Laboratory Experiments:
The lab will cover the following experiments:
1. Familiarization with simple resistance measurements
2. Resistors in series and parallel circuits, and their faults as shorts and opens.
3. Oscilloscope
4. Resistors networks, Millman’s and reciprocity theorems.
5. Solution of resistive network, power at DC.
6. Electromotive force and internal resistance of voltage source, maximum power transfer, and star/delta conversion.
7. RMS value of an AC waveform.
8. Capacitors in series and parallel.
11. Damping in RLC circuits

Objectives:
- This course aims to give a practical view on your theoretical subject.
- To be familiar with resistors’ circuits, connections, and faults
- To get to know the oscilloscope device and its usage.
- To be familiar with resistors networks and their solutions with different electrical theorems.
- To get to know power calculations and rms value of any signal.
- To be familiar with capacitors and inductors and the response of their circuits.


Grades:
- Attendance.......................... 10 Pts
- Midterm Exam....................... 20 Pts
- Final Practical Exam .......... 15 Pts
- Final Exam............................. 35 Pts
- Reports................................. 10 Pts
- Quizzes................................. 10 Pts
- Prelab ................................. 05 Pts
- Total .................................. 105 Pts

Lab Policy:
- No late reports or pre-labs will be accepted
- Avoid copy-paste Technology
- Reports should be done in (2-3) students groups.
- Mid term Exam will be at the end of Lab(5)
Laboratory Instruments and Measurements

Objectives:

• To learn how to make basic electrical measurements of current, voltage, and resistance using multi-meters.
• To be familiar with the bread board.

Theoretical Background:

Definitions:

a. Electric current (i or I) is the flow of electric charge from one point to another, and it is defined as the rate of movement of charge past a point along a conduction path through a circuit, or \( i = \frac{dq}{dt} \). The unit for current is the ampere (A). One ampere = one coulomb per second.

b. Electric voltage (v or V) is the "potential difference" between two points, and it is defined as the work, or energy required, to move a charge of one coulomb from one point to another. The unit for voltage is the volt (V). One volt = one joule per coulomb.

c. Resistance (R) is the "constant of proportionality" when the voltage across a circuit element is a linear function of the current through the circuit element, or \( v = Ri \). A circuit element which results in this linear response is called a resistor. The unit for resistance is the Ohm (Ω). One Ohm = one volt per ampere. The relationship \( v = Ri \) is called Ohm’s Law.

Typical standard resistor values are 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 7.5, 8.2, and 9.1 multiplied by a power of 10

d. Electric power (p or P) is dissipated in a resistor in the form of heat. The amount of power is determined by \( p = Vi \), \( p = i^2R \), or \( p = \frac{v^2}{R} \). The latter two equations are derived by using Ohms Law (\( v = Ri \)) and making substitutions into the first equation. The unit for power is the watt (W). One watt = one joule per second.

Instruments and equipments that will be used in this lab:

1- Multimeter:

Meters are used to make measurements of the various physical variables in an electrical circuit. These meters may be designed to measure only one variable such as a voltmeter or an ammeter. Other meters called multimeters are
designed to measure several variables, typically voltage, current and resistance. These multimeters have the capability of measuring a wide range of values for each of these variables. Some multimeter operate on battery power and are therefore easily portable, but need battery replacement. Others operate on A.C. power.

The read-out, or display, of value being measured on the multimeter may be of the digital type or the analog type. The digital type displays the measurement in an easy to read form. The analog type has a pointer which moves in front of a marked scale and must be read by visually interpolating between the scale markings.

In this lab we will use a digital multimeter which is as shown in figure 1.

![Figure (I): The multimeter device](image)

It consists of:

- **Ammeter which** is used to measure A.C or D.C current passing in a branch and is connected in series with the circuit’s elements.

- **Voltmeter** for measuring the A.C or D.C voltage drop across any two point in the circuit, and is connected in parallel.

- **Ohmmeter** for measuring the resistance, and is connected across the resistive.

2- **Oscilloscope:**
An oscilloscope (abbreviated sometimes as 'scope or O-scope) is a type of electronic test instrument that allows signal voltages to be viewed, usually as a two-dimensional graph which a potential differences plotted as a function of time. Although an oscilloscope displays voltage on its vertical axis, any other quantity that can be converted to a voltage can be displayed as well. Oscilloscopes are commonly used when it is desired to observe the exact wave shape of an electrical signal. In addition to the amplitude of the signal, an oscilloscope can show distortion and measure frequency, time between two events (such as pulse width or pulse rise time), and relative timing of two related signals. (figure2.2)
The wattmeter is an instrument for measuring the electric power in watts of any given circuit. The traditional analog wattmeter is an electrodynamics instrument. The device consists of a pair of fixed coils, known as current coils, and a movable coil known as the potential coil. The current coils connected in series with the circuit, while the potential coil is connected in parallel.

A current flowing through the current coil generates an electromagnetic field around the coil. The strength of this field is proportional to the line current and in phase with it. The potential coil has, as a general rule, a high-value resistor connected in series with it to reduce the current that flows through it.

The result of this arrangement is that on a dc circuit, thus conforming to the equation $W=VA$ or $P=VI$. (figure 3)
Prelab 1
Resistance Measurements

a)
1- Why the voltmeter must be connected in parallel?
2- If the voltmeter is connected in series, why its reading will equal the reading of the power supply?
3- Why the ammeter must be connected in series?
4- What is the behaviour of the capacitor and inductor at dc?

b)
1- For the circuit shown in figure(1.1), if the power supply=10V, then compute the value of I(mA) for the R=2.2 KΩ, and record them in table (1.1).
2- Compute the values of R (KΩ), and G (m moh), where $R = \frac{V}{I}$ and $G = \frac{1}{R}$.

![Figure (1.1)](image)

<table>
<thead>
<tr>
<th>R(KΩ)</th>
<th>V(v)</th>
<th>I(mA)</th>
<th>R(KΩ)</th>
<th>G(m moh)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (1.1)

3- Repeat steps 1 and 2, but use as source with v=5Vrms and f=500Hz.

Note: Read the theoretical part of experiment (1) to be able to answer this part.
Fill in the spaces:

For the circuit shown in figure (1.2)
1- Wheatstone bridge measurements method is used to measure __________ values of resistance because ______________
2- At stability, if R1>R3, then R_{unk.} __________ R_{var.}
3- When the readings of voltmeter is zero, if R1=R3=1\,\text{K}\Omega, R_{var.}=10\,\text{K}\Omega, then R_{unk.} = ____________.

d) For the circuit shown in figure (1.3):

Fill in the spaces:
1- At dc, inductor acts as a __________ and the capacitor acts as a__________, then the circuit shown in figure (1.3) may be considered as in figure ____________
2- When the reading of voltmeter is zero, R1=1.8\,\text{K}\Omega, R3=10\,\text{K}\Omega, R_{var.}=10\,\text{K}\Omega then R_{unk.} = ____________.
Experiment 1  
Resistance Measurements

Part A: Familiarization
Objective:
- To measure and calculate resistors by several methods.
- Discussing the behaviour of capacitor and inductor in dc circuits.

Methods of calculating and measuring resistance:
I- By using OHM’s Law:

Experiment procedure:
- Connect the circuit as shown in figure (1.1)
- Set the power supply output voltage to 10v.
- Record the value of I(ma) for R=1K, R=2.2K, and R=10K in table (1.1)
- Compute the values of R(KΩ) using OHM Law, and G (m moh), and compute the percentage of error for the values of R, where the percentage of error can be computed as:

\[
\% \text{Error} = \left( \frac{| \text{true value} - \text{measured value} |}{\text{true value}} \right) \times 100
\]

![Figure(1.1)](image)

<table>
<thead>
<tr>
<th>R(KΩ)</th>
<th>V(v)</th>
<th>I(mA)</th>
<th>R(KΩ)</th>
<th>G(m moh)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

II- By using ohmmeter:
1- Connect the circuit as shown in figure (1.2).
2- Measure the value of R (KΩ) directly by connecting the digital multimeter in parallel with the resistor and using it as a ohmmeter.
3- Record the value of R (KΩ) and compute the percentage of error.
III- By using Wheatstone Bridge:

**Theory:**

ohm’s law method can’t be used to measure low values of resistors, because it causes a high current passes through the resistor from the power supply and these resistors can’t bear a high current. In contrast Wheatstone Bridge method is used to measure high and medium values of resistances.

