Facility of Engineering
Department of Biomedical Engineering

BME (311)
Electric Circuits lab

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<td>10</td>
<td>References</td>
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</table>
Exp#1  : Introduction to Basic Laboratory Test and Measurement Equipment

1.1 Objectives:

This experiment is intended to give the student a quick exposure to the laboratory equipment which will be used in this course.

1.2 Laboratory Equipment:

1.2.1 The DC Power Supply:

Generally, this is a dual power supply with (+) and (-) voltage terminals, and a ground (common) terminal. A dual-output laboratory power supplies voltage and current are indicated on three-digit display, can be operated in parallel or in series, and can be operated as constant voltage source or as constant current source.

- The main attributes of this device is:

1. Voltage and current are indicated on separate LED-meters.
2. The output voltages are available through safety sockets on the front panel.
3. Dual Tracking (Serial and parallel operation) Both lab-outputs can be connected in parallel or in series by means of a switch on the front panel. The left hand unit is then operating as the master control unit.
4. The output values are indicated on the meters of the master unit (left side).
5. The units are equipped with a third output supplying a fixed voltage of 3...6 Volts and a max. Current of 2 A. This output is located on the right side with safety sockets.
6. Output on/off switch.(see Figure1-1)
1.2.2 **The Digital Multimeter:**

Most digital multimeters are designed to measure DC resistance, direct current and voltage, and the RMS value of sinusoidal current and voltage. Some meters measure the true RMS (TRMS) value of any waveform.

**Note:** At this laboratory we will use two different type of DMM (see Figure 1-2), because one of the DMM tolerate higher current than the other DMM as listed below:

1. **GWINSTEK (GDM-8034) DMM**: tolerate 2A maximum current at the lower range, and 20A maximum current at the higher range.

2. **MASTECH (M9803R) DMM**: tolerate 400mA maximum current at the lower range, and 10A maximum current at the higher range.

---

1.2.3 **The Function Generator:**

A FG provides voltages of different forms. These may include: sinusoidal, triangular, and square. An adjustable level of DC off set (+ or -) may also be available. In addition, a control may be present to vary the waveform symmetry. Output-voltage frequency and amplitude may have a wide dynamic range. (see Figure 1-3)
1.2.4 **The Oscilloscope:**

This is one of the most important pieces of laboratory test equipment. It is basically a voltage sensing and display device; it cannot measure current directly. However, it can be used to measure a voltage proportional to a desired current, e.g., across a small sampling resistance.

Most modern Scopes have two input channels with adjustable, calibrated, gain. Two signals can thus be viewed separately, or simultaneously if they are synchronized. Calibrated gain settings enable the measurement of voltage amplitude.

A horizontal Time axis is provided by an internal generator. This generator produces a calibrated variable-frequency voltage the amplitude of which varies linearly with time. Thus, a voltage waveform applied to either input channel can be viewed as a function of time. And a plot of the relationship between two signals at both channels can be performed also.

An important Scope function is the Trigger. Circuits in this subsection enable the selection of the amplitude of the input signal at $t = 0$ relative to its peaks. This corresponds to having a selectable phase angle. Another important Scope function is applying a mathematical operation on the signal, such as inverting, add the two signals, and subtract them. (see Figure 1-4)

![Figure 1-4: The Oscilloscope](image)

**Figure 1-5** represents the front panel of the function generator, each part of the panel listed at the below table.

|------------------------------|---------------|------------------|------------------|---------------------------|-----------------|-----------------------------|-------------|---------------------|---------------------|-------------------|-----------------|-------------|-------------------|-----------------|-------------------|-----------------|----------------------|------------------|------------------|

![Figure 1-5: Oscilloscope (GWINSTEK) GDS-1152A-U Digital Scope Front panel.](image)
1.2.5 **Project Board:**

A breadboard (protoboard) is a construction base for prototyping of electronics, because the solderless breadboard does not require soldering, it is reusable. This makes it easy to use for creating temporary prototypes and experimenting with circuit design. *(See Figure 1-6)*

![Example breadboard drawing](image)

**Figure 1-6 : Example breadboard drawing**

1.2.6 **Electrical connector:**

1.2.6.1 *The BNC connector (Bayonet Neill-Concelman) (see Figure 1-7)*

![Oscilloscope probe BNC - double clips (crocodile) and BNC-BNC Wires respectively.](image)

**Figure 1-7 : Oscilloscope probe BNC - double clips (crocodile) and BNC-BNC Wires respectively.**
1.2.6.2 Banana connectors. (See Figure 1-8)

![Figure 1-8: Banana plug to Banana plug wire](image)

1.2.6.3 Banana Plug to Alligator (crocodile) Clip wire. (See Figure 1-9)

![Figure 1-9: Banana to crocodile connector](image)
1.3 Procedure:

1.3.1 The DC Power Supply:

1- Apply input power.

2- Turn the Voltage limit control from the Minimum to Maximum, and then record both values of the Minimum to Maximum voltage.

\[ V_{\text{minimum}} = \ldots \ldots \ldots \ldots \ldots \ldots \]  
\[ V_{\text{maximum}} = \ldots \ldots \ldots \ldots \ldots \ldots \]

3- Turn the Current limit control from the Minimum to Maximum, and observe the effect on the Voltage value.

**Q1:** Does the Voltage value change when the Current controls are turned up or down?

………………………………………………………………………………………………

4- Turn the Voltage limit control to set the voltage value to 5V.

5- Place short circuit (S.C) between (+) & (-) output terminals.

6- Turn the Current control from the Minimum to Maximum, and then record both values of the Minimum to Maximum current.

\[ I_{\text{minimum}} = \ldots \ldots \ldots \ldots \ldots \ldots \]  
\[ I_{\text{maximum}} = \ldots \ldots \ldots \ldots \ldots \ldots \]

7- Turn the Voltage limit control from the Minimum to Maximum and observe the effect on the Current value.

**Q2:** Does the Current value change when the Current controls are turned up or down?

………………………………………………………………………………………………

8- Disconnect the S.C

1.3.2 The Digital Multimeter:

1.3.2.1 (A) Resistance Measurements:

1- Obtain a resistance.

2- Prepare the DMM for resistance (Ω) measurements.

3- Connect the DMM probes to the two terminals of the resistor.

4- Select the DMM auto range and record its reading.

5- Repeat with the smallest range setting.

Also you can measure:
1.3.2.2 Direct Current Measurements.

1.3.2.3 Alternating Current Measurements.

1.3.2.4 Direct Voltage Measurements.

1.3.2.5 Alternating-voltage measurements.

1.3.3 Oscilloscope and Function Generator:

1. Turn the function generator and the Oscilloscope power on.

2. Set the frequency of the function generator to 1000 Hz.

3. Set the function Selector to sinusoidal output.

4. Set the amplitude to Maximum value.
   Maximum value = ..............

5. Measure the rms value of the output with DMM.

6. Set the output amplitude to Minimum.

7. Measure the output with DMM.
   Minimum value = ..............

1.3.4 Oscilloscope:

1. Turn the function generator and the Oscilloscope power on.

2. Set the frequency of the function generator to 1000 Hz.

3. Set the function Selector to sinusoidal output.

4. Set the amplitude to 5Vp-p.

5. Connect the circuit shown at Figure 1-10.

6. Measure Vo using channel 2 of the Oscilloscope.
   Vo = ......................
Exp#2 : Resistors, Potentiometers, and Rheostats

2.1 Objectives:
1. Gain familiarity with available types of resistors, potentiometers, and rheostats.
2. Determine the nominal value of resistance using the color code, and the actual value using different types of measurement.
3. Determine the linearity of a potentiometer, and use it as a voltage divider or control element.

2.2 Introduction:

2.2.1 Resistors:
As discrete components, resistors come in various sizes and shapes depending on their power rating and use. The resistive element material may also vary, e.g., metallic wire, carbon, etc. the resistor most commonly used in the laboratory is made of carbon encased in a tubular form with axial leads as shown in Figure 2-1.

Some resistors may have their nominal ohmic value stamped on the body of the resistor, e.g., 1100 or 2.2M. More often, however, color code is used to indicate the nominal value. Three color bands are used for this purpose, each having a numerical value between 0 and 9, as shown in Table 1.

Table 1: Numerical Values of Color Codes

<table>
<thead>
<tr>
<th>Black</th>
<th>Brown</th>
<th>Red</th>
<th>Orange</th>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
<th>Violet</th>
<th>Gray</th>
<th>White</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

Starting with the band closest to one end of the resistor, as shown in Figure 2-1, the three represented numbers, n1, n2, and n3 mean: R= ( 10*n1 + n2 )*10^n3 ohms. For example, Orange-Blue-Black means 36*10^0 =36 ohms, and Gray-Red-Yellow means 82*10^4 = 820 Kohm.

The percent tolerance around the nominal value is indicated by a fourth band according to Table 2.

Table 2: Percent-Tolerance Color Code

<table>
<thead>
<tr>
<th>Gold</th>
<th>Silver</th>
<th>No Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 5</td>
<td>± 10</td>
<td>± 20</td>
</tr>
</tbody>
</table>
The physical size of a resistor depends on its power rating, and vice versa. To keep its temperature at a safe level, a resistor must be large enough to dissipate its rated power into the surrounding design environment.

2.2.2 Potentiometer:

Potentiometers provide an adjustable resistance between two points as shown in Figure 2-2. The arrowhead represents a movable contact point. Thus the resistance between the terminals a and b (or c and b) can be varied from 0 to 100 percent of the total resistance between a and c. If this variation is proportional to the physical length of the resistive element, the potentiometer is said to be linear. Otherwise, it is nonlinear, e.g., logarithmic.

![Figure 2-2: Potentiometer Schematic Diagram](http://fddrsn.net/pcomp/examples/potentiometers.html)

Two popular shapes of potentiometers are: circular and straight-line, as shown in Figure 2-3.

![Figure 2-3: Circular and Straight line Potentiometers](http://fddrsn.net/pcomp/examples/potentiometers.html)

A potentiometer is used as a voltage control device to obtain a variable fraction of the potential between two points as shown in Figure 2-4. Here $V_o$ can be varied between zero and $V_s$.

![Figure 2-4: Potentiometer Voltage Control](http://fddrsn.net/pcomp/examples/potentiometers.html)
2.2.3 **Rheostat:**

A rheostat is similar to a potentiometer in structure. However, it differs in its intended use. It is used as a series element to control current as shown in Figure 2-7. Thus, it is usually a higher-power device.

2.3 **Procedure:**

2.3.1 **Resistance Measurements:**

Several methods will be used to measure resistance. Their results will be compared with each other and with nominal color-code value.

1. Obtain two resistors having arbitrary values between 100 ohms and 100 K ohms and arbitrary power ratings.
2. Tabulate their color codes, nominal values, percent tolerances, and power ratings.

<table>
<thead>
<tr>
<th>Color-code</th>
<th>Nominal value (Calculated)</th>
<th>Tolerance</th>
<th>Power rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R1) Brown-black-brown -Gold</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R2) Red-red-red-Gold</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3.1.1 **Ohmmeter Measurements:**

1. Use the DMM to measure the value of each resistor directly on the most sensitive range.

   R1 (measured) - ………………………………………………

   R2 (measured) - ………………………………………………

2. As an aside, measure and record your body resistance by holding the probes firmly One with each hand ………………………………

2.3.1.2 **Voltage and Current Measurements:**

Construct a measurement circuit as shown in Figure 2-5, where Rx is the resistance to be determined by Ohm’s law:

\[ Rx = \frac{Vx}{Ix}. \]

**Note:**

1. While using the DMM as a voltmeter, you must connect it in parallel with the component you need to measure the voltage across it.

2. While using the DMM as an ammeter, you must connect it in series with the component you need to measure the current passing through it.
1- Increase Vs from 0 to near the highest responsible value. (Within limits that are safe for the resistor $R_x$)

<table>
<thead>
<tr>
<th>Vs (V)</th>
<th>3</th>
<th>5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_x$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_x$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_x = V_x / I_x$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2- Record the measure value of $V_x$, $I_x$.
3- Calculate the value of $R_x$ by the Ohm’s law.

