National Institute of Technology

Durgapur

Network Analysis & Synthesis Lab

(EES-451)

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→ 3rd Sem (Lab)

Experiment - 1

Transient Response of RC & RL circuits

Experiment No. EES/451/01

Title: Transient Response of RC and RL Circuits

Objective -

1. Study the transient response of a series RC circuit and understand the time concept ~~at~~ using pulse waveforms.

Theory:

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 current in RC and RL circuits. generally, when the elapsed time exceeds five time constants (5τ) after switching has occured, the currents and voltages have reached their final value, which is called steady state response.

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

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

A pulse is a voltage or current that changes from one level to the other and back again. If a waveform's ~~height~~ high time equals its low time it is called a square wave.

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

→ Then frequency, $f = \frac{1}{2t_p}$

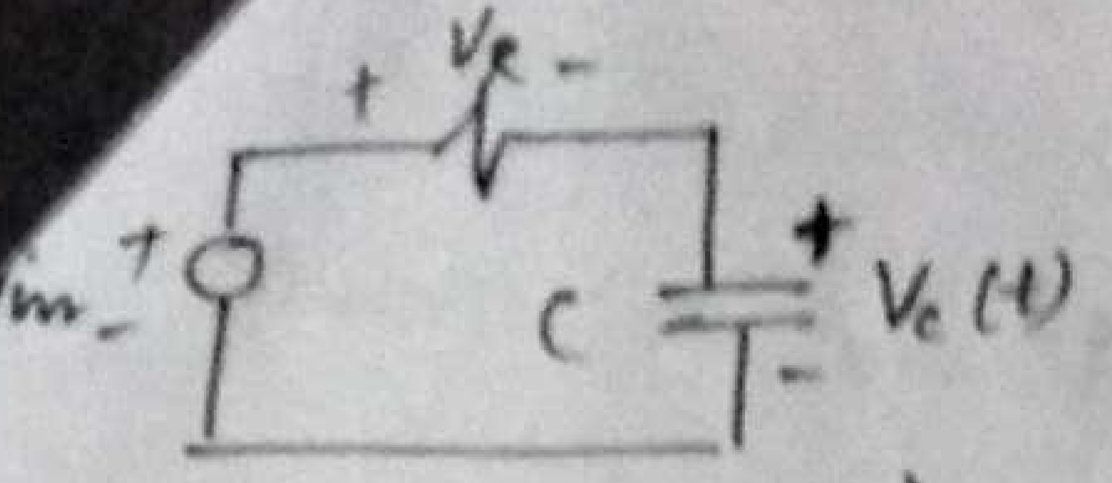


Fig-1 (Series RC ckt)

From Kirchoff's law, it can be shown that the charging voltage $V_c(t)$ across the capacitor is given by: $v_c(t) = V(1-e^{-t/RC})$ $t \geq 0$; --- (3)
where V is the applied source voltage to the circuit for $t \geq 0$.
$RC = \tau$ is the time constant. The response is shown in the figure below.

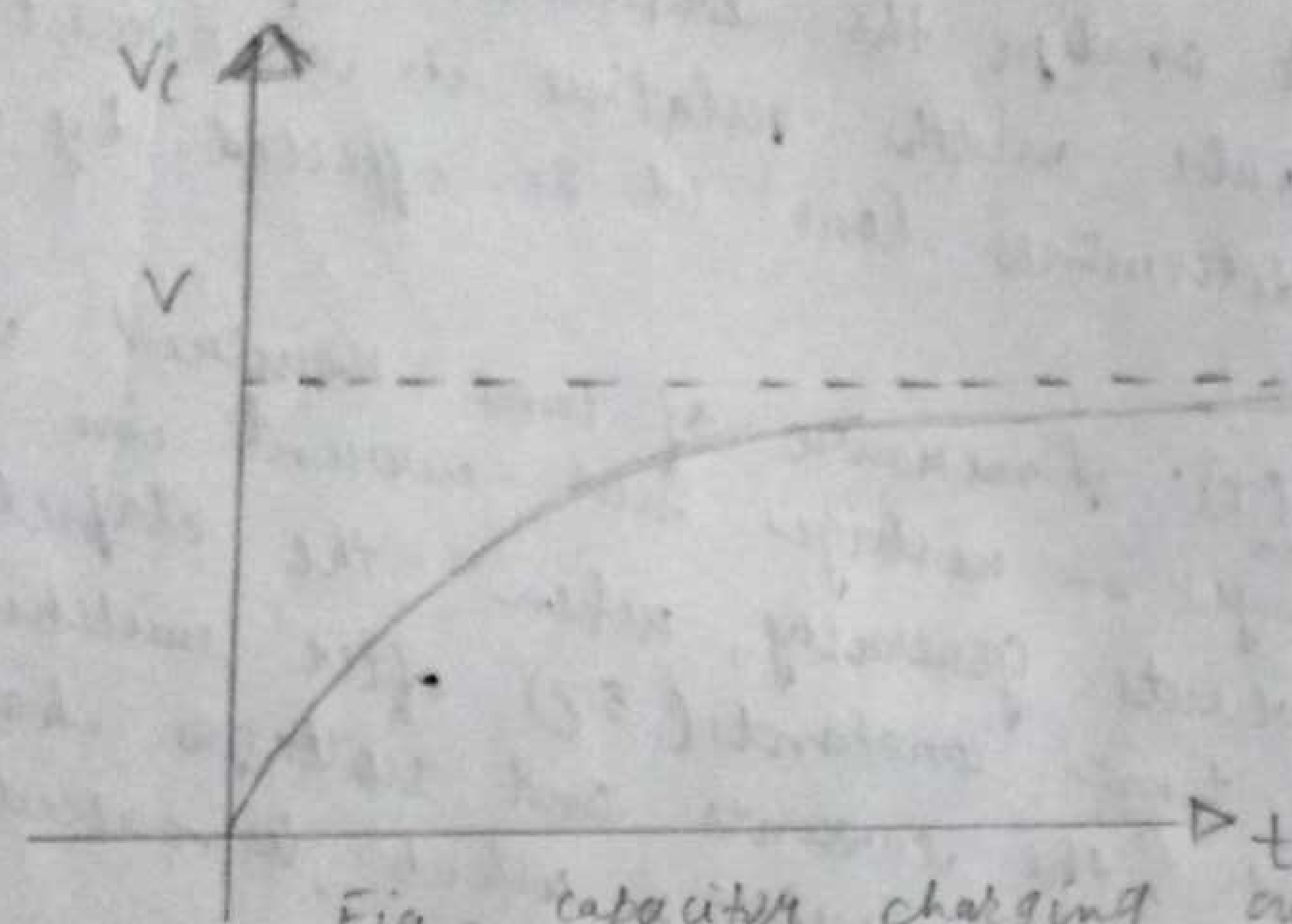


Fig - capacitor charging voltage.

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 the time constant. The response curve is decaying exponential as shown below -

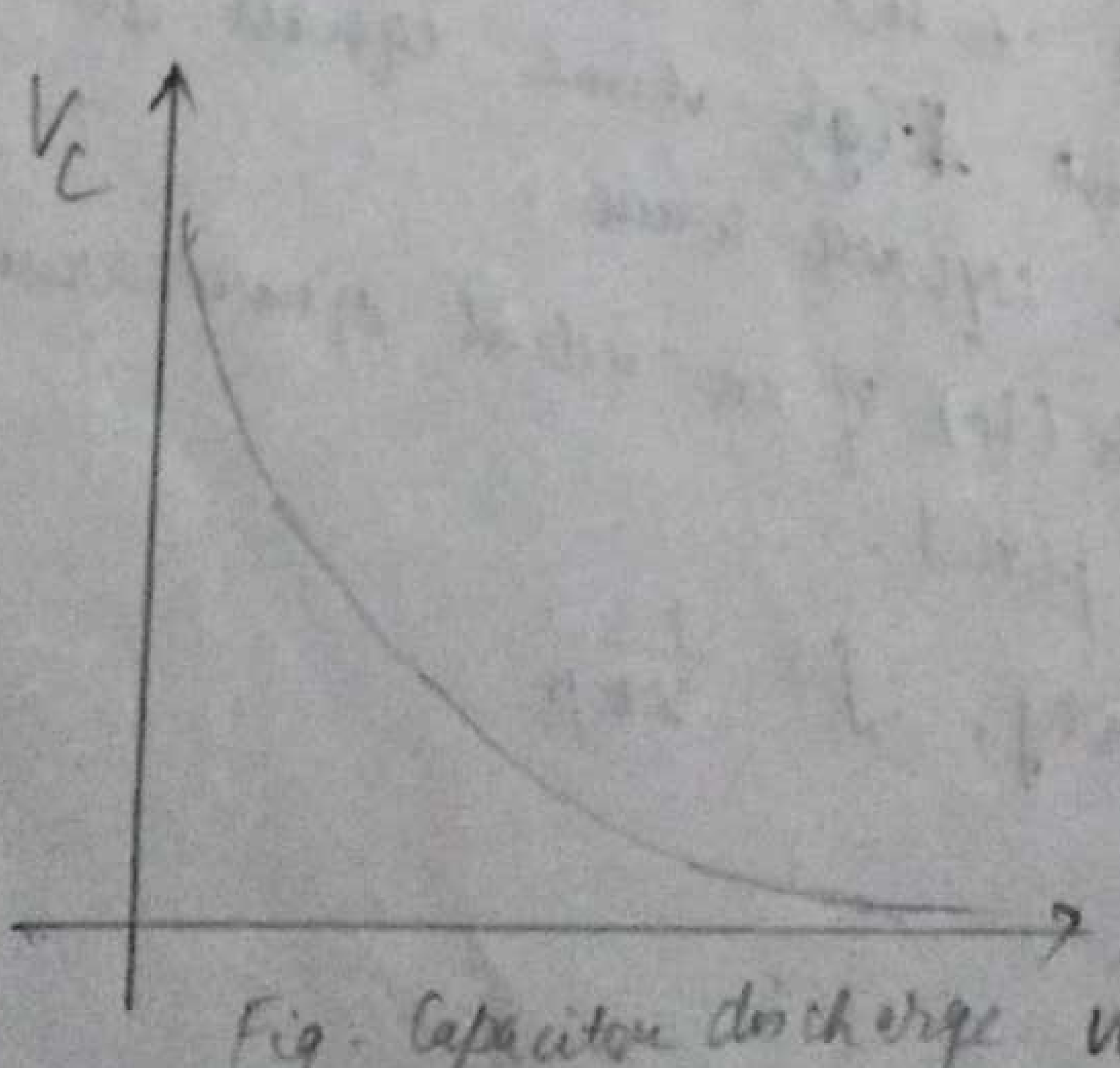


Fig. Capacitor discharge voltage.

Objective

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

Theory:

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 R-L circuit.

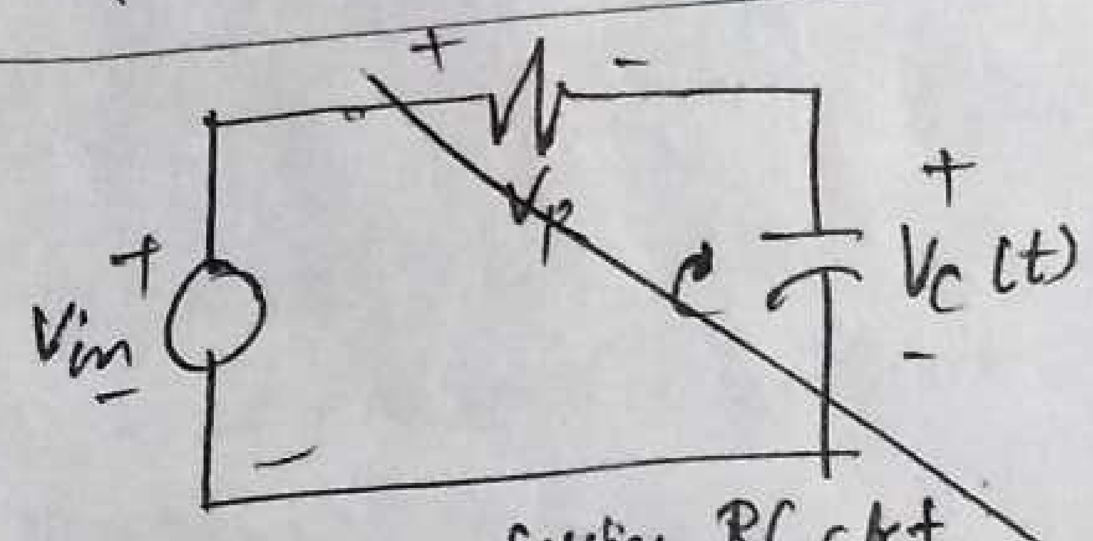


Fig - Series RC ckt

~~From Kirchoff's law it can be shown that the charging voltage $V_c(t)$ accross the capacitor is given by $V_c(t) = V(1- e^{-t/RC})$ for $t \geq 0$~~

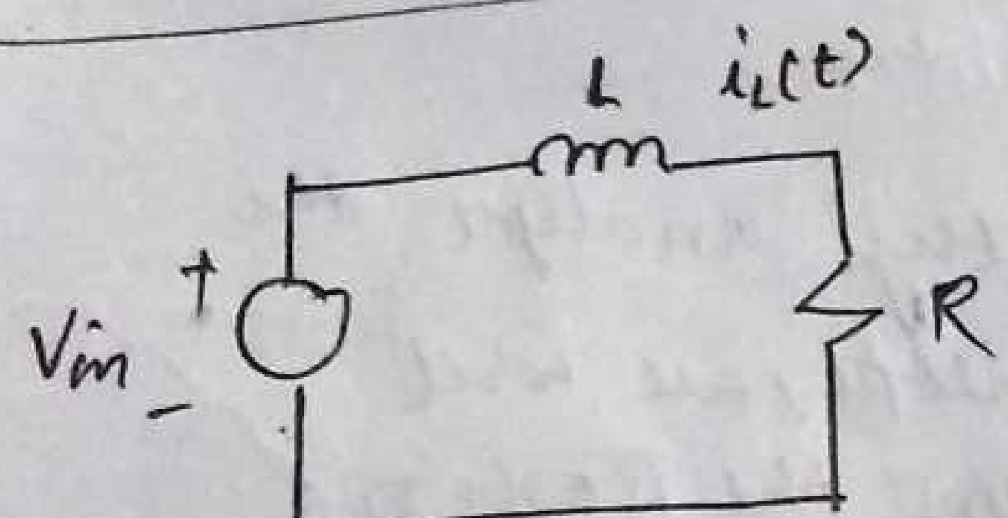


Fig - R L series ckt

In an RL circuit, voltage accross the inductor decreases with time while in the RC circuit the voltage accross the capacitor increases with time. Thus, current in an R L circuit has the same waveform as voltage in an RC circuit they both rise to their final value exponentially according to $1 - e^{-t/\tau}$. The expression for the current build-up accross the inductor is given by

$$i_L(t) = \frac{V}{R}[(1- e^{-(R/L)t})] \quad t \geq 0 \quad --- (3)$$

where V is the applied source voltage to the circuit. The response curve is increasing and is for $t \geq 0$. The response curve is shown in figure 2.

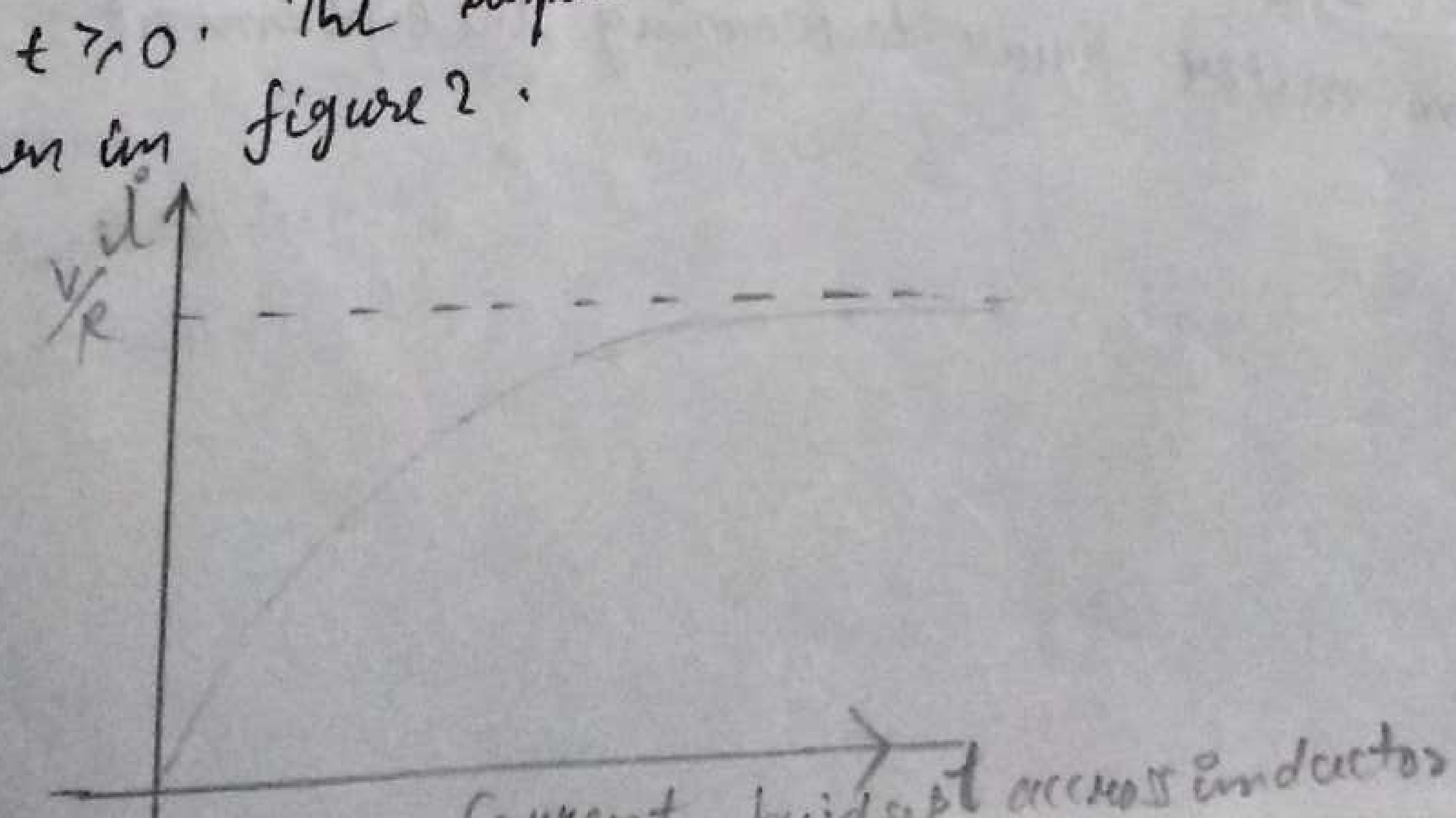


Fig - Current buidup accross inductor.

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

$$i_L(t) = i_0 e^{-(R/L)t} \quad \text{- - - -} \quad (4)$$

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.

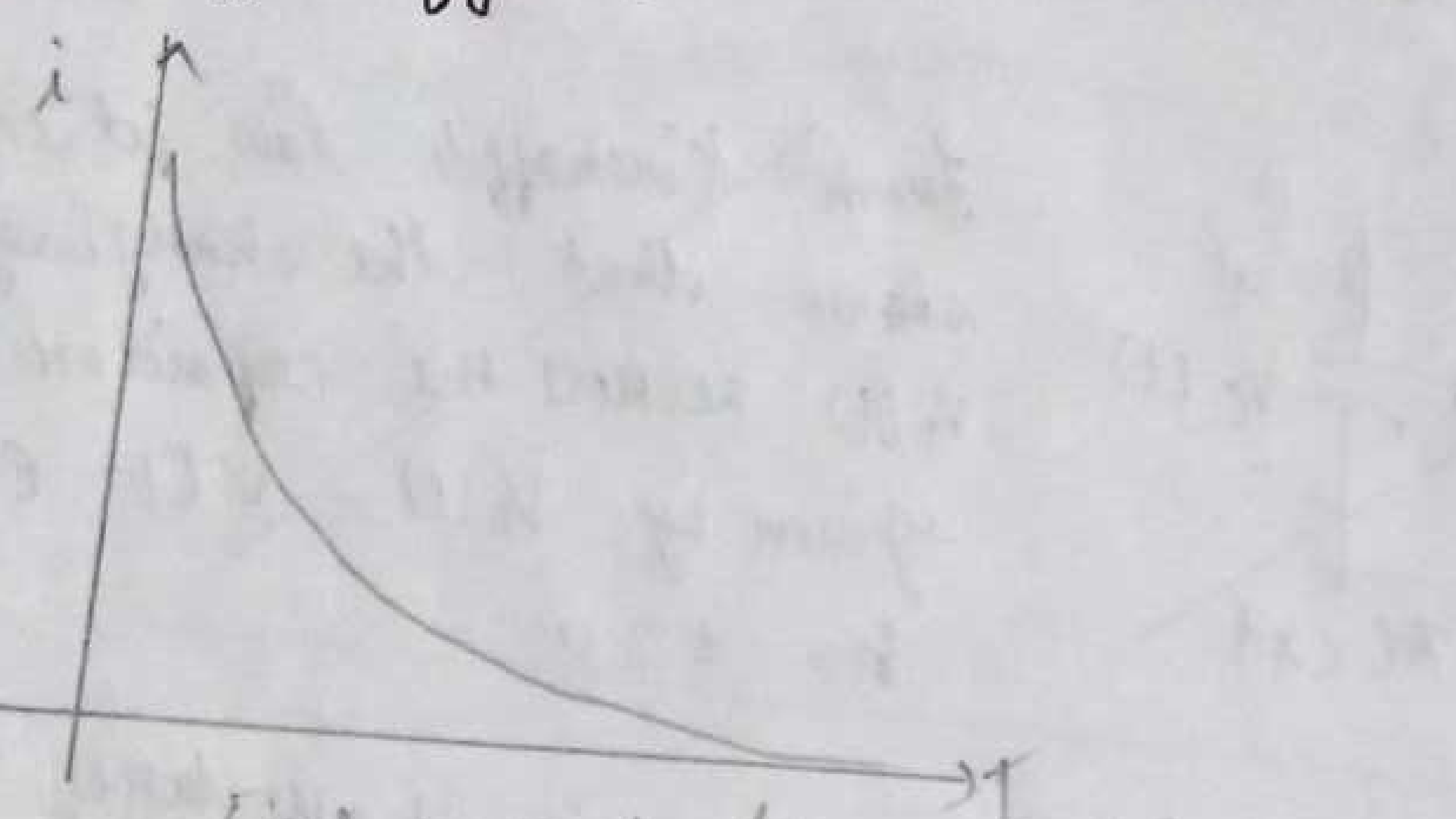


Fig 3 current decay across inductor

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 will be similar to the inductor current as $V_R = I_R R$. 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 $R_{total} = R_{inductance} + R$.

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

Observation Table --

Table - I : For RC circuit, $R_1 = 1.48 K\Omega$, $C = 3.9 \mu F$

Sl. No.	Frequency of square wave (Hz)	Amplitude (V) (P-P)	Time constant (s)		% Error
			Exp. Calc.	Theo. calc.	
1.	56.07	3.0	3.56×10^{-3}		38%
2.	62.25	3.0	3.0×10^{-3}	5.772×10^{-3}	48%
3.	45.05	3.0	3.75×10^{-3}		35%

Questions -

1) Calculate the time constant using eqn (1) and compare it to the measured values.

Ans: Time constant $\tau = RC = 1.48 K\Omega \times 3.9 \mu F$

$= \cancel{14.8 \times 1} = 1.48 \times 10^3 \times 3.9 \times 10^{-6}$ s

$= 5.772 \times 10^{-3}$ s.

Variation from Readings.