In Wheatstone Bridge method, the current is divided between the two branches. This is why this method is preferable in measuring low values of resistances.

**Wheatstone Bridge:**

<table>
<thead>
<tr>
<th>R (KΩ)</th>
<th>R (KΩ) meas.</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10K</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Let R4 is unknown resistance. If resistors R1, R2 and R3 are arranged in such away as to produce zero deflection of the voltmeter which is connected
between the points B and A, the voltage droops across R1 and R2 are equal and the voltage drops across R3 and R4 are also equal.

\[ I_1 R_1 = I_2 R_{var} \quad \text{(1)} \]
\[ I_3 R_3 = I_4 R_4 \]

But \( I_1 = I_2 \), \( I_3 = I_4 \)

so, \( I_1 R_3 = I_2 R_4 \quad \text{...(2)} \)

\[
\frac{R_4}{R_{var}} = \frac{R_3}{R_{var}} = \frac{R_3}{R_1} \\
\therefore \text{R}_{\text{unk}} = R_{\text{var}} \times \frac{R_3}{R_1}
\]

Experimental procedures:

1- Connect the circuit as shown in figure (1.4)
2- Let R1=R3=1 KΩ, R4=10KΩ (to be proved), R2 variable is of the rang 10 KΩ.
3- Vary R2 until V=0, then measure R2 var and use this value to compute R_{\text{unk}}.
   From the relation
   \[ \text{R}_{\text{unk}} = R_{\text{var}} \times \frac{R_3}{R_1} \]
4- Compute the percentage of error.
5- Repeat the previous four steps if:
   - R1= 1KΩ, R3=1.8 KΩ , R4(unk) = 22KΩ (to be proved), R2 variable of the range 10KΩ.
   - R1= 1.8 KΩ, R3=1 KΩ , R4(unk) = 6.8KΩ (to be proved), R2 variable of the range 10KΩ.

<table>
<thead>
<tr>
<th>R1(KΩ)</th>
<th>R3(KΩ)</th>
<th>R_{unk}(KΩ)</th>
<th>R_{var}(KΩ)</th>
<th>R_{unk} measured</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.8</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>1</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (1.3)
- Repeat steps 1-4 for the figure (1.5).
- Is there any difference between the result of figure (1.4) and figure(1.5)? comment.
- Note:
  - \( x_l = \omega L = 2\pi fL \)
  - \( x_C = \frac{1}{2\pi fc} \)
Prelab 2
Resistor circuits and their faults

Part A: Resistors in series and parallel:

I. For the circuit in figure (2-3):
   1. Compute the equivalent resistance (kΩ)
   2. Compute the current (ma) from Ohms Law.
   3. Tabulate your results in table (2.1P).

<table>
<thead>
<tr>
<th>V(v)</th>
<th>Req = R1 + R2 (kΩ)</th>
<th>I (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (2.1P)

II. Repeat steps 1, 2, 3 of figure (2-3) for the circuit in Figure (2-4):

<table>
<thead>
<tr>
<th>V(v)</th>
<th>Req = (R1 * R2) / (R1 + R2) (kΩ)</th>
<th>I (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
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<td>6</td>
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<td>8</td>
<td></td>
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<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (2.2P)

Part B: Faults in electrical circuits:

I. For the circuit in figure (2-8):
   1. Compute VAO, VBO, VCO.
   2. With R1 is only shorted, repeat step (1).
3. With R2 is only shorted, repeat step (1).
4. With R3 is only shorted, repeat step (1).
5. With R1 is only opened, repeat step (1).
6. With R2 is only opened, repeat step (1).
7. With R3 is only opened, repeat step (1).
8. Tabulate your results in the "Calc" columns of table (2-2).

II. **For the circuit of figure (2-9):**

1. Compute $V_A$, $V_B$, and $V_C$ with respect to ground.
2. With R1 is only shorted, repeat step (1).
3. With R2 is only shorted, repeat step (1).
4. With R3 is only shorted, repeat step (1).
5. With R1 is only opened, repeat step (1).
6. With R2 is only opened, repeat step (1).
7. With R3 is only opened, repeat step (1).
8. Tabulate your results in the "Calc" columns of table (2-3).

III. **For the circuit of figure (2-10):**

1. Compute $I$, $I_1$, $I_{12}$, $I_2$, $I_3$.
2. With R1 is only shorted, repeat step (1).
3. With R2 is only shorted, repeat step (1).
4. With R3 is only shorted, repeat step (1).
5. With R1 is only opened, repeat step (1).
6. With R2 is only opened, repeat step (1).
7. With R3 is only opened, repeat step (1).
8. Tabulate your results in the "Calc" columns of table (2-4).
Experiment 2
Resistor circuits and their faults

Objectives:
• This experiment aims to describe the different circuits of resistors which are series, parallel and series-parallel.
• Being familiar of these circuits’ faults as shorts and opens and how to detect these faults.

Part A: Resistors in series and parallel:
Theoretical background:
1. Series resistors:

   \[ R_{eq} = R_1 + R_2 + \ldots + R_n \]
   \[ I = \frac{V}{R_{eq}} \]
   \[ V = V_{R1} + V_{R2} + \ldots + V_{Rn} \]

   ![Figure (2-1)](image)

2. Parallel resistors:

   \[ \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n} \]
   \[ V = I_{eq} \cdot R_{eq} \]
   \[ I = I_{R1} + I_{R2} + \ldots + I_{Rn} \]

   ![Figure (2-2)](image)
Experimental work:

I.

1) Connect the circuit shown in figure (2-3)
2) Increase the applied voltage in 2 volts steps from 0 V up to 10V
3) At each step measure the current flowing in the resistors, at each point calculate the value of the resistors $R = \frac{V}{I}$ and fill table (2-1).
4) Plot a graph of $V$ against $I$
5) Simulate the circuit using OrCAD.
6) Comment on your results

![Circuit Diagram](image)

Figure (2-3)

II. Repeat the steps of part I for the circuit of figure (2-4)

![Circuit Diagram](image)

Figure (2-4)

<table>
<thead>
<tr>
<th>$V$ (volt)</th>
<th>$I$ (mA)</th>
<th>$R_{\text{meas}}$</th>
<th>$R_{\text{calc}} = \frac{V}{I}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Table (2-1)
Part B: Faults, shorts and opens in series, parallel and parallel-series circuits:

Theoretical background:

1. Open circuits:

![Open Circuit Diagram](https://via.placeholder.com/150)

Before opening the circuit in figure (2-5a), the current passing in the circuit is:

\[ I = \frac{V_s}{R_1 + R_2} \]

When a cut is made in the circuit as shown in figure (2-5b), the resistance between the terminals of the cut approaches to infinity, then the value of the current passing through the circuit is:

\[ I = \frac{V_s}{R_1 + R_2 + R_{cut}} \rightarrow 0 \]

Taking Kirchhoff’s voltage law around the circuit:

\[ V_{AB} - V_s = 0 \rightarrow V_{AB} = V_s \]

2. Short Circuits:

![Short Circuit Diagram](https://via.placeholder.com/150)

Before adding a short circuit across the resistor in the circuit of figure (2-6a), the current passing in the circuit is

\[ I = \frac{V_s}{R} \]

When we add the short circuit as shown in figure (2-6b), the resistance of this short is zero and then the equivalent resistance of the circuit is
Then the value of the current passing through the circuit is

\[ I = \frac{V_s}{R_{eq}} \rightarrow \infty \quad \text{and} \quad V_{sc} \rightarrow 0 \]

The infinite current value may cause the power supply to break down, so in order to prevent this, an interior resistor must be added in series with the power supply as shown in figure (2-7). This will limit the current so as the power supply not to break down if there is a sudden short circuit across it.

\[
R_{eq} = \frac{R_{sc} \cdot R}{R_{sc} + R} \rightarrow 0
\]

Experimental work:

I.