**2.3.1.3 Bridge Measurements:**

A Wheatstone bridge for measuring resistance is shown in Figure 2-6. When the Bridge is balanced, i.e., $I_b = 0$,

![Figure 2-6]

The following relation holds:

$$R_x = R_3 * R_2 / R_1$$

*Derive this formula in your report.
*Generally, a good measurement is obtained when all Resistors values are not too far from each other; for example, within a factor of 3 or less.

1- Select reasonable values for $R_1$ and $R_2$, and measure them with the DMM before placing them in the Circuit.
2- Use decade box for the adjustable resistor $R_3$. Use approximately 10 V for $V_s$.
3- Set the DMM initially to the highest Current range. and adjust $R_3$ to make $I_b$ approach 0. Stop adjusting when a minimum value of $I_b$ is obtained on the lowest possible range. Record this value for reference only.
4- **Disconnect $R_3$ and measure it directly with the DMM…**
5- Calculate the value of unknown $R_x$ using above formula.
6- Compare with the nominal values.
2.3.2 **Potentiometers and Rheostat Measurements:**

1. To demonstrate the rheostat principle, one of the Potentiometer you tested may be used in the following measurements.

![Figure 2-7]

2. For the circuit shown in Figure 2-7. Obtain a Potentiometer. Select Ro such that the maximum variation in the Current Io is 5 to 1. Measure and record the value of Ro.

3. Construct the circuit using 10 v for vs. Measure Io on the lowest possible range using the 4 marked sections of the potentiometer for Rs, i.e, 0, 25, 50, 75, and 100 percent.

\[
\begin{array}{|c|c|}
\hline
R_s (K\Omega) & Io \\
\hline
5 & \\
4 & \\
3 & \\
2 & \\
1 & \\
\hline
\end{array}
\]
Biomedical Engineering Department

Electric Circuits lab

BME (311)

Pre-lab Report #1

Experiment# 2

Resistors, potentiometers, and Rheostat

Student Name ...........................................................................................................................................

Student ID...............................................................................................................................................
Objectives:
1.

2.

3.

Q#1: For the resistor shown in figure 2-8 answer the below questions:

A) Calculate the nominal value of the resistor using color-code rule.

B) Which color is indicating the tolerance, and what is the tolerance value?
Q#2: For the Wheatstone bridge circuit shown in figure 2-9 derive this formula:

\[ R_x = \frac{R_2 \cdot R_3}{R_1} \]
Q#3: For the circuit shown in figure 2-10 Select Ro such that the maximum variation in the Current Io is 5 to 1.

**Note:**
1. Rs is a rheostat.
2. Show all your calculation.

Figure 2-10
Biomedical Engineering Department

Electric Circuits lab

BME (311)

Post lab #1

Experiment #2

Resistors, potentiometers, and Rheostat

1. Student Name .........................................................................................

   Student ID..........................................................................................

2. Student Name .........................................................................................

   Student ID..........................................................................................

3. Student Name .........................................................................................

   Student ID..........................................................................................
I. Resistance measurements:

(A) Ohmmeter Measurements:
- Fill the below table according to what you measured at the laboratory:

Note: you should show your calculations.

<table>
<thead>
<tr>
<th>Color-code</th>
<th>Nominal value (Calculate using Rule)</th>
<th>Measured value (DMM)</th>
<th>Tolerance</th>
<th>Power rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown-black-brown –Gold</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red-red-red-Gold</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Your body resistance is ………………………………………………………………………

Rx=Vx/Ix.

(B) Voltage and Current Measurements :( Ohm’s law)

- Fill the below table:

<table>
<thead>
<tr>
<th>Vs (V)</th>
<th>3</th>
<th>5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ix</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vx</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rx=Vx/Ix</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(C) Bridge Measurements:

For the bridge circuit shown below the following formula should be satisfied.

\[ R_x = \frac{R_2 \cdot R_3}{R_1} \] \quad \text{only when } I_b = 0

1. \( R_3 = \ldots \ldots \)

2. Calculate the value of unknown \( R_x \) using above formula, Compare with the nominal values.
2. Rheostat Measurements:

❖ The selected Ro=.........................

❖ Fill the below table:

<table>
<thead>
<tr>
<th>Rs (KΩ)</th>
<th>Io</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

❖ Plot Io Vs Rs.

❖ What functional relation does this plot indicate?
Conclusion and discussion:

- List your Conclusion about all parts of this experiment, and discuss the results as points:
Exp#3  : DC Circuit Measurements

3.1 **Objectives:**

At this experiment the objective is to verify Kirchhof’s voltage and current laws and some of their consequences by measurements on dc circuits.

3.2 **Introduction:**

3.2.1 **Series Circuits:**

Kirchhoff’s Voltage Law (KVL) states that the sum of voltages around a closed path is zero. This can be verified by measurements on simple series circuits as circuit shown at Figure 3-1.

3.2.2 **Parallel Circuits:**

Kirchhoff’s Current Law (KCL) states that the sum of all currents at any node in a circuit is zero. This can be verified by measurements on a simple parallel circuit as shown at Figure 3-2.

3.2.3 **Series-Parallel Circuits:**

Both KVL and KCL are now verified by measurements in a rather arbitrary circuit containing series and parallel combinations of resistors as shown at Figure 3-3.

3.3 **Procedure:**

3.3.1 **Series Circuits:**

- Use $R_1=330 \, \Omega$, $R_2=1 \, K \, \Omega$, $R_3=2.2K \, \Omega$, then connect the circuit in Figure 3-1.
1. Measure the value of Is by using the DMM as an ammeter.
\[ I_s = \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \]

2. Move the connection of the voltmeter around the circuit to measure the voltages:

<table>
<thead>
<tr>
<th>Vs/ Parameter Name</th>
<th>Vab</th>
<th>Vbc</th>
<th>Ved</th>
<th>Is</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vs=15V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Disconnect the power supply from the circuit, and use the DMM as an ohmmeter to measure the resistances values; (you need to use the measured values of resistances and Vs to calculate the different voltages, and compare the results with the measured values of these voltages.)

<table>
<thead>
<tr>
<th>Resistance name</th>
<th>Measured Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td></td>
</tr>
</tbody>
</table>

### 3.3.2 Parallel Circuits:
- Construct the circuit shown in Figure3-2 below with the given values:

Measure the value of Is by using the DMM as an ammeter,
\[ I_s = \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \]

1. Now place the ammeter in series with R₁, R₂, and R₃ to measure the values of the different currents:

<table>
<thead>
<tr>
<th>Vs/Parameter Name</th>
<th>I₁</th>
<th>I₂</th>
<th>I₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vs=15V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Disconnect the power supply, and use the DMM as an Ohmmeter to measure the parallel combination of R1, R2, and R3, then measure each resistance separately. (you need to use the measured values of resistances and Vs to calculate the different currents, and compare the results with the measured values of these currents.)

<table>
<thead>
<tr>
<th>Resistance name</th>
<th>Measured Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td></td>
</tr>
<tr>
<td>R_{eq}</td>
<td></td>
</tr>
</tbody>
</table>

3.3.3 **Series-Parallel Circuits:**
- Construct the circuit shown in Figure 3-3, with the given values

![Figure 3-3](image)

1. Use the DMM as a voltmeter to measure Vs, and the different voltages across the individual resistors, as indicated:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vs</td>
<td></td>
</tr>
<tr>
<td>V1</td>
<td></td>
</tr>
<tr>
<td>V2</td>
<td></td>
</tr>
<tr>
<td>V3</td>
<td></td>
</tr>
<tr>
<td>V4</td>
<td></td>
</tr>
<tr>
<td>V5</td>
<td></td>
</tr>
<tr>
<td>V6</td>
<td></td>
</tr>
</tbody>
</table>
2. Use the DMM as an ammeter to measure the different currents across the resistors, as below:

<table>
<thead>
<tr>
<th>Current</th>
<th>DMM value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I₁</td>
<td></td>
</tr>
<tr>
<td>I₂</td>
<td></td>
</tr>
<tr>
<td>I₃</td>
<td></td>
</tr>
<tr>
<td>I₄</td>
<td></td>
</tr>
<tr>
<td>I₅</td>
<td></td>
</tr>
<tr>
<td>I₆</td>
<td></td>
</tr>
</tbody>
</table>

3. Use the DMM as an Ohmmeter to measure the different resistances, as below:

<table>
<thead>
<tr>
<th>Resistance name</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁</td>
<td></td>
</tr>
<tr>
<td>R₂</td>
<td></td>
</tr>
<tr>
<td>R₃</td>
<td></td>
</tr>
<tr>
<td>R₄</td>
<td></td>
</tr>
<tr>
<td>R₅</td>
<td></td>
</tr>
<tr>
<td>R₆</td>
<td></td>
</tr>
</tbody>
</table>

4. Now, use the measured values of voltages to verify KVL on all closed paths, and use the measured values of currents to verify KCL at all nodes. Finally, use the measured values of resistances with Ohm’s law to calculate voltages using measured currents and vice versa, then compare all the measured quantities.
Biomedical Engineering Department

Electric Circuits lab

BME(311)

Pre-lab Report #2

Experiment#3

Dc Circuit Measurements- Part A

Student Name ………………………………………………………………………………………………………

Student ID……………………………………………………………………………………………………
Objectives:

**Q#1:** For the circuit shown in Figure 3-4 calculate $I_s$, $V_{bc}$, $V_{cd}$, and $V_{de}$.

Note: use KVL and/or KCL

Figure 3-4
Q#2: For the circuit shown in Figure 3-5 calculate $I_S$, $I_1$, $I_2$, and $I_3$.

Note: use KVL and/or KCL
Q#3: For the circuit shown in Figure 3-6 calculate all the currents and voltages signed at the circuit.

Note: use KVL and/or KCL
Biomedical Engineering Department

Electric Circuits lab

BME(311)

Post Report #2
Experiment #3

Dc Circuit Measurements- Part A

1. Student Name ..............................................................................................................

Student ID.....................................................................................................................

2. Student Name ..............................................................................................................

Student ID.....................................................................................................................

3. Student Name ..............................................................................................................

Student ID.....................................................................................................................
1. Series Circuits:

After connect the circuit shown in Figure 3-1 fill the below tables and answer the following questions:

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>$V_{ab}$</th>
<th>$V_{bc}$</th>
<th>$V_{cd}$</th>
<th>$I_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_s = 15V$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Compare the sum of these voltages to $V_s$?

<table>
<thead>
<tr>
<th>Resistance name</th>
<th>Measured Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td></td>
</tr>
</tbody>
</table>

- Use the above values and the measured value of $I_s$ to calculate different voltages by Ohm's law, and compare them with the values obtained previously.

<table>
<thead>
<tr>
<th>Voltage name</th>
<th>Measured value</th>
<th>Calculated values using Ohm's law</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{bc}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{cd}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{de}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Now, use voltage division to calculate different voltages, and compare your results with the measured values.

<table>
<thead>
<tr>
<th>Voltage name</th>
<th>Calculated value</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{ab}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{bc}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{cd}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Parallel Circuits:

- After connect the circuit in Figure 3-2 fill the table below and answer the following questions:

<table>
<thead>
<tr>
<th>$V_s$ Parameter</th>
<th>$I_1$</th>
<th>$I_2$</th>
<th>$I_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_s$=15V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. measure the value of $I_s$ as indicated by DMM2

$I_s$=.................................................................