Frequency (Hz)	τ (Theoritical) (s)	τ (Experimental) (s)	% Error
56.07	5.772×10^{-3}	3.56×10^{-3}	38%
62.25	5.772×10^{-3}	3.0×10^{-3}	48%
45.05	5.772×10^{-3}	3.75×10^{-3}	35%

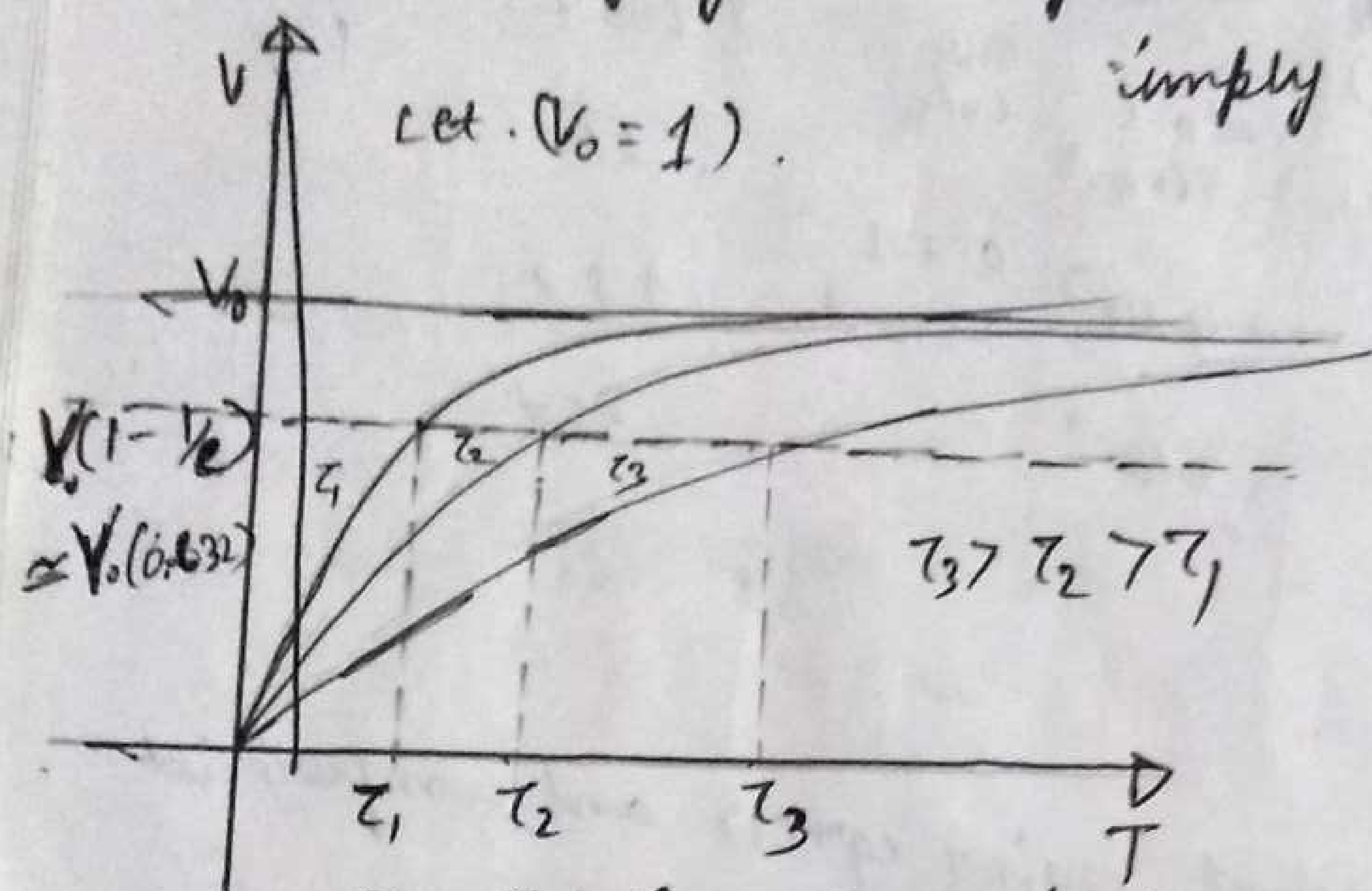
2) Discuss the Effect of changing component value.

Ans: We know $\tau = RC$. Thus changing R, or C ~~to~~ is directly proportional to increasing the time constant. A higher value of R or C will give a higher time constant and vice versa.

Increasing R or C increases the time constant.

Charging:

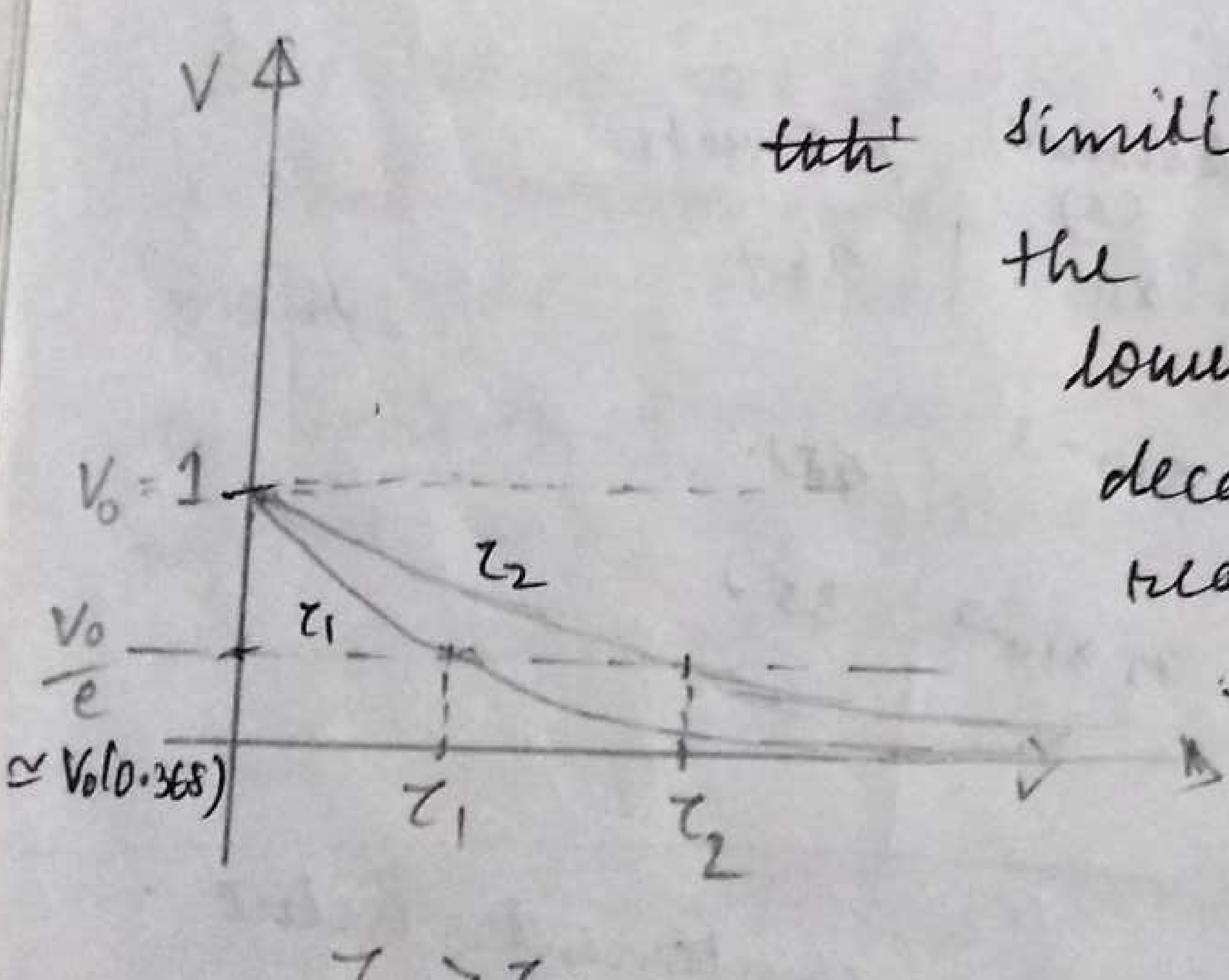
While charging a larger time constant would imply a larger time required for the system to reach steady state.



The smaller the Time constant the faster the response.

Fig - Plot of curves having different time constant for $V_0 = 1$.

Discharging:



~~tah~~ Similarly while discharging the system with lower time constant decays faster and hence reaches steady state faster ~~and is fast~~ Thus smaller time constant implies faster response.

$\tau_2 > \tau_1$

Fig - Plot of Discharge for 2 different ~~to~~ curves with ~~of~~ different time constants

Table-II: For RL circuit, $R_L = 0.6272\ k\Omega$, $L = 1.12H$, $R_L = 47.5\Omega$

Sl. No.	Frequency of square wave (Hz)	Amplitude V (p-p)	Time constant Exp. Calc.	Time constant Theo. Calc.	% Error
1.	59.73	2.1	2.17×10^{-3}		31.5%
2.	65.85	2.1	1.97×10^{-3}	1.65×10^{-3}	19.3%
3.	50.10	2.1	2.79×10^{-3}		69%

Q) A capacitor stores charge. What do you think an Inductor store? Answer in brief.

Ans: → It stores energy in the ~~form~~ of magnetic field the surrounds it.

Suppose an inductor of inductance L is connected to a variable DC ~~sup~~ voltage supply. The supply is adjusted so as to increase the current is flowing through the inductor from zero to some final vale I. As current through the inductor is ramped up an emf

$$dW = Pdt = -\varepsilon i dt = iL\frac{di}{dt}dt = Li\,di$$

Here $P = -\varepsilon i$ is the instantaneous rate of work done by voltage.

$$\therefore\ W = \int_0^I Li\,di = \frac{1}{2}LI^2$$

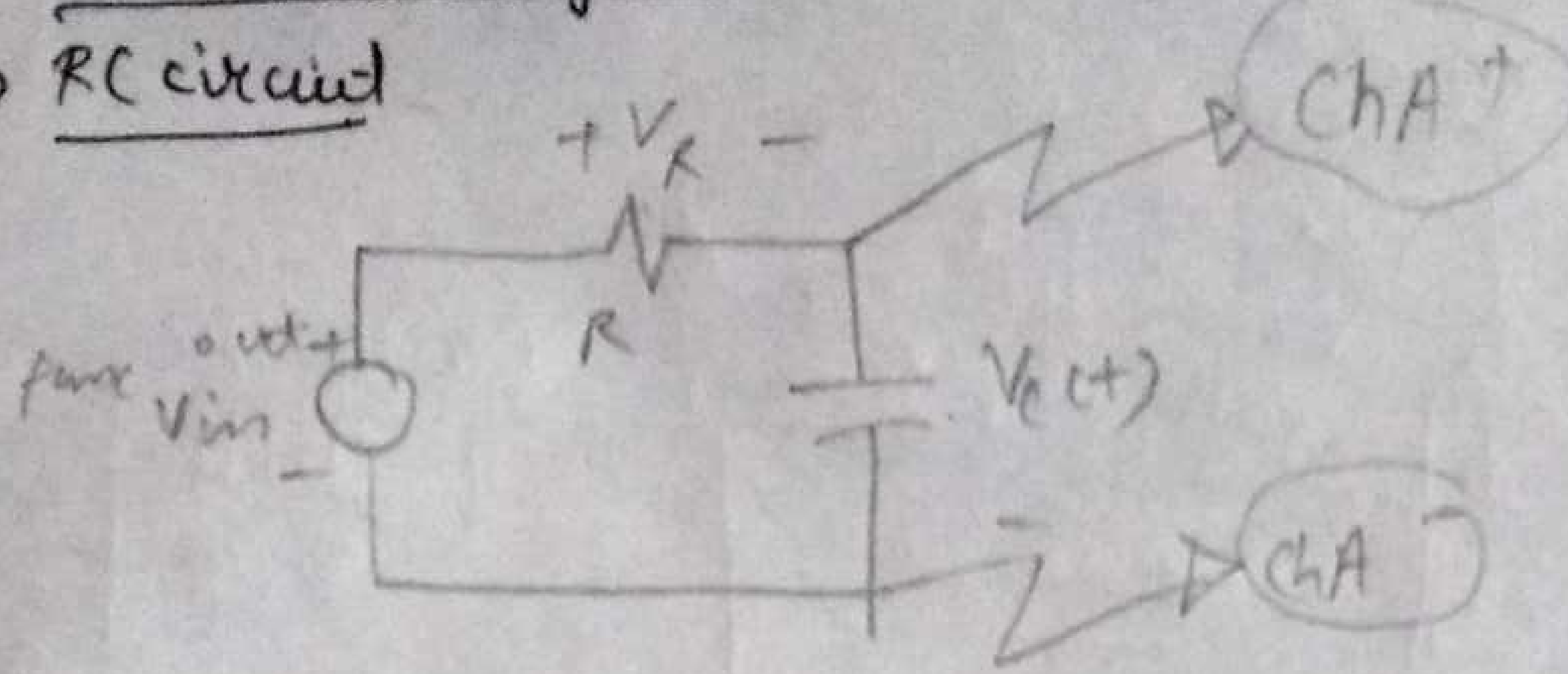
This energy is actually stored in the magnetic field generated by the current flowing through it. In a pure inductor the energy is stored without loss, and is returned to the rest of the circuit, when the current through the inductor is ramped down, and its associated magnetic field collapses.

$$W = \frac{1}{2}LI^2 = \frac{\mu_0 N^2 A}{2l}\left(\frac{Bl}{\mu_0 N}\right)^2$$

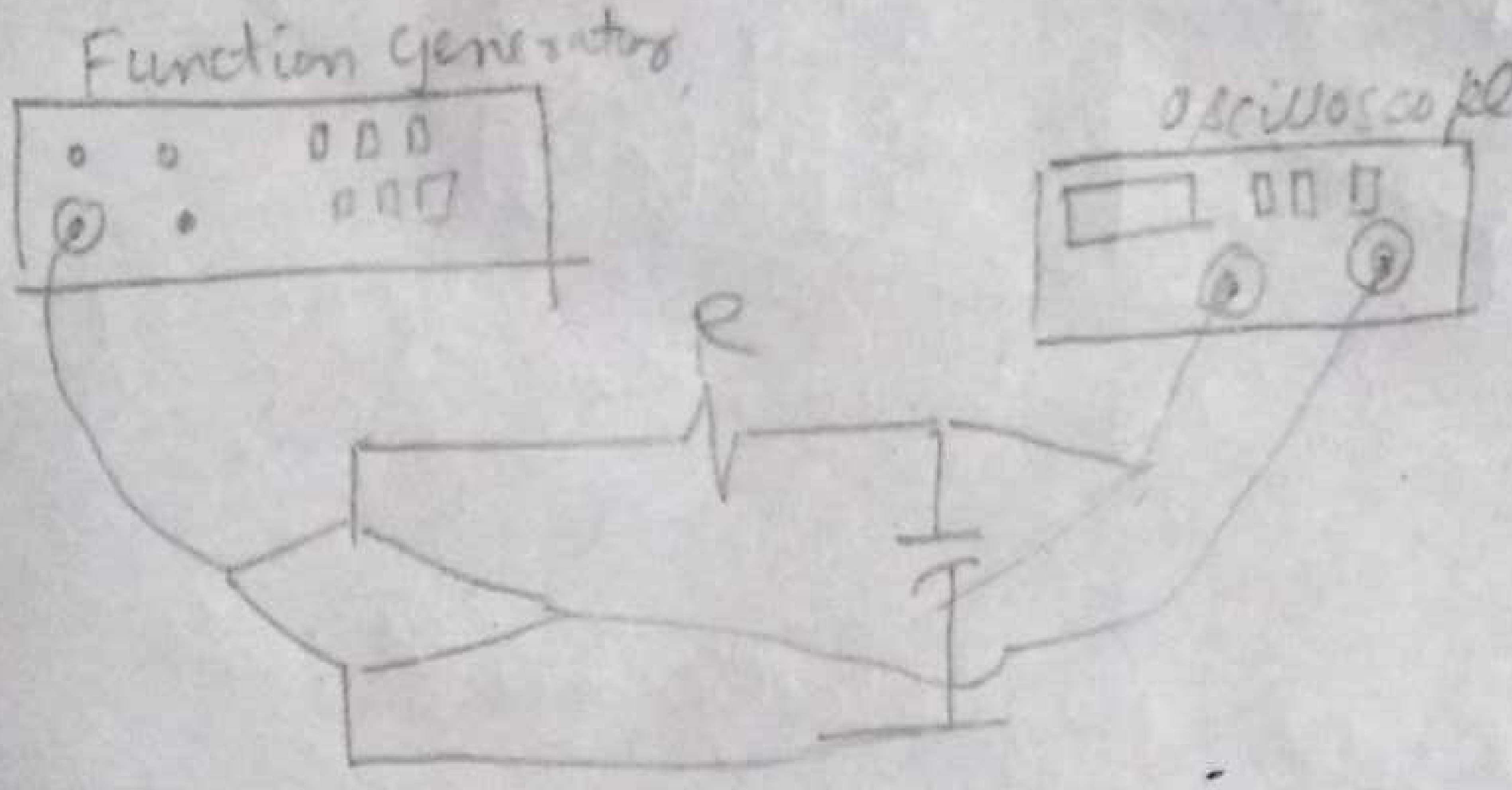
$$= \frac{B^2}{2\mu_0}$$

Circuit Diagram

1) RC circuit

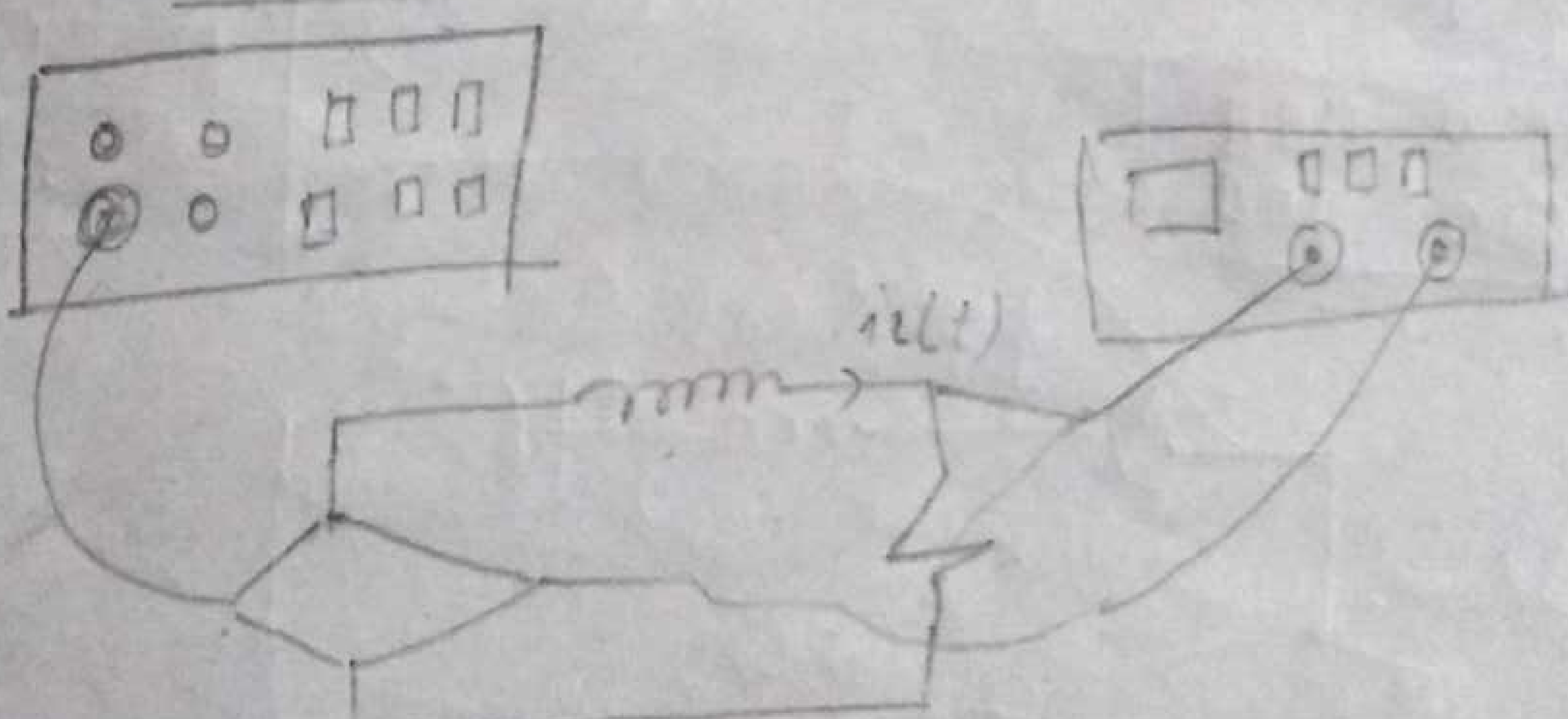


Experimental Ckt diagram

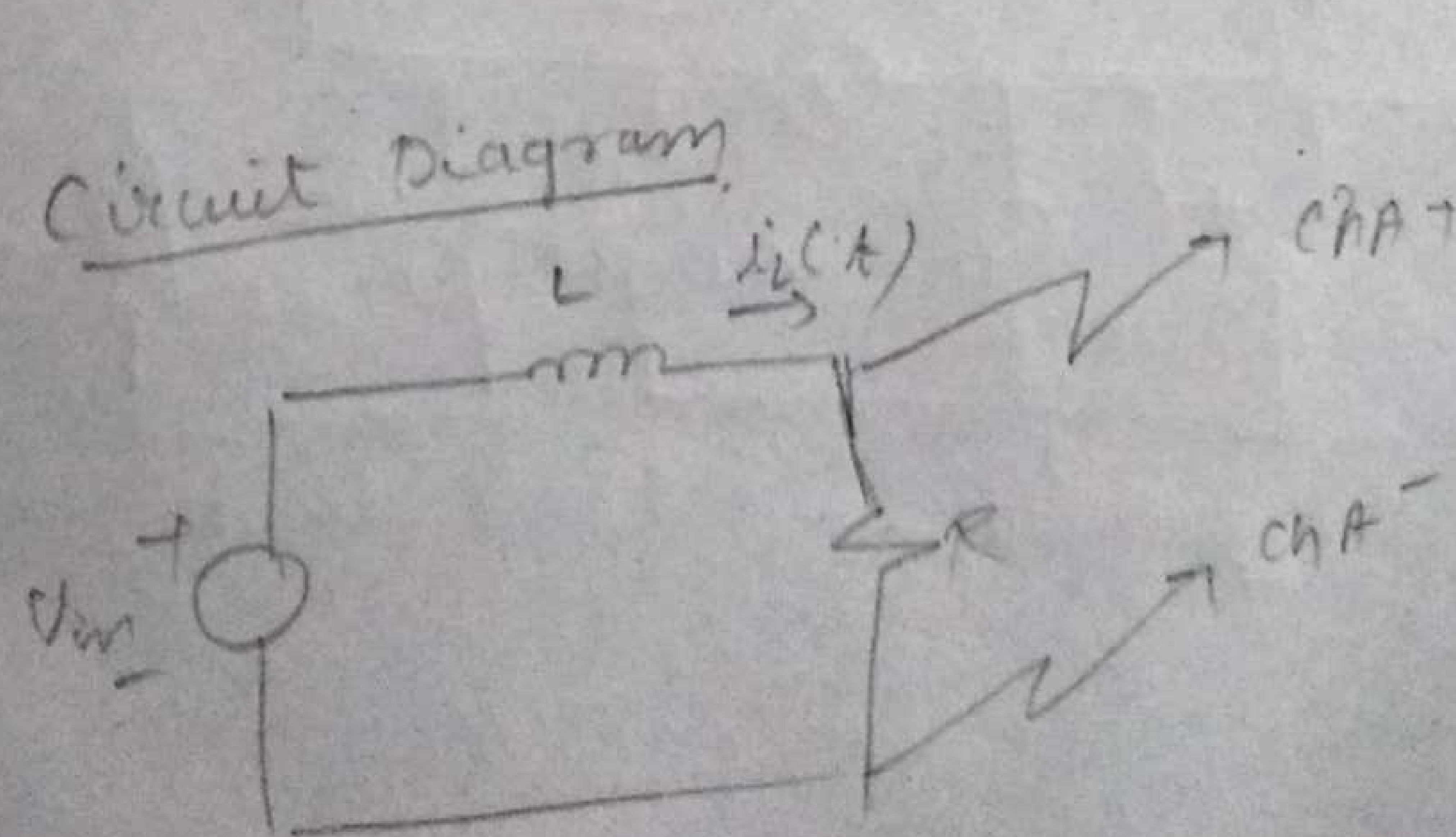


2) RL circuit

Experimental Setup



Circuit Diagram



Experiment I

given $R_1 = 2k\Omega$, $C_1 = 1\mu F$, $V_p = 4V$ (peak to peak)