1) For the circuit in figure (2-8), calculate the nominal values for the voltage \(V_A\), \(V_B\), \(V_C\), and record them in table (2-3). All voltages are with respect to ground.

2) Construct the circuit and verify your calculations in step (1).

3) Consider now a shorted R1. Calculate the resulting voltages at A, B and C if this were to occur. Enter the calculated values in the first column of table (2-3) under the heading “Fault Conditions”. Repeat this for each resistor in turn.

4) Consider now removing R1. Calculate the resulting voltages at A, B and C if this were to occur. Enter the calculated values in the fourth column of table (2-3) under the heading “Fault Conditions”. Repeat this for each resistor in turn.

5) Verify your calculations in steps (3) and (4) by connecting a piece of wire across each resistor in turn, and then removing each resistor in turn. Measure each fault condition and be sure to check its consistency with your calculated values. Record all measured data in table (2-3).
6) Simulate the circuit using OrCAD.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Normal</th>
<th>Short Resistors</th>
<th>Open Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R1 S/C</td>
<td>R2 S/C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meas</td>
<td>Calc</td>
</tr>
<tr>
<td>$V_A$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_B$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_C$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (2-2)

II.

1) For the circuit in figure (2-9), calculate the nominal values for the currents $I$, $I_1$, $I_{12}$, $I_2$, and $I_3$, and record them in table (2-4).

2) Construct the circuit and verify your calculations in step (1).

3) Consider now a shorted $R_1$. Calculate the resulting currents if this were to occur. Enter the calculated values in the first column of table (2-4) under the heading “Shorted resistors “. Repeat this for each resistor in turn.

4) Consider now removing $R_1$. Calculate the resulting currents if this were to occur. Enter the calculated values in the first column of table (2-4) under the heading “Open resistors “. Repeat this for each resistor in turn.

5) Verify your calculations in steps (3) and (4) by connecting a piece of wire across each resistor in turn, and then removing each resistor in turn. Measure each fault condition and be sure to check its consistency with your calculated values. Record all measured data in table (2-4).

6) Simulate the circuit using OrCAD.

<table>
<thead>
<tr>
<th>Current</th>
<th>Normal</th>
<th>Short Resistors</th>
<th>Open Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R1 S/C</td>
<td>R2 S/C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meas</td>
<td>Calc</td>
</tr>
<tr>
<td>$I$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{12}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (2-3)
III.

1) For the circuit in figure (2-10), calculate the nominal values for the voltage \( V_A \), \( V_B \), \( V_C \), and record them in table (2-5). All voltages are with respect to ground.

![Figure (2-10)](image)

2) Construct the circuit and verify your calculations in step (1).

3) Consider now a shorted \( R_1 \). Calculate the resulting currents if this were to occur. Enter the calculated values in the first column of table (2-5) under the heading “Shorted resistors”. Repeat this for each resistor in turn.

4) Consider now removing \( R_1 \). Calculate the resulting currents if this were to occur. Enter the calculated values in the first column of table (2-4) under the heading “Open resistors”. Repeat this for each resistor in turn.

5) Verify your calculations in steps (3) and (4) by connecting a piece of wire across each resistor in turn, and then removing each resistor in turn. Measure each fault condition and be sure to check its consistency with your calculated values. Record all measured data in table (2-5).

6) Simulate the circuit the circuit using OrCAD.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Normal</th>
<th>Short Resistors</th>
<th>Open Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R1 S/C</td>
<td>R2 S/C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meas</td>
<td>Calc</td>
</tr>
<tr>
<td>( V_A )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_B )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_C )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (2-4)
Pre-Lab 3
Oscilloscope

1- For the circuit shown in figure (3.1):

![Figure (3.1)](image)

**Sketch the expected oscilloscope output for the following cases:**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Scale of CH1 in volt/division</th>
<th>Voltage power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.a</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1.b</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1.c</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>1.d</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>1.e</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Table (3.1)

2- For the circuit shown in figure (3.2):

![Figure (3.2)](image)

**Sketch the oscilloscope output for the following cases:**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Scale</th>
<th>Amplitude of the function generator (Vp-p)</th>
<th>Frequency of the function generator (Hz)</th>
<th>$T = \frac{1}{f}$ (in sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.a</td>
<td>5 msec/div. 2v/div.</td>
<td>10</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2.b</td>
<td>5 msec/div. 5v/div.</td>
<td>20</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>2.c</td>
<td>5 msec/div. 5v/div.</td>
<td>14</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Table (3.2)
Experiment 3
Oscilloscope

Objective:
In this experiment we shall study how to use the oscilloscope to make some measurements in the lab.

Introduction:
We can use the oscilloscope to measure the frequency of a wave, the peak-to-peak value, and the rms value of voltage, also to measure the phase between two waves.

Apparatus Required:
- Power supply unit.
- Function wave generator.
- Oscilloscope

Theory:
If a dc wave is appeared on the screen of osc. and ch1 5v/Division.
The value of the voltage = # of square * scale of ch1 = 1.5 * 5 = 7.5v

![Graph](image)

If two sinusoidal waves appeared on the screen, where the scale of ch1 is 2v/Div., and the scale of the ch2 is 5v/Div. and the time base = 1 msec/Div

- \( V_{1_{\text{max}}} = 1.5 \times 2 = 3V \)
- \( V_{1_{p-p}} = V_{1_{\text{max}}} \times 2 = 6V \)
- \( V_{1_{\text{rms}}} = V_{1_{\text{max}}} \sqrt{2} = 1.12V \)
- \( V_{2_{\text{max}}} = 0.375 \times 5 = 1.875V \)
- \( V_{2_{p-p}} = V_{1_{\text{max}}} \times 2 = 3.75V \)
- \( V_{2\text{max}} = V_{2\text{max}}/\sqrt{2} = 1.41V \)
- \( T(\text{period}) = 2.5 \times 1 \text{m} = 2.5\text{ms} \)
- \( f(\text{frequency}) \) for each wave = \( 1/2.5\text{m} = 400 \text{Hz} \)
- Each wave take 360\(^\circ\) for one period.
- Each division = 360 \( / \) 2.5 = 144\(^\circ\)
- Phase shift = 0.5 \( \times \) 144\(^\circ\) = 72\(^\circ\)

![Figure (3.2)](image)

**Phase shift between the two waves:**
If you put time base on XY mode, you will obtain a shape according to the type of the circuit.

![Figure (3.3)](image)

Where \( \text{phase shift} = \sin^{-1} \left( \frac{a}{b} \right) \)

**Experimental Procedure:**
1- Connect the circuit as shown in figure (3.4).
2- Switch the Power supply, OSC and voltmeter.
3- Change the voltage supply in steps of 2V to 10V, take readings of voltage on voltmeter and OSC. At each step, then compare between the two results.
### Table (3.1)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Power Supply (V)</th>
<th>Volt. scale</th>
<th># of squares</th>
<th>OSC. reading</th>
<th>Voltmeter reading</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4- Connect the circuit as shown in figure (3.5)

5- Put the sine wave generator on 10V p-p, 50 HZ. Satisfy these results with that obtained from the screen of the OSC. Use the scale of ch1 to be 2V/Div and time base of 5 msec/Div.

6- Repeat procedure (5) with other voltage and frequency, as shown in table (3.2)

### Table (3.2)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Scale</th>
<th>f(Hz)</th>
<th>f(Hz) meas.</th>
<th>% Error</th>
<th>$V_{rms}$ - voltmeter reading</th>
<th>$V_{rms}$ by OSC.</th>
<th>%Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>5msec/div 2v/div</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>5msec/div 5v/div</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>5msec/div 5v/div</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7- Connect the circuit as shown in figure (3.6)

![Figure (3.6)](image)

8- Set the sine wave generator to give a 10V Peak-to-Peak at 250 Hz.

9- Set the OSC. As follows:
   a. CH1 : voltage to 2v/div.
   b. CH2 : current channel to 5v/div.

Time base to 1 msec/div.

10- Zero both traces and then observe the two waveforms on the OSC. Carefully draw the two waveforms, showing their positions with respect to each other, and the value of voltage and current.