2. Compare the sum of the above currents with $I_s$?
3. A consequence of KCL is that the current through one conductance
\( G_k = 1/R_k \) in a parallel circuit can be calculated using the current division rule

\[ I_k = \left( \frac{G_k}{G_t} \right) I_t \]

\( G_t \): the sum of all conductance in parallel, including \( G_k \)
\( I_t \): the current into the circuit

- Calculate \( I_1, I_2, \) and \( I_3 \) using this rule, and compare the results with the measured values.
3. Series-Parallel Circuits:

- After connect the circuit in Figure 3-3 record the following results:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_8$</td>
<td></td>
</tr>
<tr>
<td>$V_1$</td>
<td></td>
</tr>
<tr>
<td>$V_2$</td>
<td></td>
</tr>
<tr>
<td>$V_3$</td>
<td></td>
</tr>
<tr>
<td>$V_4$</td>
<td></td>
</tr>
<tr>
<td>$V_5$</td>
<td></td>
</tr>
<tr>
<td>$V_6$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current</th>
<th>DMM value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_1$</td>
<td></td>
</tr>
<tr>
<td>$I_2$</td>
<td></td>
</tr>
<tr>
<td>$I_3$</td>
<td></td>
</tr>
<tr>
<td>$I_4$</td>
<td></td>
</tr>
<tr>
<td>$I_5$</td>
<td></td>
</tr>
<tr>
<td>$I_6$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resistance name</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td></td>
</tr>
<tr>
<td>$R_3$</td>
<td></td>
</tr>
<tr>
<td>$R_4$</td>
<td></td>
</tr>
<tr>
<td>$R_5$</td>
<td></td>
</tr>
<tr>
<td>$R_6$</td>
<td></td>
</tr>
</tbody>
</table>
Now, use the measured values of voltages to verify KVL on all closed paths, and use the measured values of currents to verify KCL at all nodes. Finally, use the measured values of resistances with Ohm's law to calculate voltages using measured currents and vice versa, then compare all the measured quantities.
Conclusion and discussion:

- List your Conclusion about all parts of this experiment, and discuss the results as points:
4.1 Objectives:
The objectives in this experiment are:
1. Measure the current-voltage (I-V) characteristic of a dc power supply with current limit.
2. Measure circuit loading caused by test equipment, viz, the Digital Multimeter (DMM) and the Oscilloscope (Scope).
3. Determine the output (source) resistance of the Function Generator (FG).

4.2 Introduction:

4.2.1 Current-Limited Power Supply I-V Characteristics:
A circuit used to determine the I-V characteristics of a dc power supply is shown in Figure 4-1. For any practical power supply, there is a maximum value of the current $I_S$, Say $I_{\text{max}}$ that can be supplied when the output voltage $V_S$ is set to some level $V_{\text{SO}}$. As long as the current, $I_S$, demanded by the load resistance $R_L$ is not greater than $I_{\text{max}}$, the output voltage $V_{\text{SO}}$ remains constant. If $R_L$ is less than the current-limiting value $R_{\text{lm}} = V_{\text{SO}}/I_{\text{max}}$, the supply voltage $V_S$ must decrease to $I_{\text{max}} \times R_L$ for KVL to be satisfied.

An idealized power-supply I-V characteristic is shown by the solid-line rectangle in Figure 4-2. The broken lines through the origin are the load lines which represent different values of the load resistance $R_L$. These lines intersect the I-V characteristic at the operating points. $V_{\text{SO}}$ is called the open-circuit voltage and $I_{\text{max}}$ the short-circuit current.

A dc power supply designed with a current limit that can be set as desired, automatically adjusts its output voltage to satisfy KVL as has been indicated. You are required to determine the laboratory power supply I-V characteristic for two combinations of $V_{\text{SO}}$ and $I_{\text{max}}$.

---

**Figure 4-1**

**Figure 4-2**
4.2.2 **Circuit Loading by Measuring Instruments:**

Ideally, a measuring instrument should have no effect on the quantity being measured. However, any practical instrument affects the quantity it measures to a certain degree. A voltmeter, for example, has a finite input resistance, although it may be very large. Therefore, it can change the measured circuit significantly if the equivalent circuit resistance is also very high. This is called circuit loading. Subsequent measurements are designed to demonstrate circuit loading caused by the ammeter, the voltmeter, and the oscilloscope. The equivalent resistance of each instrument will be calculated from measurement data.

4.2.2.1 **Ammeter Loading:**

When the DMM used as an ammeter, the equivalent resistance of the DMM may be different for each measurement range. The circuit shown in Figure 4-3(a) is used to measure the equivalent resistance of the ammeter.

4.2.2.2 **Voltmeter Loading:**

Measurements are now made to determine the equivalent resistance of the DMM when used as a voltmeter, and how it affects the accuracy of experimental results. The circuit shown in Figure 4-3(b) is used to measure the equivalent resistance of the ammeter.

Like any other practical voltage source, the FG has a nonzero equivalent resistance, \( R_g \). Therefore, at any fixed amplitude setting, its output voltage changes with load. The extent of this change depends on the value of load resistance relative to that of \( R_g \). The circuit shown in Figure 4-3(d) is used to measure the equivalent resistance of the ammeter.

4.3 **Procedure:**

* ideally the equivalent resistance of the ammeter equal to zero

** ideally the equivalent resistance of the voltmeter is infinity

Figure 4-3: (a) Ammeter Loading circuit (b) Voltmeter Loading circuit (c)
4.3.1 Measure the I-V chars of a DC power supply limited by a current ($I_{\text{max}}$).

1. Set, and adjust the Current Limit control in your power supply to ($I_{\text{max}}$ or $I_{\text{sc}} = 130 \text{ mA}$.) by connect short circuit between (+) and (–) terminals.
2. Disconnect the short circuit, adjust the power supply for $V_{\text{so}} = 10.4\text{V}$.
3. Connect the circuit shown in Figure 4-4 use decade box for $R_1$.
4. Measured the below Values.

<table>
<thead>
<tr>
<th>$R_1$ (Ω)</th>
<th>$\infty$</th>
<th>400</th>
<th>200</th>
<th>100</th>
<th>80</th>
<th>50</th>
<th>20</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{out}}$ (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_s$ (mA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Readjust current limit to $I_{\text{max}} = 80 \text{ mA}$
- Remove $R_1$, adjust the power supply for $V_{\text{so}} = 16\text{V}$.

<table>
<thead>
<tr>
<th>$R_1$ (Ω)</th>
<th>$\infty$</th>
<th>1000</th>
<th>500</th>
<th>300</th>
<th>200</th>
<th>100</th>
<th>50</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{out}}$ (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_s$ (mA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4-4
4.3.2 Circuit Loading By Measurement Instruments:

4.3.2.1 Ammeter Loading:

*Note use the bench top multimeter (GDM-8034) to measure current*

1. Construct the circuit shown in Figure 4-5.
2. Choose \( R = 2.2 \, \text{K} \)
3. Measure \( R \) Using DMM.
   \[ R = \ldots \]

4. Record Current by DMM. Using lowest possible range.
5. Move the voltmeter to measure:
   \[ V_a = \ldots \]
   \[ V_r = \ldots \]

<table>
<thead>
<tr>
<th>Ammeter Range (A)</th>
<th>20m</th>
<th>200m</th>
<th>2000m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculate ( r_a ) (Ω) ( V_a/I )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3.2.2 Voltmeter Loading:

*Note use the bench top multimeter (M 9803 R) to measure voltage*

Measurements are now made to determine the equivalent resistance of the DMM when used at voltmeter, and how it affects the accuracy of results.

1. Construct the Circuit shown in Figure 4-6,
   \( R_1 = 470 \, \text{KΩ}; \, R_2 = 1 \, \text{MΩ}, \, V_s = 30 \, \text{V}. \)

2. Record DMM Mode number .........................................................
3. Measure \( R_1 \) and \( R_2 \) Using ohmmeter
R1=…………………….
R2=…………………….

4. Measure \( V_2 \).

\( V_2 = \ldots \ldots \ldots \)

5. Calculate the equivalent resistance of the DMM using the measured values of \( R_1 \) and \( R_2 \).

**Hint Assume:**

\[
\left( \frac{R_{DMM}}{R_2} \right) = R_{eq} \\
\left( \frac{R_{eq}}{R_{eq} + R_1} \right) \times V_s = V_2
\]
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Electric Circuits lab

BME (311)

Pre-lab Report 3

Experiment#4

Dc Circuit Measurements- Part B

Student Name ………………………………………………………………………………………………………

Student ID…………………………………………………………………………………………………………
Objectives:

1. 

2. 

3. 

Q#1: The circuit shown in Figure4-9 is used to determine the I-V characteristics of DC power supply. If you know that: \(I_{\text{max}} = 100\text{mA}, \) and \(V_{\text{so}} = 16\text{V}:\) Demonstrate the effect of using \(R_1 = 100\Omega\) at both \(I_s\) and \(V_s.\)

![Figure 4-9](image)

Q#2: 1. Use the circuit shown in Figure4-10 to calculate the equivalent resistance of the ammeter.

![Figure 4-10](image)
2. Does the equivalent resistance of the ammeter affected by changing the range of the ammeter? Explain?

Q#3: Use the circuit shown in Figure 4-11 to calculate the equivalent resistance of the voltmeter.

Figure 4-11
Biomedical Engineering Department

Electric Circuits lab

BME (311)

Post Report #3

Experiment #4

**Dc Circuit Measurements- Part B**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Student Name</th>
<th>Student ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Student Name

   Student ID

2. Student Name

   Student ID

3. Student Name

   Student ID
1. Measure the I-V characteristics of DC power supply limited by a current (I_{max}): 

After connecting the circuit shown in Figure 4-4 fill the tables below and answer the following question:

- For $I_{\text{max}}=130\,\text{mA}$, $V_{\text{so}}=10.4\,\text{V}$:

<table>
<thead>
<tr>
<th>R_1 (\Omega)</th>
<th>\infty</th>
<th>400</th>
<th>200</th>
<th>100</th>
<th>80</th>
<th>50</th>
<th>20</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{out} (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_s (mA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- For $I_{\text{max}}=80\,\text{mA}$, $V_{\text{so}}=16\,\text{V}$:

<table>
<thead>
<tr>
<th>R_1 (\Omega)</th>
<th>\infty</th>
<th>1000</th>
<th>500</th>
<th>300</th>
<th>200</th>
<th>100</th>
<th>50</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{out} (V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_s (mA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- For the first table, Plot the I-V characteristics from the taken measurements. Show the load lines and the operating points for $R_I=400$, 80 and 40 $\Omega$. 

\[\text{Is} \quad \text{Vs}\]

1. Ammeter Loading:

After connecting the circuit shown in Figure 4-5 fill the below Values and answer the following questions:

- Measure R Using DMM……………………………………………………………………………
- Record Current By DMM 2. Using lowest range:
- Move the voltmeter to measure:
  \( V_a = \)……………………………….
  \( V_r = \)………………………………
- Calculate \( r_a (\Omega) \)…………………………

<table>
<thead>
<tr>
<th>Ammeter Range (A)</th>
<th>20m</th>
<th>200m</th>
<th>2000m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculate ( r_a (\Omega) )</td>
<td>( V_a/I )</td>
<td>( V_r/I )</td>
<td>( V_r/I )</td>
</tr>
</tbody>
</table>

- Write your observations:-
  …………………………………………………………………………………………………………………
  …………………………………………………………………………………………………………………

2. Voltmeter Loading:-

After connecting the circuit shown in Figure 4-6 fill the below Values and answer the following questions:

- \( V_2 = \) …………..
- \( R_1 \) (measured)=………………
- \( R_2 \) (measured)=………………
• Calculate the equivalent resistance of the voltmeter using the measured values of $R_1$ and $R_2$.

Hint Assume:

$\frac{(R_{\text{DMM}}/R_2)}{R_{\text{eq}}}=R_{\text{eq}}$

$(R_{\text{eq}}/(R_{\text{eq}}+R_1))V_s=V_2$

• How does this value affect the accuracy of experimental results?

Conclusion and discussion:

• List your Conclusion about all parts of this experiment, and discuss the results as points:
5.1 **Objectives:**
1. Verify the Mesh Analysis and the Nodal Analysis methods.
2. Verify the Superposition Principle.
3. Verify Thevenin’s and Maximum Power Transfer theorems.
4. Verify voltage-current Source Transformations.

