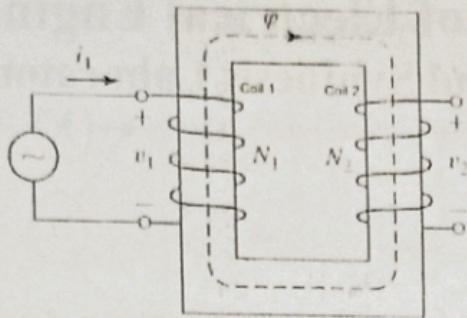


Fig. 2: Two magnetically-coupled coils.

Therefore,

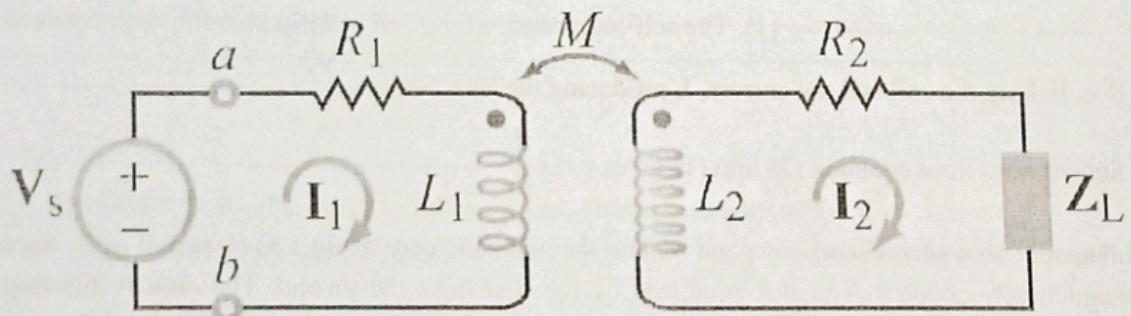
$M_{12} = \frac{N_2 \phi}{i_1}$ ----- (4). When the terminals of coil 2 are open circuited, ie, no current flowing in the coil 2, then the following equations can be written.

$V_1 = \frac{d}{dt}(N_1 \phi) = L_1 \frac{di_1}{dt}$ ----- (6) and $V_2 = \frac{d}{dt}(N_2 \phi) = \pm M_{12} \frac{di_1}{dt}$ ----- (6), where V_2 is the induced voltage in coil 2 due to current i_1 in coil 1. It can be shown that $M_{12} = M_{21}$.

Coefficient of coupling: Since all the flux are not linking a coil flow inside the magnetic core then a small percentage of the flux produced by a coil leak away from the core. This is known as leakage flux. The

measurement of the leakage flux is the coupling coefficient k and can be expressed as $k = \frac{M}{\sqrt{L_1 L_2}}$ ----- (7)

Input impedance: In addition to the two coupled coils, a realistic transformer circuit should be including two resistors R_1 and R_2 , to account for ohmic losses in the coils. The circuit shown in fig below reflects this reality by including resistor R_1 on the side of the coil 1 and resistance R_2 on the side of coil 2. The circuit is driven by the voltage source V_s on the primary side and terminated in the complex load Z_L on the secondary side.



In terms of the designated mesh current I_1 and I_2 , the KVL mesh equations are

$$V_s = I_1 R_1 + j\omega L_1 I_1 - j\omega M I_2 ----- (i)$$

$$\text{And } 0 = I_2 R_2 + j\omega L_2 I_2 - j\omega M I_1 + I_2 Z_L ----- (ii)$$

The input driving point is given by $Z_D = \frac{V_S}{I_1} = R_1 + j\omega L_1 + \frac{\omega^2 M^2}{R_2 + j\omega L_2 + Z_L}$

$$= R_1 + j\omega L_1 + Z_R \text{ ----- (iii), where } Z_R \text{ defined as reflected}$$

impedance $Z_R = \frac{\omega^2 M^2}{R_2 + j\omega L_2 + Z_L}$

In a similar manner, we can derive the expression of transfer impedance,

$$Z_t = \frac{V_1}{I_2} = -j\omega M + \frac{(R_2 + R_L + j\omega L_2 + Z_L)(R_1 + j\omega L_1)}{j\omega M} \text{ ----- (iv)}$$

Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

Procedure I: Determination of Self Inductance L_1 and L_2 .

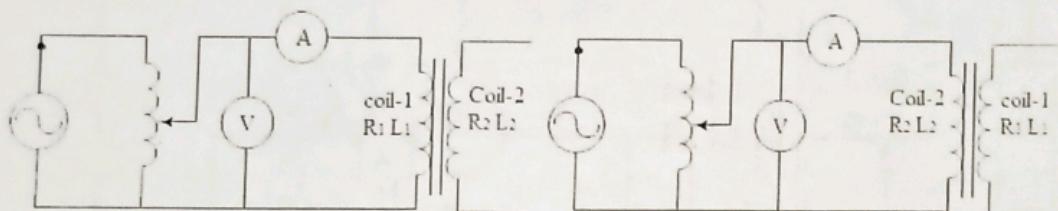


Fig-4 circuit diagram for measurement of L_1 and L_2

1. Measure the resistance R_{dc} of coil 1 with the help of volt-ampere method. This is dc resistance of coil 1.
2. Determine the coil 1 ac resistance R_1 by allowing 15% increase due to skin effect, such that

$$R_1 = 1.15 R_{dc}$$
3. Similarly find out R_2 , the ac resistance of coil 2.
4. Connect coil 1 to a variable 50 Hz voltage source as shown in Fig. 4.
5. Adjust the magnitude of the applied voltage to a particular value and then take the readings of both the ammeter and voltmeter.
6. Calculate the coil (self) inductance as follows:

$$Z_1 = \frac{V_1}{I_1} = \sqrt{R_1^2 + X_1^2} \text{ and } X_1 = \sqrt{Z_1^2 - R_1^2}$$

$$\text{So } L_1 = \frac{X_1}{\omega}$$

7. Repeat the procedure 4 to 6 for coil 2 and calculate the self-inductance, L_2 .

Procedure II: Determination of mutual Inductance.

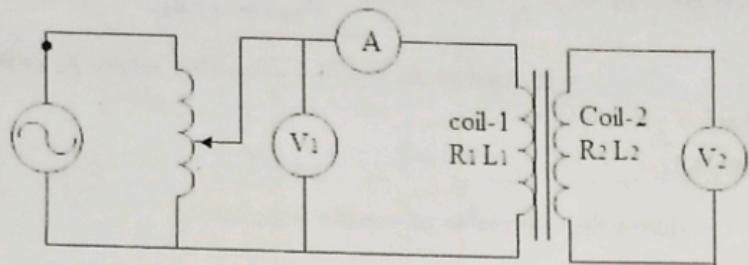


Fig-5, measurement of mutual inductance

1. Connect the circuit as shown in Fig. 5, with coil 2 magnetically coupled to coil 1.
2. Adjust the magnitude of the applied voltage to a particular value and then take the readings of both the voltmeters and ammeter.
3. Calculate the mutual inductance as follows:

$$X_M = \frac{V_2}{I_1} \text{ and } M = \frac{X_M}{\omega}$$

Procedure III: Determination of Polarity of Magnetically Coupled Coils

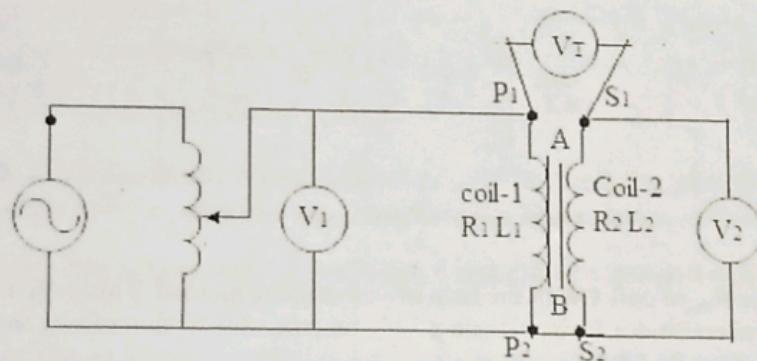


fig-6,Determination of polarity

1. Connect the electric circuit as shown in Fig. 6
2. With specified voltage applied to coil 1, take the reading of V_T .
3. If V_T is the difference between V_1 and V_2 , the dot is to be put at point A, otherwise it is to be put at point B.

Procedure IV - Series Connected Magnetically Coupled Coils

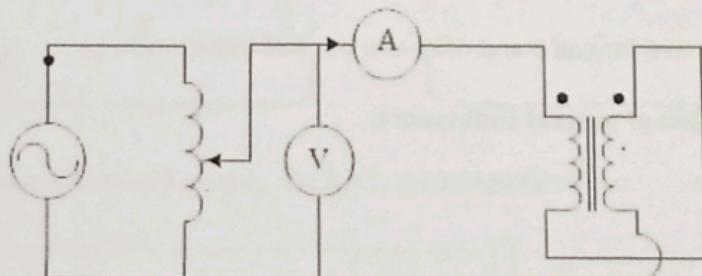


Fig. 7 : Series-connected magnetically -coupled coils (adding).

1. According to the polarity determined above, connect the electric circuit as shown in fig.7.

2. Adjust the magnitude of the applied voltage to a particular value and then take the readings of both the ammeter and voltmeter.
 3. Calculate the equivalent impedance in this case as follows:

$$X_{eq1} = \sqrt{(V/I)^2 - (R1 + R2)^2} = \omega(L_1 + L_2 + 2M)$$

4. Repeat steps 1 and 2 but with the two coils connected in opposition

$$X_{eq2} = \sqrt{(V/I)^2 - (R1 + R2)^2} = 0 (L_1 + L_2 - 2M)$$

5. Determine the mutual inductance M_{12} using the relation, $M_{12} = (X_{eq1} - X_{eq2})/4\omega$
 6. Check with the value obtained before and comment on any discrepancy between these results.
 7. Determine the coupling coefficient k . Where, $k = \frac{M}{\sqrt{L_1 L_2}}$

Procedure V -Determination of driving point and transfer impedance of Magnetically Coupled Coils.

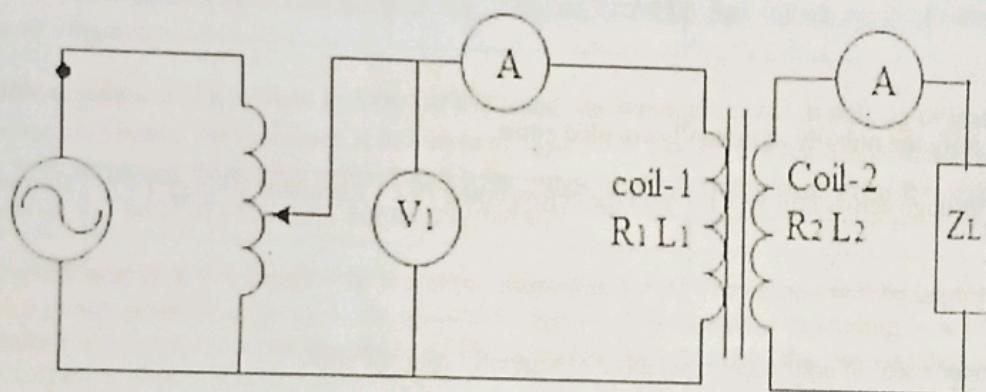


Fig-8,determination of D.P. & Transfer impedance.

1. Connect the electric circuit as shown in Fig. 8.
 2. Adjust the magnitude of the applied voltage to a particular value and then take the readings of both the voltmeters and ammeter.
 3. Calculate the driving point and transfer impedance.

Observation:

Table-I: Measurement of resistance of primary and secondary coils:

Table-II: Measurement of self-inductance of primary and secondary coils:

SI No	Inductance of coil 1				Inductance of coil 2			
	Applied Voltage (V)	Current flow through the coil (A)	Impedance Z_1 (Ohm)	Inductance L_1 (henry)	Applied Voltage	Current flow through the coil (A)	Impedance Z_2 (Ohm)	Inductance L_2 (henry)

Table-III: Measurement of mutual-inductance of primary and secondary coils:

SI No	Mutual Inductance of coil 1 and coil 2				
	Applied Voltage (V)	Current flow through the coil 1 (A)	Voltage drops across the coil 2 (V)	Mutual Impedance Z_M (Ohm)	Mutual Inductance L_M (henry)

Table-IV: Identify the polarity of mutually coupled coils:

SI No	Voltage across coil 1 (V)	Voltage across coil 2 (V)	Resultant Voltage (V)	Remark

Table-V: Measurement of equivalent reactances of mutually coupled coils:

SI No	Equivalent reactance X_{eq1}			Equivalent reactance X_{eq2}		
	Applied Voltage (V)	Current flow through the coil (A)	X_{eq1} (Ohm)	Applied Voltage (V)	Current flow through the coil (A)	X_{eq2} (Ohm)

Table-VI: Measurement of driving point and transfer impedance of Magnetically Coupled Coils:

SI No	Driving point impedance Z_D			Transfer impedance Z_t		
	Applied Voltage V_s or V_1 (V)	Current flow through the coil 1, I_1 (A)	Driving point impedance Z_D (Ohm)	Applied Voltage V_s or V_1 (V)	Current flow through the coil 2, I_2 (A)	Transfer impedance Z_t (Ohm)

Table-VII:

	Theoretical	Practical
Driving point impedance Z_D		
Transfer impedance Z_t		

Report: Show all calculations in details and compare the theoretical and practical values of Z_D and Z_t .

National Institute of Technology, Durgapur

Department of Electrical Engineering

Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/07

Title: Locus diagram of R-L, R-C circuit.

Objective: To plot locus diagram of series R-L and R-C circuits by varying various parameter.

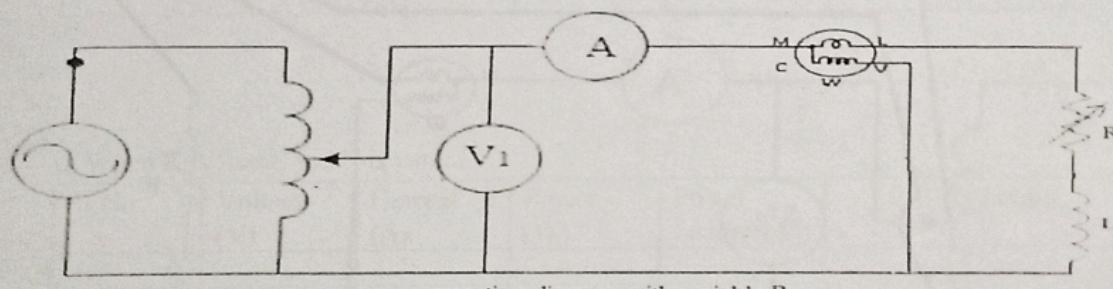
Theory: A phasor diagram may be drawn and is expanded to develop a curve known as a locus. Locus diagrams are useful in determining the behaviour or response of an R-L-C circuit when one of its parameters is varied while the frequency and voltage kept constant. The magnitude and phase of the current vector in the circuit depends upon the values of R, L and C and frequency at the fixed source voltage. The path traced by the terminus of the current vector when the parameter R, L or C are varied while the frequency and voltage are kept constant is called the current locus diagram.

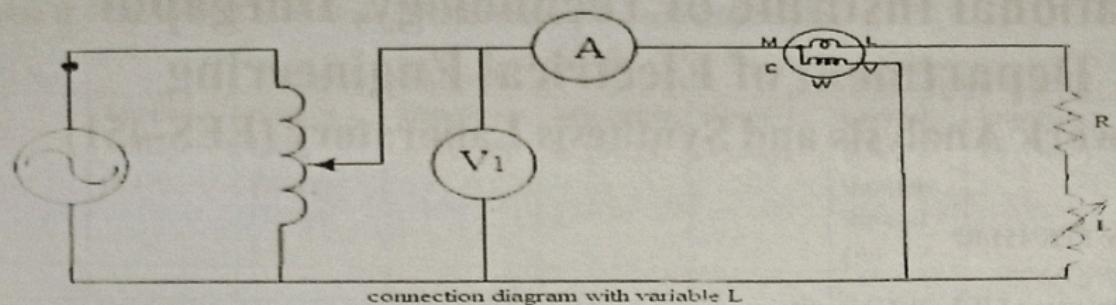
a. With variable resistance: If $R=0$ then $I = V/X_L$ or V/X_C and has maximum value. It will lag or lead the voltage by 90° depending on whether the reactance is inductive or capacitive. The angle θ represents phase angle $\{\theta = \tan^{-1}(V_X/R)\}$. As R is increased from zero value, I and θ decreases. In the limiting case when $R = \infty$, then $I=0$ and $\theta=0^\circ$. The locus of end point of I is a semi-circle of radius V/X .

b. With fixed resistance: If $X = 0$, then $I = V/R$ and has maximum value. The current will be in phase with voltage as it is a purely resistive circuit i.e., the phase θ is zero. As X is increased depending on whether the reactance is inductance or capacitance the current starts lagging or leading V i.e., the current I decreases and phase angle θ increases. In the limiting case when $X = \infty$, then $I = 0$ and $\theta = 90^\circ$. The locus of end point of I is a semi-circle of radius V/R

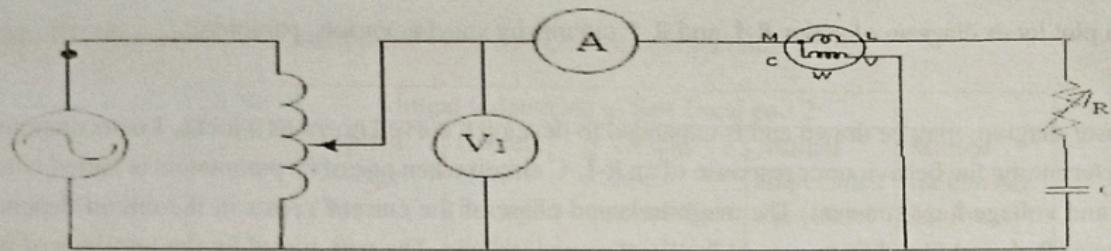
Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

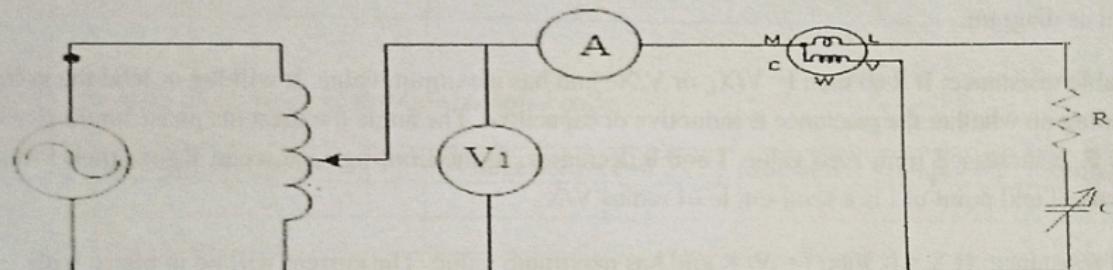




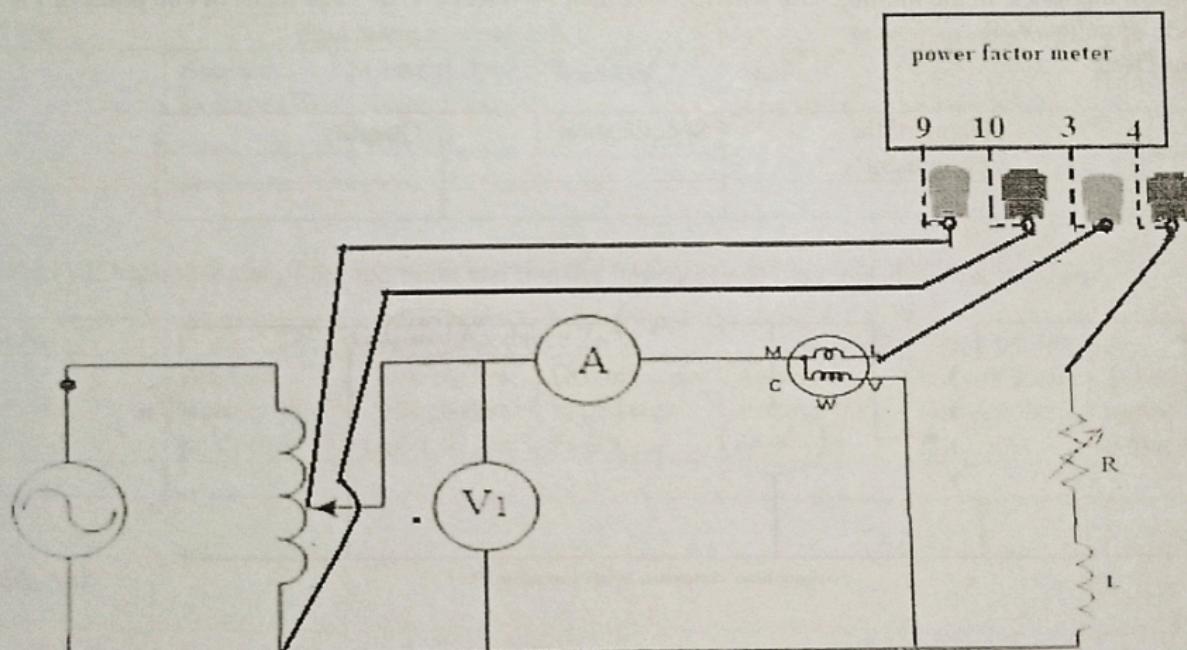
connection diagram with variable L



connection diagram with variable R



Connection diagram with variable C



Experimental circuit diagram

National Institute of Technology, Durgapur
Department of Electrical Engineering
Network Analysis and Synthesis Laboratory (EES-451)

Experiment no: EES/451/08

Title: Verification of AC Network Theorems.

Objective: To verify the Thevenin's, the Norton's and the maximum power transfer theorems for the given circuit.

Apparatus Used:

SL No	Name of the Equipment's	Specification	Quantity

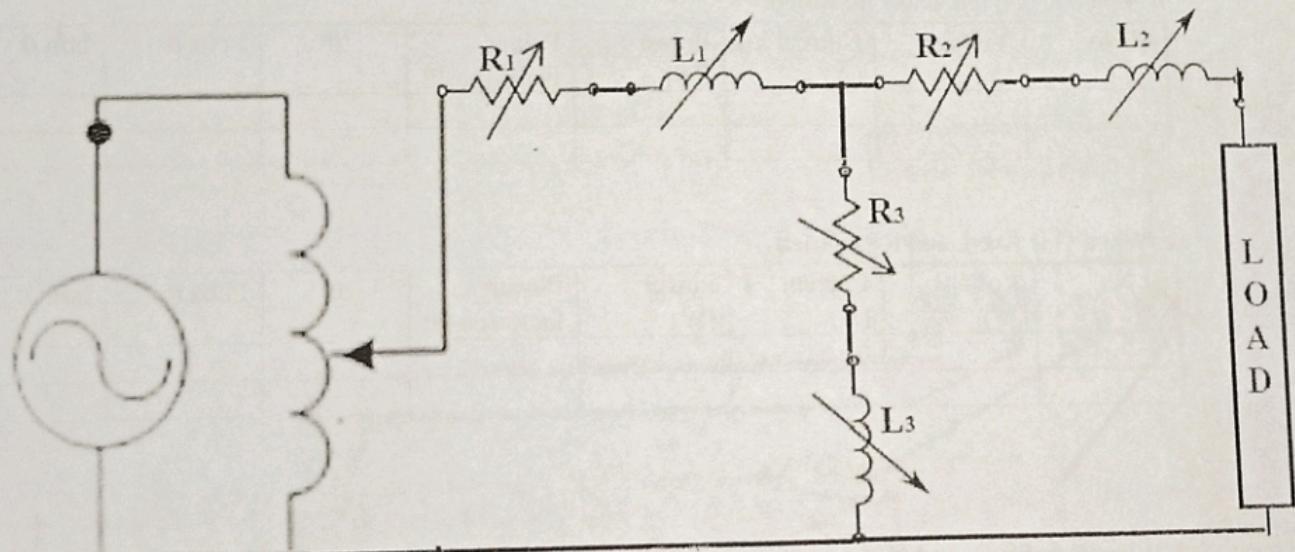


Fig.1 Circuit Diagram

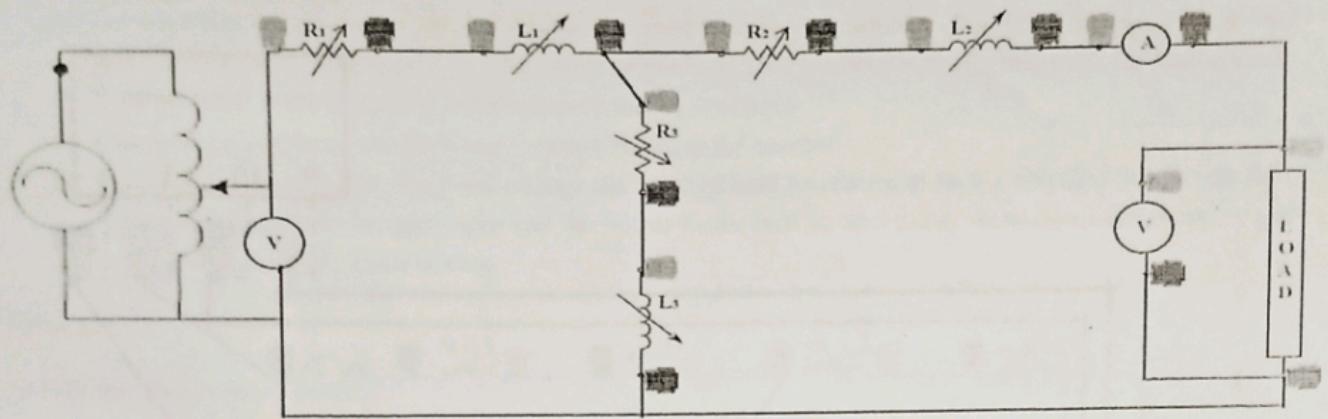


Fig.2 Practical circuit diagram, without power factor meter.

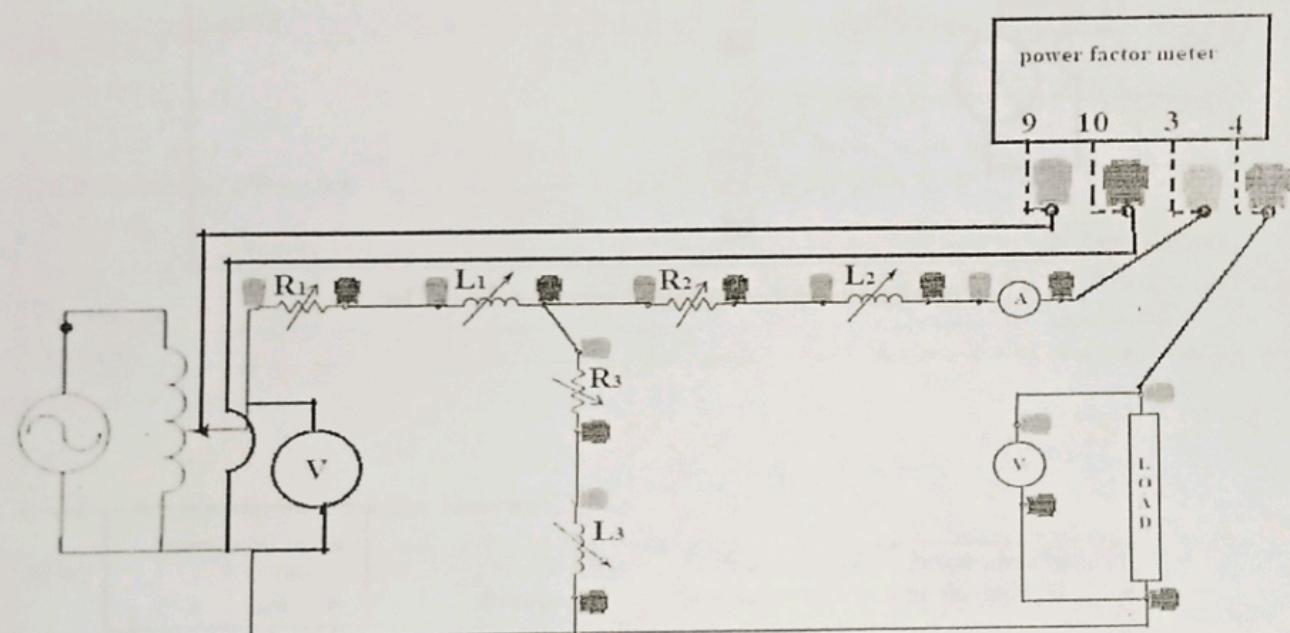


Fig.3 Experimental circuit diagram to measure the load current.

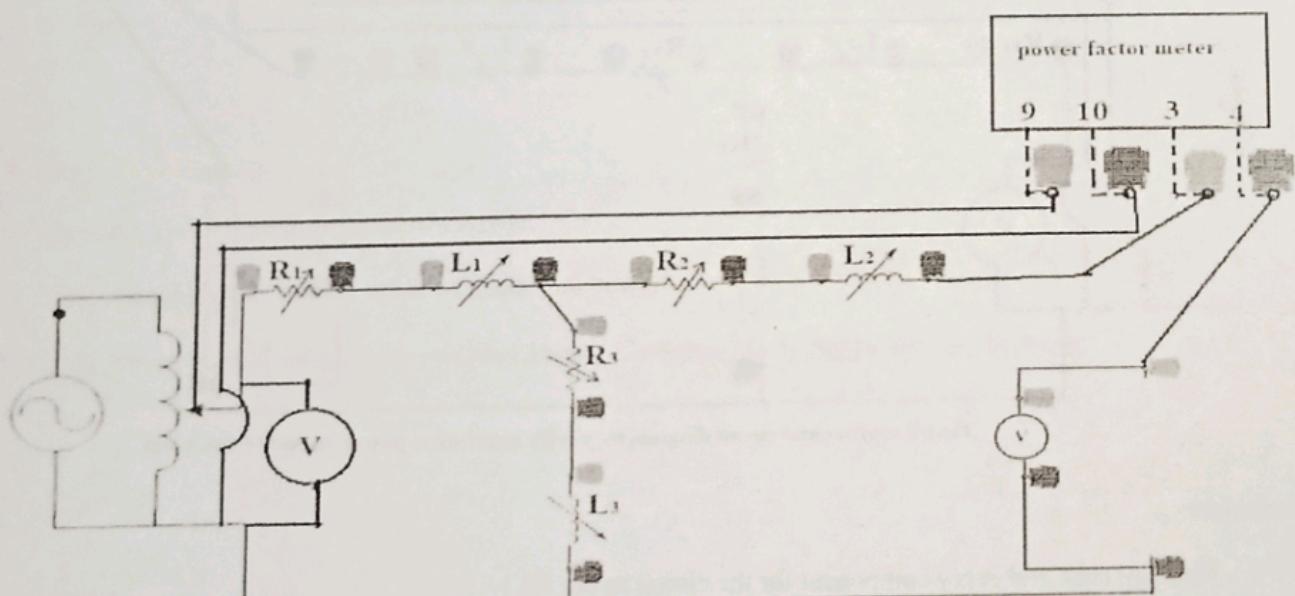


Fig.4 Experimental circuit diagram to measure V_{Th}

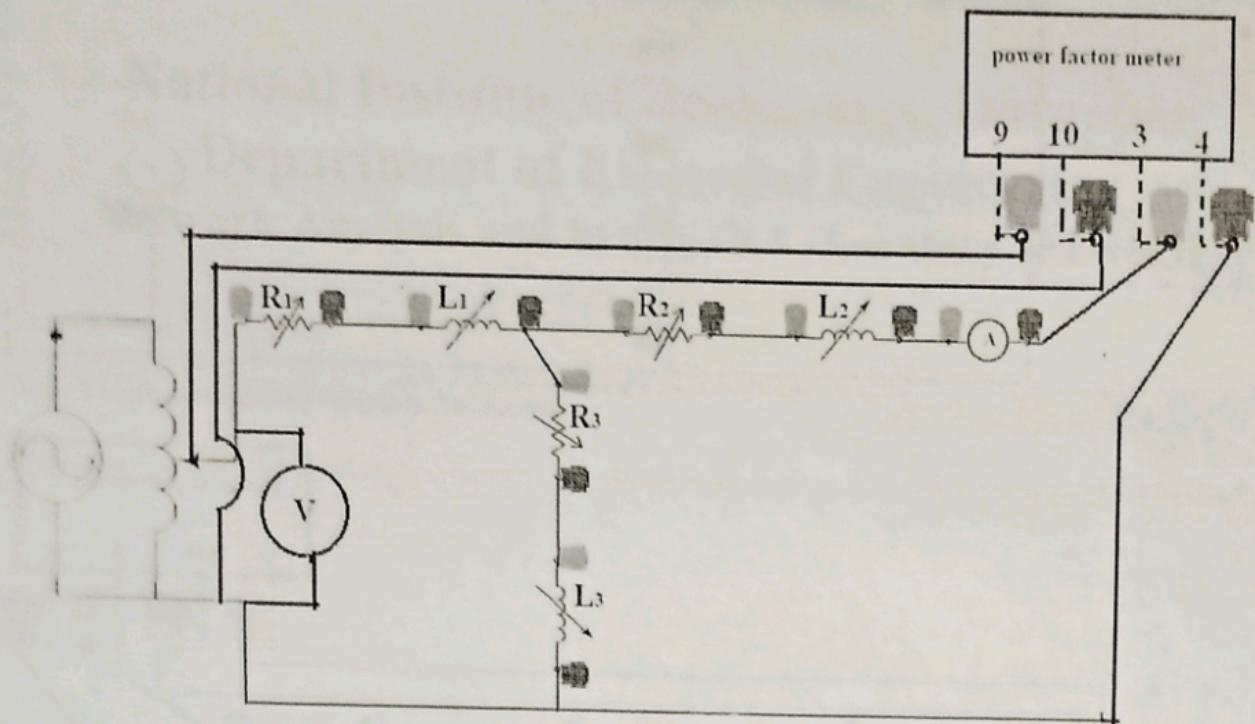


Fig.5 Experimental circuit diagram to measure I_N or I_{SC}

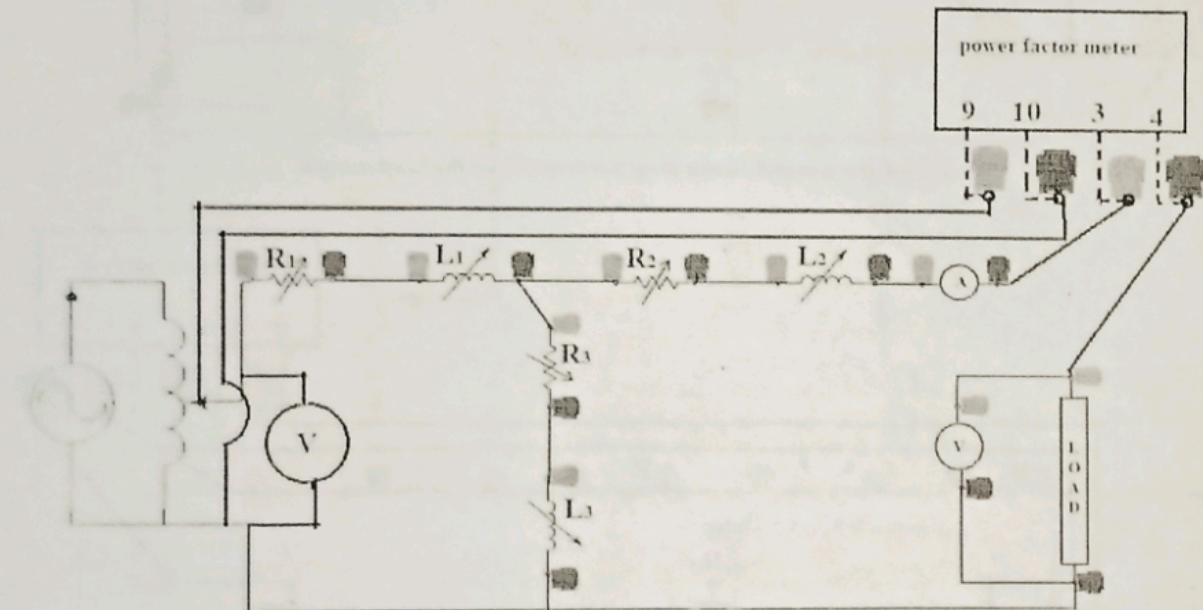


Fig.6 Experimental circuit diagram to verify maximum power transfer theorem.

Procedure:

1. Measure each and every component for the circuit as per fig.1.
2. Connect the circuit as per fig.2, increase the supply voltage gradually and note down the voltmeter and ammeter reading.

3. Connect the circuit as per fig.3, increase the supply voltage gradually. For fixed supply voltage and different values of load note down the ammeter reading. This ammeter actually measures the load current.
4. Connect the circuit as per fig.4 and measure the V_{Th} voltage.
5. Connect the circuit as per fig.5 and measure the I_N or I_{SC} current.
6. Connect the circuit as per fig.6 and change the value of load resistance in such a way that the current flow through the load will be maximum and the power factor will be also unity. Note down the ammeter and voltmeter (across the load) reading.

Observation:

Result for Thevenin's Theorem:

	Supply Voltage (V)	V_{Th} (V)	Z_{Th} (Ohm)	Load Current (A)	Load Current (A)
Theoretical					
Practical					

Result for Norton's Theorem:

	Supply Voltage (V)	I_N (A)	Z_N (Ohm)	Load Current (A)	Load Current (A)
Theoretical					
Practical					

Result for Maximum power transfer Theorem:

SI No	Value of Load (ohm)	Current Flow through the Load (A)	Voltage Across the load (V)	Power absorbed by the load (W)

Report:

1. Draw the graph load impedance Vs Power.
2. From the graph find out the value of maximum power.
3. Compare theoretical values with practical values. Comment on the application of theorems.

- b. $t_p = 5\tau$: Set the frequency such that $t_p = 5\tau$ (this should be 50 Hz). Since the pulse width is exactly 5τ , the capacitor should just be able to fully charge and discharge during each pulse cycle. From the figure determine τ (see Figure 2 and Figure 6 below.)
- c. $t_p \ll 5\tau$: In this case the capacitor does not have time to charge significantly before it is switched to discharge, and vice versa. Let $t_p = 0.5\tau$ in this case and set the frequency accordingly

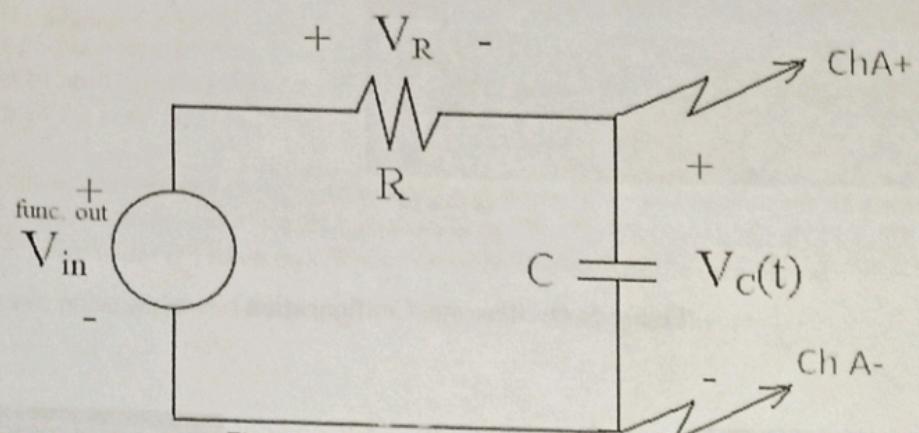


Fig-4, experimental setup

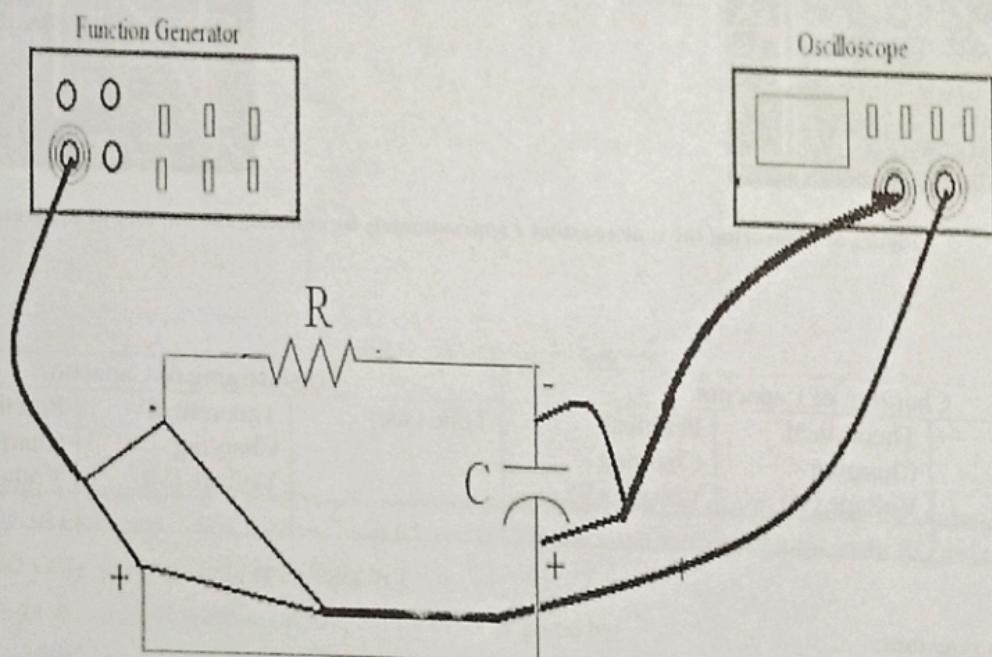


Fig-5, experimental circuit diagram