Find the phase shift between the current and the voltage in the circuit in figure (3.6).

11- Set the time base at X-Y mode and obtain the value of phase shift.

12- Replace the 1 uf, by 1KΩ, then repeat steps 10 and 11.

![Figure (3.7)](image)
I. **For the circuit in figure (4-7a) and figure (4-7b):**
   a) Calculate:
      - The voltage across the terminals A- B with the 1kΩ resistor connected.
      - The current in the 1kΩ resistor.
      - The voltage across the open-circuited terminals A- B after having removed the 1kΩ resistor.
   b) Using the resistor values measured in step1; compute the millman equivalent voltage and resistance $E_M$ and $R_M$.
   c) Connect the circuit as shown in figure (4-7b). $E_M$ and $R_M$ are the values computed in step 3.
   d) Repeat step (b) for the circuit in figure (4-7b).

II. **For the circuit in figure (4-8a) and figure (4-8b):**
   a) Calculate the currents I₁, I₂ and I₃ flowing as shown in the figure.
   b) Now connect the power supply in series with the 1.8kΩ resistor and calculate the current I. See the figure (4-8b), and note the polarity of the relocated power source.
   c) In a similar way, relocate the power supply so that it will be in series with the 2.2kΩ and the 470Ω resistance and again calculate the current I.
Experiment 4
Resistor Networks, Millman’s and Reciprocity Theorems

Part A: Resistor Networks

Objectives:
- To investigate what happens when resistor are interconnected in a circuit.
- To investigate the effect of more than one voltage source in a network. (superposition)
- To satisfy KVL and KCL for a resistive circuit.

Theoretical Background:
The student has to study the solution of the network from any book for electric circuit using Kirchhoff’s law (KCL and KVL) or superposition theorem.

Experimental Procedure:
I.

1) Connect the circuit as shown in Figure(4-1)

2) Adjust the output voltage from power supply unit (PSU) to be 20 volts.

3) Using 0 – 10 V voltmeter, measure the voltage across each resistor (Note the polarity of each voltage), then tabulate your results in table (4-1).

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Marked value (kΩ)</th>
<th>Current (mA)</th>
<th>Voltage (V)</th>
<th>Actual value (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4</td>
<td>0.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5</td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4-1)
4) Measure the current in each component using the multi-meter then tabulate your results in table (4-1).

5) From the measured values of current and voltage in each branch, calculate using ohms law the value of the resistance in each leg of the network, and copy the results in table (4-1).

6) Solve the circuit using node voltage method and mesh current method, and compare the results.

7) Simulate the circuit using OrCAD.

II.

1) Connect the circuit as shown in Figure (4-2).

```
+-------------------+-------------------+
| R1  1.8k Ohm      | R4  0.33k Ohm     |
|                   |                   |
|                   |                   |
| R2  1k Ohm        | R3  2.2k Ohm      |
|                   |                   |
| 20V               | 15V               |
|                   |                   |
+-------------------+-------------------+
```

Figure (4-2)

2) Switch on the PSU, measure the current in each branch of the network, this will give the currents in R1, R2, R3 and R5 respectively due to the two sources. Note both the magnitude and polarity of each current and tabulate them in table (4-2).

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Marked value (kΩ)</th>
<th>I (mA)</th>
<th>I' (mA)</th>
<th>I'' (mA)</th>
<th>I' (mA) + I'' (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4</td>
<td>0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5</td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (4-2)

3) Now disconnect the 15 V source and link the resistors R3 and R5 as shown in the circuit in figure (4-3).
4) Measure and tabulate the magnitude and polarity of the currents $I_1'$, $I_2'$, $I_3'$, $I_4'$ and $I_5'$.

5) Remove the link between R3 and R4 and replace the 15 v source connections they were initially.

6) Disconnect the 20V source and link R2 and R3 as shown in figure (4-4). Measure the branch currents $I_1''$, $I_2''$, $I_3''$, $I_4''$ and $I_5''$ as before.

7) Calculate using Kirchhoff’s Maxwell’s (mesh) current method the current in total network shown in figure (4-2).

8) Simulate the circuit using OrCAD.

**Part B: Millman’s Theorem and the Reciprocity Theorem**

**Objectives:**
After completing this experiment, you should be able to:

- Verify experimentally Millman’s theorem for parallel-connected voltage sources.

- Verify experimentally the reciprocity theorem for single-source DC networks.
Theoretical Background:

a) Millman’s Theorem:

If we have a circuit like this shown in figure (4-5a), then Millman’s Theorem provide us with an analytical tool that allows us to replace the parallel sources by one single equivalent source in series with a single equivalent resistance. Millman’s Theorem is applicable to circuits of the general form illustrated in figure (4-5a). With respect to the terminals A-B in this figure, the Millman equivalent circuit is shown in figure (4-5b), where \( R_M \) is the parallel equivalent resistance of \( R_1, R_2, \ldots R_n \); can be computed by the relation:

\[
R_M = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}} = \frac{1}{G_M}
\]

and

\[
E_M = \left(\frac{E_1 + E_2 \pm \ldots \pm E_n}{R_1 + R_2 \pm \ldots \pm R_n}\right) * R_M
\]

or

\[
E_M = \frac{\left(\frac{E_1 + E_2 \pm \ldots \pm E_n}{R_1 + R_2 \pm \ldots \pm R_n}\right)}{G_M}
\]

We use then (+) sign in front of \( E \) if it has the polarity of one of those shown in figure (4-5a), and the sign (-) if it has the opposite polarity.

b) The Reciprocity Theorem:

The reciprocity theorem states that when a voltage source is moved to another location in a DC circuit, the current where it was originally located will be the same as the current that was originally in the location to which it was moved. This theorem is only applicable to circuits which contain a single voltage source. Also, when the voltage source is moved to a new location, it must be placed with a polarity that produces current in the same direction as the current that was originally flowing in that location.

Figure (4-6) illustrates the reciprocity theorem. This figure shows that when the 20 V source is moved from the branch A-B to the branch C-D, the 0.1 A current that was flowing in C-D then flows in A-B. Note in figure (4-6b) that the polarity
of the located voltage source is such that it will produce current in the same
direction as the current originally in C-D of Figure (4-6a).

**Experimental Procedure:**

I.

e) After measuring the actual resistance values of resistors used, connect the
circuit shown in figure (4-7a), E1 and E2 are power supplies that has been
set to 5V and 10V before being connected in the circuit.

f) Measure and record the following:

- The voltage across the terminals A- B with the 1kΩ resistor connected.
- The current in the 1kΩ resistor.
- The voltage across the open-circuited terminals A- B after having
  removed the 1kΩ resistor.

g) Using the resistor values measured in step1; compute the millman
equivalent voltage and resistance \( E_M \) and \( R_M \).

h) Connect the circuit as shown in figure (4-7b). \( E_M \) and \( R_M \) are the values
computed in step 3.

i) Repeat step (b) for the circuit in figure (4-7b).

j) Simulate the circuit using OrCAD.

II.
1) Connect the circuit as shown in figure (4-8a).

![Figure (4-8a)](image1)

![Figure (4-8b)](image2)

2) Measure and record the currents $I_1$, $I_2$ and $I_3$ flowing as shown in the figure.

3) Now connect the power supply in series with the 1.8kΩ resistor and measure the current $I$. See the figure (4-8b), and note the polarity of the relocated power source.

4) In a similar way, relocate the power supply so that it will be in series with the 2.2kΩ and the 470Ω resistance and again measure the current $I$. 
Pre-lab 5

Part A: solution of resistive network by:

1- Thevenin theorem:

- For the circuit shown in figure (5.1), calculate the current in the 470Ω resistor.

\[ \text{Figure (5.1)} \]

- Remove the 470 Ω resistor from the circuit, and calculate the voltage between terminals X,Y (this will give a value of the thevenin voltage ,\( E_t \))

\[ \text{Figure (5.2)} \]

- Remove voltage source and short the points together(as shown in figure(5.2)) then calculate the resistance of the circuit between them and calculating the corresponding current, as shown in figure (5.3). Tabulate you results in table (5.1).

\[ \text{Figure (5.3)} \]
<table>
<thead>
<tr>
<th>V(v)</th>
<th>I(mA)</th>
<th>R(KΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (5.1)

- Then \( r = \frac{\sum I \cdot R}{n} \) where \( n \) is the number of readings.