5.2 **Introduction:**

5.2.1 **Mesh and Nodal Analyses:**

Mesh and Nodal equations are verified using experimental data. Figure 5-1 shows the circuit used for this purpose, where the indicated resistances are in kΩ.

Before coming to the laboratory, the student is required to write these equations using $R_1 = 150\,\Omega$. The equations should be solved for the mesh currents $I_1$, $I_2$, and $I_3$ and the node voltages $V_a$ and $V_b$ indicated in the figure.

![Figure 5-1](image)

5.2.2 **Superposition Principle:**

The circuit of Figure 5-1 is also used to verify the superposition principle, by following the below steps:

1. Replace the first voltage source ($V_{b1}$) with short circuit, but leave the second one ($V_{b2}$) applied. Then measure $I_1'$, $I_2'$, $I_3'$, $V_a'$ and $V_b'$.
2. Repeat the previous step with the first source reapplied ($V_{b1}$), but the second source ($V_{b2}$) replaced with short circuit. Denote these measurements by $I_1''$, $I_2''$, $I_3''$, $V_a''$ and $V_b''$.
3. Compare the sum of each two measurement components with the corresponding total quantity measured.
5.2.3 **Thevenin Equivalent and Maximum Power Transfer:**

Again, the circuit of Figure 5-1 will be used to verify Thevenin’s and the Maximum Power Transfer theorems experimentally.

5.2.3.1 **Thevenin Equivalent:**

Thevenin equivalent circuit wanted is that seen by the load resistance $R_L$. Different methods will be used to determine this circuit, as follows:

1. With both voltage source applied, remove $R_L$ and measure the open-circuit voltage $V_{ao}(o.c.)$. This is the equivalent Thevenin $V_{Th}$.
2. Measure the short-circuit current $I_{ao}(s.c.)$.
3. Determine an experimental value for $R_{Th}$ as $V_{ao}(o.c.)/I_{ao}(s.c.)$.
4. Replace voltage sources with short circuits, and measure the Thevenin equivalent resistance, $R_{Th}$, between node a and the reference node 0 with an ohmmeter.

The Thevenin circuit will be represented by a voltage source equal to $(V_{Th})$ in series with resistor equal to $(R_{Th})$ see figure 5-2.

![Thevenin Equivalent Circuit](image1)

**Figure 5-2: Thevenin equivalent circuit**

5.2.3.2 **Maximum Power Transfer:**

The value of $R_L$ that will receive maximum power is determined experimentally as following:

1. Use decade box for $R_{Lin}$ Figure 5-1.
2. Measure the voltage $V_L$ across each $R_L$ value you select using voltmeter.
3. Calculate the power $P_L = v^2/R_L$.
4. Plot $P_L$ vs $R_L$, and $V_L$ vs $R_L$.
5. Form the plot determine $R_{mp}$ and $V_{mp}$ as following : see Figure 5-3
   a. $R_{mp} = R_{Th}$.
   b. $V_{mp} = V_{Th}/2$

![Power vs Resistance](image2) ![Voltage vs Resistance](image3)

**Figure 5-3: (a) $P_L$ vs $R_L$ curve (b) $V_L$ vs $R_L$ curve**
5.2.4 **Source Transformations**:

As we learned from the previous experiment, there is no ideal sources (the voltage source has a series internal resistor, whereas the current source has a parallel internal resistor). Therefore the goal of Source Transformations is to simplify the circuit and end up with all the sources in the circuit as voltage sources or current sources.

The voltage source with a resistor in series is equal to a current source in parallel with the same resistor. See Figure 5-4

![Figure 5-4](image)

5.3 **Procedure**

5.3.1 **Mesh and Nodal Analysis**:

- Connect the circuit shown in Figure 5-5:

  ![Figure 5-5](image)

  **Note:** Note: $R_1$, $R_2$, $R_3$, and $R_4$ are in $\text{K}\Omega$

  1. Measure the actual resistance values used with DMM.
  2. Use a nominal $150\Omega$ for $R_L$.
  3. Adjust the two outputs of the dual power supply to $16V$ & $24V$.
  4. Measure the currents $I_1$, $I_2$, and $I_3$ using the ammeter on the lowest possible range. Similarly, use the voltmeter to measure the node voltage $V_a$, $V_b$. 


5.3.2 **Superposition Principle:**

The circuit in the Figure 5-5 is also used to verify the superposition principle using the following procedure.

1-Replace the 24-v source with S.C, but leave the 16-vsource applied measure the mesh current and voltages:

<table>
<thead>
<tr>
<th>Current</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I'_1</td>
<td></td>
</tr>
<tr>
<td>I'_2</td>
<td></td>
</tr>
<tr>
<td>I'_3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V'_a</td>
<td></td>
</tr>
<tr>
<td>V'_b</td>
<td></td>
</tr>
</tbody>
</table>

2- Replace the 16-v source with S.C, but leave the 24-vsourc applied measure the mesh current and voltages:

<table>
<thead>
<tr>
<th>Current</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I''_1</td>
<td></td>
</tr>
<tr>
<td>I''_2</td>
<td></td>
</tr>
<tr>
<td>I''_3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V''_a</td>
<td></td>
</tr>
<tr>
<td>V''_b</td>
<td></td>
</tr>
</tbody>
</table>
5.3.3 Thevenin Equivalent:

The circuit of Figure 5-5 will be used to verify Thevenin’s and the maximum power transfer theorems.

1- With 16-v and 24-v sources applied, remove \( R_L \) and measure the open-circuit voltage \( V_{ao \ (O.C)} \) this is the equivalent voltage \( V_{th} \).

2- Measure the S.C current \( I_{ao} \).

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{th} )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{ao} )</td>
<td></td>
</tr>
</tbody>
</table>

3- Replace both voltage sources with S.C and measure the Thevenin Equivalent resistance \( R_{TH} \) between node a and the reference node.

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{TH} )</td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{Determine the Experimental values for } R_{TH} : \]
\[ V_{ao \ (O.C)} / I_{ao \ (S.C)} = \]

5.3.4 Maximum Power Transfer Theory:

1- Use the Decade box for \( R_L \) in Figure 5-5.

2- Measure the voltage \( V_L \) across \( R_L \) and fill the below table.

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Voltage</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500 ( \Omega )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3- Calculate the power:
   \[ P_L = \frac{(V_L)^2}{R_L} \]

4- Plot \( P_L \) & \( V_L \) Vs \( R_L \):

5- From the plot determine the value \( R_{mp} \) of \( R_L \) where \( P_L \) is the Maximum

6- Find the Corresponding value \( V_{mp} \) of \( V_L \):

<table>
<thead>
<tr>
<th>( R_{TH} )</th>
<th>( R_{mp} )</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( V_{TH} / 2 )</th>
<th>( V_{mp} )</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3.5 Source Transformations:

1- Connect the circuit shown at Figure 5-6:

2- Set the short circuit **current limit on each supply to about 200mA**, And then set the open circuit voltages \( V_{S1} = 20V \) and \( V_{S2} = 10V \).
3- Construct the above circuit using 2-Watt resistors \( R_1 = 330\Omega \) and \( R_2 = 100\Omega \). And use a decade box for \( R_o \).

4- Now use two DMM to measure \( V_o \) and \( I_o \) for different values of \( R_o \)

<table>
<thead>
<tr>
<th>( R_o )</th>
<th>Measured ( V_o )</th>
<th>Measured ( I_o )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 K ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 K ( \Omega )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5- For the Circuit Shown at Figure 5-7:
\[ I_{s1} = \frac{V_{s1}}{R_1} = \]
\[ I_{s2} = \frac{V_{s2}}{R_2} = \]
\[ I_{se} = I_{s1} + I_{s2} \]

6- For \( I_{se} \) use a short-circuit-current limited supply

7- Set the open-circuit voltage of the power supply to a value slightly above say 10% above, the value

\[ R_{eq} = \frac{R_1 \parallel R_2}{R_1 \parallel R_2} = \frac{R_1 R_2}{R_1 + R_2} = \]

\[ I_{se} \cdot \left[ \frac{R_1 R_2}{(R_1 + R_2)} \right], \text{ the value is:} \]

\[ V_{se} = I_{se} \times R_{eq} = \]

\[ V_{se} + 10\% \ V_{se} = \]
8- Now measure $V_o$ and $I_o$ for this circuit, for the values of $R_o$ as shown in the following table.

<table>
<thead>
<tr>
<th>$R_o$</th>
<th>Measured $V_o$</th>
<th>Measured $I_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 $K\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 $K\Omega$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9- We now construct the equivalent (transformed) circuit shown below with one voltage source as shown in Figure 5-8

![Figure 5-8](image)

10- set the open-circuit output voltage to the value $I_{se}.[(R_1.R_2/(R_1+R_2))]$ exactly.

$V_{se} =$
11- With $V_{se}$ calculated from previous part $V_{se} = 12$, measure $V_o$ and $I_o$ for this circuit, for the values of $R_o$ as shown in the following table.

<table>
<thead>
<tr>
<th>$R_o$</th>
<th>Measured $V_o$</th>
<th>Measured $I_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 , \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$20 , \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$50 , \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$100 , \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$200 , \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$500 , \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1 , \text{K} , \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$5 , \text{K} , \Omega$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- By comparing the results of the three experiments we can see that the values are equal with small differences. So we can simplify the circuit by transforming it into another form to simplify the measurements and calculations.
Biomedical Engineering Department

Electric Circuits lab

BME (311)

Pre-Report #4

Experiment#5

DC Circuit Analysis

Student Name ………………………………………………………………………………………………………

Student ID……………………………………………………………………………………………………
Objectives:

1.

2.

3.

4.

Q#1: For the circuit shown in figure 5-9 answer the following questions:

Note: R_1, R_2, R_3, and R_4 are in KΩ

1- Calculate I_1, I_2, I_3, V_a, and V_b using mesh and nodal analysis.
2- For the same circuit Calculate $I_1, I_3, V_a,$ and $V_b$ using superposition principle.
3- For the same circuit calculate $V_{TH}$, $R_{TH}$ as seen by $R_L$. 
Q#2: For the circuit shown in figure 5-10 answer the following questions:

![Circuit Diagram](image)

**Figure 5-10**

**Note:** Assume $R_1=330\,\Omega$, $R_2=100\,\Omega$, and $R_O=500\,\Omega$ for all questions.

1. Calculate $I_O$ and $V_O$. 
2- Covert the circuit to a circuit has only one current source and three resistor with the previous values, then calculate the current passing through $R_o$ and the voltage across $R_o$.

3- Cover the circuit that you had at part(2) to a circuit has one voltage source and three resistor with the previous values, then calculate the current passing $R_o$ and the voltage across $R_o$. 
Biomedical Engineering Department

Electric Circuits lab

BME (311)

Post Report #4

Experiment #5

DC Circuit Analysis

1. Student Name …………………………………………………………………………………

Student ID………………………………………………………………………………

2. Student Name …………………………………………………………………………………

Student ID………………………………………………………………………………

3. Student Name …………………………………………………………………………………

Student ID………………………………………………………………………………
I. Mesh and Nodal analysis:

- Measure the currents $I_1$, $I_2$, and $I_3$ using the ammeter on the lowest possible range. Similarly, use the voltmeter to measure the node voltage $V_a$, $V_b$, then record all values at the below table.

<table>
<thead>
<tr>
<th>Current</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_1$</td>
<td></td>
</tr>
<tr>
<td>$I_2$</td>
<td></td>
</tr>
<tr>
<td>$I_3$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_a$</td>
<td></td>
</tr>
<tr>
<td>$V_b$</td>
<td></td>
</tr>
</tbody>
</table>

- Substitute the measured values of resistances, source voltages, and mesh currents into the mesh equations, group all terms in every equation on one side and compare their sum with zero. Explain any discrepancies.
Substitute the measured values of resistances and voltages into the nodal equations, group all terms in every equation on one side and compare their sum with zero. Explain any discrepancies.