~~$R_2 = 100k\Omega$~~, ~~$C_2 = 0.01\mu$~~

Equation while charging –

$$V_c(t) = V_p(1 - e^{-t/\tau}) \quad \& \quad V_d = V_p e^{-t/\tau}$$

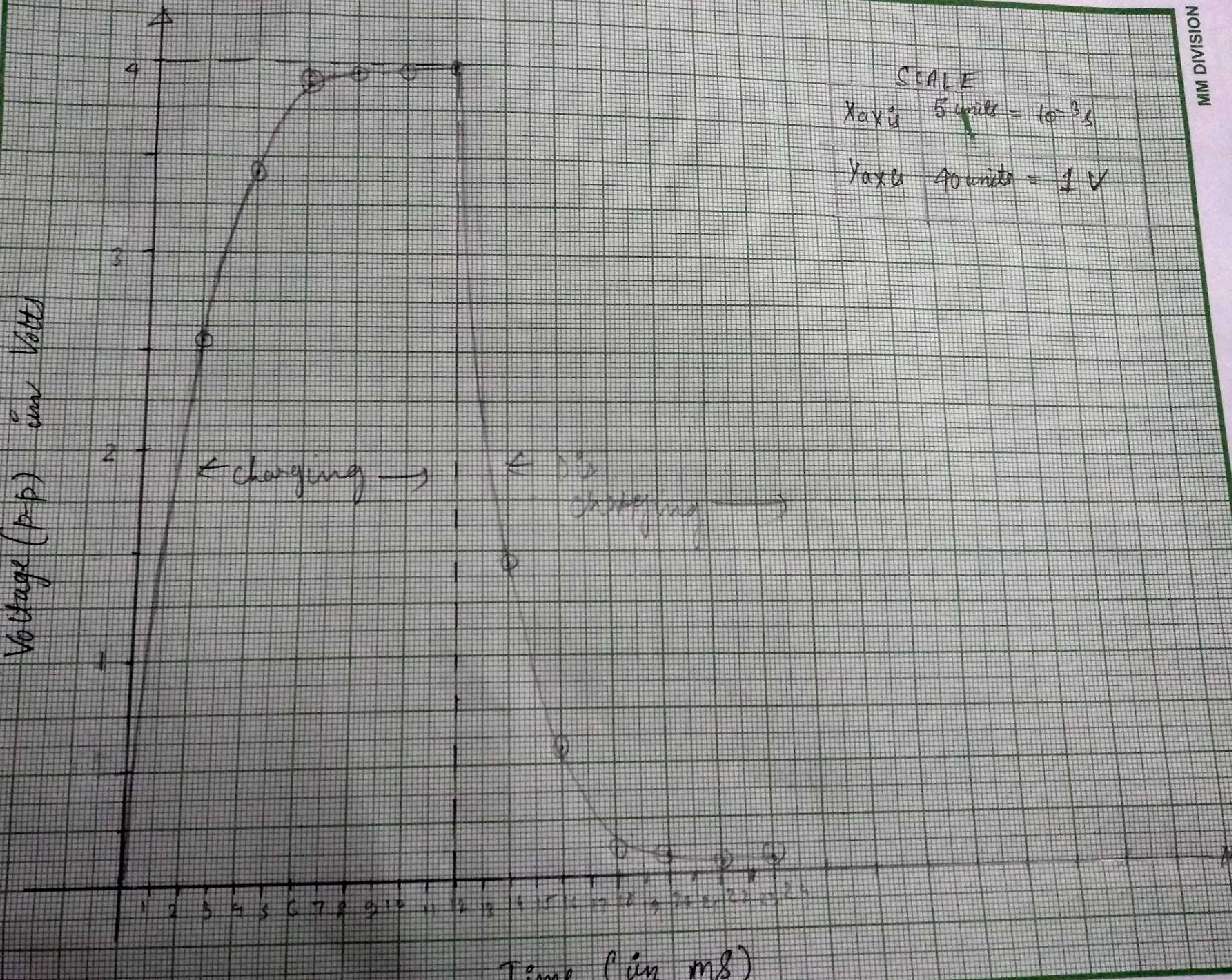
$$= 4(1 - e^{-500t}) \quad \& \quad V_d = 4e^{-500t}$$

Values for the graph.

Time Constant	τ Value while charging	Voltage across capacitor (V)	~~Time constant~~ Voltage value (discharging)	Time constant (while discharging)
0	0	0	3.990	0.012
τ	0.002	2.5284	1.4678	0.014
2τ	0.004	3.486	0.5399	0.016
3τ	0.006	3.80085	0.1986	0.018
4τ	0.008	3.9267	0.07308	0.02
5τ	0.01	3.9730	0.02688	0.022
6τ	0.012	3.9900	0.00900	0.024

Experiment-1 (RC circuit)

$-500t)$ & $v_d = 4e^{-500t}$



Experiment 1.

Part II : RL circuit

Time constant	τ Value (charging) (in s)	Current ~~Voltage~~ (charging) (in A)	τ value discharging (in s)	Current discharging (in A)
0	0	0	0.009	0.00399
1	0.00015	0.00252	0.00105	0.001467
2	0.0003	0.00345	0.0012	0.005399
3	0.00045	0.00380	0.00135	0.0019865
4	0.0006	0.00392	0.0015	7.381×10^{-5}
5	0.00075	0.00397	0.00165	2.685×10^{-5}
6	0.0009	0.00399	0.0018	9.8904×10^{-6}

Calculation.

→ $R = 10^3\,\Omega$

→ $L = 150\,mH$ → $\tau_c = \frac{L}{R} = 1.5\times10^{-4}$, $V_p = 4V\,(p-p)$

$$\therefore I_c = \frac{V_p}{R}\left(1 - e^{-t/\tau}\right)$$

$$I_c = \frac{4}{10^3}\left(1 - e^{-666t}\right)$$

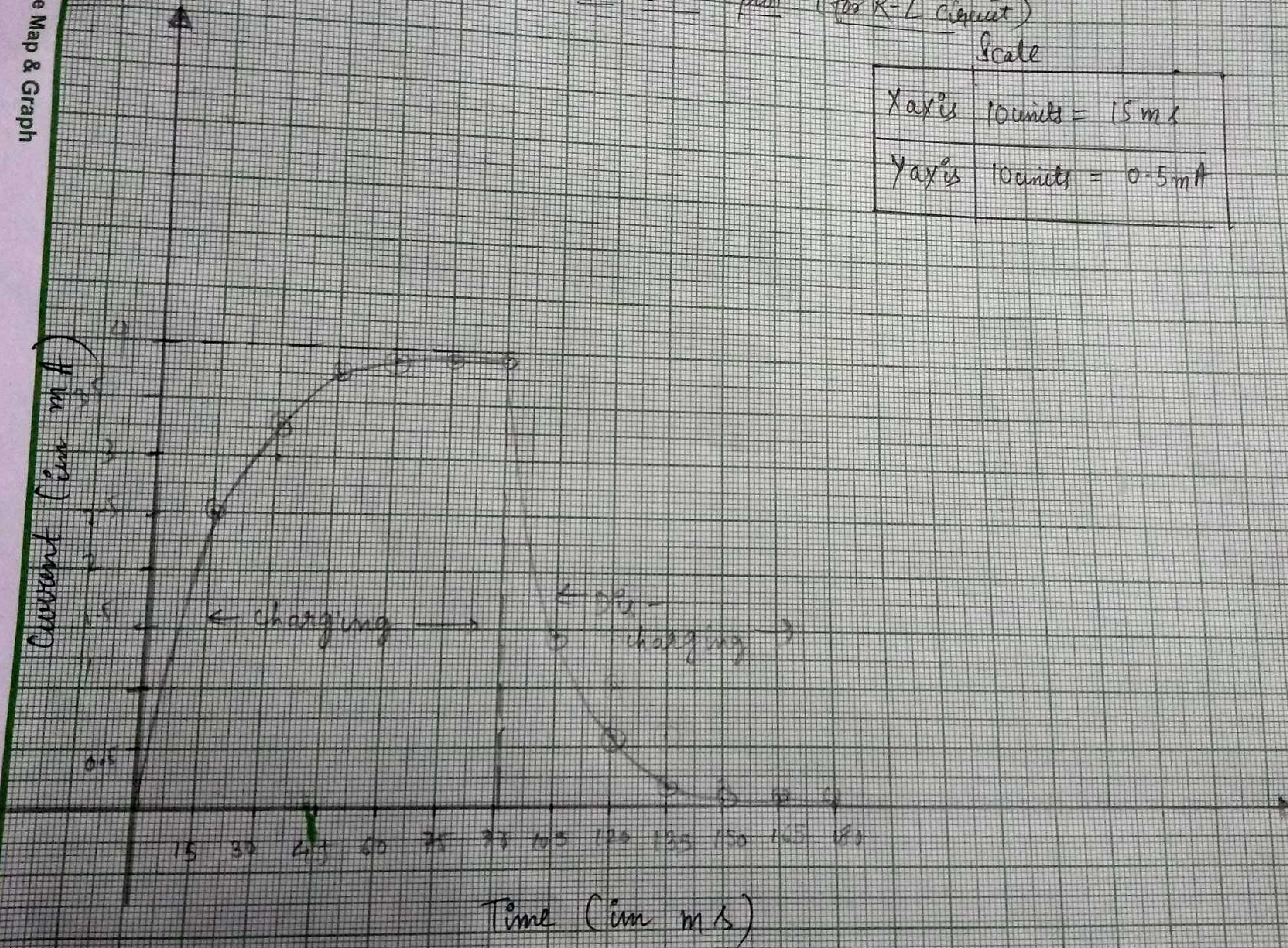
$$I_c = 0.004\left(1 - e^{-666t}\right)$$

$$I_d = 0.004\left(e^{-666.66t}\right)$$

Current Vs time plot (for R-L circuit)

Scale

X axis	10 units = 15 ms
Y axis	10 units = 0.5 mA



Experiment - 2

Transient Response of RLC series circuit

→ Experiment No: EES/951/02

→ Title: Transient Response of RLC series circuit

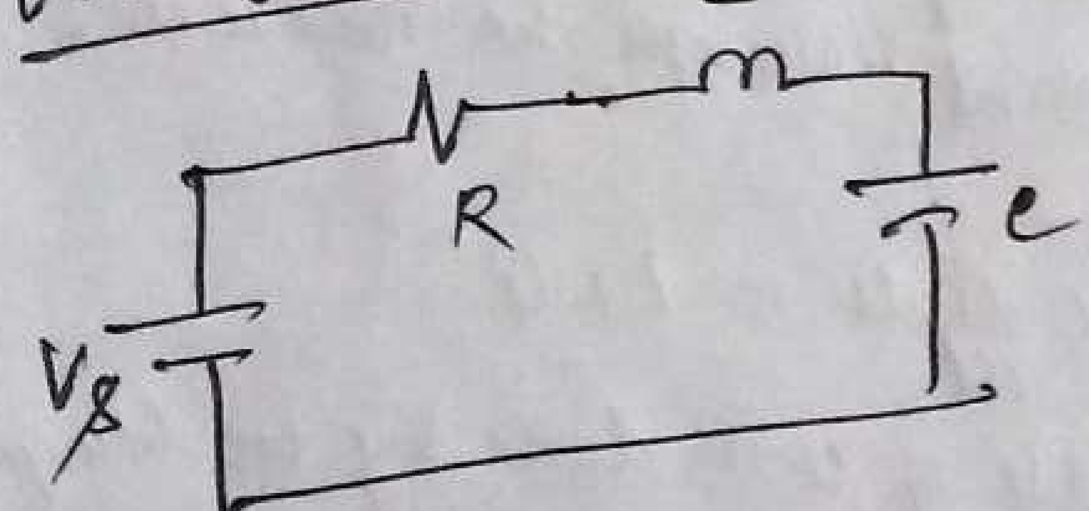
→ objective. To design an over-damped, under-damped and critically damped series RLC circuit and observe their transient response.

→ Theory.

A series RLC ckt can be modelled as a 2nd order differential equation, having solution under three condition of roots.

1) Critically damped → Roots are real & equal
2) Over damped → Real & unequal roots
3) Under damped → ~~Roots are~~ Roots are complex conjugate pairs.

Analysis.



Using KVL,

$\Rightarrow V_R + V_L + V_C = V_s$ --- (1)

The current flowing in the ckt.

$$I = C\frac{dV}{dt} \quad \text{-- (2)}$$

&, $V_R = IR = RC\frac{dV}{dt}$ -- (3)

Substituting all values in eq(1)

$$\frac{d^2V}{dt^2} + \frac{R}{L}\frac{dV}{dt} + \frac{1}{LC}V = \frac{1}{L}(V) \quad \text{.. (5)}$$

The sol^n is a linear combination of homogenous & particular solution

The particular sol^n is $V_{cp} = V_s$ --- (6)

and the homogeneous eq^n satisfies

$$\frac{d^2V}{dt^2} + \frac{R}{L}\frac{dV}{dt} + \frac{1}{LC}V = 0$$

Assuming the ~~eqn~~ $soln$ is of form $A \cdot e^{st}$ and substituting

$\alpha = R/2L$ = Damping ratio --- (9) and

$w_0 = \frac{1}{\sqrt{LC}}$ --- natural frequency --- (10)

The characteristics eqn

$\Rightarrow \quad s^2 + 2\alpha s + w_0^2 = 0$

Its roots are

$s_1 = -\alpha + \sqrt{\alpha^2 - w_0^2}$ --- (12) and $s_2 = -\alpha - \sqrt{\alpha^2 - w_0^2}$

And the homogenous solution becomes

$V_{cn} = A_1 e^{s_1 t} + A_2 e^{s_2 t}$ --- (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 initial conditions of the system.

The value of the term $\sqrt{\alpha^2 - w_0^2}$ determines the behaviour of the response.

1) If $\alpha = w_0$, then $s_1 = s_2$ and $s_1, s_2 \in \mathbb{R}$

Response is Critically damped.

2) If $\alpha > w_0$, then ~~b~~ $s_1, s_2 \in \mathbb{R}$, and no oscillatory behaviour, the ckt is over damped.

3) If $\alpha < w_0$, i.e. $\sqrt{\alpha^2 - w_0^2} = j\sqrt{w_0^2 - \alpha^2}$. In this case s_1 and s_2 are complex numbers, system exhibits ~~complete~~ oscillatory behaviour i.e. Underdamped.

Over Damped

Condition $(\alpha > \omega_0)$,

$$V_c(t) = V_c(\infty) + A_1 e^{S_1 t} + A_2 e^{S_2 t}$$

Equating at time $t=0$, we get

$$V_c(0) = V_c(\infty) + A_1 + A_2$$

and also, $\frac{dv_c}{dt}(0) = \frac{i_L}{C}(0^+) = S_1 A_1 + S_2 A_2$

Once S_1, S_2 are known from,

$$S_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2} \quad \& \quad S_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2}$$

A_1, A_2 can be easily found out

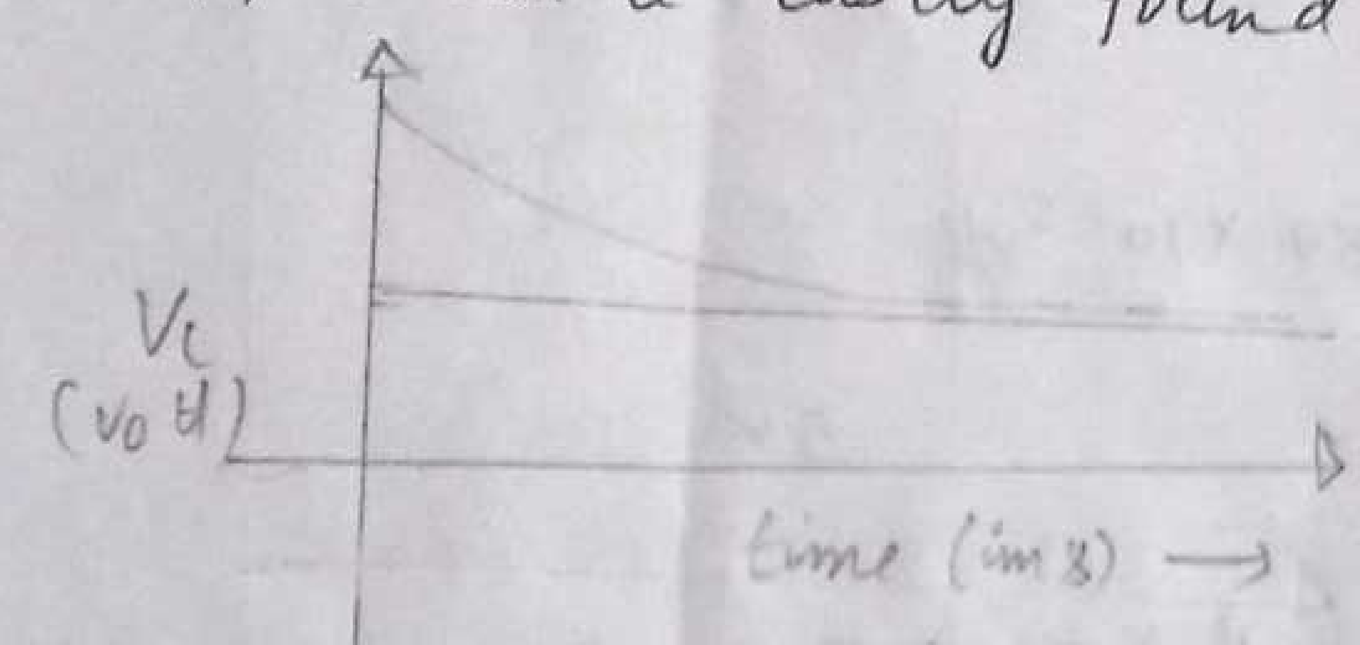


Fig - over damped

Under Damped

Condition $(\alpha < \omega_0)$

~~As~~ in Eq^n → $V_c(t) = V_c(\infty) + (B_1 \cos \omega_d t + B_2 \sin \omega_d t) e^{-\alpha t}$

to get B_1, B_2 we ~~equate~~ find the voltage at $t = 0$

$$V_c(0) = V_c(\infty) + (B_1 \cos(0) + B_2 \sin(0)) e^{-\alpha t(0)}$$

$$V_c(0) = V_c(\infty) + B_1 \quad \text{--- (1)}$$

from here we get B_1 now to calculate B_2 we differentiate $V_c(t)$ w.r.t time

$$\frac{dv_c(t)}{dt} = (B_1 \cos \omega_d t + B_2 \sin \omega_d t)(-\alpha e^{-\alpha t})$$
$$+ (-\omega_d B_1 \sin \omega_d t + \omega_d B_2 \cos \omega_d t) e^{-\alpha t}$$

Again equating at $t = 0$ we get

$$\frac{dv_c(0^+)}{dt} = \frac{i_L(0^+)}{C} = \cancel{(B_1 \cos \omega_d t + B_2 \sin \omega_d t)(-\alpha}$$
$$= (B_1)(-\alpha) + \omega_d(B_2)$$

Thus we calculate the value of B_1 & B_2

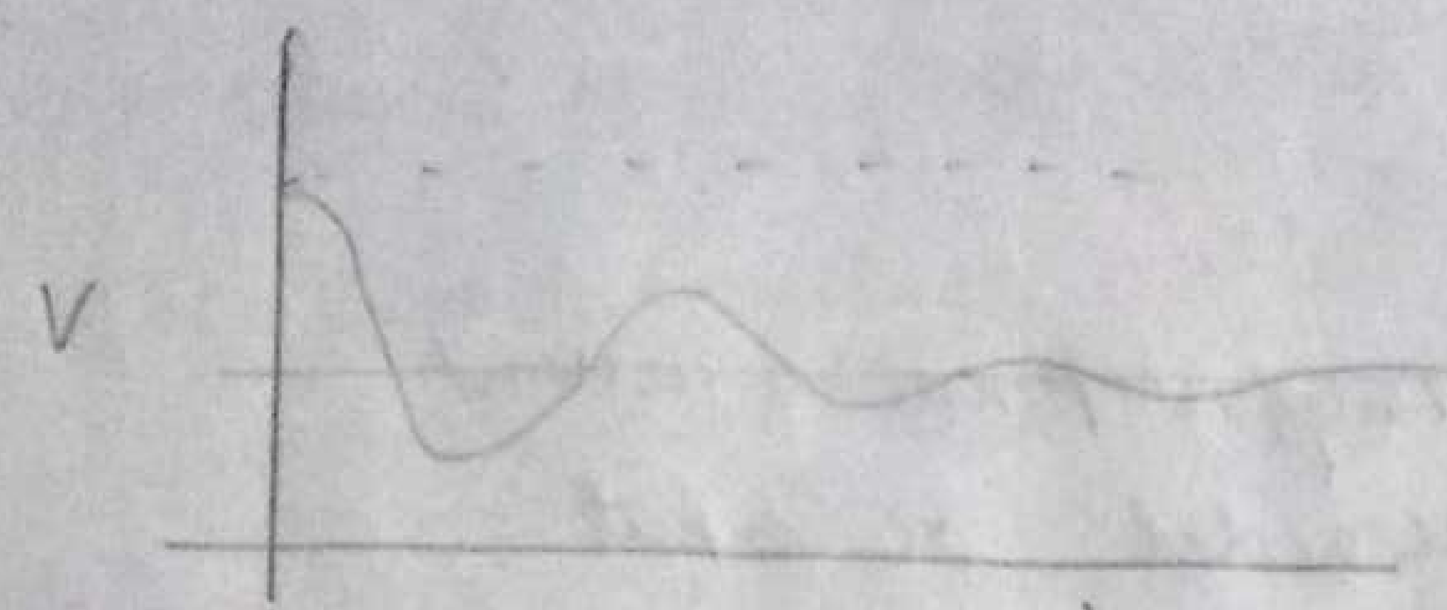


Fig - Response for Under damped ckt

Critically ~~Over~~ damped.

$V_c(t) = V_c(\infty) + (C_1 + C_2 t)\, e^{-\alpha t}$

at time $t = 0$

$V_c(0) = V_c(\infty) + [C_1 + C_2(0)]\, e^0$

$V_c(0) = V_c(\infty) + C_1$

from here we get C_1, and we calculate C_2 by differentiating.

$\frac{dV_c(t)}{dt} = [C_1 + C_2(0)]\,(-\alpha e^0) + C_2 e^0$

$\frac{dV_c(0^+)}{dt} = C_1(-\alpha) + C_2$

From this we get C_1, C_2

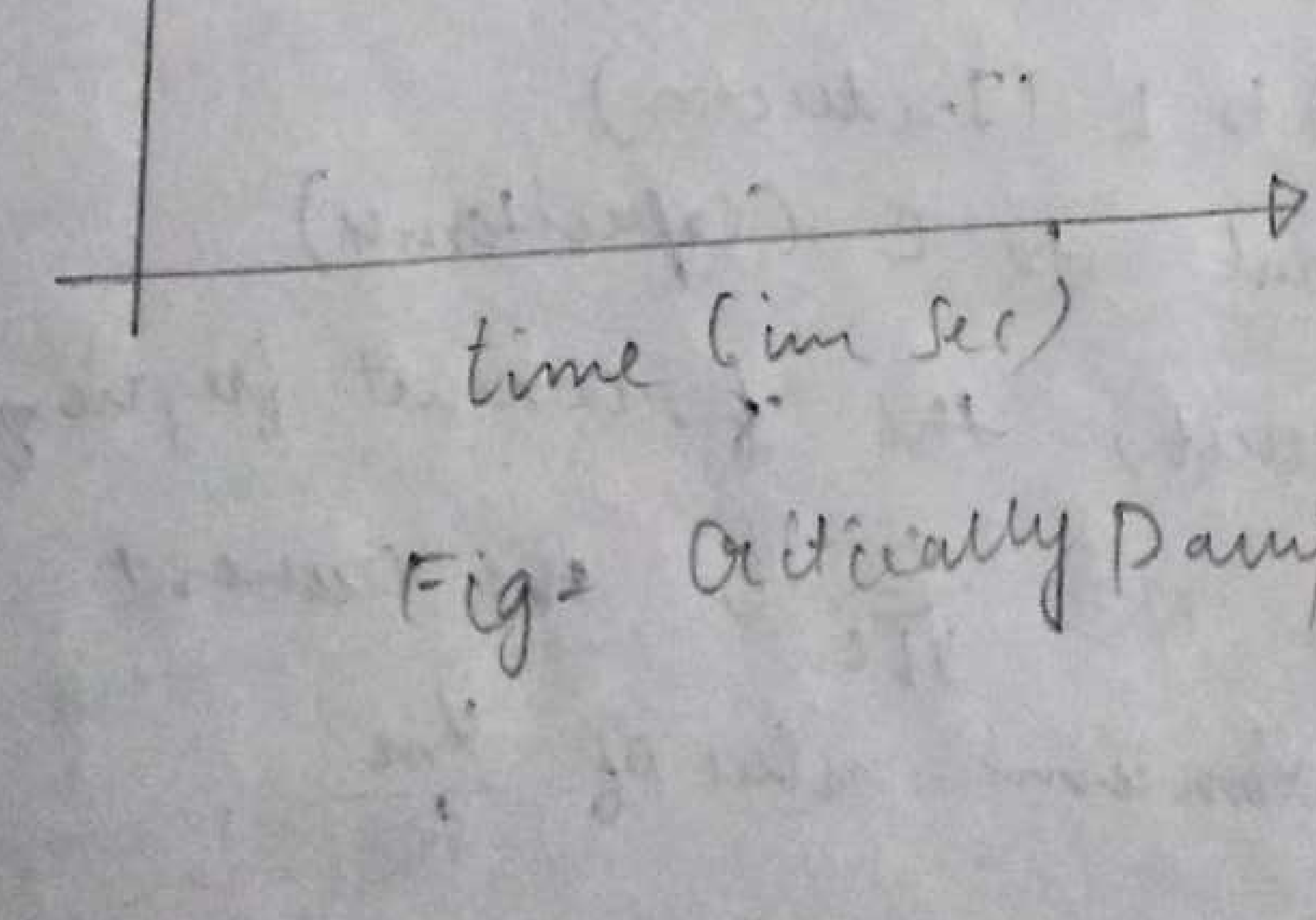


Fig - Critically Damped.

Observation Table – I

Table for reading data for overdamped RLC circuit

Sl. No	Quantity	Calculated Values	Measured Values
1.	R	–	3180 Ω
2.	α	$\frac{3180}{2} \times 44 \times 10^{-3}$ $= 0.036$	–
3.	ω_0	48.309×10^3	–
4.	s_1, s_2	$s_1 = 0.032$ $s_2 = -72272.68$	–
5.	$V_C(0)$	–	0 V
6.	$\frac{d}{dt}[V_C(0)]$	1.57×10^{-5} V/s	–
7.	$V_C(\infty)$	–	5 V
8.	A_1 and A_2	$A_1 \approx 0$, $A_2 \approx -5$	–
9.	Equation for $V_C(t)$		
10.	$V_C(0.03ms)$	4.2	4.4 V
11.	$V_C(0.04ms)$	4.8 V	4.7 V
12.	$V_C(0.5ms)$	5 V	5 V

Calculations

Over damped

→ The damping factor $\alpha = \frac{R}{LC} = \frac{3180}{2} \times 44 \times 10^{-3} = \underline{0.036}$

→ The undamped natural frequency $(\omega_0) = \frac{1}{\sqrt{LC}} = 48.369 \times 10^3$

Analysis & Result.

1) Over Damped.

Condition ? α (damping factor) > ω_0 (undamped frequency)

The voltage accross capacitor in this case

$$\rightarrow V_C(t) = V_C(\infty) + A_1 e^{s_1 t} + A_2 e^{s_2 t}$$

We calculate A_1, A_2, by putting $t=0$, we get the following equation (from the observation tab ii)

$$\Rightarrow V_C(t) = 5 + 0(e^{0.032t}) + (-5)e^{(-72272.68}$$

$$\Rightarrow V_C(t) = 5 - 5e^{-72272.68t}$$

$$\Rightarrow V_C(t) = 5(1 - e^{-7227.68t})$$

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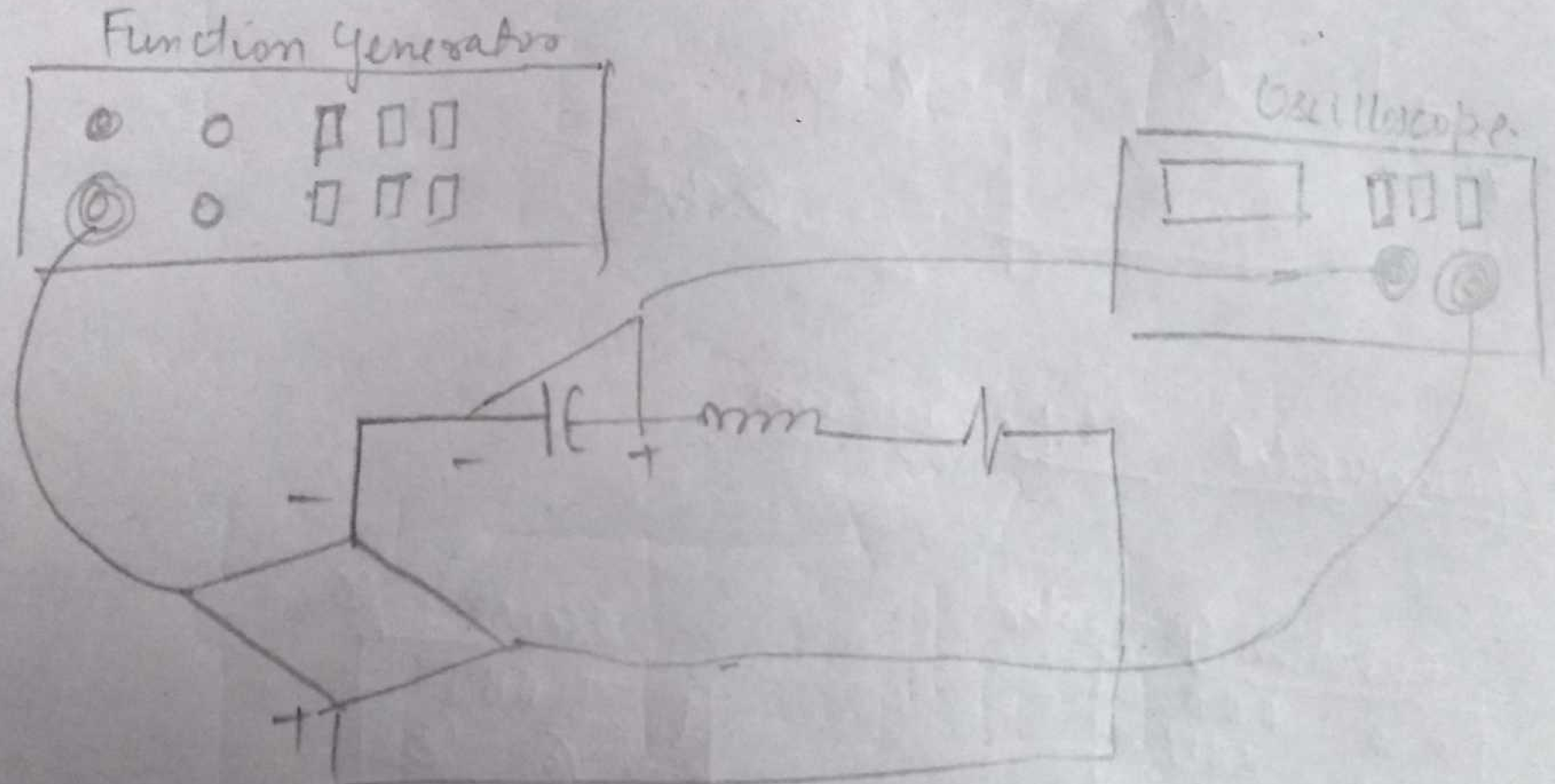
Experiment - 2

Circuit Diagram



Experiment - 3

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

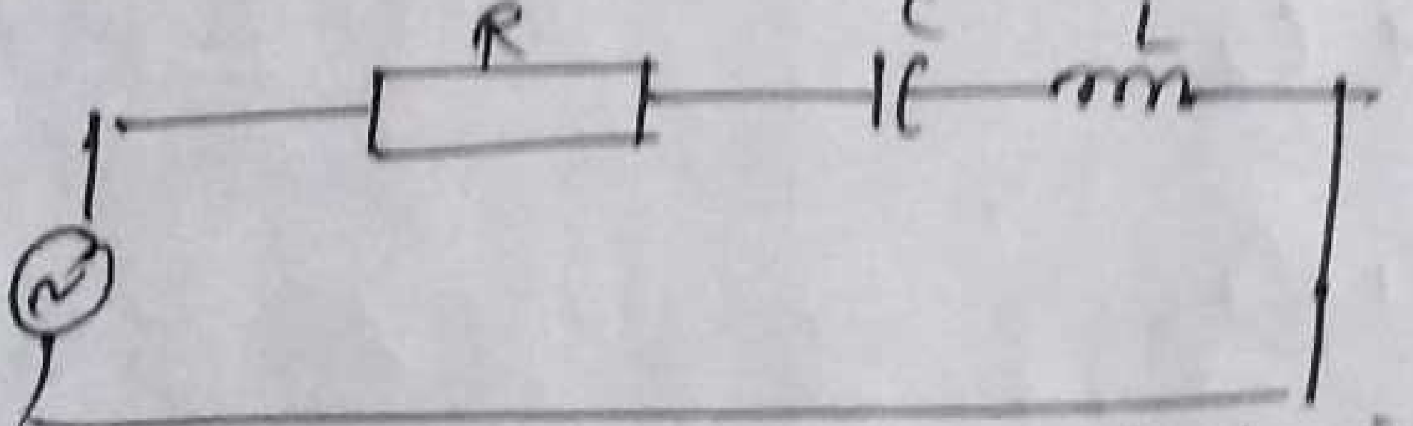
Experiment No EES/PS1/03

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 network is in resonance when the voltage and current at the network input terminals are in phase and the input impedence of the network is purely resistive

1) Series Resonant ~~ckt~~ circuit – The frequency at which ~~when~~ $X_L = X_C$, is called Resonant frequency (f_R)



For the above circuit

$$I = \frac{V}{R + j\omega L + \frac{1}{j\omega C}}$$

Fig-1 (series RLC circuit).

If $V = V_m \angle 0^\circ$, we get the following characterestics, the amplitude of current depends on various factors—

1) Directly proportional to forcing signal V_m.
2) Inversely related to R. (Resistance)
3) Inversely related to L (Inductor)
4) Directly proportional to C (Capacitance)

In series resonant circuit, the resonant frequency $f_R = \frac{1}{2\pi\sqrt{LC}}$, when $\omega = \frac{1}{\sqrt{LC}}$, the current will have a maximum value of $\frac{V_m}{R}$.

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 frequency is further increased, the current starts to lag and when $\omega \to \infty$, the phase angle will ~~tend~~ start to approach 90° lagging.

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.

2) Parallel Circuit Resonance -

→ When resultant current through the parallel combination is in phase with supply voltage the circuit is said to achieve parallel resonance or anti resonance.

→ At resonance there will be a large circulating current between the inductor and capacitor due to the energy of oscillations.

→ At resonance the inductor and capacitor draws zero current from the supply, as $I_C = I_L$, hence ~~they~~ their vector addition cancels each other.

Only current flows through the resistor.

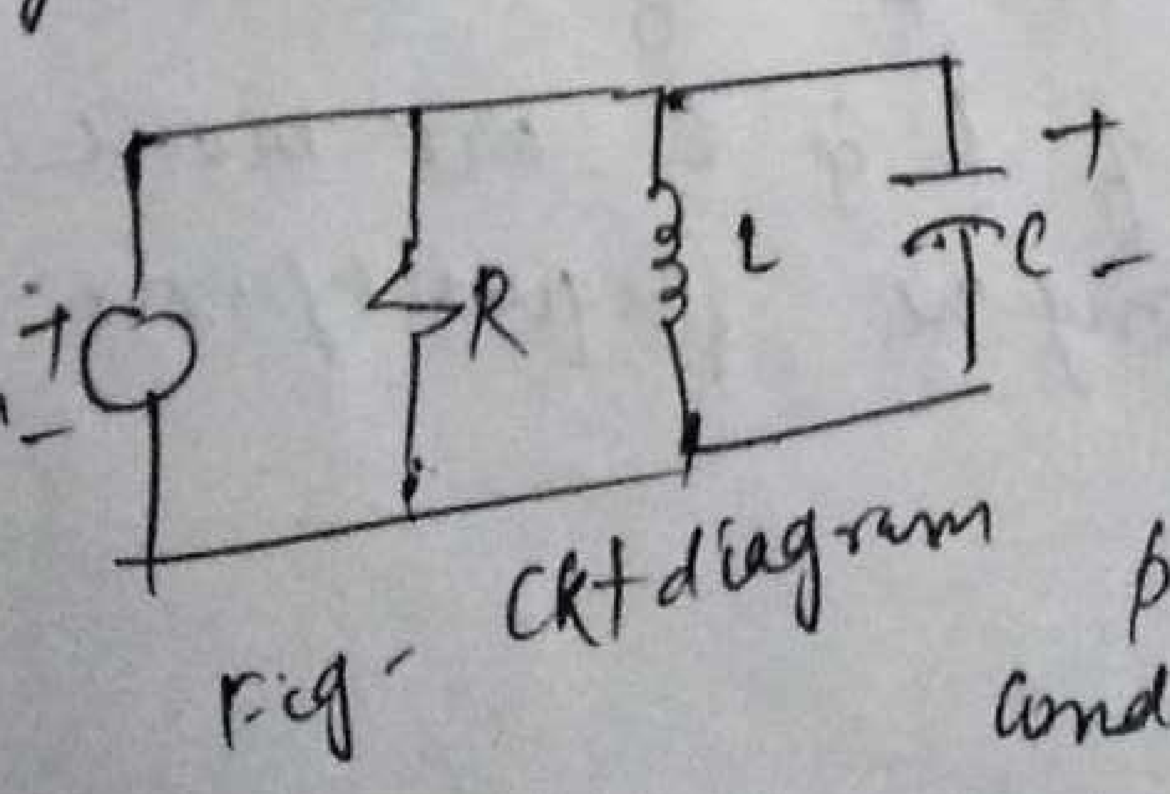


Fig. Ckt diagram

~~At~~ Steady State admittance,

$$Y = \frac{1}{R} + j\left(\omega C - \frac{1}{\omega L}\right)$$

Resonance occurs when current and voltage are in phase, this corresponds to purely real admittance, so necessary condition $\Rightarrow \omega C - \frac{1}{\omega L} = 0 \Rightarrow \omega = \frac{1}{\sqrt{LC}}$

The forced response is in the form

$$I = \left(\frac{1}{R} + j\omega C + \frac{1}{j\omega L}\right)V$$

If we let $V = V_m \angle 0^\circ$, the amplitude of current depends on

i) Directly proportional to amplitude of forcing signal V_m and value of capacitor.

ii) Inversely proportional to R and L.

~~The current st.~~

With increase in frequency, the current ~~starts~~ to decrease from a value of ~~zero~~ close to infinity upto a point where $\omega = \frac{1}{\sqrt{LC}}$ where the current will have a minimum value / amplitude of $\frac{V_m}{R}$, as ω is increased further the current will increase back to infinity as $\omega \to \infty$.

The phase angle of current –

1) At $\omega \to 0$, the ~~source vo ltage~~ current will be lagging by 90°. With increase the lagging angle will start to decrease upto a point where $\omega = \frac{1}{\sqrt{LC}}$ at which there will be no phase shift.

As ω is increased further current will ~~lead~~ start to lead ultimately when $\omega \to \infty$, ~~by 9~~ $\phi \to 90^\circ$ leading

2) A decrease in R, serves to decrease the sharpness of curve and expands the pt. of inversion.

3) A change in the value of L & C will move the pt. of inversion along the frequency axis.

Frequency

Output

of freque

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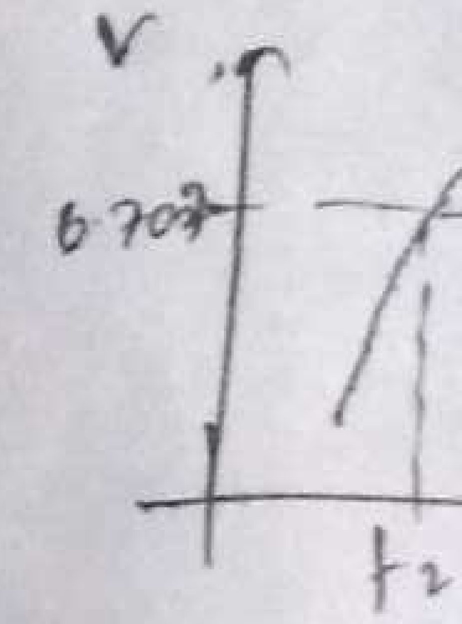
infinite



value.

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Observatio

Sl. No.
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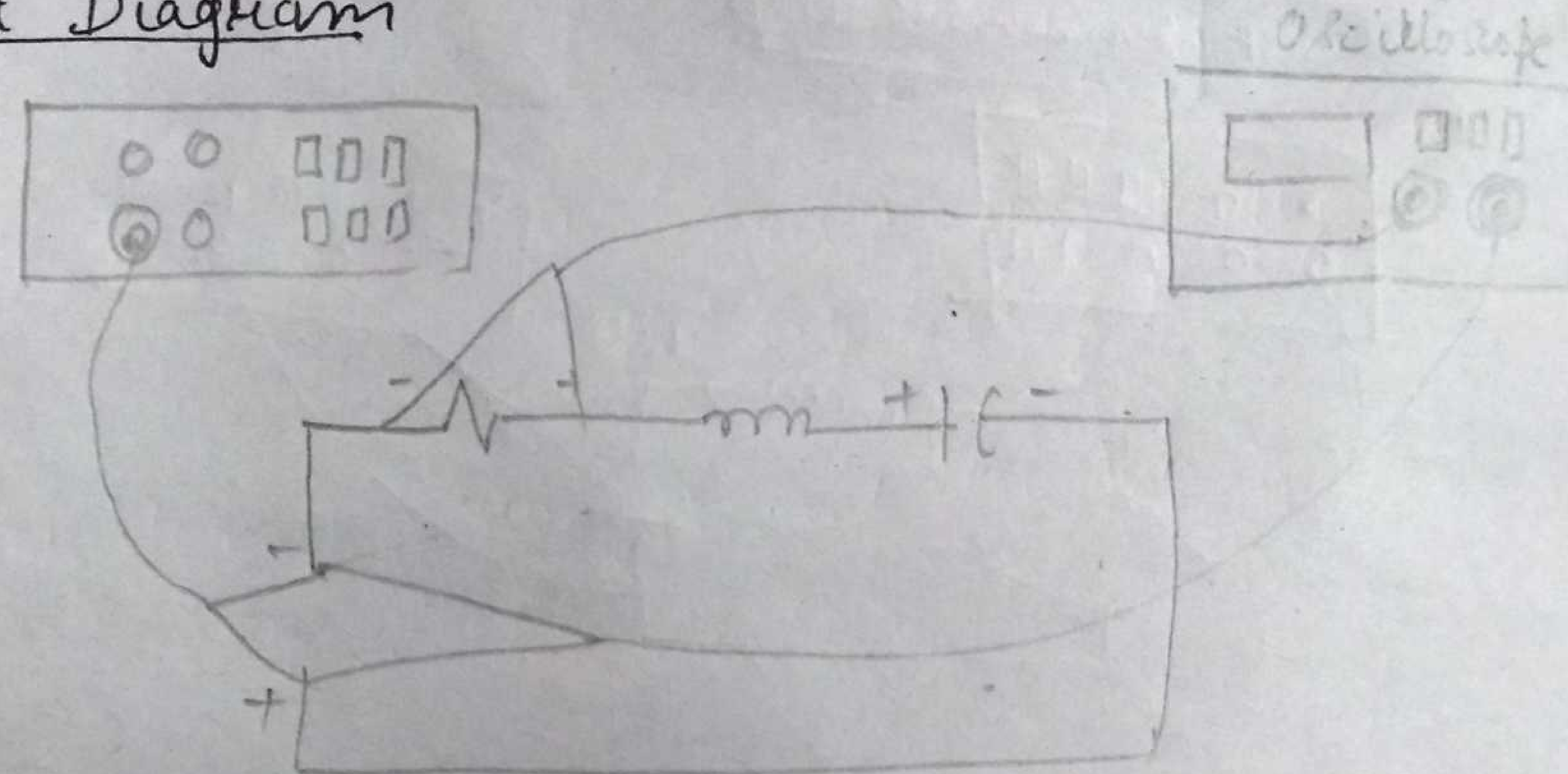
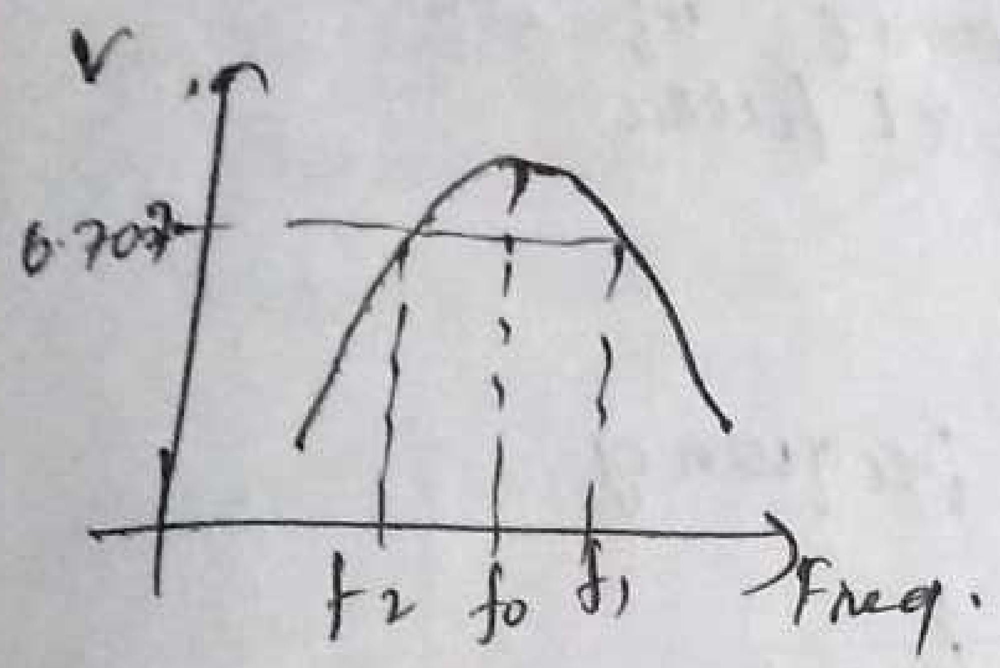
Experiment-3

Circuit Diagram



Frequency Response - Plot of magnitude of the output voltage of a resonant circuit as a function of frequency. The curve start at zero reaches a maximum and again drops to zero as ω becomes infinite

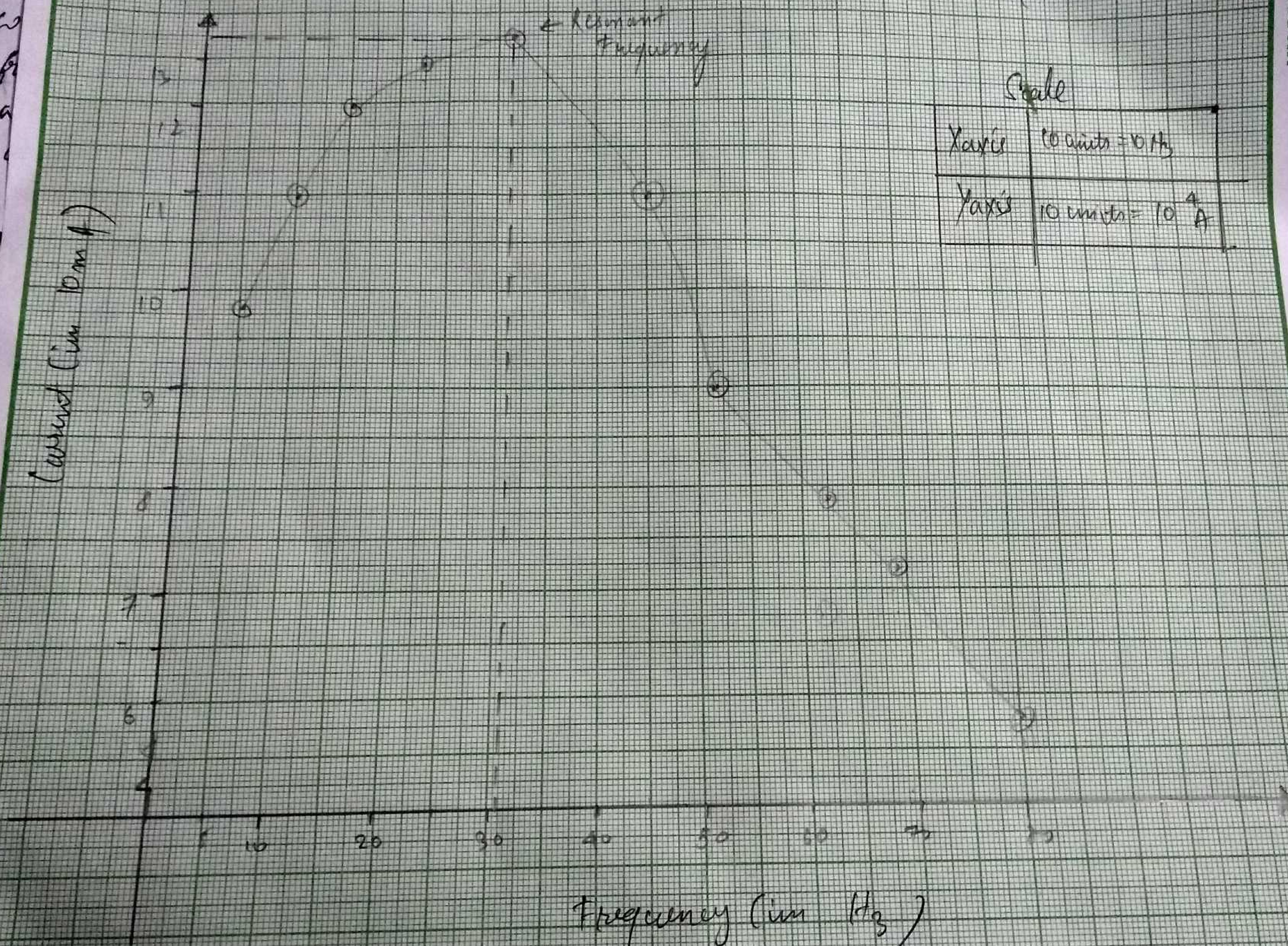


The frequencies f_1 and f_2 are called half power frequencies. They locate at those points on the curve at which voltage response is $\frac{1}{\sqrt{2}}$ or 0.707 times the maximum value. They are used to measure the band width of the response curve. They are called half power ~~frequency~~ bandwidth of the resonant curve and is denoted by $\beta = f_2 - f_1$.

Observations table (Series Resonance)

Sl. No.	Frequency (Hz)	Voltage drop across R (V_R) (V)	Current (A)
1.	5	1.12	9.86×10^{-4}
2.	10	1.23	1.083×10^{-3}
3.	15.4	1.37	1.207×10^{-3}
4.	22	1.51	1.321×10^{-3}
5.	31.47	1.53	1.348×10^{-3}
6.	45	1.25	1.101×10^{-3}
7.	51.8	1.04	9.162×10^{-4}
8.	61.4	0.88	7.753×10^{-4}
9.	69.08	0.80	7.048×10^{-4}
10.	80.05	0.65	5.726×10^{-4}
11.	89.07	0.58	5.11×10^{-4}

Current Vs Frequency for Series Resonance



Scale

X axis	10 units = 10 Hz
Y axis	10 units = 10^{4} A

Exp 3

Table - II :

For parallel circuit -

Sl. No.	Frequency (Hz)	Voltage drop across R (V_R) (V)	Current (in A)
1.	0.605	0.3	0.264×10^{-3}
2.	0.86	0.4	0.352×10^{-3}
3.	5.44	1.0	0.88×10^{-3}
4.	15	1.5	1.32×10^{-3}
5.	25	1.7	1.49×10^{-3}
6.	33.177	1.9	1.67×10^{-3}
7.	40	1.5	1.32×10^{-3}
8.	62.316	1.4	1.23×10^{-3}
9.	80.083	1.2	1.057×10^{-3}
10.	100.43	1.0	0.88×10^{-3}
11.	126.90	0.8	0.748×10^{-3}

Table - III

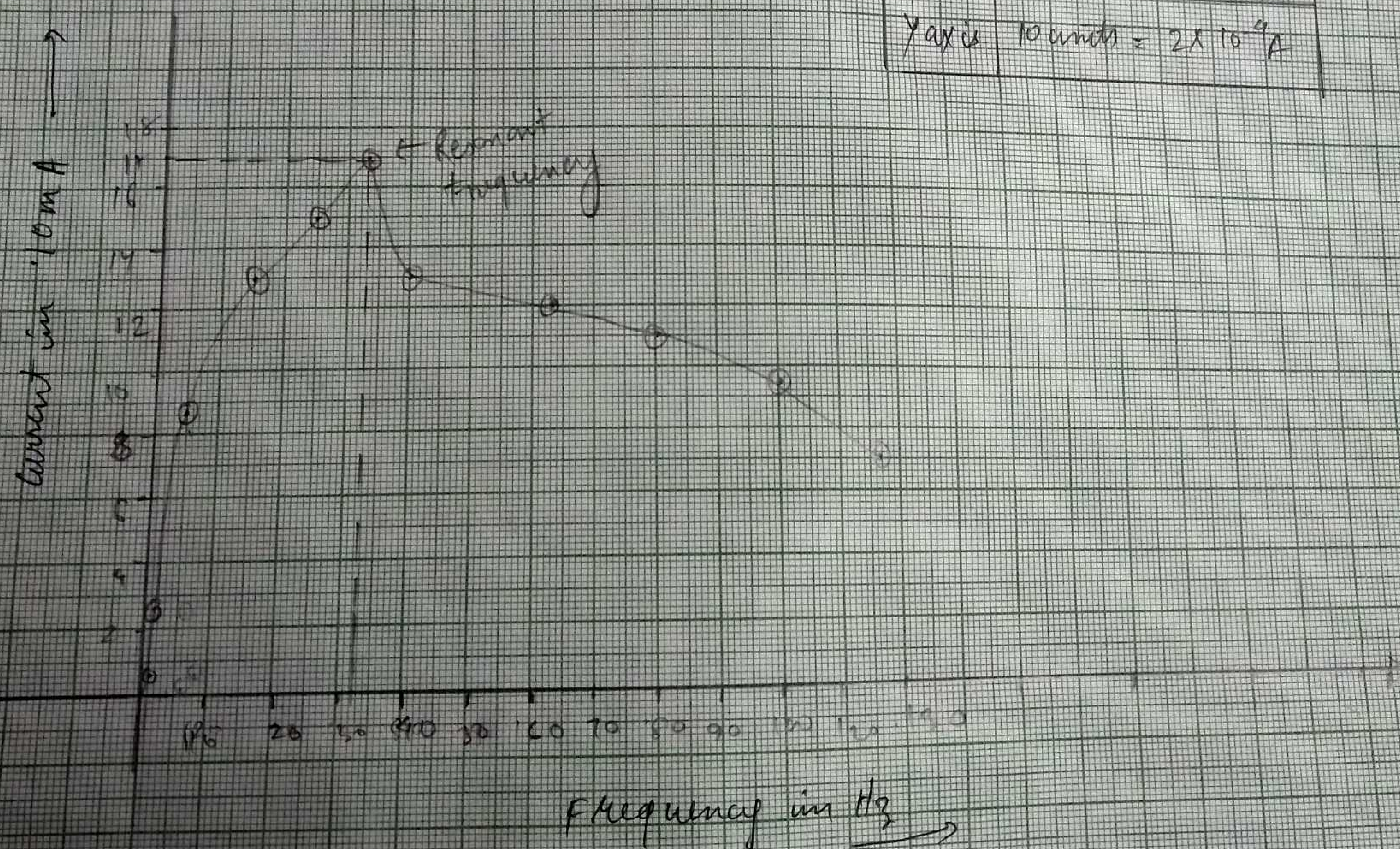
Summary of the experiment performed.

Sl. No.	Parameters	Series Resonance		Parallel Resonance	
		Theoritical	Practical	Theoritical	Practical.
1.	Resonant frequency	50.34 Hz	31.97 KHz	50.32 KHz	33.14 KHz
2.	Bandwidth	181.607 KHz	45.6 KHz	14.02 KHz	54.4 KHz
3.	Q-factor	0.275 KHz	0.176 Hz	3.5891 Hz	5.44 KHz

Current Vs Frequency (for Resonance (parallel))

Scale

X axis	10 units = 10 Hz
Y axis	10 units = 2×10^{-4} A



Experiment - 4

Determination of Frequency Response of low pass and High pass passive filters

Experiment - 5

Experiment No. EE/451/04

Title: Determination of frequency response 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 impedence of the inductor $\propto$ frequency

→ the impedence of capacitor $\propto \frac{1}{\text{frequency}}$.

→ These characteresterestics can be used to select and reject a particular frequency. The selection and rejection of frequency is called filtering the corresponding ckt is the filter ckt.

→ High pass - passes high frequency and rejects low frequency.

→ Low pass - passes low frequency and rejects high frequency.

→ A frequency is considered passed if magnitude within 70% (or $\frac{1}{\sqrt{2}}$) of maximum ~~frequency~~ amplitude or rejected otherwise.

→ The 70% frequency is called corner frequency, roll of frequency or half power frequency.

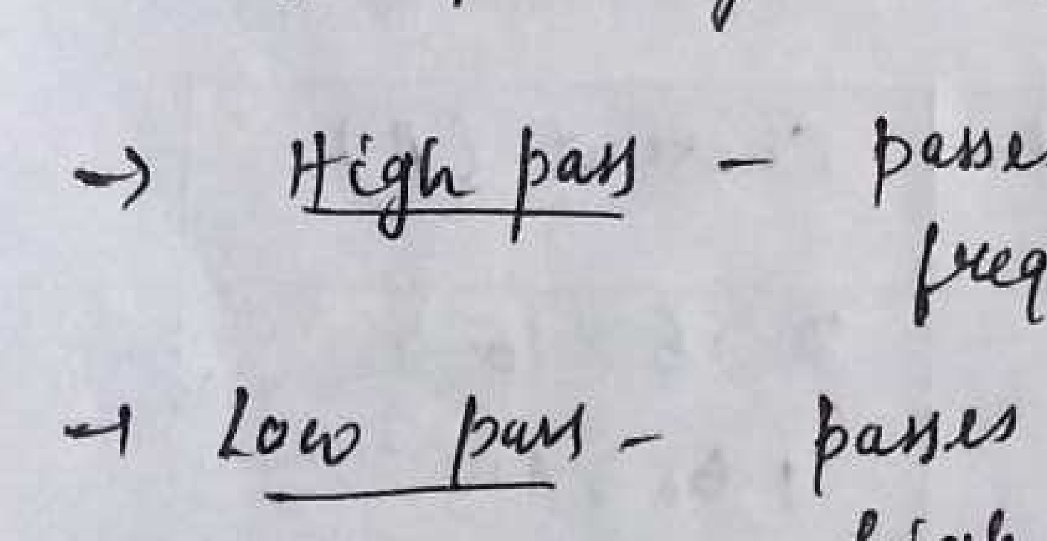


Fig - Low pass RC filter.

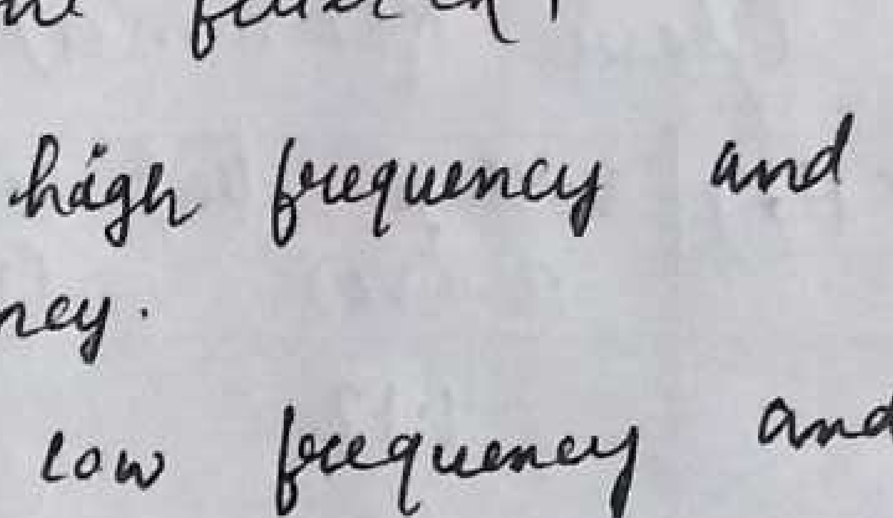


Fig - High pass RL filter

For RC filter,

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

<u>Frequency Response</u> - It is the graph of magnitude of the output voltage 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.

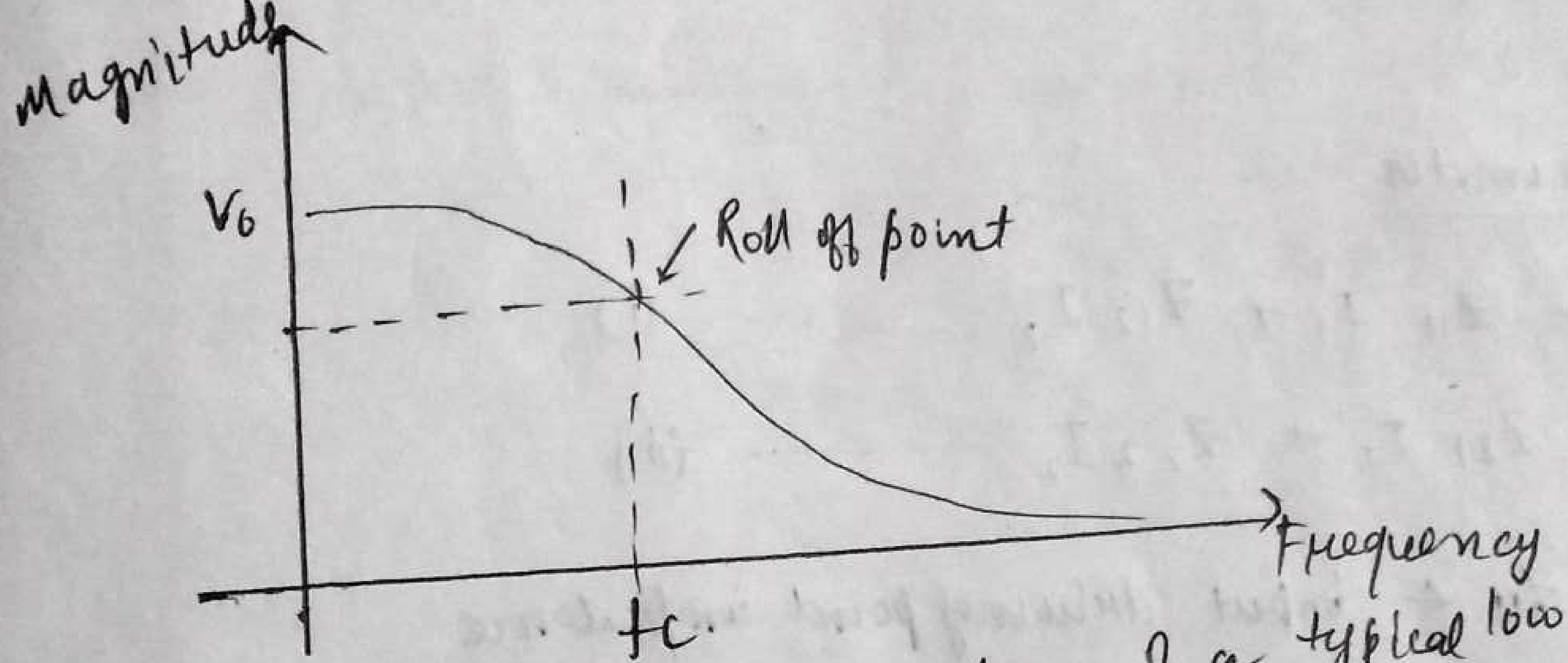


Fig - Frequency response of a typical low pass filter with a cut-off frequency fc (Low Pass RC filter)

Observation Table:

Frequency (Hz)	Vo (output voltage)	Voltage gain $= 20\log_{10}\left(\frac{V_o}{V_i}\right)$ dB
		-1.1
		-1.31
	4.32	-1.61
28.1	4.24	-1.93
34.3	4.08	-2.12
40.1	3.92	-2.38
49.8	3.84	-2.48
57.2	3.76	-2.68
54.7	3.68	-3.04
56.6	3.60	-3.79
63.3	3.44	-3.72
65.0	3.2	-3.93
72.1	3.2	-3.93
79.6	3.12	-3.93
80.0	3.12	-4.152

Exp- 9.

Table 1 for (Low pass RC filter)

Sl. No.	Frequency (Hz)	V_o (output voltage)	Voltage gain $= 20\log_{10}\left(\frac{V_o}{V_i}\right)$ (dB)
1.	28.1	4.32	-1.1
2.	34.3	4.24	-1.31
3.	40.1	4.08	-1.61
4.	49.8	3.92	-1.93
5.	51.2	3.84	-2.12
6.	54.4	3.76	-2.38
7.	56.6	3.68	-2.48
8.	63.3	3.60	-2.68
9.	65.0	3.52	-2.8
10.	72.1	3.44	-3.07
11.	79.6	3.2	-3.74
12.	80.0	3.12	-3.93
13.	81.1	3.12	-3.93
14.	82.0	3.12	-3.93
15.	84.9	3.04	-4.152
16.	89.0	2.96	-4.43
17.	90.6	2.88	-4.62
18.	95.5	2.64	-4.88
19.	98.3	2.56	-5.51
20.	110.6	2.48	-5.6

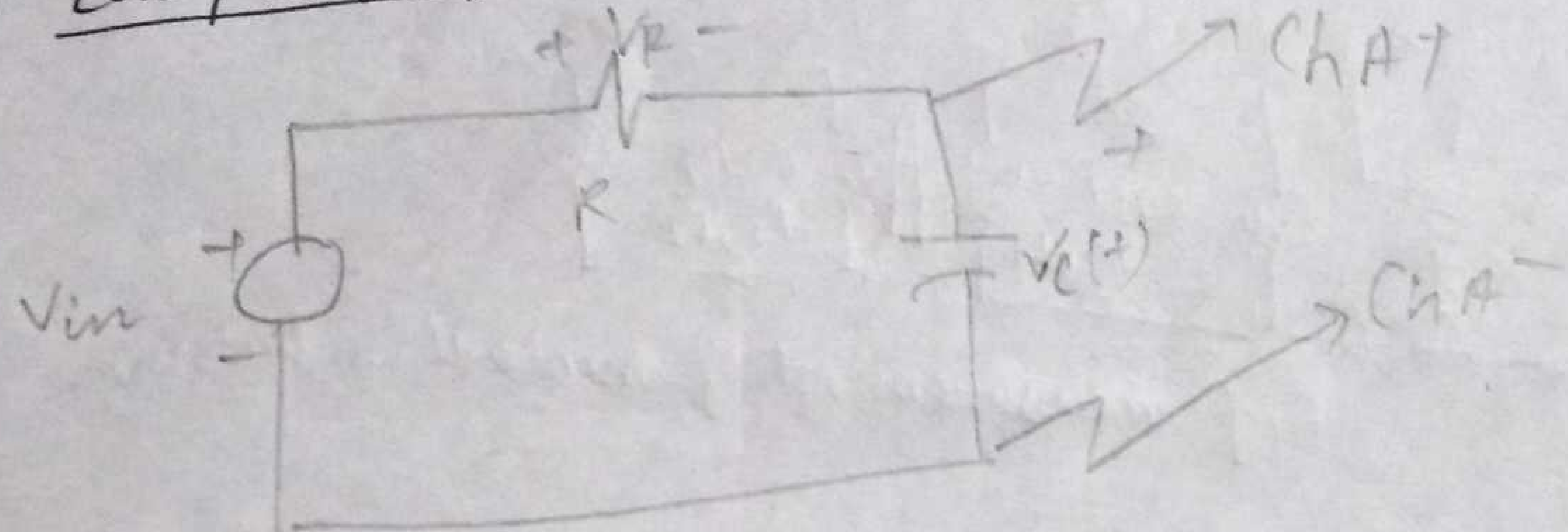
Table 2:

For High pass RL filter :-

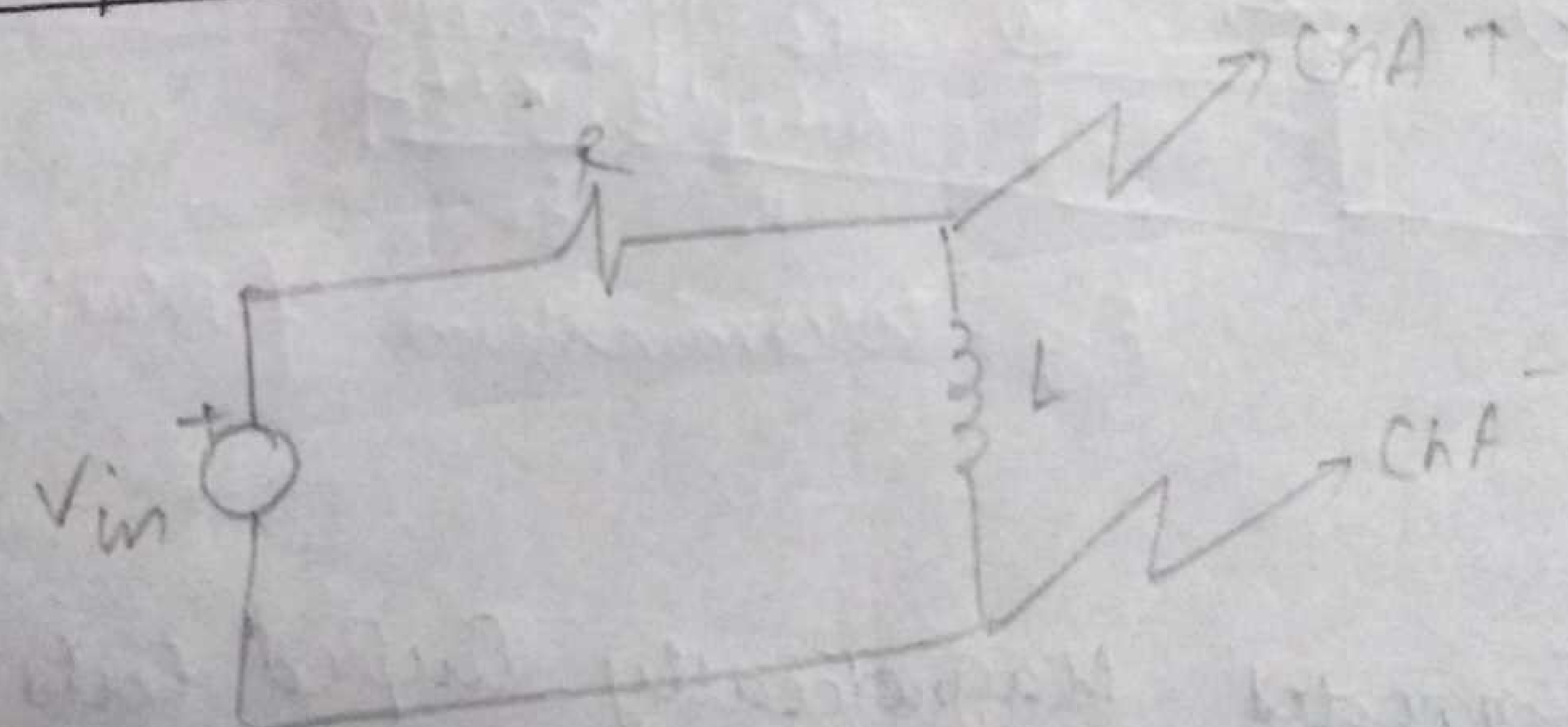
Frequency (Hz)	V_o (Output Voltage)	Voltage Gain $= 20\log\left(\frac{V_o}{V_{in}}\right)$
47.9	2.40	-6.37
50.2	2.44	-6.79
52.8	2.56	-5.67
55.3	2.64	-5.88
57.0	2.68	-5.35
58.08	2.72	-5.19
61.90	2.88	-4.73
68.0	2.96	-4.37
70.2	3.00	-4.25
72.5	3.08	-4.26
75.6	3.12	-4.01
79.6	3.20	-3.74
81.7	3.28	-3.6
90.1	3.40	-3.22
91.1	3.44	-3.09
97.6	3.52	-2.97
100.9	3.56	-2.85
104.2	3.60	-2.68
107.6	3.64	-2.59
109.8	3.68	-2.48
116	3.76	-2.3
122	3.80	-2.27

Experiment - 4

1) Loss pass filter (RC)



2) High pass Filter (RL)

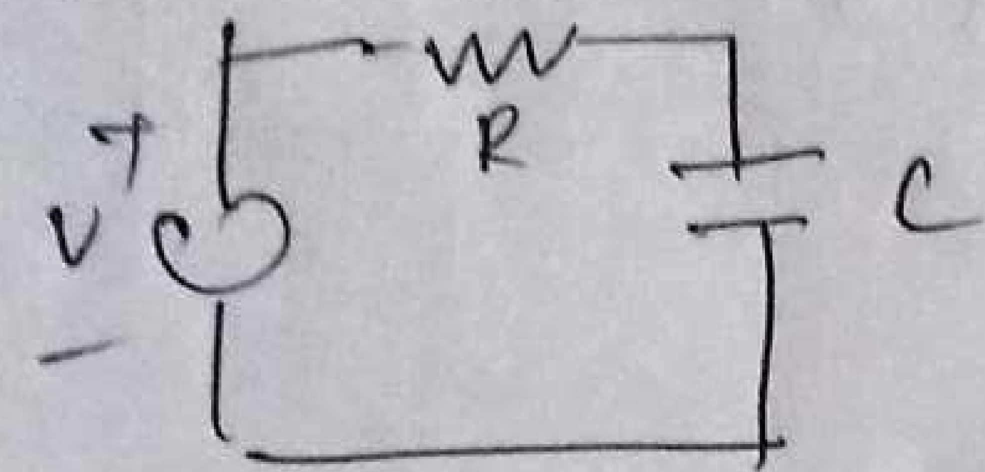


Experiment - 5

$\cancel{\omega} = \cancel{RC\ 909.09\ (from\ graph)}$

Bode plot Calculation

1) RC circuit



Transffer Function:

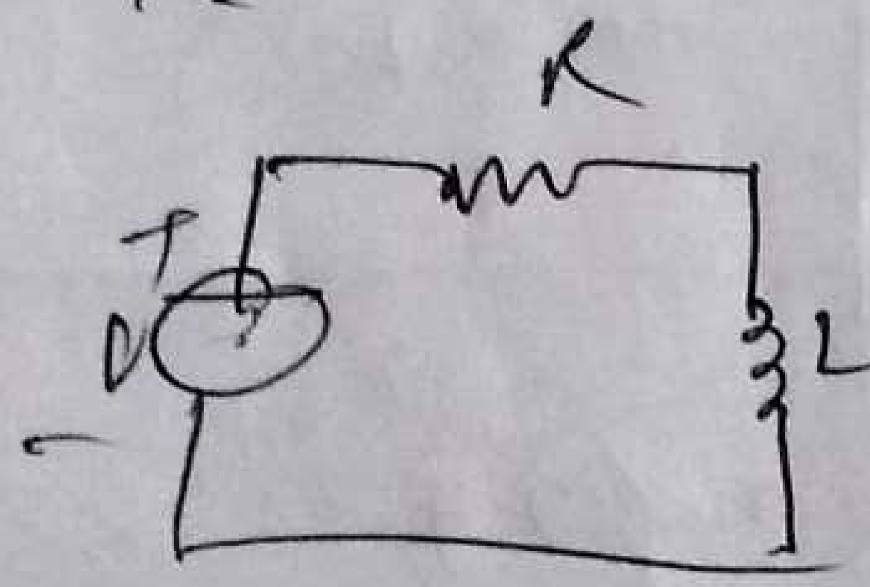
$$= \frac{V_C}{V_C + V_R} = \left(\frac{X_C}{X_C + R}\right) V$$

$$= \frac{\left(\frac{1}{Cs}\right)}{\left(\frac{1}{Cs} + R\right)}$$

$$= \frac{1}{1 + RCs}$$

$$= \frac{1}{1 + 0.0011s} = \frac{1}{1 + \frac{s}{909.09}}$$

2) RL circuit



Transffer Function $= \frac{V_L}{V_L + R} = \left(\frac{X_L}{X_L + R}\right) V$

$$= \frac{Ls}{Ls + R} = \frac{s}{s + (R/L)}$$

$$= \frac{(s) \times 3 \times 10^5}{\left(1 + \frac{s}{3.3 \times 10^4}\right)}$$

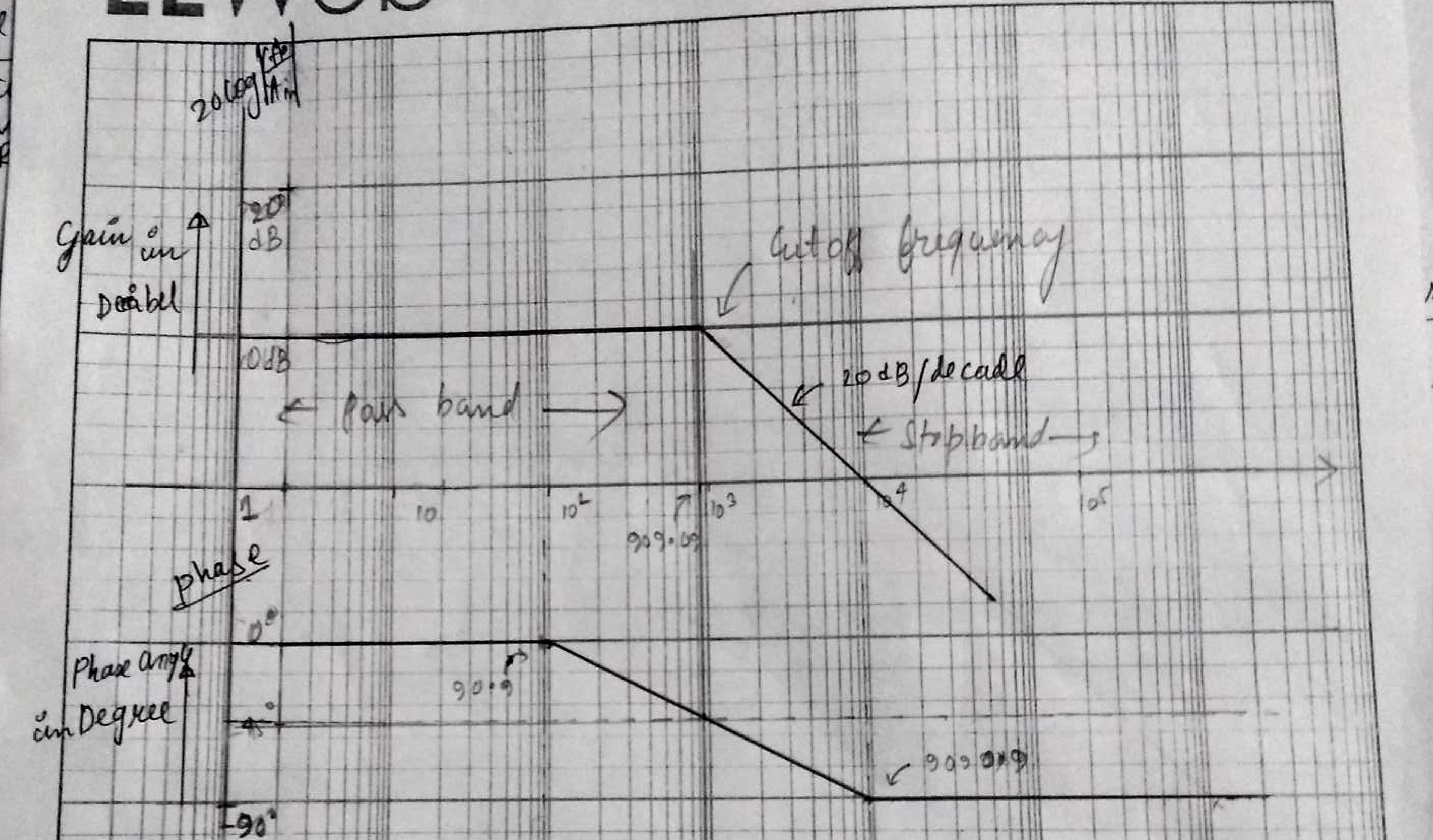
Cut off frequency

$\omega =$ ~~909.09~~

cut off frequency

TITLE	Bode plot of RC circuit
NAME Sayan Mondal	DATE 5/07/21

EEWeb



Frequency (in Hz)

$$\text{Transfer Function} = \left(\frac{1}{1+\frac{s}{909.09}}\right)$$

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cut off frequency

EEWeb

TITLE Frequency Response of High pass RLCkt
NAME Sayan Mondal
DATE 5/07/21

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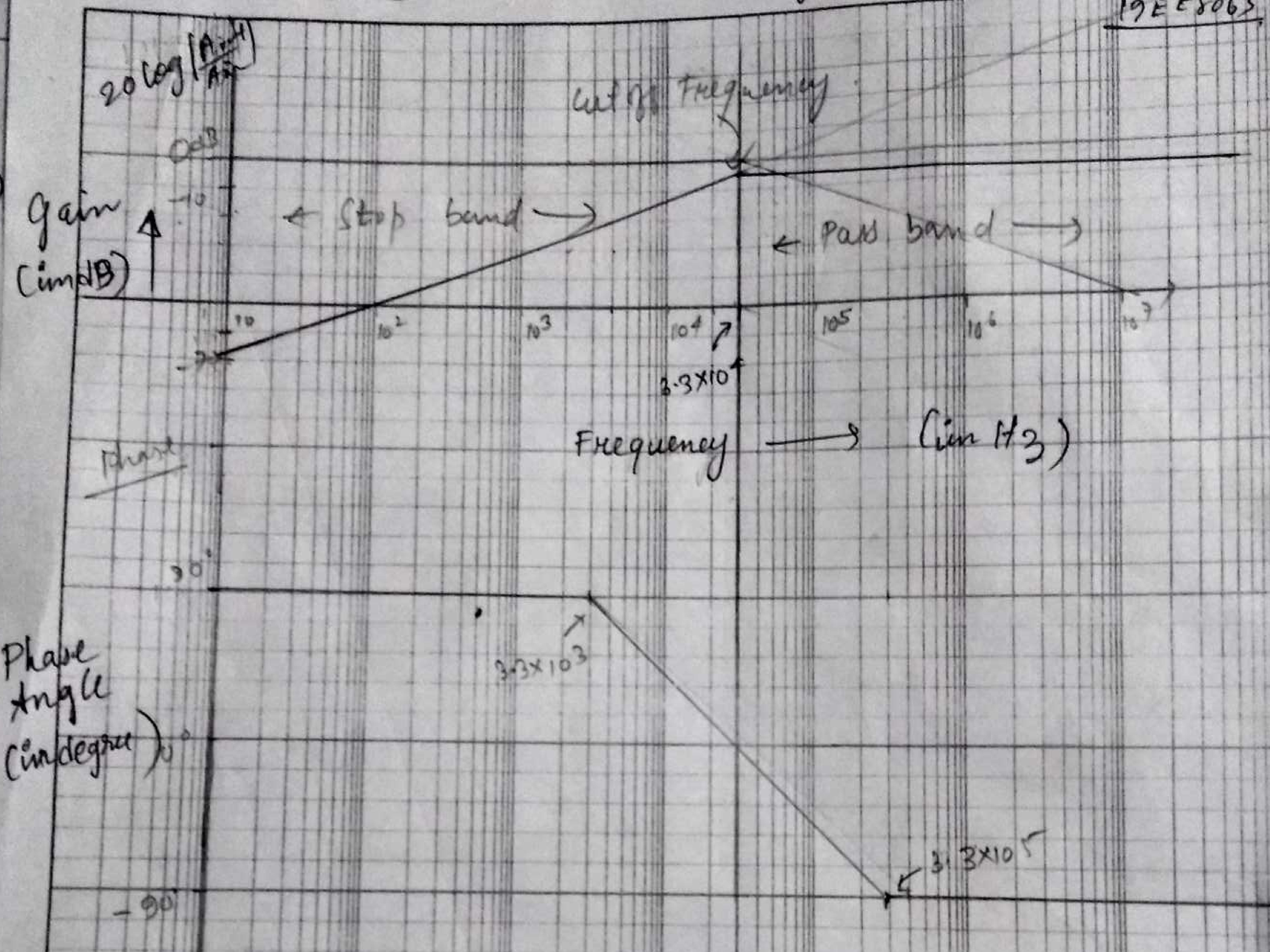


$$\text{Transfer Function} = \frac{3\times10^5 s}{\left(1+\frac{s}{3.3\times10^4}\right)}$$

cut off frequency

1) $\Rightarrow$ Tf $= \frac{1}{1+SRC}$ (Transfer function)

$\therefore$ cut off frequency $\Rightarrow \omega_f = \frac{1}{RC}$

$\therefore$ f $= \frac{1}{1.1\times10^{3}\times10^{-6}}$

$= 909.09$

$\therefore$ and $f = \frac{1}{2\pi RC}$

$\simeq 289.519$ Hz.

2) For RL circuit

$Tf = \frac{s}{(s + L/R)}$

$\therefore$ cut off frequency $\Rightarrow f = \frac{R}{2\pi L}$

$= \frac{1100}{2\times3.14\times33\times10^{-3}}$

$= 5.307\times10^{3}$ Hz.

Experiment - 5

Determination of Z and Y parameters (dc only) for two port network

Experiment No. EE /451/ 05

Title - Determination of Z and Y parameters (dc only) for two port network.

Objective -

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

Theory

Z parameter.

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

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

Here, $Z_{11} \leftarrow$ input driving point impedence

$Z_{12} \leftarrow$ output driving pt. impedence

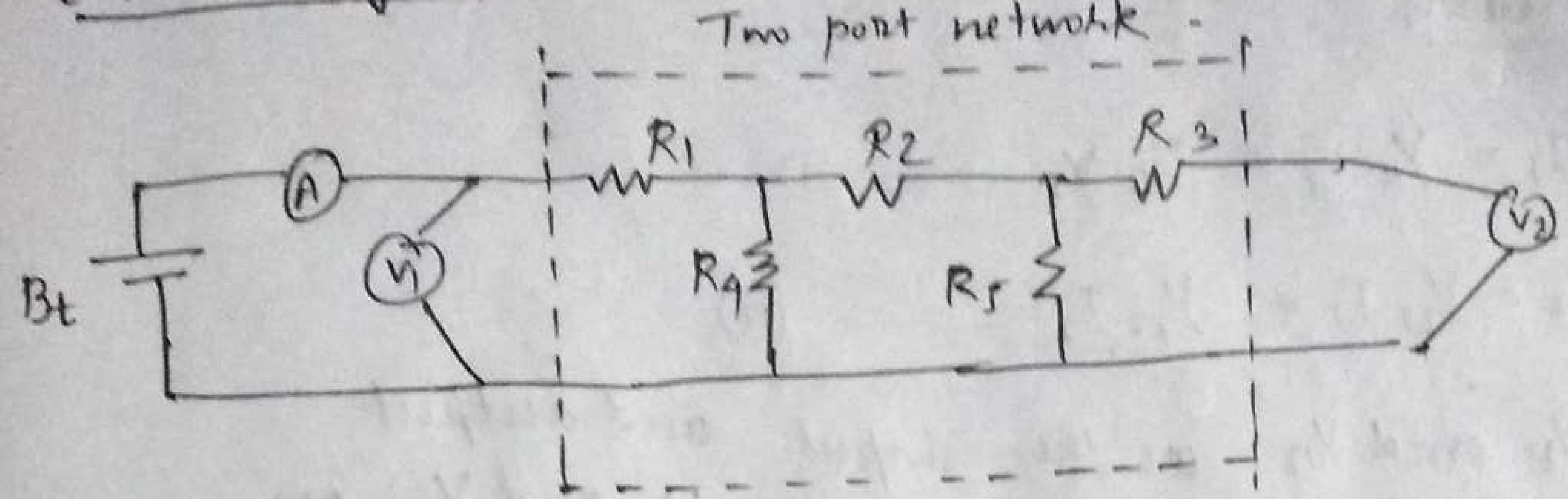
$Z_{12} \leftarrow$ reverse
$Z_{21} \leftarrow$ forward } transfer impedence.

Now, $Z_{11} = \dfrac{V_1}{I_1}$ at $I_2 = 0$;

$Z_{21} = \dfrac{V_2}{I_1}$ at $I_2 = 0$;

$Z_{12} = \dfrac{V_1}{I_2}$ at $I_1 = 0$;

$Z_{22} = \dfrac{V_2}{I_2}$ at $I_1 = 0$, Circuit Diagram



Observation Table

For Z parameters

	When input port is open circuited			When output port is open circuited		
	V_1(V)	V_2(V)	I_2(A)	V_1(V)	V_2(V)	I (A)
1)	2.2	9.6	0.2	10.8	2.25	0.2
2)	4.45	19.8	0.4	19.8	4.35	0.4
3)	4.9	21.6	0.42	25.2	4.75	0.41

Verification table

Parameters	Practical Values (Ω)
Z_{11}	54
Z_{12}	11
Z_{21}	11.25
Z_{22}	48

Result

	Z parameter (Practical)	Z parameter (Theoritical)	% error $= \left\lvert \frac{\text{Practical} - \text{Theory}}{\text{Theory}} \right\rvert \times 100$
Z_{11}	54 Ω	44.57 Ω	21%
Z_{12}	11 Ω	11.11 Ω	0.9%
Z_{21}	11.25 Ω	11.11 Ω	1.26%
Z_{22}	48 Ω	43.65 Ω	10%

Y parameter

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

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

Here Y_{11} and Y_{12} are the input and output driving pt. admittances while Y_{12} and Y_{21} are the reverse and forward transfer admittances

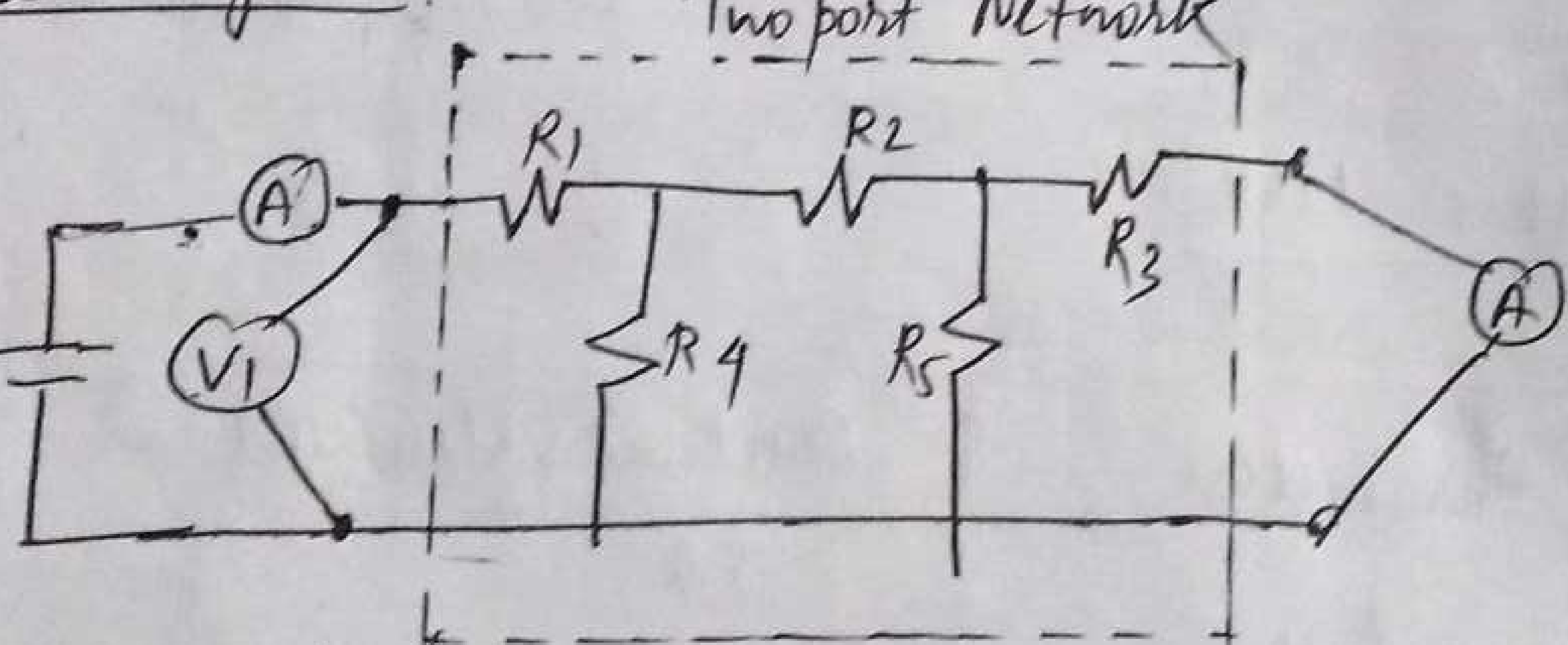
Now, $Y_{11} = \frac{I_1}{V_1}$ at $V_2 = 0$

$Y_{21} = \frac{I_2}{V_1}$ at $V_2 = 0$

$Y_{12} = \frac{I_1}{V_2}$ at $V_1 = 0$

$Y_{22} = \frac{I_2}{V_2}$ at $V_1 = 0$

Circuit Diagram



Observation Table

• Y parameter.

	When input is short circuited			When output is short circuted		
	V_2 (V)	I_1 (A)	I_2 (A)	V_1 (V)	I_1 (A)	I_2 (A)
1.	9.6	0.06	0.2	10.8	0.2	0.04
2.	18.6	0.1	0.4	19.6	0.4	0.1
3.	27.6	0.12	0.6	27.6	0.6	0.12

Verification Table

Parameters	Practical Values
Y_{11}	0.018
Y_{12}	6.25×10^{-3}
Y_{21}	3.7×10^{-3}
Y_{22}	0.02

Results

Y parameters

	Y-parameter (practical).	Y-parameter (theoritical)	% error
Y_{11}	$0.018\ \Omega^{-1}$	$0.02\ \Omega^{-1}$	10%
Y_{12}	$-6.25 \times 10^{-3}\ \Omega^{-1}$	$-0.01\ \Omega^{-1}$	57.5%
Y_{21}	$-3.7 \times 10^{-3}\ \Omega^{-1}$	$-0.01\ \Omega^{-1}$	63%
Y_{22}	$0.02\ \Omega^{-1}$	$0.02\ \Omega^{-1}$	0%

Experiment - 6

Magnetically Coupled circuit

Experiment No. EE/751/06

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 impedence of a coupled circuit.

Theory:

Consider a single coil wound around a magnetic core as shown in fig1. below.

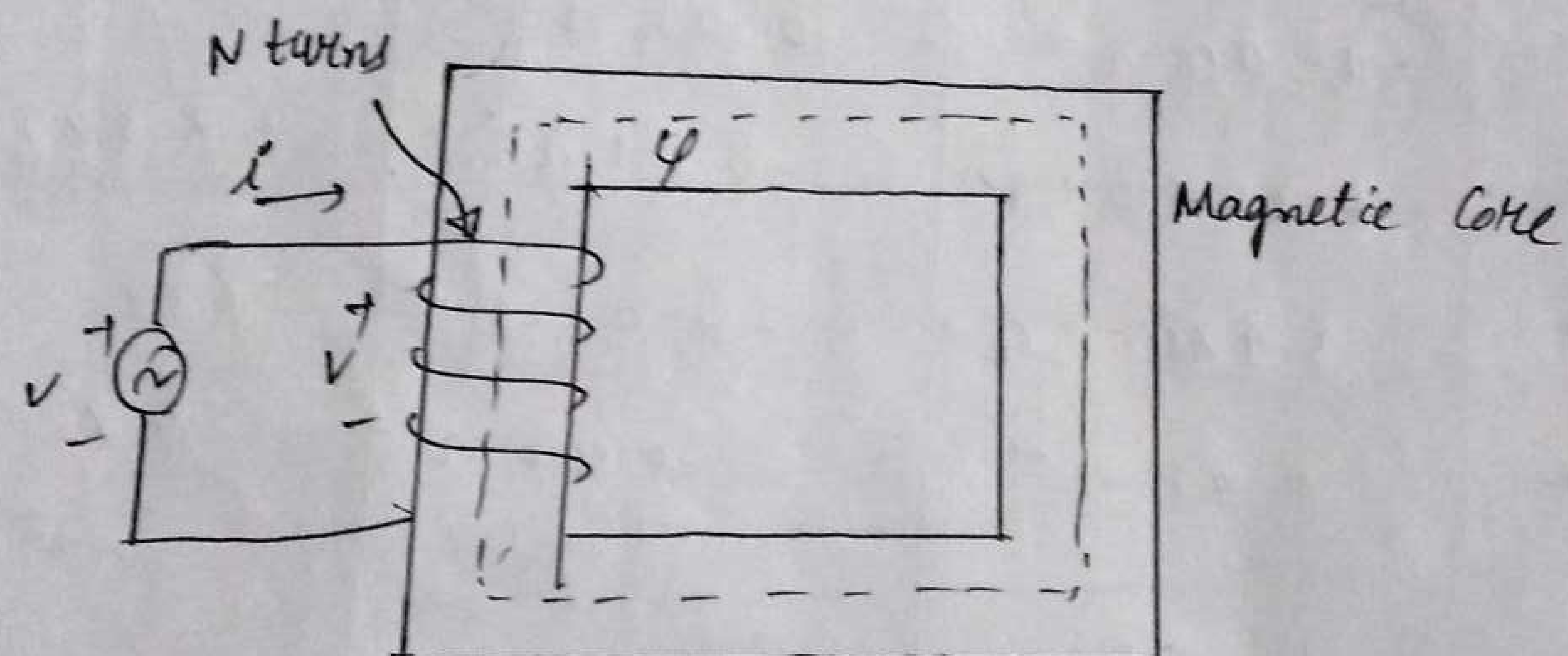


Fig1. Single coil wound around a magnetic core.

A time varying current produces an induced voltage v accross the coil terminals

$$\Rightarrow V = N\frac{d\Phi}{dt} \quad \text{--- (i)}$$

→ The self inductance of the coil is defined as the ratio between the flux linkage, N, φ linking the coil and the current I, producing the flux

So, $L = N\frac{d\phi}{di}$ --- (ii)

→ Substituting from equation (2) into (1) gives

$$V = L\frac{di}{dt} \quad ----(3)$$

<u>Mutual Inductance</u>: If a second coil is wound around the magnetic core of fig 1 as shown in fig 2 the two coils are 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

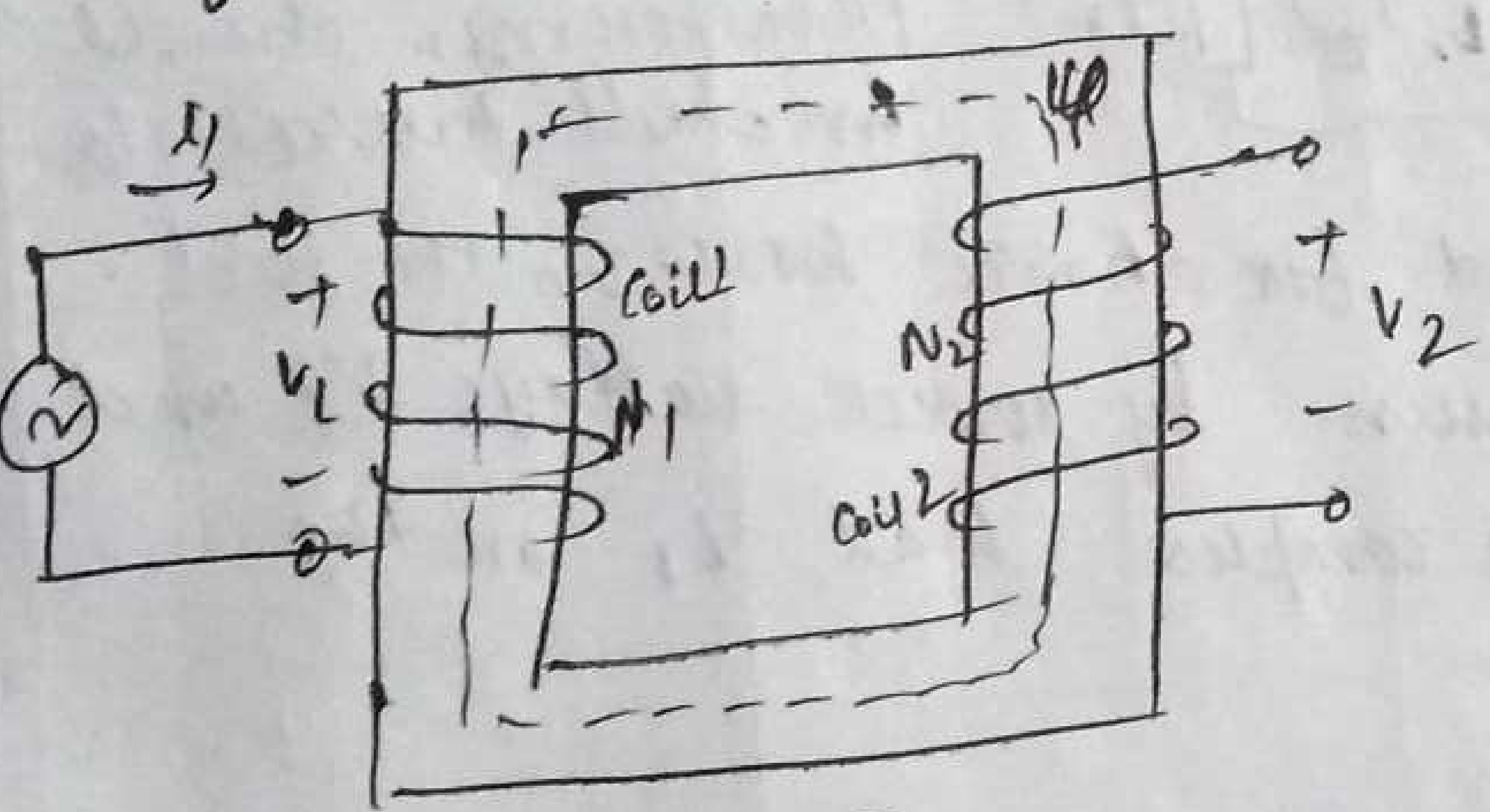


Fig-2: Two magnetically coupled coils

Therefore,

$$M_{12} = \frac{N_2 \phi}{i} \quad --(4)$$

when the the terminals of coil 2 are open circuited, ie no current flowing in the coil 2, then the following equations can be written.

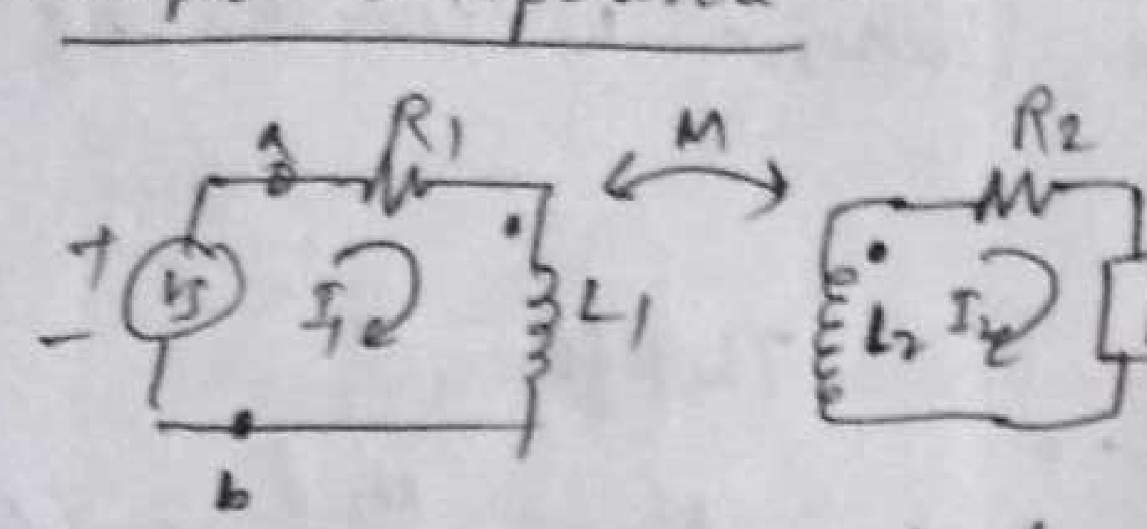
$$V_1 = \frac{d}{dt}(N_1 \phi) = L_1 \frac{di}{dt} \quad ---(6)$$

$$V_2 = \frac{d}{dt}(N_2 \phi) = \pm M_{12}\frac{di_1}{dt} \quad ---(5)$$

Where V_2 is the induced voltage in coil 2 due to current i_1 in coil 1.

coefficient of coupling – A small amount of flux produced by the core leaks away from the core. This is known as leakage flux. The measurement of leakage flux is the coefficient of coupling k and can be expressed as $k = \frac{M}{\sqrt{L_1 L_2}}$ ---- (7)

Input Impedance –



In addition to the coupled coils a realistic transformer should include two resistors R_1 and R_2 to account for ohmic losses in the coil. The circuit is driven by source voltage V_s and terminated in the complex load Z_L on the secondary side.

In terms of designated mesh currents I_1 and I_2 the KVL equations are –

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

and

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

The input driving point is given by

$$Z_D = \frac{V_s}{I_1} = R_1 + j\omega L_1 + \frac{\omega^2 M^2}{R_2 + j\omega L_2 + Z_L}$$

$$= R_1 + j\omega L_1 + Z_R \quad \text{-------(iii)}$$ where

Z_R is defined as reflected impedance and given by

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

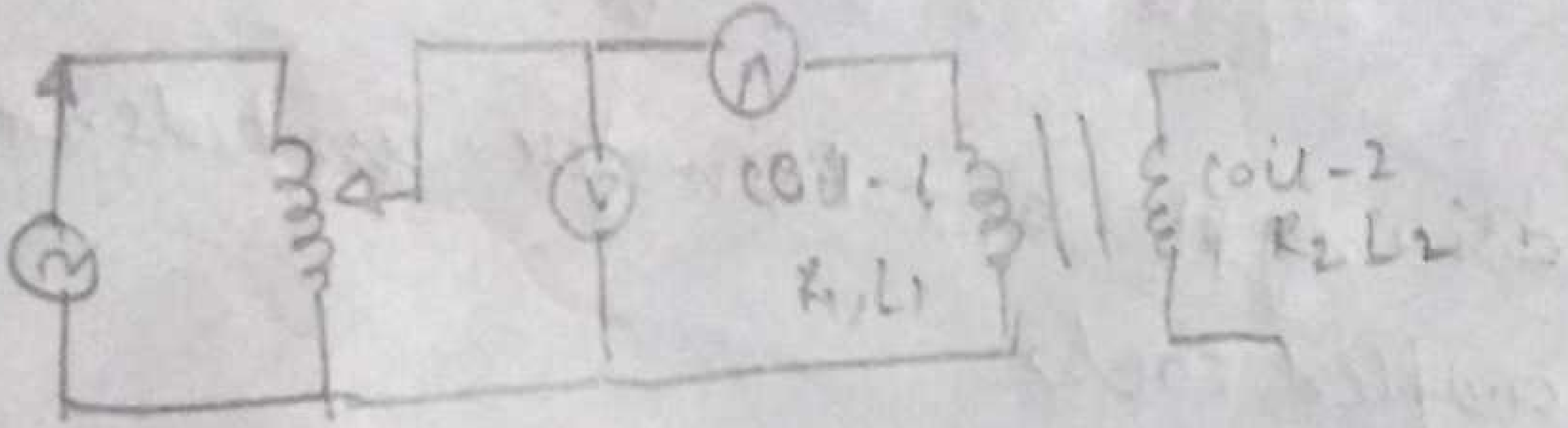
In a similar manner we can derive the expression for transfer impedance –

$$Z = \frac{V_s}{I_2} = j$$

Experiment - 8

Circuit Diagram

1) Determination of Self Inductance L_1 & L_2



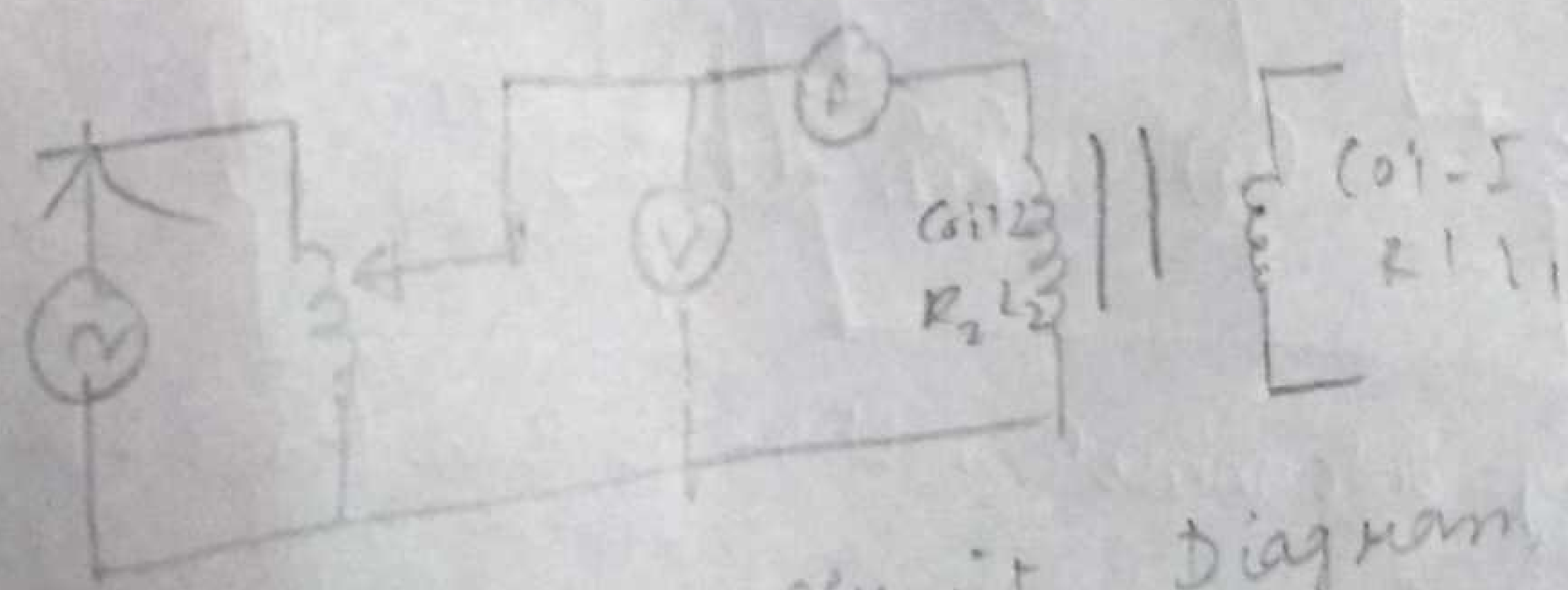


Fig. Circuit Diagram for L_1, L_2

II) Determination of mutual Inductance.

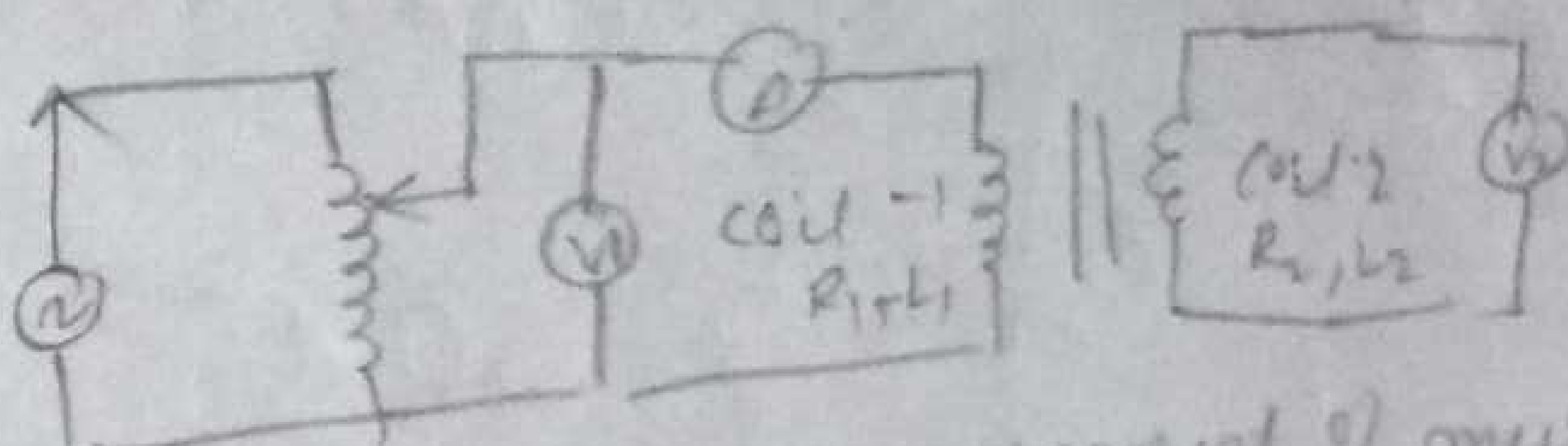


Fig - measurement of mutual inductance

III) Determination of Polarity of Magnetically Coupled Coils

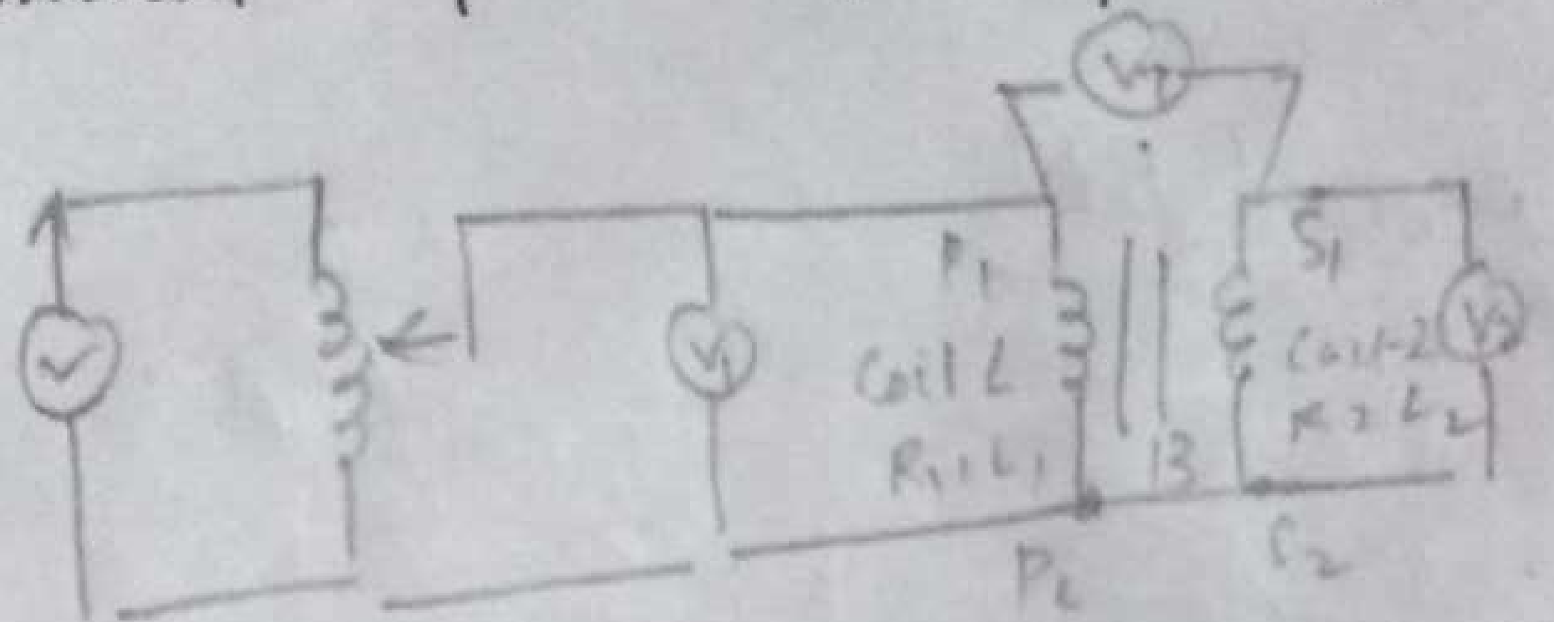


Fig - Determination of Polarity

IV) Series-Connected Magnetically Coupled Coils

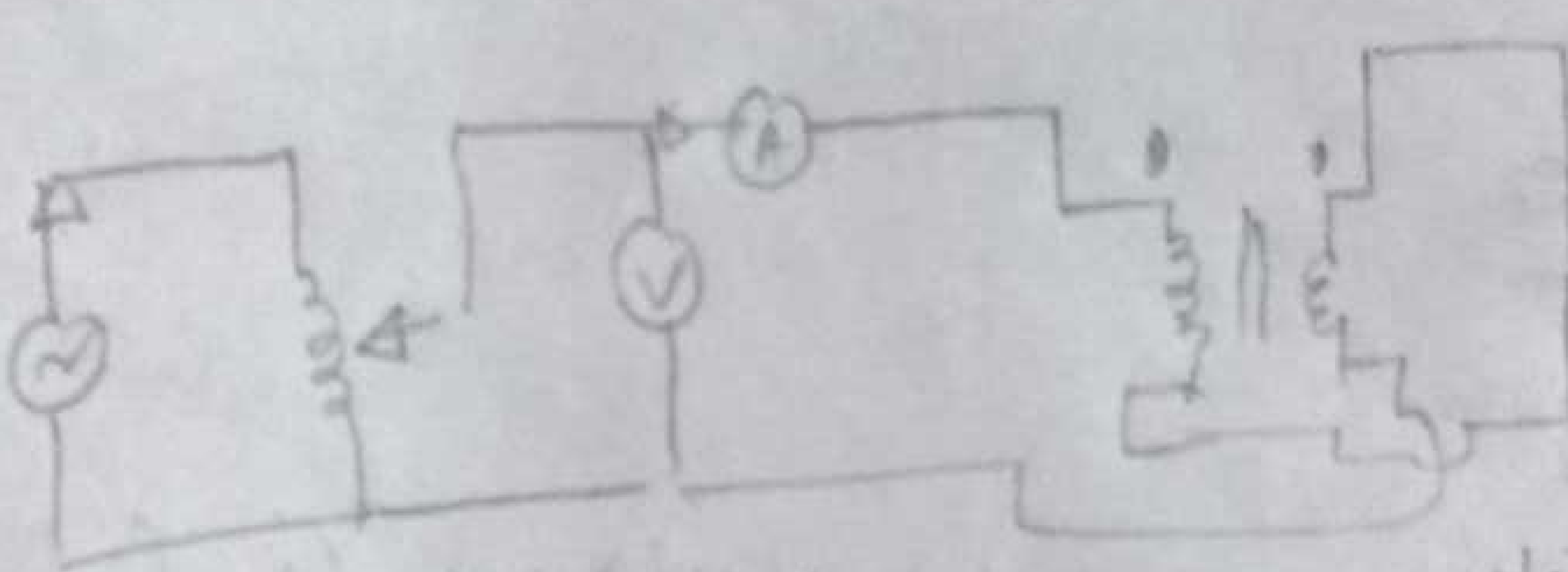


Fig - Series Connected Magnetically coupled coils (adding)

V) Determination of driving pt. and transfer impedence of Magnetically coupled coils.

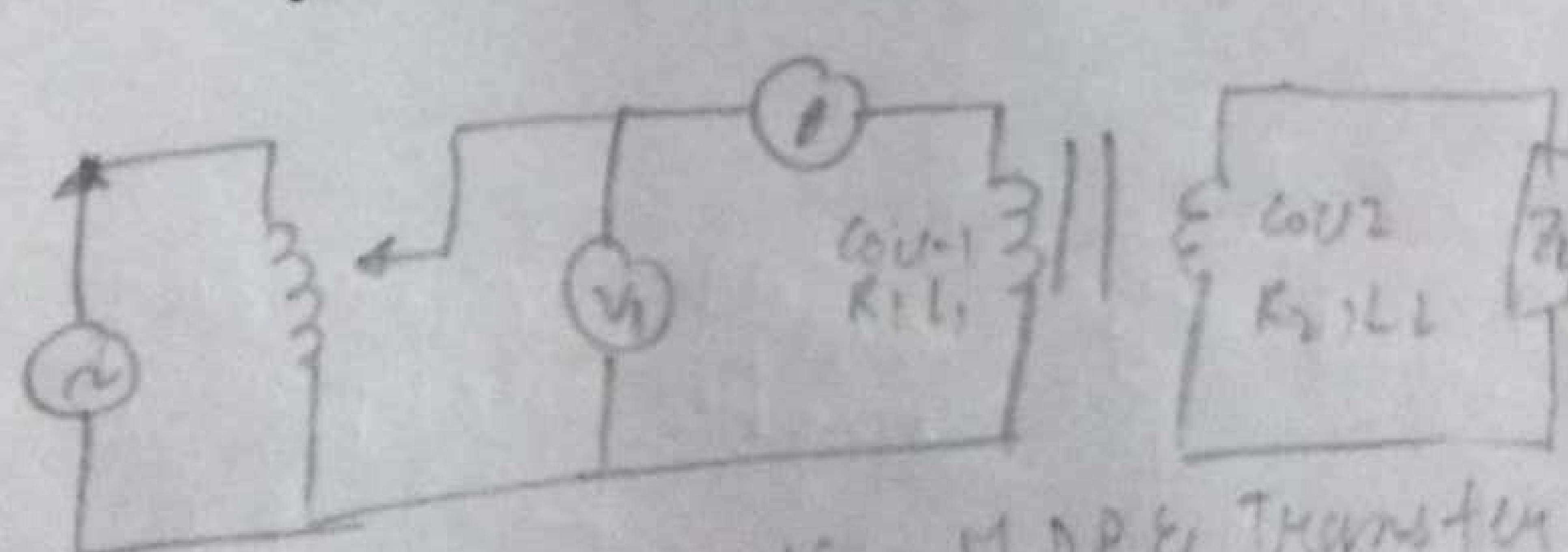


Fig - Determination of DP & Transfer Impedence

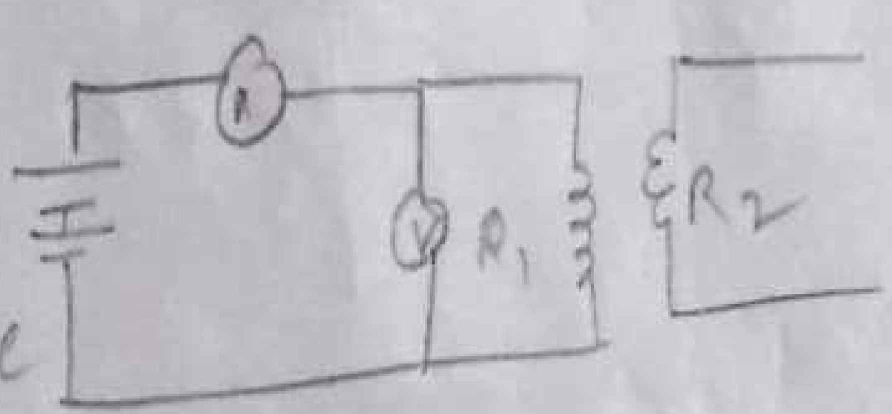
Experiment - 6

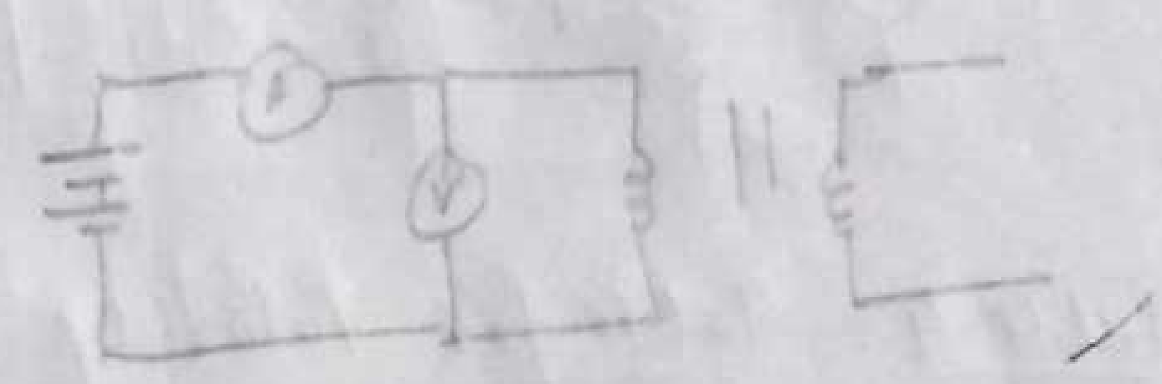
Observation Table

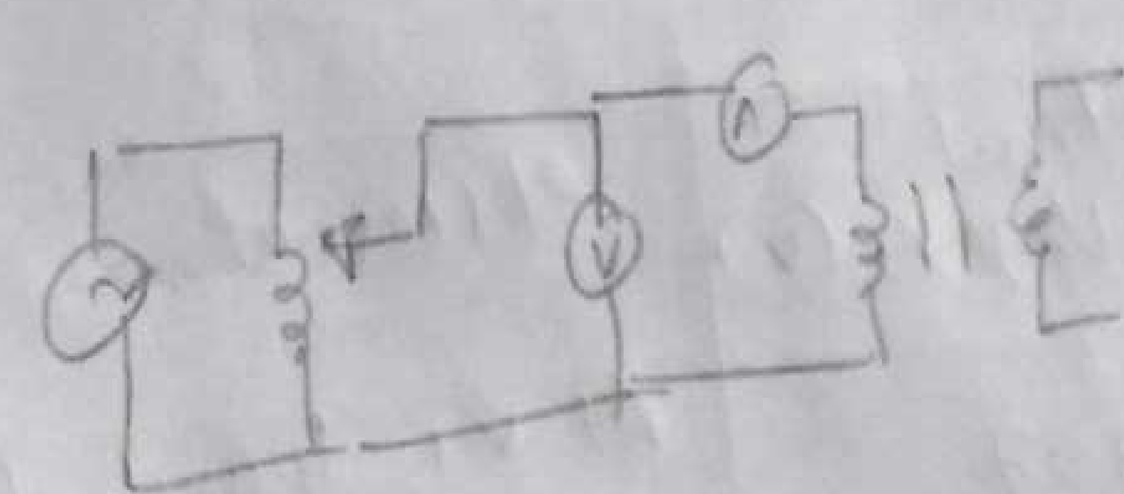
Table 1: Determination of Resistance.

Primary Winding					Secondary Winding				
Supply Voltage (V)	Ammeter Reading I_1 (A)	Voltmeter Reading (V)	Rdc (Ω)	$R_{AC} = R_1 = 1.6\,R_{dc}$ (Ω)	Supply Voltage (V)	Ammeter Reading I_2 (A)	Voltmeter Reading (V)	Rdc (Ω)	$R_{dc} = R_2 = 1.15\,R_{dc}$ (Ω)
3.44	1	1.7	1.7	1.45	3.44	1.1	1.8	1.6363	1.88

DC Supply Voltage







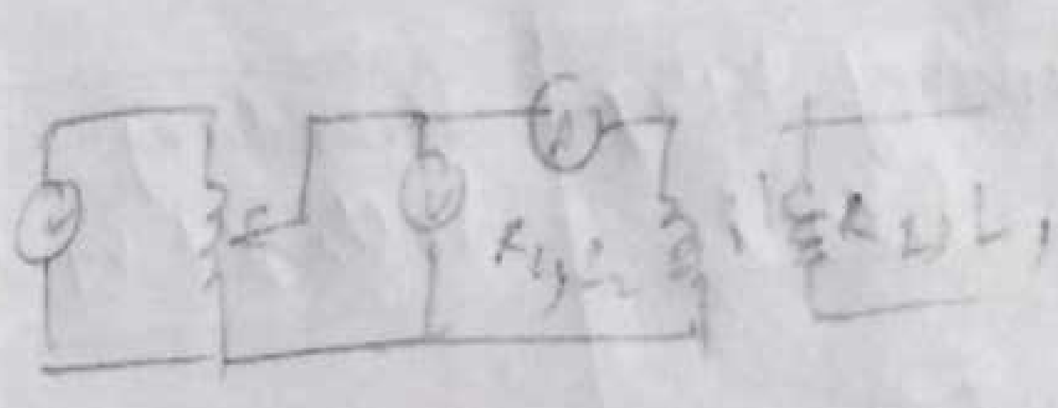
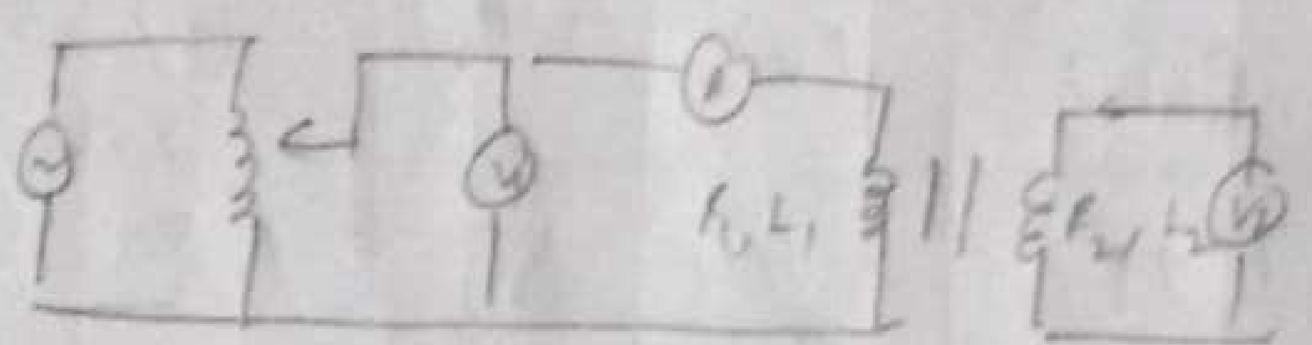


Table 2: Determination of Self Inductance

Winding Side	Voltage Applied V_1 (V)	Current flow I_1 (A)	Net Impedance Z_1 (Ω)	Net Reactance X_1 (Ω)	Self Inductance $L = X_1/\omega$ (H)
Primary	210	0.3	700	699.99	2.22
Secondary	110	0.5	220	219.9	0.7

Table 3: Determination of mutual inductance.

Sl. No	Secondary Voltage V_2 (V)	Primary Voltage and Current		$X_m = \frac{V_2}{I_1}$ (Ω)	Mutual Inductance $M = X_m/\omega$ (H)
		V_1	I_1		
1	96V	200V	0.2A	480Ω	1.52
2.	102V	210V	0.3A	340Ω	1.08



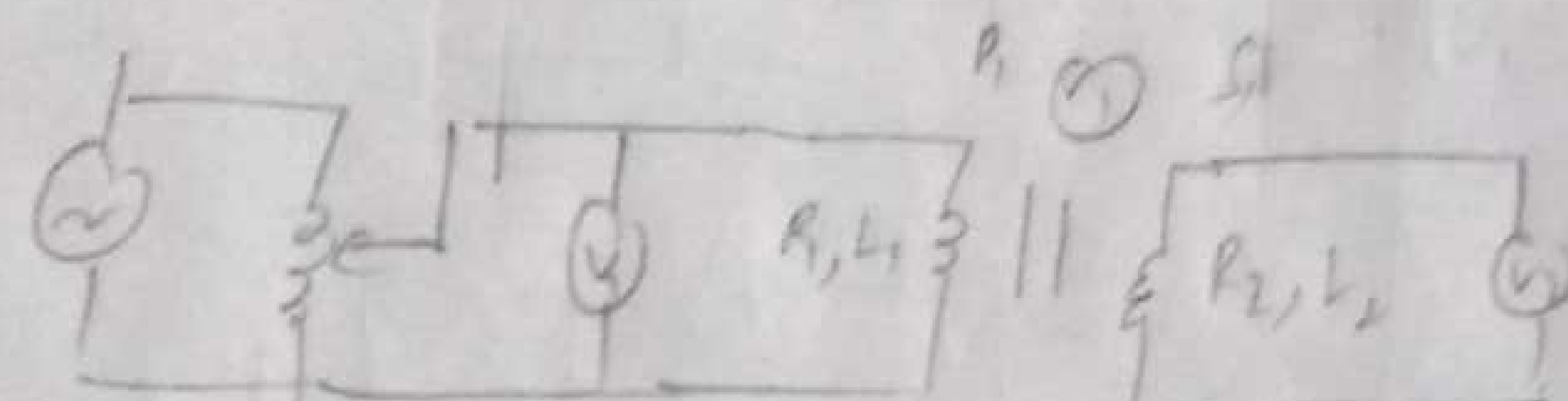


Table 4: Table for Polarity Test

Primary Voltage (V_T)	Secondary Voltage (V_T)	Resultant Voltage V_T (V)	Observation
200	103	297	At V_T found from experiment is the addition of the 2 induced voltages i.e, V_1 & V_2
210	109	311	& its opposite polarity dots are on opposite side

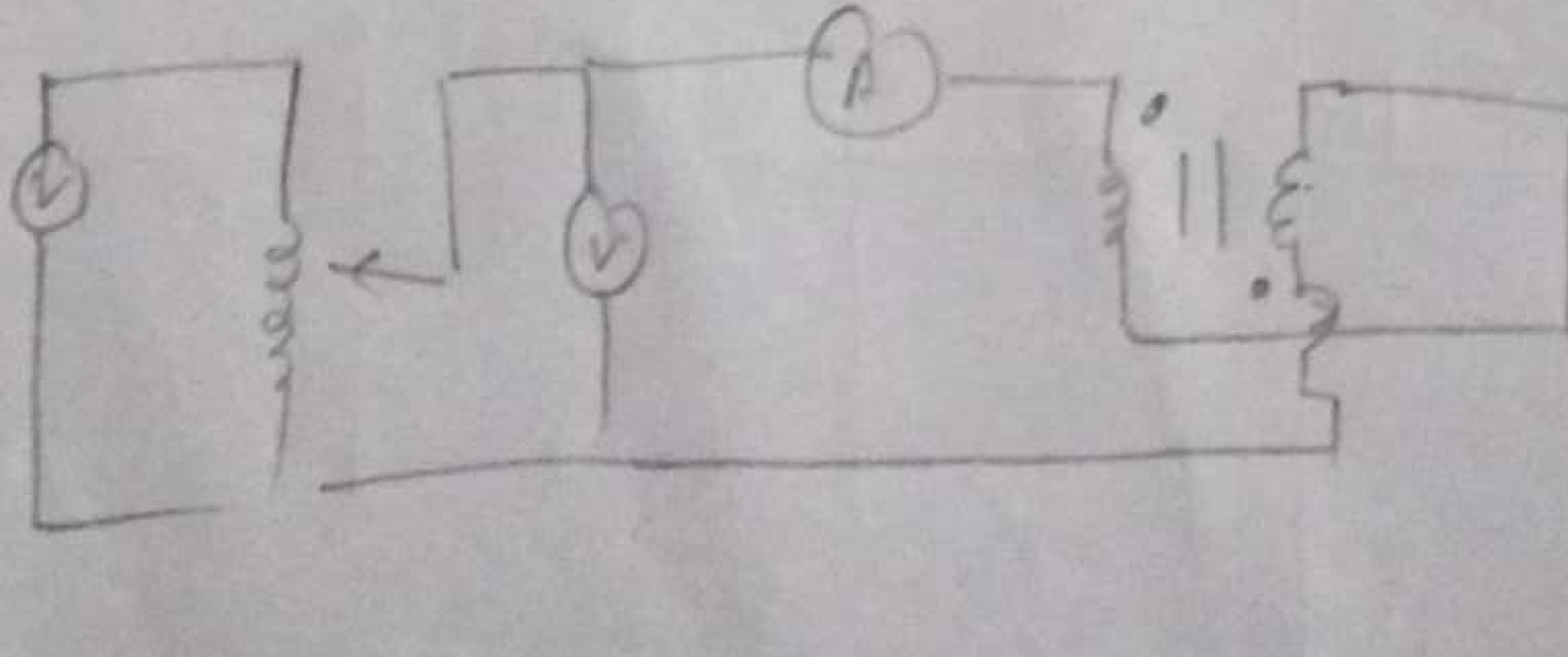


Table 5: Determination of magnetic reactance for series connected coupled coils.

Voltage Applied (V_T)	Current I_1 (A)	Net impedence $Z_1 = V_1/I_1$ (Ω)	$X_{eq} = \sqrt{Z_1^2 - (R_1+R_2)^2}$ (Ω)
100	0.25	400	400.00 = Xeq (connected as per polarity)
110	0.44	250	249.97
100	0.51	196	195.9 = Xeq (connected in opp.)
110	0.77	142.85	145.7

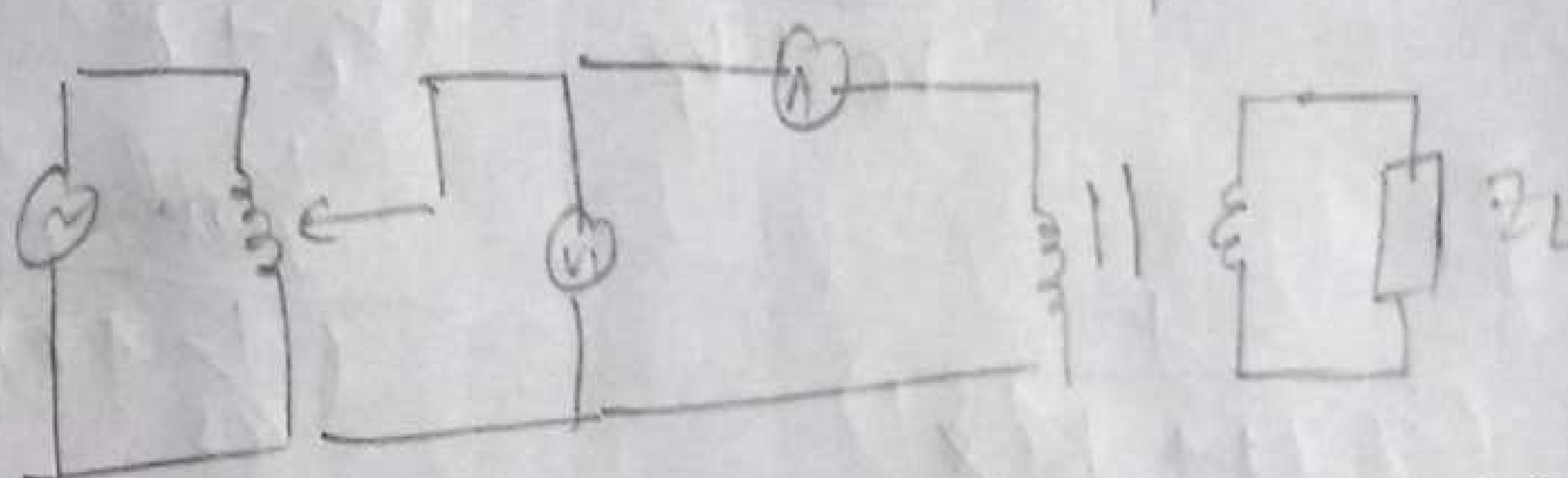


Table6: Determination of driving pt. & for transfer impedence

Primary Voltage (V_1)	Primary current (A)	Secondary current I_2 (A)	Driving pt impedence $Z_D = V_1/I_1$ (Ω)	Transffer Impedence $= \frac{V_1}{I_1}$ (Ω)
200	0.36	6.54	555.5 Ω	370.3 Ω
210	0.42	0.5	500 Ω	420 Ω

Table 7: Comparision b/w measured values of Z_D and Z_T

	Measured	Calculated
Driving pt Impedence Z_D (Ω)	555.5	535.59
Transfer Impedence Z_T (Ω)	370.3	477.58