- Now both the thevenin voltage \( E \), and the thevenin resistance \( r \), have been calculated. Construct the thevenin circuit as shown in figure (5.4), and from this circuit calculate the current in 470Ω resistor. Compare this value with that obtained in step (1).

![Figure (5.4)](image)

2- Norton’s theorem:

- For the circuit in figure (5.5), calculate the voltage across the 4.7KΩ resistor.

![Figure (5.5)](image)

- If the 4.7KΩ resistance in figure (5.5) is replaced by short circuit to obtain the circuit in figure (5.6), calculate the current passing through this short circuit, \( I_{sc} \). This will be the Norton’s current \( I_N \).
With the voltage sources are replaced by short circuits and inserting a voltage source between the two points X,Y, with 2,4,6,8 volts, calculate the current passing through this voltage source, tabulate your results in table (5.2).

<table>
<thead>
<tr>
<th>V(v)</th>
<th>I(mA)</th>
<th>R(KΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (5.6)

Then \( r \) \( (KΩ) \) = \( \frac{\sum \text{Volts}}{n} \) where \( n \) is the number of readings.

The equivalent Norton circuit between the points X,Y is shown in figure (5.7).

Calculate the voltage across the 4.7 KΩ resistor and compare the results with the obtained in step (1).

Part B: Power in DC circuits:

I. For the circuit in figure (5.8), if \( E \) varied as shown in table (5.3), calculate I (mA), and P (watts) in each case.
II. For the circuit in figure (5.9), calculate:

- The current passing through
- $P_T$, $P_{R1}$ and $P_{R2}$.

Then prove that $P_{RT} = P_{R1} + P_{R2}$.

![Figure (5.9)](image)

<table>
<thead>
<tr>
<th>V</th>
<th>I (mA)</th>
<th>P (watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table (5.3)

III. For the circuit shown in figure (5.10), calculate:

- The current passing through the circuit.
- $P_T$, $P_{R1}$ and $P_{R2}$.

Then prove that $P_{RT} = P_{R1} + P_{R2}$.

![Figure (5.10)](image)
Experiment 5
A: Solution of a resistive network
B: Power in DC circuit

Part A: The solution of a resistive network using:
- The’venin Theorem
- Norton Theorem

Objective:
To find a method of simplifying a network in order to obtain the current flowing in one particular branch of the network.

Theory:
The’venin’s theorem states that: the current through a resistor R connected across any two points X and Y of a network containing one or more sources of emf is obtained by dividing the P.d between X and Y, with R disconnected by (R+r), where r is the resistance of the network measured between the points X and Y with R disconnected and sources of emf replaced by their internal resistance.

Experimental Procedure:
I. Solution of the network using The’venin’s theorem:
   1- Connect the circuit shown in figure (5.1).

   ![Figure (5.1)](image)

   2- For the dc voltage equal to 10v, measure the current in the 470Ω resistor.
   3- Remove the 470 Ω resistor from the circuit, and measure the voltage between terminals X and Y (this will give a value for the the’venin voltage, E).
   4- Remove the source of the voltage and short the points together, this gives the network in figure (5.2).
5- The resistance of this network may be found by connecting a voltage to points X,Y and measuring the total current as shown in figure (5.2). Measure the current for voltages of 2,4,6 and 8 Volts and tabulate your results in table(5.1), then calculate the resistance using Ohm’s law and take the average of r.

\[
\begin{array}{|c|c|c|}
\hline
V(v) & I(mA) & R(K\Omega) \\
\hline
2 & & \\
4 & & \\
6 & & \\
8 & & \\
\hline
\end{array}
\]

Table (5.1)

6- Thus we have now found the values of E and r, and a circuit shown in figure (5.1) is simplified to the circuit shown in figure (5.4).
From figure (5.4) the required current I can be easily found by dividing the emf(E) by the total resistance (R+r).
Where R= Resistance of required branch (470Ω).

\[ I = \frac{E}{R+r} \]

7- The the’venin resistance can also be determined by using the digital multimeter directly as an ohmmeter between the points X and Y, with the load resistance is being removed and the power supply is deactivated (voltage source is replaced by short circuit and current source is replaced by open circuit), as shown in figure (5.4).

![Figure (5.5)](image)

8- Repeat step 6 using the value of r obtained in step 7, and calculate the current passes through the 470Ω resistor.
- Compare this value with the current measured initially in the 470Ω resistor.
- Satisfy your experiment results theoretically.

II. Solution of the network using Norton’s theorem:

1- Remove the resistance R3 (0.33KΩ) in figure (5.6) and make shunt instead of it.

![Figure (5.6)](image)
2- Measure the current flowing through the branch XY, this current is called the Norton’s current (I_N).

![Figure (5.7)](image)

3- Remove e1 and E2 and make short instead of them then remove the short between X and Y as shown in figure (5.8), and measure the The’venin’s resistance (R_th) between the points X and Y. This is also called Norton’s resistance.

![Figure (5.8)](image)

4- Plot the equivalent circuit as shown in figure (5.9), then measure the voltage across the 4.7KΩ resistor and the current passing through it.

![Figure (5.9)](image)
Part B: Power in DC Circuits:

Objective:
To investigate the concepts of electrical dc, power transfer, and the power dissipated at dc by various components.

Important Definitions:

- **Work**: the force which is needed to move charge through a circuit (Joule).
- **Volt**: the potential difference between two points that exist when it takes one joule of work to move one coloumb of charge from one point to another.
- **Power**: the rate of doing work.

\[
\text{Power} = \text{rate of doing work} \left( \frac{\text{joule}}{\text{sec}} \right)
\]

\[
\text{PO} = \frac{dW}{dt}
\]

\[
\text{One volt} = \frac{\text{one joule}}{\text{coloumb}}
\]

\[
1V = \frac{W}{q}
\]

where \(W\) = work in Joule, \(q\) = charge in coloumb.

\[
\text{Power} = \frac{dW}{dt} = \frac{d(qV)}{dt} = V \frac{dq}{dt}
\]

when the volt \(V\) is constant with respect to time.

\[
\text{But } \frac{dq}{dt} = I
\]

So power \(P = VI\) (watts)

\[
\text{But } V = IR \text{ or } I = \frac{V}{R}
\]

\[
\text{Power} = VI = I^2R = \frac{V^2}{R}
\]

The power is measured by wattmeter, where:

Reading of wattmeter (watts) = deflection * scale of current (A) * scale of volts (v).

Experimental Procedures:

1- Connect the circuit as shown in figure (5.10).

![Circuit Diagram](image)
2- Switch on the power supply and take measurements of current, power at voltage settings of 0, 2, 4, 6, 8 and 10 volts, tabulate your results in table (5.2), and calculate $VI, I^2R$ and $V^2/R$ and satisfy the readings of wattmeter.

<table>
<thead>
<tr>
<th>$V_{\text{supply}}$</th>
<th>$I_{\text{mA}}$</th>
<th>$V_{\text{volt}}$</th>
<th>$P_{\text{watt}}$</th>
<th>$I^2R$</th>
<th>$V^2/R$</th>
<th>$P_{\text{calc}}$</th>
<th>$%$ Error</th>
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</tbody>
</table>

Table (5.10)

3- Draw a graph of voltage against power and current against power.

4- Connect the circuit as shown in figure (5.10). Measure the power dissipated by $R_1$ and $R_2$, then measure the total power $P_T$ and prove that:

$$P_T = P_{R1} + P_{R2}$$

5- Repeat step 4 for the circuit shown in figure (5.11).
Prelab 6

A: Electromotive Force (emf) and internal resistance of voltage source, and maximum power transfer:

For the circuit in figure (6-1), if RL varies then $I^{-1}$ will also vary according to the relation:

$$I^{-1} = \frac{1}{\frac{R}{E} + \frac{R_{in}}{E}}$$

Where $R_{in}$ is the internal resistance of the voltage supply in this circuit, and it could be considered, in general, as the thevenin equivalent resistance of the circuit.