2. **Part Two: Superposition Principle:**

- Replace the 24-v source with S.C, but leave the 16-vsource applied measure the mesh currents and voltages:

<table>
<thead>
<tr>
<th>Current</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I'_1)</td>
<td></td>
</tr>
<tr>
<td>(I'_2)</td>
<td></td>
</tr>
<tr>
<td>(I'_3)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V'_{a})</td>
<td></td>
</tr>
<tr>
<td>(V'_{b})</td>
<td></td>
</tr>
</tbody>
</table>
• Replace the 16-v source with S.C, but leave the 24-vsource applied measure the mesh currents and voltages:

<table>
<thead>
<tr>
<th>Current</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I''_1$</td>
<td></td>
</tr>
<tr>
<td>$I''_2$</td>
<td></td>
</tr>
<tr>
<td>$I''_3$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V''_a$</td>
<td></td>
</tr>
<tr>
<td>$V''_b$</td>
<td></td>
</tr>
</tbody>
</table>

• Compare the sum of each two measurement components with the corresponding total quantity measured.

1. $(I'_1 + I''_1 = I_1)$

2. $(I'_2 + I''_2 = I_2)$

3. $(I'_3 + I''_3 = I_3)$

4. $(V'_a + V''_a = V_a)$

5. $(V'_b + V''_b = V_b)$
3. **Thevenin Equivalent:**

- Fill the below measurements:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{th} )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{ao} )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{TH} )</td>
<td></td>
</tr>
</tbody>
</table>

- Determine the Experimental values for \( R_{TH} \):

\[
\frac{V_{ao \ (O.C)}}{I_{ao \ (S.C)}} =
\]

4. **Maximum Power Transfer:**

- Fill the below table:

<table>
<thead>
<tr>
<th>Resistance (( R_L ))</th>
<th>Voltage</th>
<th>Power (( P_L = \frac{(V_L)^2}{R_L} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500 ( \Omega )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Plot $R_L$ & $V_L$ vs $p$:

• From the plot determine the value $R_{mp}$ of $R_L$ where $P_L$ is the Maximum.

• From the plot determine the Corresponding value $V_{mp}$ of $V_L$ where $P_L$ is the Maximum.

<table>
<thead>
<tr>
<th>$R_{TH}$</th>
<th>$R_{mp}$</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$V_{TH} / 2$</th>
<th>$V_{mp}$</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Source Transformations:

Fill the below table with the measurement taken from the circuit at Figure 5-6

<table>
<thead>
<tr>
<th>Ro</th>
<th>Measured Vo</th>
<th>Measured Io</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 K Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 K Ω</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Perform the following calculations to find the value of the short circuit current at Figure 5-7:

\[ I_{S1} = \frac{V_{S1}}{R_1} = \]

\[ I_{S2} = \frac{V_{S2}}{R_2} = \]

\[ I_{se} = I_{s1} + I_{s2} \]

Perform the following calculations to find the value of the open circuit voltage at Figure 5-4:

\[ I_{se} \times \frac{R_1 \times R_2}{R_1 + R_2}, \text{ the value is:} \]

\[ R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} = \]

\[ V_{se} = I_{se} \times R_{eq} = \]

\[ V_{se} + 10\% \ V_{se} = \]
- Fill the below table with the measurement taken from the circuit at Figure 5-7:

<table>
<thead>
<tr>
<th>Ro</th>
<th>Measured Vo</th>
<th>Measured Io</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 K Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 K Ω</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Calculate the open-circuit output voltage.

\[ V_s = I_{se} \cdot \frac{R_1 \cdot R_2}{R_1 + R_2} \]

- Fill the below table with the measurement taken from the circuit at Figure 5-8:

<table>
<thead>
<tr>
<th>Ro</th>
<th>Measured Vo</th>
<th>Measured Io</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 K Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 K Ω</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Compare the results of the three sets of measurements made, and explain any discrepancies.
Conclusion and discussion:

- List your Conclusion about all parts of this experiment, and discuss the results as points:
6.1 **Objectives:**
The objectives in this experiment are:
1. Measure circuit loading caused by Oscilloscope (Scope).
2. Determine the output (source) resistance of the Function Generator (FG).

6.2 **Introduction:**

6.2.1 **Oscilloscope Loading:**

A measurement procedure is now used to determine the equivalent input resistance $R_{in}$ of one of the Scope channels. The effect of this resistance on the accuracy of voltage amplitude measurements will then be evaluated. The circuit shown in Figure 6-1(a) is used to measure the equivalent resistance of the ammeter.

6.2.1.1 **Function Generator equivalent resistance:**

Like any other practical voltage source, the FG has a nonzero equivalent resistance, $R_g$. Therefore, at any fixed amplitude setting, its output voltage changes with load. The extent of this change depends on the value of load resistance relative to that of $R_g$. The circuit shown in Figure 6-1(b) is used to measure the equivalent resistance of the ammeter.

---

![Figure 6-1](image)

Figure 6-1: (a) Oscilloscope equivalent resistance circuit (b) Function generator equivalent resistance circuit
6.3 **Procedure:**

6.3.1 **Oscilloscope equivalent resistance:**

1. Construct the Circuit shown in Figure 6-2.
2. Use Decade box for $R_2$.
3. Use $R_1 = 1$ MΩ.
   
   $R_1$ measured

4. Set the function generator frequency to **1 KHz sine wave 8 V<sub>pp</sub>** then connect it to CH₁ of the scope.
5. Connect CH₂ with the voltage o/p at $R_2$ **set the scope DC coupling**.

![Figure 6-2](image)

6. Measure $V_2$:

<table>
<thead>
<tr>
<th>R2</th>
<th>$R_2$ measured By DMM</th>
<th>$V_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 KΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 MΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2 MΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 MΩ</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- You need to use the above results to calculate the equivalent Scope input resistance $R_{in}$ using the measured values of $R_1$ and $R_2$. 
6.3.2 Function generator equivalent resistance:

![Function Generator Circuit Diagram](image)

Figure 6-3

1. Construct the circuit shown in Figure 6-3 (use decade box for R_L).

2. Set the function generator frequency to **10 KHz sine wave With 1V_{rms}** (Apply the o/p of function generator to the DMM, AC measurements, or to Ch1 of the oscilloscope direct).

3. Measure \( V_o \) for different values of R_L.

<table>
<thead>
<tr>
<th>R_L</th>
<th>( V_{out} ) (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 KΩ</td>
<td></td>
</tr>
<tr>
<td>1 KΩ</td>
<td></td>
</tr>
<tr>
<td>500Ω</td>
<td></td>
</tr>
<tr>
<td>200Ω</td>
<td></td>
</tr>
<tr>
<td>75 Ω</td>
<td></td>
</tr>
<tr>
<td>50 Ω</td>
<td></td>
</tr>
</tbody>
</table>

4. Change the frequency of function generator but keep its amplitude constant at 1V_{rms}. Then measure \( V_o \). (With R_L=50Ω)

<table>
<thead>
<tr>
<th>Frequency Value</th>
<th>( V_{out} ) (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f = 1 ) KHz</td>
<td></td>
</tr>
<tr>
<td>( f = 10 ) KHz</td>
<td></td>
</tr>
<tr>
<td>( f = 100 ) KHz</td>
<td></td>
</tr>
<tr>
<td>( f = 1 ) MHz</td>
<td></td>
</tr>
</tbody>
</table>

- You need to use the above results to calculate the equivalent resistance of the FG At 10 KHz frequency.
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BME (311)

Pre-lab Report 5

Experiment#6

Laboratory Instrument Loading Effect Part-B

Student Name ………………………………………………………………………………………………..

Student ID………………………………………………………………………………………………..
Objectives:

1.

2.

Q#1: Use the circuit shown in Figure 6-4 to calculate the oscilloscope equivalent input resistance $R_{in}$.

Note: assume $R_g=0$.  

![Figure 6-4](image)
Q#2: Use the circuit shown in Figure 6-5 to calculate the equivalent resistance of the Function generator $R_g$. 

Figure 0-5
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Electric Circuits lab

BME (311)

Post Report #5

Experiment#6

Laboratory Instrument Loading Effect Part-B

1. Student Name .................................................................

Student ID............................................................................

2. Student Name .................................................................

Student ID............................................................................

3. Student Name .................................................................

Student ID............................................................................
1. Oscilloscope equivalent resistance:

After connecting the circuit shown in Figure 6-2 fill the below Values and answer the following question:

- R₁ measured = .................................................................

- Measure V₂:

<table>
<thead>
<tr>
<th>R₂</th>
<th>R₂ measured By DMM</th>
<th>V₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 KΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 MΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 MΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3 MΩ</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Use the above results to calculate the equivalent Scope input resistance Rᵢᵢ using the measured values of R₁ and R₂. **Hint 1. Use data measured with R₂ = 1 MΩ**
  1. (the same equation as voltmeter at experiment #4)
2. Function generator equivalent resistance:

After connecting the circuit shown in Figure 4-8 fill the below tables and answer the following questions:

<table>
<thead>
<tr>
<th>RL</th>
<th>V_{out} (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 KΩ</td>
<td></td>
</tr>
<tr>
<td>1 KΩ</td>
<td></td>
</tr>
<tr>
<td>500Ω</td>
<td></td>
</tr>
<tr>
<td>200Ω</td>
<td></td>
</tr>
<tr>
<td>75 Ω</td>
<td></td>
</tr>
<tr>
<td>50 Ω</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency Value</th>
<th>V_{out} (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F = 1 \text{ KHz} )</td>
<td></td>
</tr>
<tr>
<td>( F = 10 \text{ KHz} )</td>
<td></td>
</tr>
<tr>
<td>( F = 100 \text{ KHz} )</td>
<td></td>
</tr>
<tr>
<td>( F = 1 \text{ MHz} )</td>
<td></td>
</tr>
</tbody>
</table>

- What is the difference between rms value and \( V_{o_{p-p}} \)?

- Use the above results to calculate the equivalent resistance of the FG at 10 KHz frequency.
Conclusion and discussion:

- List your Conclusion about all parts of this experiment, and discuss the results as points:
7.1 **Objectives:**
2. Measurement verification of current-voltage (i-v) relations for inductance and capacitance.
3. Measurement verification of RL and RC circuit time constant.

7.2 **Introduction:**

7.2.1 **Inductance and Capacitance: Voltage-Current Relations:**

Ideal inductors and capacitors can store energy, but their average power loss is zero. Practical components, however, lose a finite amount of energy. Therefore, in addition to inductance and capacitance, their electrical circuit models include resistance as shown in Figure 7-1.

![Figure 7-1: Circuit Models for Practical Inductors and Capacitors](image)

From the figure,

\[ v_t = v_L + v_{RL} = L \frac{di_L}{dt} + R_L i_L \]  

(1)

and

\[ it = iC + i_{RC} = C \frac{dv_C}{dt} + RL i_L \]  

(2)

For high quality components, \( R_L \) is relatively small and \( R_C \) is relatively large. Thus, if \(\frac{di_t}{dt}\) are large enough, then \( V_{RL} \ll V_L \) and \( i_{RC} \ll i_C \). Consequently,

\[ v_t \approx v_L = L \frac{di_L}{dt} \]  

(3)

and

\[ i_t \approx i_C = C \frac{dv_C}{dt} \]  

(4)
7.2.2 RL and RC Circuit Transients:

A series RL circuit with a step input voltage is shown in Figure 7-2 (a). For an initial current \( i_L(0) = I_0 \), which may be positive or negative, the inductor current and voltage transient responses for \( t \geq 0 \) are given by:

\[
i_L(t) = \frac{V_m}{R} - \left( \frac{V_m}{R} - I_o \right) e^{-t/\tau} \tag{5}\]

and

\[
v_L(t) = (V_m - I_o R)e^{-t/\tau} \tag{6}\]

Where

\[
\tau = \frac{L}{R} \tag{7}\]

is the circuit time constant. Figures 7-2 (b) and 7-2 (c) depict the responses given by equations (5) and (6) with \( V_m > 0 \) and \( I_o < 0 \).

A basic feature of the exponential function having the general form

\[
y(t) = y_f - \left[ y_f - y_i \right] e^{-t/\tau} \tag{8}\]

where \( y_i \) is the final value of \( y \) and \( y_i \) is its initial value, is that \( \tau \) can be calculated using any two points, \( y_1 \) and \( y_2 \), corresponding to \( t_1 \) and \( t_2 \), respectively, viz,

\[
\tau = \frac{t_2 - t_1}{\ln(y_f-y_1) - \ln(y_f-y_2)} \tag{9}\]

It is noted that \( y_i \approx y(t \geq 5 \tau) \).

For the special case where \( (t_2 - t_1) = \tau \), equation (9) yields:

\[
y_2 - y_1 = (1 - e^{-1}) (y_f - y_1) = 0.632 (y_f - y_1) \tag{10}\]

That is, about 63% of the change from \( y_1 \) to \( y_f \) occurs in one time constant. Likewise, one can show that 99.3% of this change occurs in five time constants.
Similarly, for the RC circuit shown in Figure 7-3(a), the transient responses $V_C(t)$ and $i_C(t)$ are shown in Figures 7-5(b) and 7-5(c) for an initial capacitor voltage $V_C(0) = V_o < 0$.

The applicable equations for this case are:

$$v_C(t) = V_m - (V_m - V_o) e^{-t/\tau} \quad (11)$$

$$i_C(t) = \frac{V_m - V_o}{R} e^{-t/\tau} \quad (12)$$

and

$$\tau = RC \quad (13)$$

**7.3 Procedure:**

**7.3.1 Inductor Test:**

1- Obtain an inductor decade box, and use DMM to measure the DC resistance $R_L$ at 400-mH setting.

2- Construct the circuit shown in Figure 7-4 Where $V_s$ is 4-Vp-p, 2-KHz square wave, and $R_s = 47 \Omega$
<table>
<thead>
<tr>
<th>RL (measured)</th>
<th>Rs = 47Ω</th>
<th>L = 400 mH</th>
</tr>
</thead>
</table>

Period of input $V_s(t)$ \((T) = \frac{1}{F}\) = ……………………………

3- Display the FG output voltage $V_S$ and $V_2$ across $R_s$. Make an accurate sketch of both signals showing values of time and amplitude.

### 3.2. Capacitor Test:

1- Obtain a capacitor decade box and use a DMM to measure the DC resistance $R_C$, at the 0.02 μF setting.

2- Construct the circuit shown in the **Figure 7-5** Where $V_s$ is 8 Vp-p 200-Hz Triangular wave, and $R_s$ = 500Ω.

3- Display the FG output Voltage $V_1$ and $V_2$ across $R_S$ together, uses DC coupling on both scope channels.
4- Sketch V₁ & V₂ showing values of time and amplitude.

3.3. RL-Circuit Transient Tests:

![RL Circuit Diagram]

**Figure 7-6**

1- Construct the RL circuit of **Figure 7-6**, using R = 1 K ohm’s L = 1 H.

2- Measure the dc resistance of the inductor and the actual value of R with an Ohmmeter.

**Note:** Remember to record the 50-ohm’s source resistance of the FG found in previous experiment.

<table>
<thead>
<tr>
<th>R&lt;sub&gt;g&lt;/sub&gt;</th>
<th>R&lt;sub&gt;L&lt;/sub&gt;</th>
<th>R(measured)</th>
<th>τ = ( \frac{L}{R_L + R_g + R} )</th>
<th>T/2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3- Use a 100-Hz symmetrical square wave from the FG, with voltage = 4 Vp-p.

4- Connect the Oscilloscope to measure VL (t). See Figure 7-7

6- Make an accurate sketch of VL(t), then expand the time scale to make an accurate measurement of \( \tau \) using the 63\% change Criterion.

7- measure \( \tau \) using two-point method:

<table>
<thead>
<tr>
<th>( t_1 )</th>
<th>( Y_1 )</th>
<th>( t_2 )</th>
<th>( Y_2 )</th>
<th>( Y_f )</th>
</tr>
</thead>
</table>

Record the measured value………………………………………………………………
8- Exchange the positions of R and L in the circuit to enable the display of $V_R$ By Using a common ground between the scope and FG, then sketch $V_R$.

### 3.4. RC transient Tests:

1. For the RC circuit shown in Fig 6-8. Use a 100-Hz symmetrical square wave from the FG, with voltage = 4 Vp-p.
2. Select $R = 100 \, \text{K} \, \Omega$ and $C = 10 \, \text{nF}$ Measure the actual value of resistance $R$ with an ohmmeter and calculate theoretical value of the time $\tau = RC$.

\[ R(\text{measured}) = \]

\[ \tau = RC \]

3. Make an accurate sketch of $V_C(t)$, then expand the time scale to make an accurate measurement of $\tau$ using the 63% change Criterion.

Record the measured value……………………………………………………………………
4- Measure $\tau$ using two-point method:

\[
t_1 = T_1 = \frac{t_2 = T_2}{Y_f = Y_f}
\]

5- Exchange the positions of R and C in the circuit to enable the display of $V_R$ by using a common ground between the scope and FG, then sketch $V_R$. 
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BME(311)

Pre-Report #6

Experiment#7

Inductance, Capacitance I-V Relations and Transients in RL and RC Circuits

Student Name ........................................................................................................................................

Student ID........................................................................................................................................
Objectives:

1. 

2. 

**Q#1:** draw the ideal and the practical circuit model for the inductors and capacitors, then explain briefly the reasons of the differences between ideal and practical model.

**Q#2:** 1. For the RL circuit shown in Figure 7-8 plot $V_{in}$ and $V_{out}$ at the same sit of axis.

**Note:** show only the shape of both signals without the nominal values of the voltages.
2. Calculate the time constant (τ) for the circuit.

Q#3: 1. For the RC circuit shown in Figure 7-10 plot $V_S$ and $V_{out}$ at the same sit of axis.

Note: show only the shape of both signals without the nominal values of the voltages

2. Calculate the time constant (τ) for the circuit.
Q#4: Derive the below equation:

\[ \tau = \frac{t_2 - t_1}{\ln(y_f - y_1) - \ln(y_f - y_2)} \]

Note: start from the following formula:

\[ y(t) = y_f - (y_f - y_i) e^{-t/\tau} \]

Q#5: use the same equation of question #4 to prove that about 63% of the change from \( Y_1 \) to \( Y_f \) occurs in one time constant.
Biomedical Engineering Department

Electric Circuits lab

BME(311)

Post Report #6

Experiment#7

Inductance, Capacitance I-V Relations and Transients in RL and RC Circuits

1. Student Name …………………………………………………………………………………

Student ID…………………………………………………………………………………………

2. Student Name …………………………………………………………………………………

Student ID…………………………………………………………………………………………

3. Student Name …………………………………………………………………………………

Student ID…………………………………………………………………………………………
1. Inductance and Capacitance Voltage-Current Relations.

1.1 Inductor Test:

1-Use DMM to measure the DC resistance $R_L$ at 400-mH setting………

<table>
<thead>
<tr>
<th>$R_L$</th>
<th>$R_s = 47\Omega$</th>
<th>$L = 400 \text{ mH}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>period of input $V_s(t)$ $(T)=$</td>
</tr>
</tbody>
</table>

2-Make an accurate sketch of both signals showing values of time and amplitude for (Ch1,Ch2)

3-Calculate $(L / R_L)$, then compare with the value of $(T/2)$.

$L / R_L =$

$T / 2 =$
4. Calculate an approximate expression for $I_L = (1/L) \int V_L \, dt$, using the 400-mH nominal value of $L$, and $V_L \approx V_s(t)$, then compared with measure $i_L(t)$.

\[ i_L(t) = \frac{1}{4} \times \int V_L \, dt = \]

\[ i_L = \frac{V_L(t)}{R_s} = \]

5. Use $V_L(t) = V_s(t)$ and $\frac{di_L}{dt}$ from measurements in the expression $V_L(t) = L \frac{di_L}{dt}$ to calculate an approximation value for $L$ compare with nominal value 400 mH. (Note: use only one point to calculate $L$)
1.2. Capacitor Test:

1- Make an accurate sketch of both signals showing values of time and amplitude for (Ch1,Ch2).

2- Calculate an approximate expression for \( i_C(t) = C \cdot \frac{dv}{dt} \), By using the 0.02 \( \mu \text{F} \) Nominal value for \( C \), and \( \frac{dv_C}{dt} = \frac{dV_2}{dt} \) then Compared with the measured \( i_C(t) \).

\[ i_C(t) = C\left(\frac{dv_C}{dt}\right) = \]

\[ i_{\text{Measured}}(t) = \frac{V_2(t)}{R_s} = \]
3- In the expression $V_C(t) = \frac{1}{C} \int i_C(t) \, dt$, use $V_C(t) \approx V_S(t)$ and the measured $i_C(t)$ to calculate an approximate value for $C$, then compare with the nominal value of .02µF. (Note: use only one point to calculate $C$)

2. RL & RC Circuit Transients:

2.1. RL-Circuit Transient Tests:

1- Measure the dc resistance of the inductor and the actual value of $R$ with an Ohmmeter and calculate the value of $\tau$.

<table>
<thead>
<tr>
<th>$R_g$</th>
<th>$R_L$</th>
<th>$R$(measured)</th>
<th>$\tau = \frac{L}{R_L + R_g + R}$</th>
<th>$T/2$</th>
</tr>
</thead>
</table>

2- Make an accurate sketch of $V_L(t)$, then calculate $\tau$ using the 63% change criterion.

Record the measured value of $\tau =$……………………………………………………………………
3- measure \( \tau \) using two-point method:

| \( t_1 \) | \( Y_1 \) | \( t_2 \) | \( Y_2 \) | \( Y_f \) |

\[ \tau = \frac{t_2 - t_1}{\ln(Y_f - Y_1) - \ln(Y_f - Y_2)} \]

4- Calculate an approximate expression for \( I_L(t) \) using the following formula:

\[ I_L(t) = \frac{V_m}{R_{total}} \cdot \left[ \frac{V_m}{R_{total}} - I_o \right] \cdot e^{(-t/\tau)} \]

where:

\[ V_m = \frac{V_s}{p-p/2} \]

\[ R_{total} = R_L + R_g + R_1 \]

Assume: \( I_o = 0 \) A

5- Exchange the positions of R and L in the circuit to enable the display of \( V_R \) By Using a common ground between the scope and FG
6. Draw \([V_L(t)+V_2(t)]\) and compare the result with input voltage.

2.2. RC transient Tests:

1. Measure the actual value of resistance \(R\) with an ohmmeter and calculate theoretical value of the time \(\tau = RC\).
   
   \[ R_{\text{Measured}} = \ldots \]
   
   \[ \tau = RC = \ldots \]

2. Make an accurate sketch of \(V_c(t)\), then calculate \(\tau\) using the 63% change criterion.

Record the measured value of \(\tau = \ldots\)
3- Measure $\tau$ using two-point method:

\[
t_1 = Y_1 = t_2 = Y_2 = Y_f = \tau = \frac{t_2 - t_1}{\ln(Y_f - Y_1) - \ln(Y_f - Y_2)}
\]

4- Calculate an approximate expression for $I_c(t)$ using the following formula:

\[
I_c(t) = \frac{V_m}{R_{total}} - \left[ \frac{V_m - V_o}{R_{total}} \right] * e^{(-t/\tau)}, \text{ where:}
\]

- $V_m = V_{sp-p}/2$
- $R_{total} = R_g + R_1$
- Assume : $V_o = 1.8V$

5- Exchange the positions of R and C in the circuit to enable the display of $V_R$ By Using a common ground between the scope and FG.
6- Draw \([V_c(t)+V_2(t)]\) and compare the result with input voltage.

- **Conclusion and discussion:**
- List your Conclusion about all parts of this experiment, and discuss the results as points:
8.1 **Objectives:**
Measurement verification of transient parameters, in RLC circuits, viz, damping factor, and natural frequency.