Depending on the last note, obtain a similar relation $I^{-1}$ and RL for the circuit in figure (6-2).

- Discuss how do you compute the values of the electromotive force (emf) and internal resistance of the voltage supply ($R_{in}$) for the circuit in figure (6-2)?

B: Star/Data Conversion:

1. For the circuit in figure (6-3), find $R_{AB}$, $R_{BC}$, and $R_{CA}$ using $\text{Y/}\Delta$ transformation.

2. Repeat step (1) for the circuit in figure (6-4).
Experiment 6
A: Electromotive Force (emf) and internal resistance of voltage source
B: Maximum power transfer
C: Star/ Data Conversion

Part A: Electromotive Force (emf) and internal resistance of voltage source:

\[ E = I \times (R_{in} + R) \]

\[ \frac{1}{I} = \frac{(R_{in} + R)}{E} \]

\[ I^{-1} = \frac{1}{E} R + \frac{R_{in}}{E} \]

If R varies then the relation of \( I^{-1} \) and R is a straight line with slope equal to \( 1/E \) and Y-intercept of \( r/E \), as shown in figure (6-2)
Part B: Maximum Power transfer:

\[ P = I \cdot V = I^2 \cdot \frac{V^2}{R} \]

If \( R = 0 \) \( \rightarrow \) \( P = 0 \)

If \( R = \infty \) \( \rightarrow \) \( P = 0 \)

\[ P = \left( \frac{E}{R + Rin} \right)^2 R \]

\[ \frac{dP}{dR} = \frac{(E^2(R+Rin)^2 \times 1) - 2E^2R(R+Rin))}{(R+Rin)^4} \]

Maximum power transfer at \( \frac{dP}{dR} = 0 \)

\[ (R+ Rin)^2 = 2R(R+Rin) \]

\( R = Rin \)

\[ P_{max} = \frac{E^2R}{(R+R)^2} = \frac{E^2}{4R} \]

Efficiency = \( \frac{P_{load}/P_{total}}{\times 100} = I^2 \cdot R \times 100/ (I^2(R+Rin)) \)

\[ P_{max \ at \ R = Rin} \rightarrow \eta \bigg|_{P_{max}} = 50 \% \]

Figure (6-3)

Experimental Procedure:

a) Connect the circuit as shown in figure (6-4).
Part C: Star / Delta Conversion:

Figure (6-5)                                             Figure (6-6)
\[ \Delta \rightarrow Y \]

\[ R_1 = \frac{(R_b \ R_c)}{(R_a+R_b+R_c)} \]

\[ R_2 = \frac{(R_a \ R_c)}{(R_a+R_b+R_c)} \]

\[ R_3 = \frac{(R_a \ R_b)}{(R_a+R_b+R_c)} \]

\[ Y \rightarrow \Delta \]

\[ R_a = \frac{(R_1R_2 + R_1 \ R_3 + R_2 \ R_3)}{R_1} \]

\[ R_b = \frac{(R_1R_2 + R_1 \ R_3 + R_2 \ R_3)}{R_2} \]

\[ R_c = \frac{(R_1R_2 + R_1 \ R_3 + R_2 \ R_3)}{R_3} \]

Experimental Procedure:

a) Connect the circuit as shown at figure (6-7)

\[ \text{Figure (6-7)} \]

b) Measure R_{AB}, R_{BC}, R_{CA} directly by ohmmeter

c) Measure R_{AB}, R_{BC}, R_{CA} using dc volt and measuring the total current.

d) Using \( Y/\Delta \) transformation to satisfy your experimental result theoretically.

e) Simulate the circuit using OrCAD.
f) Repeat steps a, b, c, d, f for figure (6-8).
Experiment 7
RMS value of an AC Waveform

Objective:
- To know the concept of rms value.
- To measure rms values for different waveforms.
- To calculate the other important relations such as: form factor and peak factor.

Theory:
There are two types of power supplies:

The rms value is the effective value of an ac voltage or current. Given an equivalent resistive load R, and equivalent time period T, the rms value of an ac source delivers the same energy to R as does a dc source of the same value. Then, the effect of the two sources is identical from a point view of energy. This has led to term effective value being used interchangeably with rms value.
\[ W = PT = I^2RT = \int_0^T t^2Rdt \]
\[ r^2 = \frac{1}{T} \int_0^T t^2dt \]
\[ I_{rms} = \sqrt{\frac{1}{T} \int_0^T t^2dt} \]

or
\[ W = PT = \frac{V^2}{R}T = \int_0^T \frac{1}{R}V^2dt \]
\[ V_{rms} = \frac{\sqrt{\frac{1}{T} \int_0^T V^2dt}}{R} \]

Experimental Procedure:

I.

1. Connect the circuit as shown in figure (7-3), with ch2 time base on a dot scale.

II.

1. Connect the circuit as shown in figure (7.4).

2. Draw the direct voltage (appeared on ch1) using oscilloscope.

3. Vary the potentiometer and notice the movement of the dot on Ch2 while varying, then draw the waveform.

Does it ever cross the zero voltage axes?
2- switch link to the left. The lamp should be one. Notice the intensity of the lamp.
3- Switch the link to the right and adjust the amplitude of the function generator until the intensity is nearly the same as before.
4- The value of the output rms value then should equal to 5V. From the oscilloscope, determine \( V_{\text{peak}} \).
5- Obtain the peak factor \( \frac{V_{\text{rms}}}{V_{\text{peak}}} \).
6- Repeat steps 1,2,3,4,5 for other as waveforms such as square and triangular waves.
7- Do all calculations and compare the results.
Experiment 8
Capacitors in Series and parallel

Objectives:

- To explore the idea of the capacitance of a component.
- To measure the value of the capacitance using DC supply.
- To investigate what happens when capacitors are connected in series and in parallel.

Theoretical Background:

The capacitor consists of two metal plates, separated by an insulating layer. The insulator may be air, or any other insulating material with suitable characteristics. The capacitance of a capacitor is determined by three factors:

- The area (A) of the plates.
- The distance (d) between the plates
- The dielectric constant (K) which depends on the type of the insulating material between the plates.

![Figure (8-1)](image)

The mathematical expression for the capacitance as a function of the three factors is given by,

\[ C = \frac{K \times A}{d} \]

The charge that accumulates in the capacitor causes a potential difference (voltage) between the plates. The mutual relationship between the charge in a capacitor of a given capacitance is given by,

\[ V = \frac{Q}{C} \]

Note: Unit of C is Farad "F". The Farad is too large unit and it is therefore we use sub-units such as the micro-farad (\(\mu F\)) = 10^{-6}, nano Farad (nF) = 10^{-9} and pico Farad (pf) = 10^{-12}
Behavior of the capacitance in DC circuits:

**Charging Process:**

After the switch “S” in figure (8-2a) is closed, the charging process begins and voltage across the capacitor rises gradually it reaches its maximum value ($V_s$) as shown in Figure (8-2b). The instantaneous voltage across the capacitor is

$$V_c = V_s \left[ 1 - e^{-t/\tau} \right]$$

$RC$ is called the time constant ($\tau$) of the circuit, that $\tau = RC$

at $t = RC = \tau$  \[ V_c = V_s \left[ 1 - e^{-1} \right] = 0.63 \ V_s \]

so time constant is the time at which the value of $V_c = 0.63 \ V_s$ or 63% of $V_s$.

The current will flow in the circuit as long as the capacitor is not completely charged. This current will be maximum at the instant the switch is closed and decreases exponentially as the charging continues.

$$i = c \frac{dV}{dt} = \frac{V_s}{R} e^{-t/RC} = I_{max} e^{-t/RC} \quad \text{where} \quad I_{max} = \frac{V_s}{R}$$
Connection of Capacitors:

I. Parallel Connection:

The total charge $Q_T$ will divide into $Q_1$ and $Q_2$

$$Q_T = Q_1 + Q_2$$

Since $C = Q / V$

So .... $Q_T = E C_T$, $Q_1 = E C_1$, $Q_2 = E C_2$

So .... $E C_T = E C_1 + E C_2$

$$C_T = C_1 + C_2$$

II. Series Connection:

$$E = V_{c1} + V_{c2}$$

But $E = Q / C_T$, $V_{c1} = Q_1 / C_1$, $V_{c2} = Q_2 / C_2$

$$Q / C_T = Q_1 / C_1 + Q_2 / C_2$$

$$1 / C_T = 1 / C_1 + 1 / C_2$$
Experimental Procedure:

I.

a) Connect the circuit as shown in figure (8-6).

![Diagram of circuit](image)

b) Switch the toggle switch forward, and raise the output of the variable DC supply until a reading of 10V is obtained in the digital multi-meter. Then switch the toggle switch back, and check that the voltmeter returns to zero, then short C until a zero indication is obtained on the multi-meter.

c) At a conventional time switch the toggle switch forward, take reading of the current on turning the switch, record the reading in the table (8-1).

d) Switch the toggle back and temporarily short circuit C to restore the original starting condition, and then follow the same procedure as before but taking readings of the voltage across the capacitor. From these results on the same graph paper, plot graph of voltage and current against time.

e) Simulate the circuit using OrCAD.

Let us now calculate the charge present on the capacitor at any time. The current is a measure of the rate of flow of charge

\[ I = \frac{Q}{t} \quad \text{i.e.} \quad Q = I \times t \quad \text{(coulombs)} \]

Thus Q is given by the area under the current curve. To estimate the area under the curve, count the squares in the graph under the curve, multiply it by the time scale curve and the current scale, and then record the result in your table. Notice that the charge accumulates on the capacitor, so you should add every charge to the following one. Then draw a graph of the charge again with time on the same paper. Plot a graph of Q against V. It should be found that the charge on C is directly proportional to the voltage across it, with a constant of proportionally equal the capacitance of the capacitor, C. So measure the slope of the Q-V graph to find C.
<table>
<thead>
<tr>
<th>Time</th>
<th>( I ; (\mu\text{A}) )</th>
<th>V (volt)</th>
<th>No. of squares</th>
<th>Q</th>
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<td>40</td>
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</table>

Table (8-1)

II.

1. **Capacitors in series:**
   a) Connect the circuit as shown in figure (8-7).

![Figure (8-7)](image)
b) Repeat previous steps, plot a graph of current against time, and count squares under the graph, and calculate the charge.

c) Plot a graph of Q against V and compute the slope to find CT, then find a relation between C total, C1, and C2 for the series connection.

2. Capacitors in parallel:

Repeat steps a, b, c, and d for the figure (8-8)
Experiment 9
Time constant and inductance

Objective:

- To investigate the factors determining the charge and discharge time for a capacitive and inductive circuits.
- To explore the idea of the inductance of a component.

Theory:

- The relationships of voltage and current of the capacitor as follows:

\[ V_C = V_S \left[ 1 - e^{-\frac{t}{\tau}} \right], \text{where } \tau = RC \]

\[ i_C = C \frac{dV_C}{dt} = \frac{V_S}{R} e^{-\frac{t}{\tau}} \]

- Charging Process:

- Discharging Process:

\[ V_C = V_S e^{-\frac{t}{\tau}} \]

\[ i_C = -\frac{V_S}{R} e^{-\frac{t}{\tau}} \]

- The relationships of voltage and current and current of the inductor are as follows:

Figure (9.2)
• Charging Process:
  \[ i_t = I_0 \left( 1 - e^{-\frac{t}{\tau}} \right), \text{ where } \tau = \frac{L}{R} \]

• Discharging Process:
  \[ i_t = I_0 \left( 1 - e^{-\frac{t}{\tau}} \right) \]
  \[ V_L = -V_0 e^{-t/\tau} \]

Experimental Procedure:

I. 1- connect the circuit as shown in figure (9.5).
2. Connect the oscilloscope settings as follows:
   • Time base: 0.5 sec/div.
   • Ch1: 5v/div.
   • Ch2: 50mv/div.

3. Draw the charge and discharge waveforms of ch1 and ch2.

II.
   1- Connect the circuit as shown in figure (9.6).

   2- Set the function generator to give a square wave of frequency= 7Hz and a peak to peak voltage of 10 volt.
   3- Set the oscilloscope setting as follows:
      • Time base: 20msec/div.
      • Ch1: 2v/div.
      • Ch2: 50mv/div.
   4- For clear waveforms press the dc button of the oscilloscope.
   5- Draw the charge and discharge waveforms of ch1 and ch2.
   6- What is the period of the waveforms?
   7- Measure the time constant from the graph.
8- Calculate the time constant theoretically, and then compare the results.

III.

1- set up the circuit as shown in figure (9.7). Then 33Ω resistor is to limit the maximum current reached. Then 10Ω resistor is to display the current waveform on the oscilloscope.

![Figure (9.7)](image)

2- Adjust the wave generator to give 10 V p-p square wave at 250Hz.
   Set the OSC as follows:
   - Time base: 0.5msec/div.
   - Ch1: 2v/div.
   - Ch2: 0.2v/div.

3- Take readings from the displayed current waveform and record them in table (9.1). Plot the current waveform on a graph paper as large as you can.
4- Repeat step (3) for the voltage waveform.
5- Draw tangent to the current curve as its origin and calculate the slope of the curve at this point.
6- Repeat step (5) to all points and record the corresponding slope in table(9.2).

\[ E = K \frac{di}{dt} \]

We call the constant K the inductance of the coil L.

7- Plot a graph of voltage against rate of change of current and measure the slope to find L.
<table>
<thead>
<tr>
<th>Time (usec)</th>
<th>Current (mA)</th>
<th>Voltage (v)</th>
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<tbody>
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</table>

Table (9.1)

<table>
<thead>
<tr>
<th>Time (usec)</th>
<th>Current (mA)</th>
<th>Voltage (v)</th>
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</table>

Table (9.2)
Experiment 10
A: Pulse Response of RL and RC
B: Resistive, Inductive, and capacitive at AC circuits

Part A: Pulse Response of RL and RC

Objective:
- To investigate the factors determining the time constant for RC, RL circuits.
- To investigate the pulse response of RL, RC circuits.

Theoretical Background:

The complete response of pulse signal flowing in RL, RC, circuit is composed of the natural and forced response for the circuit at the same time. There are three factors that affected the pulse response waveform:

1. Components of the circuit:
   \[ \tau = RC \text{ in RC circuits} \]
   \[ \tau = \frac{L}{R} \text{ in RL circuits} \]
   For example: reducing R in RC circuit will reduce \( \tau \) so the response will reach the steady state value in faster time, and increasing R will make the response to have a ramp form.

2. Time period = \( \frac{1}{f} \)
   The variation of frequency also affects the waveform of the pulse response.
   For example: reducing frequency will expand the waveform and vice-versa.

3. Type of the input signal will affect the pulse response. It may be sine wave, square wave, triangular wave ... etc.

Experimental procedure:

I. Pulse response as a function of frequency:

1. Set up the circuit as shown in figure (10-1). Set the output of the generator to 10 Vp-p square wave with the suitable frequency for the steady state response.
2. Connect the channels of the oscilloscope to monitor the current and voltage as in figure (10-1).

3. Draw the voltage and current waveforms. Determine the magnitude and time period.

4. Change the frequency of the generator so that the response did not reach the steady state. After that continue changing the frequency until you have a ramp function response. Draw the voltage and current waveform, determine their magnitude and time period.

5. Simulate the circuit using Or-CAD.
   - Did the change of the frequency affect the waveform of the circuit? Explain?

6. Repeat the above steps for figure (10-2), and answer the question above.

II. **Time constant with respect to the change of R, C, and L values:**

1. Set up the circuit as shown in figure (10-1), set the output of the generator to 10 Vp-p square wave frequency at which you have obtained the steady state response.
2. Connect the channels of the oscilloscope to monitor the voltage and circuit.
3. Replace the 1 kΩ resistor by 220 Ω resistor. Draw the voltage waveform.
4. Replace the 1 kΩ resistor by 10 kΩ resistor. Draw the voltage waveform.
5. Replace the 1 kΩ resistor by 220 kΩ resistor. Draw the voltage waveform.
- What is the effect of changing $R$ on the response of the circuit of figure (10-1)?

6. Replace the 1 $\mu$F by 100 $\mu$F in figure (10-1).
   - What is the effect of changing $C$ on the response of the circuit of figure (10-1)?

7. Replace the 1 k$\Omega$ resistor by 220 $\Omega$ resistor in figure (10-2). Draw the current waveform.
8. Replace the 1 k$\Omega$ resistor by 10 k$\Omega$ resistor. Draw the current waveform.
   - What is the effect of changing $R$ on the response of the circuit of figure (10-2)?

9. Simulate the circuit using Or-CAD

**Part B: Resistive, Inductive, and capacitive at AC circuits**

**Objectives:**

- To investigate ohm’s law for a simple ac resistive, inductive, and capacitive circuit.
- To investigate the effect of frequency on the impedance of a simple ac resistive, inductive, and capacitive circuit.

**Preliminary Exercise:**

From the following electrical circuit in figure (10-3):

1. Calculate the current $I_p$ at frequency 50 Hz.

![Figure (10-3)](image)

2. Calculate the capacitance of the capacitor which have the capacitance ($X_C$) as the inductive ($X_L$) in the previous circuit at the frequency $f = 50$ Hz
3. Calculate the current and the voltage drop across a resistance $R$ which equal to the reactance $X_L$ at $f = 50$ Hz which connected in series with the inductor of the previous circuit.

**Experimental procedure:**

1. Connect up the circuit as shown in figure (10-4)
2. Vary the ac supply $f = 1$kHz from 1, 2, …., 5 V, and record your result in table (10-1). Then plot a graph of I against V and calculate R using Ohm's law.

<table>
<thead>
<tr>
<th>V(V)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>I(mA)</td>
<td></td>
<td></td>
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<tr>
<td>R Ω</td>
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<td>XL Ω</td>
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<tr>
<td>Xc Ω</td>
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</table>

Table (10-1)

3. Set the generator frequency to 50 Hz with amplitude of 4 Vrms. Calculate the resistance of the resistor at 50 Hz.

4. Repeat the reading for a frequency of 100 Hz, and then for 100 Hz increment to 1 kHz and tabulate your result in table (10-2)

- How do the current, voltage, and resistance change with frequency.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Voltage (Vrms)</th>
<th>Current (mA)</th>
<th>Resistance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
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<tr>
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</table>

Table (10-2)
5. Connect the circuit as shown in figure (10-5) with \( f = 4 \text{ kHz} \)

![Figure (10-5)](image_url)

6. Adjust different voltage values and record the current in table (10-1), then plot a graph of \( I \) against \( V \) and calculate \( L \) where:

\[
XL = \frac{V_{\text{rms}}}{I_{\text{rms}}} = 2\pi f \cdot L
\]

\[
I_{\text{rms}} = \left( \frac{1}{2\pi f \cdot L} \right) \cdot V
\]

- Deduce the slope of the graph.
- What is the average value of impedance of the coil at 4 kHz?

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Voltage (Vrms)</th>
<th>Current (mA)</th>
<th>Resistance (ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
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<td>24</td>
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</table>

Table (10-3)

7. Adjust the generator output of 1 Vrms sinewave for frequencies 4kHz, 8kHz, 12 kHz, ……… And 24 kHz.
- Copy the result in table (10-3)
- Calculate the average impedance for each frequency.
- Plot a graph of impedance for each frequency.
- How does the impedance vary with frequency.

Important Note:

For an inductor:

\[
I = I_{\text{max}} \sin \omega t
\]

Applied voltage

\[
V = -L \frac{di}{dt} = (L \cdot I_{\text{max}} \cdot \omega) \cos \omega t
\]

At \( \cos \omega t = 1 \)

\[
V_{\text{max}} = L \cdot I_{\text{max}} \cdot \omega
\]

\[
\frac{V_{\text{max}}}{I_{\text{max}}} = \omega \cdot L = Z = X = 2\pi f \cdot L
\]

\[
X \propto f
\]
Thus the impedance (inductive reactance) of an inductor is directly proportional to the frequency.

8. Connect the circuit as shown in figure (10-6)

![Circuit Diagram](image)

Figure (10-6)

9. Set the frequency of the function generator to 800 Hz, adjust the output of the generator to give 1 Vrms as read on the meter then take the current reading for this voltage.

10. Repeat this procedure for voltage 2, 3, 4, and 5 V
   - Repeat your result in table (10-1), and calculate the ratio of rms voltage to rms current.
   - Is there any relationship between rms voltage and rms current?
   - What is the average value of the impedance?
   - Thus we can say that the impedance of the capacitor is ........ ohm's at frequency of 800 Hz.
   - Calculate the impedance of pure capacitor at dc.

11. At frequency 50 Hz, take readings of current for voltages settings at 1, 2, 3, 4, 5, and 6 V in rms values.

12. Do the same for frequencies 100, 200, 40, and 1600 Hz.

**Important Note:**

\[
V = V_{\text{max}} \sin \omega t \quad i = C \frac{dv}{dt} = (C V_{\text{max}} \omega) \cos \omega t = (C V_{\text{max}} \omega) \sin (\omega t + (\Pi/2))
\]

\[
I_{\text{max}} = C V_{\text{max}} \omega \quad V_{\text{max}}/I_{\text{max}} = 1/\omega C = V_{\text{rms}}/I_{\text{rms}} = Z_c
\]

\[
Z_c = 1/ (2\Pi f C) \quad Z_c \propto 1/ f
\]

Thus the impedance of the capacitor is inversely proportional to both the frequency and the capacitance.
<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Voltage (Vrms)</th>
<th>Current (mA)</th>
<th>Resistance (ohms)</th>
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</thead>
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Table (10-4)
Experiment 11
Damping in RLC circuits

Objective:
To investigate the over, under, and critical damping in series and parallel RLC circuits.

Theory:

\[ L \frac{d^2i}{dt^2} + R \frac{di}{dt} + \frac{1}{C} i = 0 \quad \text{For} \quad i = Ae^{st}, \quad \text{we get} \]

\[ s^2L + \frac{sR}{C} + \frac{1}{LC} = 0 \]

which is satisfied when the roots of this equation are,

\[ s_1 = \frac{-R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}} \]
\[ s_2 = \frac{-R}{2L} - \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}} \]

The character of the natural response is determined by the discriminant

\[ \left(\frac{R}{2L}\right)^2 - \frac{1}{LC} \]
If the discriminant is positive, the response is over-damped and

\[ R > 2 \sqrt{\frac{L}{C}} \]

If the discriminant is negative, the response is oscillatory and it is called under-damped for which

\[ R < 2 \sqrt{\frac{L}{C}} \]

If the discriminant is zero the response is critical damped and

\[ R = 2 \sqrt{\frac{L}{C}} \]

Exercise:

Derive the condition of three types of damping for a parallel RLC circuit.

Experimental procedure:

I. Series RLC:

1. Connect the circuit as shown in figure (11-3).

2. Vary R for low values to get your under-damped signal.

3. Draw the signal you get and answer the questions at the end of the experiment.
4. Change the frequency and explain what happens.

5. Now vary the resistor for mid values to get your critical damping signal and repeat steps 3 and 4.

6. Vary R for high values to get your over-damping signal, and then repeat steps 3,4.

II. Parallel RLC:

1. Connect the circuit as shown in figure (11-4).

2. Vary R to get your under-damping signal and repeat steps 3 and 4 from part I.

3. Now vary R to get your critical damping signal. Repeat steps 3,4.

4. Vary R to get your over-damping signal. Repeat steps 3,4 above.

Discussion:

1. Find the time period for the oscillating signal and the range of resistor variation.

2. Find the maximum peak value for the signal.
3. What happens when you increase or decrease R?

4. Calculate the resonance frequency, damping coefficient and damping factor.

5. By calculation, draw V(t) for over-damping parallel circuit, and under damping series RLC circuit.