8.2 **Introduction:**

8.2.1 **Series RLC Circuit Transients:**

A series RLC circuit is shown in Figure 8-1(a) with a step input voltage. This circuit exhibits three types of transient responses. These are determined by the roots of the characteristic equation (complex frequencies):

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

(1)

Viz,

\[ s_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_o^2} \]  

(2)

The **damping factor**, \( \alpha \), and the **resonant frequency**, \( \omega_o \), are given by:

\[ \alpha = \frac{R}{2L} \]  

(3)

and

\[ \omega_o = \frac{1}{\sqrt{LC}} \]  

(4)

![Figure 8-1: (a) RLC circuit, and transient responses (b) underdamped, (c) critically damped, (d) overdamped.](https://voer.edu.vn/m/second-order-circuits/072b46c4)
8.2.1.1 The Underdamped Case:

If \( \omega_o > \alpha \) the two roots \( s_1 \) and \( s_2 \) given by equation (2) are complex conjugate, and the response is an exponentially decaying sinusoidal oscillation. Such a response is said to be underdamped. Figure 1(b) shows the current response with initial conditions \( V_C(0) = V_{C0} \) and \( i(0) = 0 \).

With assumed initial conditions \( V_C(0) = V_{C0} \) and \( i(0) = 0 \), the current in Figure 8-1(b) is given by:

\[
i(t) = I_e e^{-\alpha t} \sin(\omega_d t),
\]

where

\[
\omega_d = \sqrt{\omega_o^2 + \alpha^2}
\]

is the natural frequency of the system, and

\[
I_e = \frac{(V_m - V_{C0})}{(\omega_d L)}
\]

is the amplitude of the exponential envelope, \( \pm I_e e^{-\alpha t} \), shown by the dotted lines, at \( t = 0 \), and \( V_m \) is the input square-wave peak. It is clear from equation (5) that the zero crossings of \( i(t) \) occur at multiples of \( T/2 \), where \( T = 2\pi/\omega_d \) is the period of oscillation. Thus, \( \omega_d \), may be found from a measurement of the period \( T \), i.e.,

\[
\omega_d = \frac{2\pi}{T}
\]

For small damping, i.e., \( \alpha \ll \omega_o \), the exponential envelope in Figure 8-1(b) is tangent to the \( i(t) \) curve near the extremum points, which are also separated by \( T/2 \). Thus, \( \alpha \) may be calculated from peak-current measurements using the relation:

\[
\alpha = \frac{1}{T} \ln(I_{p1}/I_{p2})
\]

8.2.1.2 The Critically-Damped Case:

If \( \omega_o = \alpha \), the two roots are real and equal, and the current response in this case is an exponential pulse as shown in Figure 8-1(c). This response is said to be critically damped, and settles toward its final value considerably faster than the underdamped response.

Assuming the initial conditions are again \( V_C(0) = V_{C0} \) and \( I(0) = 0 \), the exponential current pulse in this case is given by:

\[
i(t) = [(V_m - V_{C0})/L] t e^{-\alpha t}
\]

The maximum value of this current is:

\[
I_m = \frac{2 (V_m - V_{C0}) e^{-1}}{R}
\]

And occurs at

\[
t_m = 1/\alpha
\]
an alternative formula to equation (12) for calculating $\alpha$ from experimental data is:

$$\alpha = \left[ \ln \left( \frac{t_2}{t_1} \right) / (t_2 - t_1) \right]$$  \hspace{1cm} (13)

where $t_2$ and $t_1$ are any two points with $i(t_2) = i(t_2) = I_{12}$, as indicated in Figure8-1(c).

8.2.1.3 The Over-Damped Case:

If $\omega_o < \alpha$, the two roots are real and unequal, and the current response in this case is an exponential pulse as shown in Figure8-1(d). However, it settles toward its final value more slowly than the critically damped response, and is said to be overdamped.

Once more assuming the initial conditions $V_C(0) = V_{C0}$ and $I(0) = 0$, the exponential current pulse in this case is given by:

$$i(t) = A(e^{-\alpha_1 t} - e^{-\alpha_2 t})$$ \hspace{1cm} (14)

Where

$$A = (V_m - V_{C0}) / [(\alpha_2 - \alpha_1) L]$$ \hspace{1cm} (15)

and

$$\alpha_1 = \alpha + \sqrt{\alpha^2 - \omega_o^2}$$  \hspace{1cm} (16)

$$\alpha_2 = \alpha - \sqrt{\alpha^2 - \omega_o^2}$$  \hspace{1cm} (17)

The maximum value, $I_m$, of this current occurs at:

$$t_m = \left[ \ln(\alpha_2/\alpha_1) \right] / (\alpha_2 - \alpha_1)$$ \hspace{1cm} (18)

In general, two distinct measurements of current, $I_1 = I(t_1)$ and $I_2 = I(t_2)$ are sufficient to determine $\alpha_1$ and $\alpha_2$. This, however, requires the numerical solution of two simultaneous transcendental equations of the form (8).

With any appreciable overdamping, $\alpha_1$ and $\alpha_2$ become widely separated, i.e., $\alpha_1 \ll \alpha_2$. For example, if $R = 2R_{cd}$, then $\alpha_2 \approx 14 \alpha_1$. In this case, for two values of $t$ appreciably greater than $t_m$, say $t > 2t_m$, the current may be well approximated by:

$$i(t) \approx A e^{-\alpha_1 t}; \hspace{1cm} t > 2t_m.$$ \hspace{1cm} (19)

Now, $\alpha_1$ is simply expressed in terms of two experimental measurements as illustrated in Figure7-1(c), viz,

$$\alpha_1 = \left[ \ln \left( \frac{I_1}{I_2} \right) \right] / (t_2 - t_1)$$ \hspace{1cm} (20)

Substituting this and the previously measured value of $\omega_o$ into equation (16) yields:

$$\alpha \approx \frac{\alpha_1^2 + \omega_o^2}{2 \alpha_1}$$ \hspace{1cm} (21)

Finally, using equations (16) and (17),

$$\alpha_2 = 2 \alpha - \alpha_1$$ \hspace{1cm} (22)
8.2.2 Parallel RLC Circuit Transients:

A parallel RLC circuit with a current source is the dual of a series RLC circuit with a voltage source. Therefore, all the formulas given previously apply to the parallel circuit provided we replace $R$ with $1/R$, $L$ with $C$, and $C$ with $L$. See figure 8-2.

![Figure 8-2](image)

8.3 Procedure:

8.3.1 The under damped Case:

Construct the circuit shown in Figure 8-3 using the following $R=1.5\,k\Omega$, $L=500\,mH$, $C=10\,nF$, and use a square wave input with $4V_p-p$ at $100Hz$ frequency.

![Figure 8-3](image)

2-Measure the resistance of the inductor used

3-Display about 2 periods of oscillation of voltage $V_R(t)$ which is proportional to the desired current $i(t)$. (See Figure 8-4).

![Figure 8-4](image)
4-Measure the following data:

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>I_{P1}</th>
<th>I_{P2}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: you need these results to calculate $\alpha$, $\omega_d$, $\omega_z$ using equations (7), (8), (6) respectively then compare these values with theoretical values.

8.3.2 The Critically damped Case:

1- Use the same circuit as in Figure8-1, but let $R$: decade Box.

2-Display $V_R(t)$ on Oscilloscope, Increase $R$ Gradually until the oscillation just disappears. **Figure8-5**

3-Measure the Following data:-

<table>
<thead>
<tr>
<th>$R_{\text{measured}}$</th>
<th>Im: $V_m/R$</th>
<th>tm</th>
<th>t_1</th>
<th>t_2</th>
<th>I_{12}: $V_{12}/R$</th>
<th>V_{eq}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4- Interchange the physical position of $R$ and $C$ in the test circuit. Display $V_C(t)$ on the oscilloscope and measure its initial value $V_{CO}$.

Note: you need the above results to calculate $\alpha$ using equations (12), (13) and compare these values with theoretical value obtained using equation (16). also compare the value of $I_{eq}$ measured directly with the value calculated using equation (11).
8.3.3 The over Damped Case:

1- Use the same circuit as in Figure 8-1, but Let $R=25\Omega$

2- Display $V_R(t)$ on Oscilloscope, which is proportional to the desired current $i(t)$, see Figure 8-6

![Figure 8-6](image)

3- Measure the following data:

<table>
<thead>
<tr>
<th>$t_m$</th>
<th>$t_1$</th>
<th>$t_2$</th>
<th>$I_m$</th>
<th>$I_1$</th>
<th>$I_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: you need these results to calculate $\alpha_1$, $\alpha_2$, and $\alpha_3$ using equations (20), (21), (22) then compare these values with theoretical values.*
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Electric Circuits lab
BME (311)

Pre-Report #7
Experiment#8

Transients in RLC Circuits

Student Name ……………………………………………………………………………………………

Student ID…………………………………………………………………………………………

Objectives:
Q#1: For the circuit shown in Figure 8-7:

1. Calculate the damping factor, the resonance frequency, the complex frequencies, and the natural frequency.

2. Determine whether the response is under-damped, over-damped, or critically-damped. 
   **Note:** Show in details how you decide the answer.

3. Plot $i(t)$. 
   **Note:** show only the shape of the signals
without the nominal values of the current.

Q#2: For the circuit shown in Figure8-8:

1. Calculate the damping factor, the resonance frequency, the complex frequencies, and the time where the maximum value of the current occurs.

2. Determine whether the response is under-damped, over-damped, or critically-damped. 
   **Note:** Show in details how you decide the answer.

3. plot i(t).
**Note:** show only the shape of the signals without the nominal values of the current.

**Q#3:** For the circuit shown in Figure 8-9:

1. Calculate the damping factor, the resonance frequency, the complex frequencies, and the time where the maximum value of the current occurs.

2. Determine whether the response is under-damped, over-damped, or critically-damped.  
   **Note:** Show in details how you decide the answer.
3. plot $i(t)$.

**Note:** show only the shape of the signals without the nominal values of the current.
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Electric Circuits lab

BME(311)

Post Report #7

Experiment#8

Transients in RLC Circuits

1. Student Name

2. Student Name

3. Student Name

1. The Under Damped Case:
1. Sketch $V_R(t)$:

![Graph](image)

2. Fill the below measured values:

<table>
<thead>
<tr>
<th>T</th>
<th>$I_{P1}$</th>
<th>$I_{P2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. From the measured data, calculate:

A. $\alpha$ from equation (9)

B. $\omega_d$ from equation (8)

C. $\omega_0$ from equation (6)

4. Calculate the above parameters using equations (3+4+5), then compare between the measured and the calculated one.
2. Critical damped Case:

1. The value of R (decade Box) = ……………………………

2. Sketch $V_R(t)$, $V_C(t)$:

3. Fill the below measured values:

<table>
<thead>
<tr>
<th>Im: $V_m/R$</th>
<th>tm</th>
<th>$t_1$</th>
<th>$t_2$</th>
<th>I_{12}: $V/R$</th>
<th>Vco</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. From the measured data, calculate, then compare with the theoretical values:
A. \[ \alpha \] from equation (12) then from equation (13)

B. \[ I_m \] from equation (11)

3. The Over Damped Case

1. Sketch \( V_R(t) \):

2. Fill the below measured values:
3. From the measured data, calculate, then compare with the theoretical values:

A. \( \alpha_1 \) from equation (20)

B. \( \alpha \) from equation (21, 4)

C. \( \alpha_2 \) from equation (22)

**Conclusion and discussion:**
*List your Conclusion about all parts of this experiment, and discuss the results as points:*
Exp#9 : Sinusoidal AC Circuit Measurements
9.1 **Objectives:**
3. Learn phase-angle measurement techniques using the oscilloscope, and verify the sinusoidal average power formula using the power factor.
2. Measure voltage and current phasors in a series-parallel RLC circuit to verify Kirchhoff’s Current and Voltage Laws, KCL and KVL.
4. Determine the Thevenin equivalent of an RLC circuit by open-circuit voltage and short-circuit current measurements.
5. Verify the Maximum Power Transfer Theorem for ac circuits.

9.2 **Introduction**

9.2.1 **Phase-Angle Measurements and Average Power:**
There are two popular methods for measuring the phase angle between two sinusoidal functions using the oscilloscope. These are now discussed and applied to measure the phase angle between current and voltage in RL and RC series circuits.

9.2.1.1 **Time-Difference Method:**
Here, the two sinusoids are displayed on the oscilloscope together using a common trigger signal. Figure 9-1 illustrates this for the two voltages:

\[ v_1(t) = v_{m1} \cos \omega t \quad (1) \]

and

\[ v_2(t) = v_{m2} \cos(\omega t - \theta) \quad (2) \]

Figure 9-1: Time-Difference Method for phase-angle Measurement.*

Two adjacent zeros on \( v_1(t) \) and \( v_2(t) \) are shown at \( t_1 \) and \( t_2 \) as well as the common period \( T = 2\pi/\omega \). Clearly, from equations (1) and (2), \( \omega t_1 = (2n + 1)\pi/2 = (\omega t_2 - \theta) \), which gives:

\[ \theta = \frac{t_2 - t_1}{T} * 2\pi \quad \text{radians}, \quad (3) \]

\[ \theta = \frac{t_2 - t_1}{T} * 360 \quad \text{degree} \quad (4) \]

Thus, the phase angle \( \theta \) is determined from the time difference \( \Delta t = (t_2 - t_1) \) and the period \( T \).

*http://www.electronics-tutorials.ws/accircuits/phase-difference.html

9.2.1.2 **Ellipse Method:**

In this method, one of the sinusoidal functions is used to provide the oscilloscope horizontal detection (x-axis), while the other is used to provide the vertical detection (y-axis). For example,
When the time parameter, \( t \), is eliminated, it can be shown that these two equations generate the ellipse equation:

\[
\left( \frac{x}{v_{m1}} \right)^2 + \left( \frac{y}{v_{m2}} \right)^2 + 2\left( \frac{x}{v_{m1}} \right) \left( \frac{xy}{v_{m2}} \right) \cos \theta = \sin \theta^2
\]  

(7)

For \( \theta \neq \pi/2 \), the ellipse is rotated as shown in Figure 9-2. For \( \theta = \pi /2 \), the ellipse axes are along the x and y axes.

Since \( x = 0 \) when \( \omega t = (2n + 1) \pi /2 \), and \( y = 0 \) when \( \omega t = (2n + 1) \pi /2 + \), equations (5) and (6) give the maximum intercept values on the x and y axes, viz,

\[
x_m = v_{m1}; \quad x_i = v_{m1} \sin \theta
\]  

(8)

and

\[
y_m = v_{m2}; \quad y_i = v_{m2} \sin \theta
\]  

(9)

Thus, the phase angle may be calculated from these measurements as:

\[
\theta = \sin^{-1}(x_i/x_m) \text{ or } \theta = \sin^{-1}(y_i/y_m)
\]  

(10)

Figure 9-2: Ellipse Method for Phase-Angle Measurement

9.2.1.3 Average Power:

To calculate the average power for RL and the RC circuits use the following two equations:
\begin{align}
  p_{avg} &= \frac{1}{2} v_m I_m \cos \theta, \\
  p_{avg} &= \frac{1}{2} I_m^2 R, 
\end{align}

where $V_{sm}$ is the amplitude of $V_s(t)$, $\theta$ is the power-factor angle, $I_m = Vm_1 / R_1$ and $R = R_1$ for the RL circuit, and $I_m = Vm_2 / R_2$ and $R = R_2$ for the RC circuit.

9.2.2 **Current and Voltage Phasor Measurements:**

A circuit containing R, L, and C elements in series and parallel combinations will be used to verify Kirchhoff’s Current and Voltage Laws experimentally. Amplitude and phase-angle measurements will be made to determine the phasors needed using circuit in Figure 9-3.

3. **Thevenin Equivalent and Maximum Power Transfer:**

Including inductors, capacitors, and linear AC sources into any linear circuit will not change the circuit linearity, accordingly same superposition principle, source transformations, and Thevenin or Norton, the geometry still applicable. (review experiment#5)

9.3 **Procedure:**

9.3.1 **Phase- angle measurements.**
1. Construct the circuit shown in Figure 9-3:

2. Display the function generator output voltage (Vs(t)) on Ch1 of the scope.

3. Display the output voltage (VL(t)) on Ch2 of the scope.

4. With Vs as reference, measure the phase angle of VL(t) by using the time difference method.

   $|V_L| = \Delta t = T = \theta = (\Delta t/T)\times360^\circ$

   VL(t) =

5. Place the scope in the XY mode to display an ellipse. Measure maximum and intercept values along both axes to determine the phase angle (see Figure 9-2)

<table>
<thead>
<tr>
<th>X_i</th>
<th>X_m</th>
<th>Y_i</th>
<th>Y_m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Repeat steps 4 and 5 above when Ch2 of scope is connected across the capacitor (VC(t)) in order to measure the phase angle

   $|V_C| = \Delta t = T = \theta = (\Delta t/T)\times360^\circ$

   VC(t) =

<table>
<thead>
<tr>
<th>X_i</th>
<th>X_m</th>
<th>Y_i</th>
<th>Y_m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9.3.2 Current and Voltage Phasor Measurements:

1-Use the same circuit in Figure 9-3:

2-Exchange the position of L and R₂ and of C and R₃
3- With Vs as reference, measure the amplitude and phase angle of $V_2(t)$ and of $V_3(t)$ and $V_{ab}(t)$ using the time difference method.

**Note:**
1. To measure $V_2$, interchange the physical position of $R_2$ and $L$ in the test circuit.
2. To measure $V_3$, interchange the physical position of $R_3$ and $C$ in the test circuit.

| $|V_{ab}|$ | $\Delta t$ | $|V_2|$ | $\Delta t$ | $|V_3|$ | $\Delta t$ |
|---------|-----------|---------|---------|---------|---------|

5- Turn the function-generator connections around so that its ground is connected to point $g_2$, then measure the amplitude and phase angle of $v_1(t)$

$|V_1| = $  
$\Delta t = $

---

9.3.3 **Thevenin Equivalent and Maximum Power Transfer Theorem:**
- Connect the circuit in Figure 9-4:
1- Measure the amplitude and phase angle of the open-circuit voltage $V_{xy}(oc)$ and the short circuit current $I_{xy}(sc)$.

2- From these two measurements find $Z_{th} = R_{th} + jX_{th} = V_{xy}(oc)/I_{xy}(sc)$.
Biomedical Engineering Department

Electric Circuits lab

BME (311)

Pre-Report #8

Experiment#9

Sinusoidal AC Circuit Measurements

Student Name …………………………………………………………………………………………………………………

Student ID………………………………………………………………………………………………………………
Objectives:

1.

2.

3.

4.

Q#1: convert the following phasor form into rectangular for:

$$3 \angle 18^\circ$$

Q#2: Figure 9-5 shows three sinusoids signal that displayed together using common trigger signal, answer the following two questions:

1. Use $V_1(t)$ as reference signal, then calculate the phase shift (in radian then in degree) between the $V_1(t)$ and $V_2(t)$. 

Figure 9-5
2. Which Signal is leading the other $V_1(t)$ or $V_2(t)$?
   Note: show the explanation.

3. Use $V_1(t)$ as reference signal, then write $V_3(t)$ in form of sin wave.

Q#3: For the circuit shown in Figure 9-6, calculate $V_{ab}$, $V_1$, $V_2$, $V_3$, $V_L$, and $V_C$. 

Figure 9-6
Q#4: For the circuit shown in Figure 9-7, calculate $V_{Th}$ and $Z_{Th}$ as seen by X and Y points.
Biomedical Engineering Department

Electric Circuits lab

BME (311)

Post Report #8

Experiment#9

Sinusoidal AC Circuit Measurements

1. Student Name .................................................................

Student ID ........................................................................

2. Student Name ................................................................

Student ID ........................................................................

3. Student Name ................................................................

Student ID ........................................................................
1. **Phase-angle measurements:**

1. Fill the below table referring to measurement at circuit of Figure9-3:

<table>
<thead>
<tr>
<th>$V_L$</th>
<th>$\Delta t$</th>
<th>$\theta$</th>
<th>$V_L(t)$</th>
<th>$V_C$</th>
<th>$\Delta t$</th>
<th>$\theta$</th>
<th>$V_C(t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. After place the scope in the XY mode Fill the below table, then compare the value of $\theta$ with that from the previous part.

A. For the inductor:

<table>
<thead>
<tr>
<th>$X_i$</th>
<th>$X_m$</th>
<th>$\theta = \sin^{-1}(\frac{X_i}{X_m})$</th>
<th>$Y_i$</th>
<th>$Y_m$</th>
<th>$\theta = \sin^{-1}(\frac{Y_i}{Y_m})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B. For the capacitor:

<table>
<thead>
<tr>
<th>$X_i$</th>
<th>$X_m$</th>
<th>$\theta = \sin^{-1}(\frac{X_i}{X_m})$</th>
<th>$Y_i$</th>
<th>$Y_m$</th>
<th>$\theta = \sin^{-1}(\frac{Y_i}{Y_m})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. **Current and Voltage Phasor Measurements:**

1. Measure the amplitude and phase angle of $V_3(t)$, $V_2(t)$, and $V_{ab}(t)$ using the time-difference method.

   **Note:** Express the phasors corresponding to the measured voltages in rectangular form.

   | $|V_2|$ | $\theta$ | $|V_3|$ | $\theta$ | $|V_{ab}|$ | $\theta$ |
   |-------|----------|-------|----------|-----------|----------|
   |       |          |       |          |           |          |
\[ V_2(t) = \]

\[ V_3(t) = \]

\[ V_{ab}(t) = \]

2. Turn the function-generator connections around so that its ground is connected to point \( g_2 \), then measure the amplitude and phase angle of \( v_1(t) \)

**Note:** Express the phasors corresponding to the measured voltages in rectangular form.

\[
\begin{array}{|c|c|}
\hline
| V_1 | \Theta \\
\hline
\end{array}
\]

\[ V_1(t) = \]

3. Calculate the current phasor using the previously measured value of voltage \( V_1, V_2, \) and \( V_3 \) and check KCL.

\[
\begin{array}{|c|c|c|c|}
\hline
I_1 = \frac{V_1}{R_1} & I_2 = \frac{V_2}{R_2} & I_3 = \frac{V_3}{R_3} & I_1 - I_2 - I_3 \\
\hline
\end{array}
\]
4. Check voltage sums and KVL. For example, \( V_{ab} = V_L + V_2 = V_C + V_3 \), and \( V_1 + V_2 + V_L - V_S = 0 \).

5. Check power balance by calculating the entries of the following table:

\[
\begin{array}{c|c|c|c|c}
V_S & * & I_1 & * \cos(\theta) & (|I_1|^2 R_1) + (|I_2|^2 R_2) + (|I_3|^2 R_3) \\
\hline
\end{array}
\]
3. Thevenin Equivalent and Maximum Power Transfer:

1- Measure the amplitude and phase angle of the open-circuit voltage $V_{xy}(oc)$, the short-circuit current $I_{XY}(sc)$, and find $Z_{th} = \frac{V_{xy}(oc)}{I_{xy}(sc)}$.

| $|V_{oc}|$ | $\theta_{oc}$ | $|I_{sc}|$ | $\theta_{sc}$ | $Z_{th} = \frac{V_{oc}}{I_{sc}}$ | $Z_{th}^*$ |
|---------|--------------|---------|-------------|--------------------|-----------|
|         |              |         |             |                    |           |

2- Find $Z_{th} = R_{th} + jX_{th}$.

3- Determine the value of L and C for the $Z_{th}$ and conjugate $Z_{th}^*$.
• Conclusion and discussion:
  • List your Conclusion about all parts of this experiment, and discuss the results as points:
References:
