The Hashemite University
Faculty of Engineering
Electrical Engineering Department
(Fundamentals of Electrical Circuits Lab)
Lab manual

Laboratory (110409260)
Perquisites :(110102103 & 110406229)

Experiments:

1. **Lab. Equipment Familiarization**
2. **Measurement on DC Circuit**
3. **Techniques of Circuit Analysis (I)**
4. **Techniques of Circuit Analysis (II)**
5. **The Function Generator & Oscilloscope.**
6. **Basic Laws on AC Circuits (I).**
7. **Basic Laws on AC Circuits (II).**

GENERAL LABORATORY RULES
AND SAFETY RULES

- Be **PUNCTUAL** for your laboratory session.
- Foods, Drinks and smoking are not allowed.
- Open- toed shoes are not allowed.
- The lab timetable must be strictly followed. Prior permission from the lab supervisor must be obtained if any change is to be made.
- Respect the laboratory and its other user. Noise must be kept to a minimum.
- Workspace must be kept clean and tidy at all time. Points might be taken off on student / group who fail to follow this.
- Handle all apparatus with care.
- All students are liable for any damage to equipment due to their own negligence.
- Students are strictly **PROHIBITED** from taken out any items from the laboratory without permission from the lab Supervisor.
- Do not work alone.
- Report any injuries to your instructor immediately.
- Know where the main lab power switch is located and how to turn off the power.
- In the event of a fire:
  - ✓ De-energize the circuit
  - ✓ Notify the instructor immediately (he or she may use an appropriate fire extinguisher)
  - ✓ Remove all fuels (such as paper), if possible
  - ✓ Administer first aid
  - ✓ Call Campus Public Safety Dept. if necessary. (Pull the fire alarm, evacuate the building and call from outside the building, if appropriate).
- Make connections to a de-energized circuit only. When in doubt, do not power-up without the instructor's inspection.
- Do not change the circuit with the power on. This can damage the components and create a safety hazard.
- Do not rely on fuses, relays, circuit breakers, interlock devices or other protective devices to protect you or your circuit.
- Turn off power to all equipment when finished.
- Many electrical components are hot when functioning – be careful.
- Do not bypass the protective third prong on an electrical plug. Use a properly grounded adapter when plugging into a two-prong outlet (check the outlet for proper grounding).
- Report defective equipment or components to your instructor immediately. Please do not return defective components to the Technical Support Center. (Your instructor will tag defective equipment with the nature of the problem along with the date).
- Pay particular attention to the polarity of polarized capacitors.
- If a component burns, avoid breathing the fumes. They could be toxic.
- Use only one hand at a time in any high-voltage circuit – prevent putting your body in the circuit.
- Avoid wearing loose or floppy clothing around moving machinery. Wear safety glasses.
- Do not attempt to pull someone from a "live" circuit. Turn the power off if possible. Otherwise, remove the person with a nonconducting object.

GRADING POLICY

The total mark for this lab is distributed as follows:

Lab Report + Prelab + Quizzes + attendance	40%
Mid-term Exam	20%
Final	40%

Laboratory Report Guidelines

Effective technical communication and documentation are essential skills for an engineer. Technical documentation can take on different forms depending on the needs of the audience. However, some common principles can be applied to all forms of technical documentation. Consideration of these principles is essential to ensure effective communication of the information that the audience needs. A few guidelines will be considered here to write effective lab reports.

The following guidelines are suggested for preparing to write:

- Define the Audience and It's Needs
- Establish a Purpose for Writing
- Determine the Type of Documentation to be Written
- Follow an Acceptable Format
- Use Proper Spelling, Grammar, and Technique

Defining the Audience

The audience for your report is a professor or technical assistant. They are familiar with the lab material and need to make an assessment of your understanding of the work completed in preparation for and during the lab session.

Establish the Purpose

The purpose of writing for this lab is to provide an opportunity to develop technical writing skills, and demonstrate understanding of the lab material. As a student, this process of organizing and writing technical documentation is a valuable tool. Write the type of documentation that you can keep as a reference for future use.

Determining the Documentation Type

The type of documentation written for these labs will be lab reports. Depending on the nature of the lab, these reports can be formal reports, informal reports, or status reports.

Following the Proper Format

The overall structure of the each type of report is shown below.

Formal Reports

- Title Page
- Objectives
- Introduction
- Methodology/Theory
- Analysis/Results
- Conclusion
- Attached Files (Outputs, Plots, Schematics, etc.)

Informal Reports

- Title Page
- Introduction
- Analysis/Summary
- Conclusion
- Attached Files (Outputs, Plots, Schematics, etc.)

Status Reports

- Introduction
- Analysis/Summary
- Attached Files (Outputs, Plots, Schematics, etc.)

A brief description of each section of the reports is provided below. Use the descriptions as an outline of what should be included in the report.

Title Page: The title page should include, in the following order, the course number, the title of the experiment, your name, your lab partners name, the TA or professors leading the lab section, and the date the report was submitted.

Objectives: The abstract should be a very concise, clear, and complete summary of the experiment. Do not include specific details or references to figures, etc. The abstract should be written after completing the lab report, and should be written in less technological terms that can be easily read and understood by a variety of individuals with different backgrounds.

Introduction: The introduction should discuss the purpose or objective of the lab experiment. It should also include a brief summary of the processes or procedures used in performing the lab experiment. Related history of the subject under investigation in the lab may also be included when appropriate. The introduction should be relatively short.

Methodology/Theory: The section on methodology or theory should discuss the experiment performed in lab. Theoretical development associated with design procedures should be discussed, particularly in the cases where it influences the choices you make in completing the lab experiment. This includes the work done in prelab, simulation, and hardware. The methodology presented should be sufficiently complete for someone reading the report to reproduce the experiment and verify the results.

Analysis/Results: The final data collected or measured should be placed in the results section. This would apply specifically to data or measurements associated with the purpose and design specifications of the experiment. Diagrams, numerical data organized in tables, etc. should be placed in this section, and any pertinent analysis (but not concluding remarks) should be included. Any intermediate results that were used to obtain the final results of the experiment do not need to be included in the report.

Summary: The summary section is for informal and status reports only. This section is a brief combination of the methodology/theory and analysis/results sections. One brief statement of what was done in the experiment and another brief statement summarizing the results (along with the pertinent figures, numerical data, etc.) is all that is necessary for the summary.

Conclusion: The conclusion should respond to the goals and objectives discussed in the introduction of the report. A general discussion of how well the experiment did (or did not) fulfill its objectives should be presented without getting personal. Applications using the results from the experiment, or a forecast of future events that relate to the work done in the experiment may also be included.

Attached Files: Any supporting documents, outputs, figures, etc. that are not included directly in the report should be placed at the end of the report.

Using Proper Spelling, Grammar, and Technique

Lab reports should be proofread for proper spelling and grammar. Use the spell check features of the word processor, and proofread. You may also want to have someone else proofread your work.

Proper technique is essential for documenting what was accomplished in the lab and for establishing the tone of the report. Several examples of poor technique, which should be avoided, are listed below.

- The lab report is not a personal experience. Do not discuss how you feel it about the experiment. Your grade will not be based on how interesting you found the experiment, how satisfied you were personally with the results, or how frustrated you became when things did not work properly or in a timely manner.

- The lab report should not document the procedure or specific steps followed in completing the experiment. For example, it is not necessary to explain how a circuit was wired and how components were placed on a breadboard, or how the equipment was plugged in and measurements were made, etc. The only exception would be when a specific procedure required to obtain the desired result is not intuitively obvious.

- Avoid using anthropomorphisms (applying human feelings or actions to inanimate objects).

- Do not talk about yourself in the third person. Document what was done without using "I," "we," "the student," etc.

Use good judgment when adding detail to your reports. Do not include unnecessary or obvious information. If there is more than one way to do something (e.g. collecting data), then add detail that describes your choice (e.g. what piece of equipment, or what measurement function, etc. was used in collecting the data).

Additional guidelines that should be followed are listed below.

- All reports must be typed, using easy to read fonts. Clip-art images, color backgrounds and borders are inappropriate for a technical report

- Figures, schematics, plots, and equations should be labeled and numbered so that they can be referred to in the report. Inline equations are not acceptable. Equations should be separated from the text, and centered in the page. Plot axes should have appropriate labels that clearly identify what is being represented. When possible, equations, schematics, figures, etc. should be placed in the body of the report near the text that first refers to them. Only include items in the appendix if they are supplementary items or if they cannot be easily included in the body of the report.

- Data that is not presented in a graph format should be organized in tables and must be identified by appropriate title, row/column heading, and units.

- Each student must submit an individual report based on individual effort. Even though partners work together in the laboratory, each student must submit their own report.

Experiment 1
Lab. Equipment Familiarization

1.1 Objective

- To introduce the Multimeter, the breadboard, the power supply, resistors and their color code.
- To learn to properly use the lab instruments and the correct method of measuring electrical quantities with each instrument.

1.2 Basic Information

The Digital Multimeter [DMM]

This devise is used to measure values of electrical quantities; such as voltage, current, resistance, etc. The DMM is easy to use, and necessary for all electronics labs.

<u>Voltage Measurement.</u>

Turn on the Multimeter. Using the rotary selector switch, select the voltage function [V_{DC}]. Select the *AUTO* range mode by making a long press on the *range* button. Insert the positive (+) lead (normally red) in the voltage socket and the negative (-) lead (normally black) in the common socket. Place the red probe on the higher voltage point and the black probe on the lower voltage point. The DMM will display the voltage drop between the probe tips.

Voltage Measurement between any two points is made in **parallel** with the components between those two points. If the probes are reversed the reading will be negative of the original value. A Voltmeter has very large internal resistance, which is considered as open circuit (O.C.) during calculations.

<u>Current Measurement.</u>

Turn on the DMM and select the current function. Place the positive (+) probe in the current socket and the negative (-) one in the common socket. Select *AUTO* range mode. Connect the tips of the probes in series with the component through which the current is being measured. A positive reading will indicate current direction from the positive (+) to the negative (-) probes.

Current Measurement through a component is made in **series** with that component. An Ammeter has very small internal resistance, which is treated as short circuit (S.C.) during calculations. Figure 1.1 shows the connection of the DMM as a Voltmeter and an Ammeter.

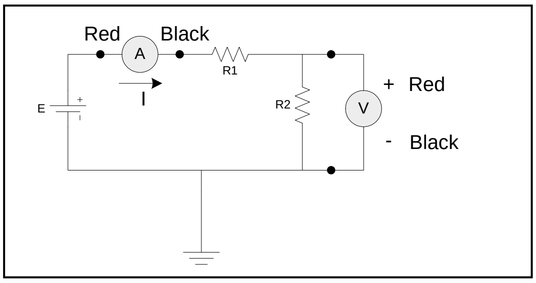


Fig.1.1: DMM Connection

Important Note: Always disconnect the probes of the DMM from the circuit before changing the selector switch from current to voltage or vise versa. Failing to do so will damage the DMM. Switching off the meter without disconnecting the probes is insufficient for protecting the DMM. Connecting the Multimeter in an incorrect way, or choosing the wrong selection of switches, may result in personal injury, damage to the Multimeter and/or the lab equipment. Observe and obey safety rules and instructions at all times. **If in doubt ask your instructor**.

<u>Resistance Measurement</u>

The ohmmeter part of a Multimeter is basically a Voltmeter and Ammeter. A built-in voltage source is connected across the resistor to be measured and an Ammeter measures the current flow. The resistance value is the ratio of voltage to current flow. Resistance should **never** be measured while it is connected in a circuit. To measure the resistance of a component: switch off the power from the circuit. Disconnect the component from the circuit. Switch the Multimeter to measure resistance, and select the *AUTO* range mode. Touch the probe tips to the end of the ends of the component, and read the value displayed.

The Breadboard

The breadboard is a tool for effecting connections between electronic components without the need for soldering. It consists of groups of rows and columns of socket (called busses) connected together in a systematic way. It enables the attachment of components such as resistors, capacitors, transistors and wiring in a versatile manner. The breadboard consists of two main parts. The thinner one, which has two long rows of sockets that are connected together. The larger unit consists of columns of 5 sockets that are connected together. The figure below shows the two parts, and how the elements are connected. The leads of any component or wire are inserted into the sockets to effect the interconnection desired. The long busses of the thin part are used for power distribution to the various parts of the circuit under test.

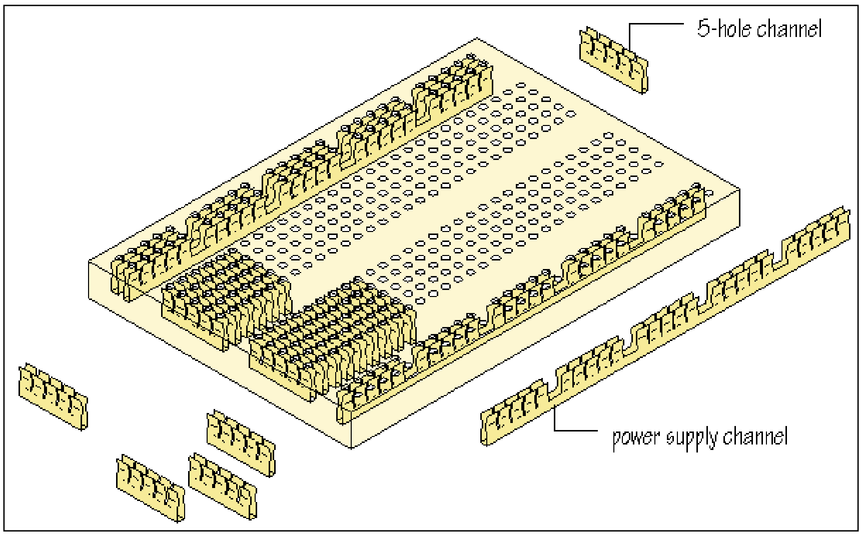


Fig.1.2: The Breadboard

The Power Supply

The DC power supply is used to generate a constant voltage (CV) or a constant current (CI). That is, it may be used as a DC voltage source or as a DC current to drive the circuit under test. The unit in the lab has two supplies: output 1 and output 2. Both outputs are variable voltage/current supplies. The variable supplies can be used independently to achieve positive or negative output.

- **Obtaining a Certain Voltage from the Variable Power Supply**

1. Switch the power on and make sure the output switch is made off.
2. Reduce the current and voltage knobs to minimum.
3. Switch on the output switch. [OUTPUT ON lamp turns on]
4. Increase the current knob until the CV (constant voltage) lamp turns on.
5. Increase the voltage knob up to the desired value using the coarse and fine voltage control.
6. If the CV lamp turns off after connecting the circuit under test, make sure there are no shorts in the circuit. Then increase the current knob until CV turns on again.

- **Obtaining a Certain Current from the Variable Power Supply**

1. Switch the power on and make sure the output switch is made off.
2. Reduce the current and voltage knobs to minimum.
3. Switch on the output switch. [OUTPUT ON lamp turns on]
4. Short the output leads of the supply. (Notice CV lamp turns off and CC lamp turns on).
5. Increase the current knob up to the desired value.
6. If the CC lamp turns off after connecting the circuit under test, increase the voltage knob until CC turns on again. If it does not turn on this means the circuit is open.

Resistors.

The flow of charge through any material encounters an opposing force due to collisions between the electrons and atoms in the material. This converts electrical energy into heat, and the force encountered is called resistance. Resistors are manufactured to a specific amount of resistance. They are used in circuits for many purposes, such as providing voltage drops and limiting current flow. The relative size of a resistor varies with its wattage (power) rating, since a larger size sustains higher current and heat dissipation. To identify the value of a resistor, the color code has been devised. Four or five color bands are printed on the end of the resistor (see Table1.1).The bands are always read from the end that has the band closest to it. The first and second bands represent the first and second digits. The third band indicates the power of 10 multiplied by the first two digits (i.e. the number of zeros that follow the second digit). The fourth band is the tolerance, with which the resistor was manufactured.

To reduce the cost of manufacturing resistors, only certain *Preferred Values* are available commercially. Resistors are manufactured as multiples of 10 of these preferred values. They are:

1.0 2.0 3.3 5.6 8.2
1.2 2.2 3.9 6.2 9.1
1.5 2.7 4.7 6.8
1.8 3.0 5.1 7.5
All in ohm

Resistors are manufactured in fixed wattage (power rating), mainly: 1/8, 1/4, 1/2, 1, 2 Watts, etc. This is identified by size, or printed on the component. Note that the size of a resistor is related to its current carrying capacity. Since large currents mean higher temperatures, a larger surface is needed for the heat to be dissipated, hence a large resistor size resistor indicates a high power rating.

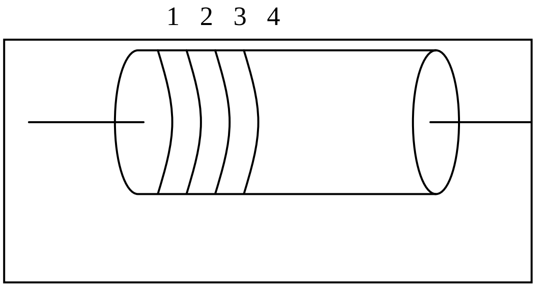


Fig. 1.3: The Color Band in the Resistor

Color	Bands 1 & 2	Band 3	Band 4
Black	0	1	-
Brown	1	10	1%
Red	2	100	2%
Orange	3	1k	-
Yellow	4	10k	-
Green	5	100k	0.5%
Blue	6	1M	0.25%
Violet	7	-	0.1%
Gray	8	-	-
White	9	-	-
Gold	-	0.1	5%
Silver	-	0.01	10%
No color	-	-	20%

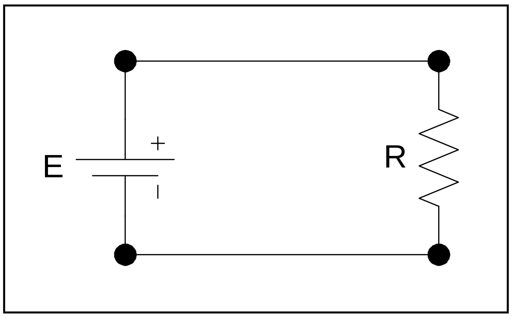
Table.1.1: Color Code for Resistance

1.3 Equipment

Digital Multimeter (DMM), Power Supply (PS)

1.4 Procedure

1. Use the DMM to measure the resistance of the five resistors provided.
2. Read the color code of these resistors. Tabulate your results.
3. Compare your measurements with the actual values. Do the actual values lie within tolerance? Show your calculations.
4. Holding one probe between the thumb and forefinger of each hand, measure and record the value of your body resistance between your hands.
5. Setup your DC PS to 3.0 volts. Measure this with your DMM.
6. Repeat step 5 for 8.0 and 6.0 volts.
7. Are the values on the display equal to the DMM reading? Why?
8. Place the resistor R = 1.5 KΩ on the breadboard. Setup the PS to 5.0 volts and connect it to the resistor as shown below in Fig.1.4.
9. Measure the voltage across, and the current through the resistor. Do these values match with what you expect theoretically? Explain.
10. How much power is this resistor dissipating



1.4: Simple Circuit Connection

Experiment 2
Measurements on DC Circuits

2.1 Objectives

The objective of this experiment is to analyze simple resistive circuits in DC. The circuits considered here are: resistors in series, resistors in parallel, series- parallel combination, voltage divider, current divider, and delta combination. This experiment will allow the experimental verification of the theoretical analysis.

2.2 Equipment and Instruments

Power Supply (PS), Digital Multimeter (DMM) and Breadboard

2.3 Basic Information

The theoretical analysis of the circuits under study is based on Ohm's and Kirchhoff's laws. The main equations relating the electrical parameters of each circuit are presented next.

1. Ohm's law: The voltage *V* (in volts, V) across a resistor is directly proportional to the current *I* (in amperes, A) flowing through it. The constant of proportionality is the resistance *R* (in ohms, Ω).

$$V = RI \qquad (2\text{-}.1)$$

2. Resistors in series: (See Figure 2-1)

- The current through *N* elements in series is the same for all of them.

$$I_S = I_1 = I_2 = \dots\dots\dots I_N \qquad (2\text{-}2)$$

- The voltage across the Ith element is *RiIi*. The sum of the voltages across each element is equal to the Voltage applied to the entire Series combination.

$$V_s = V_1 + V_2 + \dots\dots + V_N = \sum_{i=1}^{N} V_i \qquad (2\text{-}3)$$

Equation 2-3 is formulated from Kirchhoff's voltage law.

- The equivalent resistance of the series combination is the sum of the individual resistances.

$$R_{eq} = R_1 + R_2 + R_3 \dots\dots + R_N = \sum_{i=1}^{N} R_i \qquad (2\text{-}4)$$

3. Resistors in parallel: (See Figure 2-2).

- The voltage across *N* elements is the same for all of them.

$$V_s = V_1 = V_2 = \dots\dots = V_N \qquad (2\text{-}5)$$

- The current through the ith element is Vi/Ri . The sum of the currents through each element is equal to the current provided to the entire parallel combination.

$$I_s = I_1 + I_2 + \dots\dots + I_N = \sum_{i=1}^{N} I_i \qquad (2\text{-}6)$$

Equation 2-6 is formulated from Kirchhoff's current law.

- The reciprocal of the equivalent resistance of the parallel combination is the sum of the reciprocal of the individual resistances.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots\dots\dots + \frac{1}{R_N} = \sum_{i=1}^{N} \frac{1}{R_i} \qquad (2\text{-}7)$$

4. Series- Parallel combination: An example of a series- parallel combination circuit is shown in Figure 2-4. The analysis of this type of circuit is accomplished by substituting the series (or parallel) combinations by their equivalent resistances, such that the circuit is transformed into a pure parallel (or series) circuit. Once the electrical parameters (voltages and / or currents) have been determined for the equivalent resistances, the voltages and/or currents for the individual resistors in series or parallel combinations can be obtained by using these parameters as *Vs* and *Is* for the corresponding combination.

5. Voltage divider: From Equation 2-3. A series circuit with two resistors will divide the applied voltage *Vs* in to two voltages V_1 and Vo across each resistor. Notice that Vo is the output of the voltage divider (See Figure 2-4), as it is referenced to ground. The proportion in which the input is divided is given by

$$V_{out} = \frac{R_2.V_s}{R_1 + R_2} \qquad (2\text{-}8)$$

In order for this circuit to operate as a voltage divider, the output current *Io* must be zero or very small Compared with the current through R_2.

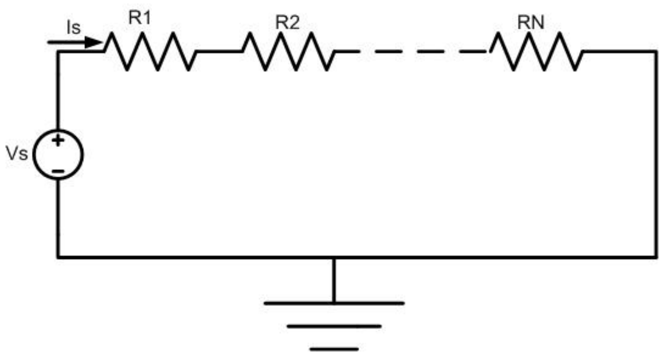
6. Current divider: (See Figure 2-5). From Equation 2-6, a parallel circuit with two resistors will divide the applied current *Is* in to two currents I_1 and I_L through each resistor. The proportion in which the input current *Is* divided is given by:

$$I_3 = \frac{R_2.I_s}{R_2 + R_3} \qquad (2\text{-}9)$$

2.4 Procedure

This part of experiment requires assembling the resistive circuits presented in figures from 1 to 5 and measuring data from all of them.

1. **Resistors in series:** Assemble the circuit in Figure 2-1 with *N=3* and the components values shown in table 2-1. Take measurements to complete the entries corresponding to the experimental values.



Fig(2-2): Resistors in series.

Parameter	R_1	R_2	R_3	R_{eq}	V_s	V_{R1}	V_{R2}	V_{R3}	I_s
Units	KΩ				V				mA
Theoretical	1.0	2.2	5.6		10				
Experimental									
%Error									

Table 2-1: Resistors in series

2. **Resistors in parallel:** Assemble the circuit in Fig (2-3) with N=3 and the component values shown in table 2-2. Take measurements to complete the entries corresponding to the experimental values.

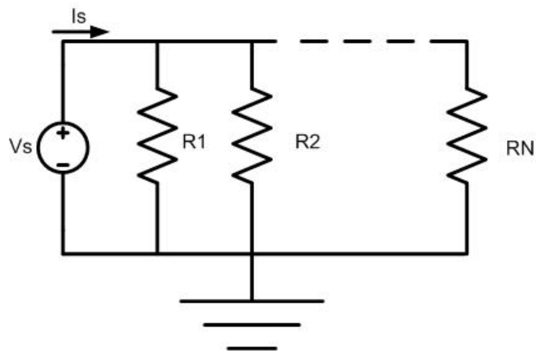


Fig (2-3): Resistors in parallel.

Parameter	R_1	R_2	R_3	R_{eq}	V_s	I_{R1}	I_{R2}	I_{R3}
Units	KΩ				V	mA		
Theoretical	1.0	2.2	5.6		10			
Experimental								
%Error								

Table 2-2: Resistors in parallel

3. **Series-parallel combination:** Assemble the circuit in figure 2-3 with the component values shown in table 2-3. Use Vs=10V. Take measurements to complete the entries corresponding to the experimental values. Notice that the resistor experimental values can be taken from the previous measurements in table 2-1 and table 2-2. Measure the voltage across each resistor and use Ohm's law (Equation 2-1) and the resistor experimental values to determine the experimental values of I_{Ri} ,I=1,2,……4.

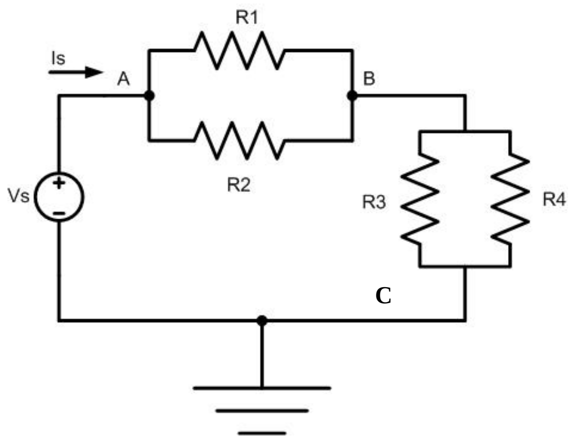
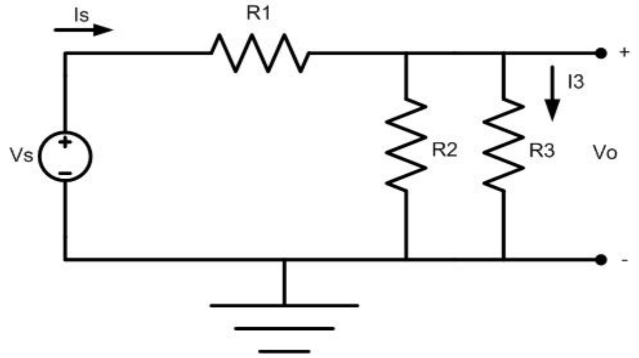


Fig 2-4: Series-parallel combination.

Parameter	Unit	Theor	Exper	%Error	Param	Unit	Theor	Exper	%Error
R_1	KΩ	1.0			I_{R1}	mA			
R_2		2.2			I_{R2}				
R_3		5.6			I_{R3}				
R_4		8.2			I_{R4}				
R_{a-c}					I_s				
V_{ab}	V				Vbc	V			

Table 2-3: Resistors in series-parallel combination

4. **Voltage and Current divider:** Assemble the circuit in Fig 2-4 with the component values shown in table 2-4. Take measurements to complete the entries corresponding to the experimental values.



Fig(2-5): Voltage and Current divider

Parameter	R_1	R_2	R_3	V_s	V_o	I_s	I_1	I_2
Units	KΩ			V		mA		
Theoretical	2.2	1.5	0.75	10				
Experimental								
%Error								

Table 2-4: Voltage and current divider

2.5 Analysis

This section is intended for the analysis and comparison of the experimental and theoretical Results. Answer all the questions.

a. Calculate the percentage error between the measured and the theoretical data and complete all the corresponding entries in Tables 2-1 through 2-5. The percentage error is given by:

$$error\% = \frac{|d_{th} - d_m|}{d_{th}} \times 100\%$$

Where d_{th} and d_m are the theoretical and measured data respectively.

b. From the above results, discuss the possible causes of error.

c. From the results of the series- parallel combination circuit select the true statements:

(a) $I_S = I_{R1} + I_{R2} + I_{R3} + I_{R4}$, (b) $V_{ab} = V_S - V_{bc}$, (c) $I_s = I_{R1} + I_{R2} = I_{R3} + I_{R4}$

d. In the last circuit, Figure 2-5, the resistors are connected in what we call Δ connection .Using mesh analysis can you solve this circuit?. but we can solve this circuit in much easier way by using another technique called delta to star transformation, by using this method find Is?

Experiment 3
Techniques of Circuit Analysis (1)
(Nodal, Mesh, Superposition)

3.1 Objectives

The objective of this experiment is to analyze resistive circuits in DC, employing the node-voltage method, the mesh-current method, superposition method. Experimental results will allow the verification of the theoretical analysis.

3.2 Basic Information

In Experiment 2 the analysis of simple circuits was carried out by Kirchhoff's laws and Ohm's laws. This approach can be used for all circuits. However, for circuits with more elements and structurally more complicated a systematic approach is preferable. The techniques of circuit analysis studied here provide an aid in the analysis of more complex circuits.

3.3 Techniques of Circuit Analysis

The purpose of circuit analysis is to determine the current in each branch can be defined as a single path in the network, composed of one simple element and the node at each end of that element - where the current is unknown. The formulation of b independent equations with these currents as variables is achieved by applying Kirchhoff's laws. In a circuit with n nodes, n -1 equations are formulated by applying Kirchhoff's current law (KCL) to any set of n -1 nodes and the remainder b – (n -1) equations can be written by applying Kirchhoff's voltage law (KVL) to that number of meshes in the circuit. In general, $n_e \leq n$ and $b_e \leq b$, where n_e and b_e are the number of essential nodes and essential branches. Therefore, the formulation of the independent equations is achieved in terms of essential nodes and branches. However, by introducing new variables (node voltages and mesh current), the circuit can be described with just n_e – 1 equations or just b_e – (n_e -1) equations. A brief description of each method is presented next.

3.3.1 Node-Voltage Method

The node-voltage method permits the description of a circuit in terms of n_e – 1 equations. Figure 3-1 shows a circuit suitable for the analysis with the node-voltage method. In this circuit three essential nodes can be identified ($n_e = 3$), therefore two (n_e -1) node-voltage equations describe the circuit. To select the set of n_e -1 nodes to perform the analysis, one of the essential nodes is selected as a reference node. If there is a ground node, it is usually most convenient to select it as the reference node, otherwise the node with the most branches is chosen. The equations are then written by applying KCL to each non reference node expressing the branch currents in terms of the node voltages. Once the equation system is solved and the node voltages are known, all the branch currents can be calculated.

3.3.2 Mesh-Current Method

The mesh-current method permits the description of a circuit in terms of b – (n_e -1) equations. Figure 3-2 shows a circuit suitable for analysis with the mesh-current method. In this circuit five essential nodes ($n_e = 5$) and eight essential branches (b_e = 8) can be identified, therefore b – (n_e -1) four mesh-current equations describe the circuit. The equations are formulated by applying KVL to each mesh, expressing the voltages across the elements on the mesh currents. Once the equation system is solved and the mesh currents are known, all the branch currents (and any other parameter of interest) can be calculated.

3.3.3 Techniques of Linear Circuit Analysis

The previous two techniques hold for all types of circuits in general, but there are some techniques that can only applied to only specific circuits not for all circuits, linear circuits are one of this type of circuits. Let us define a *linear* element as a passive element that has a linear voltage-current relationship. By a "*Linear voltage-current relationship*" we simply mean that multiplication of current through the element by a constant K results in the multiplication of the voltage a cross the element by the same constant K. We must also define a *linear dependent source* as a dependent current or voltage source whose output current or source is proportional only to the first power of a specified current or voltage variable in the circuit or to the sum of such quantities. We must define also a *Linear circuit* as a circuit composed entirely of independent sources, linear dependent sources, and linear elements.

The Superposition Principle

Some circuits have more than one current or voltage source. Superposition theorem defines a method to determine the currents and voltages in such a circuit. This is done by considering each source at a time, while all other sources are replaced by their internal resistances. The superposition theorem states:
Current (or voltage) in any given branch of a multiple-source linear circuit can be found by determining the currents (or voltages) in a particular branch, produced by each source acting alone, with all other sources replaced by their internal resistances. The total current (or voltage) in the branch is the algebraic sum of the individual source currents (or voltages) in that branch.

The steps in applying the theorem are as follows:

1. Choose one source at a time, and replace all other voltages sources with a short circuit (R=0), and all other current sources with an open circuit(R=∞).
2. Determine the currents and voltages required.
3. Repeat steps 1 & 2 for each source in the circuit.
4. The total current or voltage in a branch is the algebraic sum of the individual source currents or voltages in that branch.

3.4 Procedure

This part of experiment requires assembling the resistive circuits presented in the previous section and measuring data from all of them.

1. Node-Voltage Method.

a. Assemble the circuit in Figure 3-1 with the component values shown in Table 3-1.

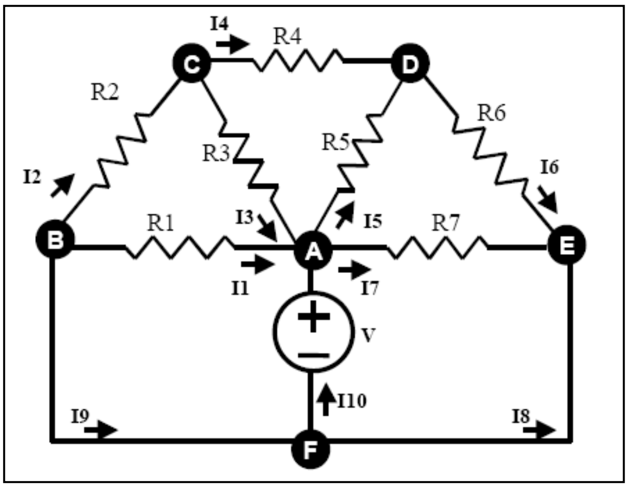


Figure 3-1: Simple Circuit to Apply Nodal Analysis

Parameter	Unit	Theoretical	Experimental	%Error
R_1	KΩ	4.7		
R_2		1.5		
R_3		1.8		
R_4		3.3		
R_5		1.0		
R_6		2.2		
R_7		6.8		
V	V	10		

Table 3-1: Results of the Measured Resistances

b. Measure the voltage and current across and through each resistance respectively

Parameter	Unit	Theoretical	Experimental	%Error
V_{AF}	V			
V_{AB}				
V_{AC}				
V_{AD}				
V_{AE}				
V_{BC}				
V_{CD}				
V_{DE}				
I_1				
I_2				
I_3				
I_4				
I_5				
I_6				
I_7				
I_8	mA			
I_9				

Table 3-2: Results of Nodal Analysis

2. Mesh-Current Method.

a. Assemble the circuit in Figure 3-2 with the component values shown in Table 3-3.

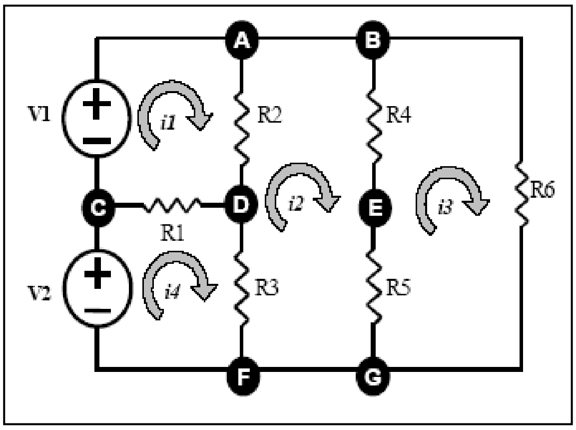


Figure 3-2: Simple Circuit to Apply Mesh an Superposition Techniques

Parameter	Unit	Theoretical	Experimental	%Error
R_1	KΩ	2.2		
R_2		3.3		
R_3		4.7		
R_4		6.8		
R_5		5.6		
R_6		8.2		
V_1	V	10		
V_2		5		

Table 3-3: Results of the Measured Resistances

b. Measure the voltage and current across and through each resistance respectively.

Parameter	Unit	Theoretical	Experimental	%Error
V_{AD}	V			
V_{DF}				
V_{BE}				
V_{EG}				
V_{CD}				
V_{BG}				
V_{FA}	mA			
I_1				
I_2				
I_3				
I_4				
I_{DC}				
I_{AD}				
I_{DF}				

Table 3- 4: Results of Mesh Analysis

3. Superposition.

Determine the experimental values in circuit Figure 3-2 by using superposition

a. Replace V_1 with a short circuit, keep V_2 ON, Take measurements to complete the entries corresponding to the experimental values in table 3-5. **Be careful to follow the passive sign convention.**

b. Replace V_2 with a short circuit, keep V_1 ON, Take measurements to complete the entries corresponding to the experimental values in table 3-6.

Parameter	Unit	Theoretical	Experimental	%Error
V'_{AD}	V			
V'_{DF}				
V'_{BE}				
V'_{EG}				
V'_{CD}				
V'_{BG}				
V'_{FA}	mA			
I'_1				
I'_2				
I'_3				
I'_4				
I'_{DC}				
I'_{AD}				
I'_{DF}				

Table 3- 5: Results of Superposition When Removing V1

Parameter	Unit	Theoretical	Experimental	%Error
V''_{AD}	V			
V''_{DF}				
V''_{BE}				
V''_{EG}				
V''_{CD}				
V''_{BG}				
V''_{FA}	mA			
I''_1				
I''_2				
I''_3				
I''_4				
I''_{DC}				
I''_{AD}				
I''_{DF}				

Table 3-6: Results of Superposition When Removing V2

3.5 Analysis

1. From your results in table 3-2, prove that KCL holds true. Write anodal equation at each node, do the summation. For your equations, choose Current going out of the node. Each node should sum to 0.

2. From your results in table 3-4, prove that KVL holds true. Write a loop (mesh) equation for each loop. Do summation. Each mesh should sum up to 0.

3. From your results in tables 3-4, 3-5 and 3-6, prove that superposition holds true. The summation of each voltage and each current in table 3-5, with its corresponding in table 3-6, should be equal to the corresponding values in table 3-4.

4. The Ammeter readings that you observe in the experiment, was a mesh current of a branch current? Justify your answer?

Experiment 4
Techniques of Circuit Analysis (2)
(Thevnin, Norton and Maximum Power Transfer).

4.1 Objectives

The objective of this experiment is to simplify resistive circuits in DC employing the Thevenin and Norton equivalents. Experimental results will allow the verification of the theoretical analysis. Also to verify the maximum power transfer theorem, this will lead us to learn about some types of variable resistors such as decade resistance box and potentiometers.

4.2 Basic Information

In experiment 2 was demonstrated the use of series-parallel reductions of resistive circuits in order to simplify the circuit analysis. In this experiment, Thevenin and Norton equivalent circuits are discussed as additional methods to simplify the circuit analysis.

4.2.1 Thevenin's Theorem

Any linear network may, with respect to a pair of terminals. be replaced by an equivalent voltage source V_{Th} (equal to the open circuit voltage) in series with a resistance R_{Th} seen between these terminals. The theorem presents a very useful method for simplifying complex circuits. We must realize that the equivalency is with respect to a selected pair of terminals. We replace the original circuit lying on one side of a pair of terminals by its equivalent Thevenin voltage source and resistance. To evaluate V_{Th} and R_{Th} follow the steps:

1. Open-circuit the terminals to which the Thevenin equivalent is desired. In other words disconnect all of the circuitry that will not be replaced by the equivalent circuit.
2. R_{Th} is the total resistance at the open-circuit terminals, when all voltages sources are replaced by short circuits, and open circuits replace all current sources.
3. V_{Th} is the voltage a cross the open-circuited terminals.
4. Replace the original circuitry by its Thevenin equivalent circuit, with the Thevenin terminals occupying the same position as the original terminals. The external circuit removed in step 1 may now be reconnected.

4.2.2 Norton's Theorem

Any linear network may, with respect to a pair of terminals, be replaced by a current source I_N (equal to the short- circuit current) in parallel with the resistance R_{Th} seen between the two terminals. Similar to Thevenin's Theorem, we are presented with a simple method of reducing a more complex circuit to a simpler one. The difference lies in converting the reduced circuit to a current source instead of a voltage source, with the equivalent resistance in parallel rather than in series. To evaluate I_N and R_N follow the steps:

1. Follow the procedure in step 1 of Thevenin's equivalents.
2. $R_N = R_{Th}$ calculated in step 2 above.
3. I_N is the short circuit current passing through the terminals?
4. Replace the original circuitry by its Norton equivalent circuit, with the Norton terminals occupying the same position as the original terminals. The external circuit removed in step 1 may now be reconnected.

4.2.3 Maximum Power Transfer Theory

An independent voltage source in series with a resistance Rs, or an independent current source in parallel with a resistance Rs, delivers maximum power to a load resistance RL when Rs = RL . The maximum power delivered, in this case, is

$$P_{\max} = {V_{th}^2}/{4R_{th}} \qquad (4\text{-}1)$$

4.3 Procedure

1. **Thevenin and Norton Equivalents:**

a. Assemble the circuit in Figure 4-6 with the component values shown in Table 4-1. (RL is 10 KΩ potentiometer (Pot), **in this section there is no need to connect this Pot. in the circuit.**

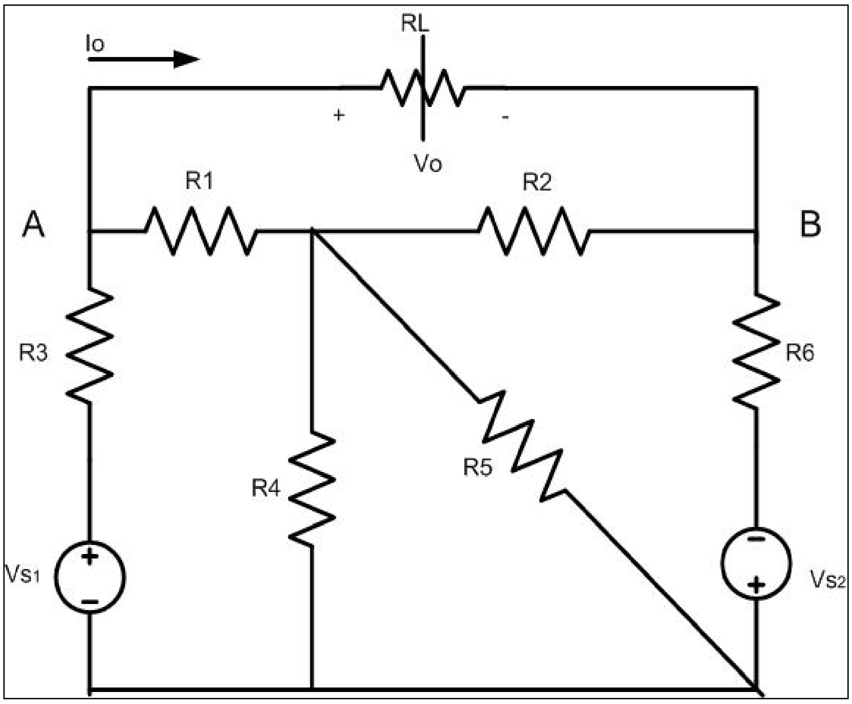


Fig. 4-6: Simple Circuit to Measure Thevenin Equivalent

Parameter	Unit	Theoretical	Experimental	%Error
R_1	KΩ	1.0		
R_2		1.5		
R_3		1.0		
R_4		3.3		
R_5		2.2		
R_6		1.0		
R_{th}				
V_{s1}	V	12		
V_{s2}		5		
V_{th}				
I_{sc}	mA			

Table 4-1: Results of Thevenin Equivalent

b. V_{th} Measurement:

to measure V_{OC}, disconnect RL, and measure VAB, Where $V_{th} = V_{OC} = V_{AB}$.

c. Isc Measurement:

to measure Isc place, A-B terminals should be Shorted by the Ammeter. (Connect the Ammeter across A- B Terminals).

d. Rth Measurement:

to measure Rth, short sources Vs1, Vs2 and Connect the Ohmmeter across terminals A-B.

2. **Maximum Power Transfer:**

a. Set the pot. To 1KΩ, reconnect it in the circuit, Measure the voltage across the pot. Calculate the power dissipated by the pot.

b. Increase the pot. Resistance in steps as illustrated in Table 4-2

c. Take measurements corresponding to the entries in the table.

R_L (KΩ)			V_L (V)			$P = \frac{VL^2}{RL}$ mW		
Theor.	Exper.	%Error	Theor.	Exper.	%Error	Theor.	Exper.	%Error
0.22								
0.33								
2.2								
1								
3.3								
4.7								
47								
100								

Table 4-2: Results of the Measured V_L and P

4.4 Analysis

1. Plot on graph paper, a graph of the power dissipated in the pot. vs. its resistance. Indicate the point of maximum power on the graph.
2. Calculate the Thevenin's equivalent circuit that can be seen from Points A,B. Calculate P_{MAX}.
3. Show whether the maximum power transfer theorem holds for this circuit or not.
4. Explain, in your words, the effect of load on the voltage relationships in a voltage divider circuit.

Experiment 5
The Function Generator and Oscilloscope

5.1 Objectives:

To introduce time varying and periodic signals.
To introduce the Function Generator as lab tool
To introduce the Cathode Ray Oscilloscope as a lab tool.

5.2 Basic Information:

5.2.1 Time varying and periodic signals:

Time varying signals are signals whose values change with time f = f(t) [Fig 5.1].

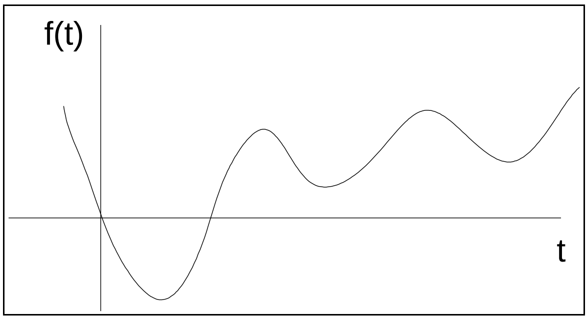
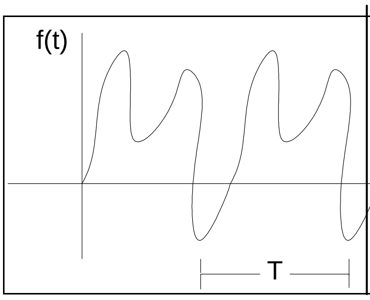


Fig 5.1: Varying Signal

Examples of such signals include:
- The ramp signal f(t) = t .
- The sinusoidal signal f(t) = A sin(ωt).
- The exponential signal f(t) = e^t .

An important subset of time varying signals is the set of periodic signals [Fig. 5.2], defined by the equation:

f(t)=f(t+T)
Where T is the period of the signal.



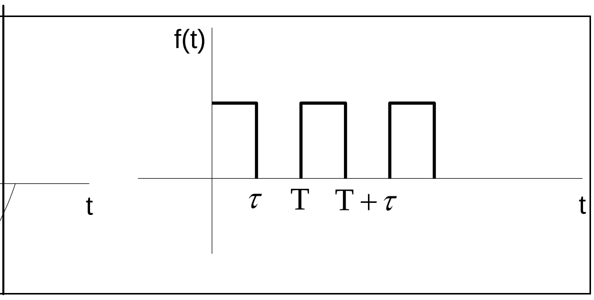


Fig. 5.2: Set of Periodic Signals   Fig. 5.3: Common Periodic Signal

A common periodic signal is the square wave [Fig 5.3], defined by the equation:

$$f(t) = \sum_{n=-\infty}^{n=+\infty} A[u(t-nT)-u(t-n(T-\tau))] \qquad (5\text{-}1)$$

Where τ is the width, if the pulse T is the period, and u(t) is the unit step function.

5.2.2 The Sinusoidal Signals:

An important periodic signal is the sinusoidal signal.

$$f(t) = A\sin(\omega t + \theta) \qquad (5\text{-}2)$$

In studying this signal several important parameters can be identified. Given the signal

$$V(t) = A\sin(\omega t + \theta) = A\sin(2\pi ft + \theta) \qquad (5\text{-}3)$$

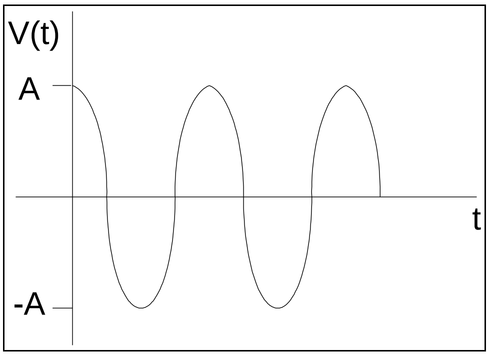


Fig. 5.4: The Sinusoidal Signal

Where:

A	: The amplitude of the signal, also known as the peak voltage $\mathbf{V_p}$.
ω	: the radian frequency measured in rad / sec.
f	: The frequency measured in Hz.
V_{p-p}	: 2A, the peak to peak voltage.
T	: The period, equal to the reciprocal of the frequency.
θ	: The phase angle of the signal.

Another important parameter of the sinusoidal signal is the RMS value, which stands for the RMS. It is calculated by the formula:

$$V_{RMS} = \frac{A}{\sqrt{2}}$$

The RMS value is defined as the effective value of the sinusoidal signal, equal to the DC signal would deliver the same power if applied to the same resistor.

For RMS value for v is given in equation (5-4)

$$v = V_m \cos(\omega t + \phi)$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} V_m^2 \cos^2(\omega t + \phi)dt} \qquad (5\text{-}4)$$

The RMS values for the triangle and the square wave are:

$V_{RMS} = \frac{A}{\sqrt{3}}$, for triangle wave.

$V_{RMS} = A$, for square wave.

Where A is the peak voltage.

5.2.3 The Function Generator (FG):

The function generator is an instrument that delivers a choice of different waveforms, with adjustable frequency over a wide range. The most common waveforms are: sine, triangle and square.

The value of the current is controlled by the frequency control circuit, the constant current ids fed to an integration circuit, the output of which is a triangular signal. A comparator uses the triangular wave to supply a sine wave. While the sine shaping circuit converts the triangular wave into a sinusoidal signal. Through a selector the amplifier provides the output signal.

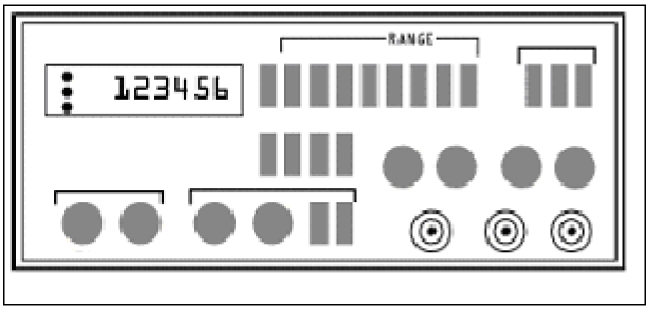


Fig. 5.5: Front View of a FG

The following table describes the controls and indicators of the FG used in lab.

COUNTER DISPLAY	Display the frequency of the internally generated waveform
RANGE switch	Select output frequency range. Seven ranges from 1Hz to 10 MHz, for example if the 100 KHz range is selected, the output frequency can be adjusted from 10 KHz to 100 KHz.
FREQUENCY CONTROL	Sets the desired frequency within the range selected. This is done by setting both the CAORSE and FINE controls.
FUNCTION switch	Selects Sine, Square or triangle waveform as OUTPUT jack
OUTPUT LEVEL control	Controls the Peak-to-Peak amplitude of the signal at the output jack.
-20 dB switch	For amplitude attenuation at –20 dB level.
OUTPUT jack	The output signal.
TTL/CMOS jack	A square (TTL/CMOS) wave and it depends on the position of the CMOS LEVEL switch.
DC OFFSET control	This control is enabled by the DC OFFSET switch.
DUTY CYCLE control	Enabled by the DUTY CYCLE switch and by rotating this dial the duty cycle of the main signal is adjusted
GATE LED	Indicates when the frequency counter display is updated. When selecting any of the RANGE switches. The LED will flash number of times depending on the selected range. As the LED turns off , the display is updated.

Table 5.1: Controls and Indicators

5.2.4 The Cathode Ray Oscilloscope (CRO):

The CRO displays the amplitude of the electrical signals, on screen, as a function of time. The horizontal axis of the CRO is deflected at a constant time rate. While the vertical axis is deflected in response to the amplitude of an input signal. The heart of the oscilloscope [Fig. 5.6] is the cathode ray tube (CRT). The CRT generates an electron beam, accelerates the beam to high velocity, and deflects it to create the image. The oscilloscope has a time base generator which supplies the correct voltage to the CRT to deflect the beam (a spot on the screen) horizontally, at a constant time rate. The signal under study is fed to the vertical amplifier, to increase its amplitude, and then to the CRT to deflect the beam vertically. To synchronize the horizontal and vertical deflections, a triggering circuit is used.

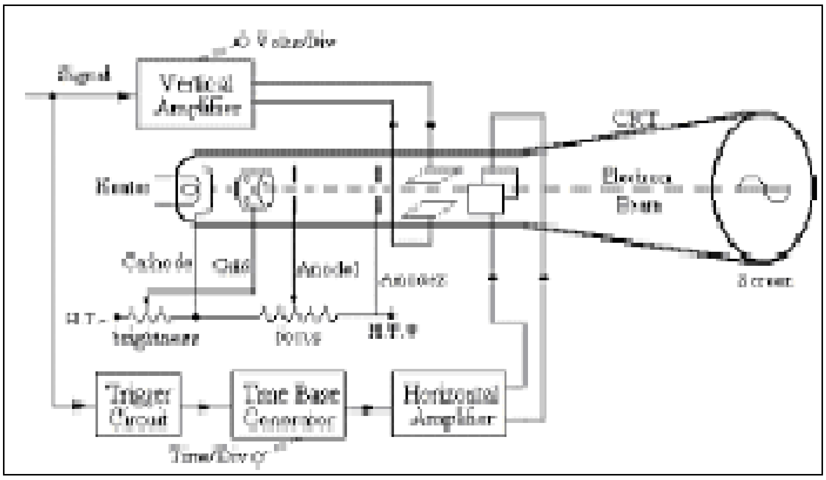


Fig. 5.6: Block Diagram of the Oscilloscope

The front panel of the CRO used in the lab can be divided into these main sections:

1- CRT controls.
2- Horizontal controls
3- Vertical controls

5.2.5 DC Offset:

A DC offset is the value of the DC voltage added to a time varying signal.

$$V(t) = d + asim(\omega t + \theta)$$

$$DC\,offset = \frac{B+C}{2} \qquad (5\text{-}5)$$

Where d is the DC offset.

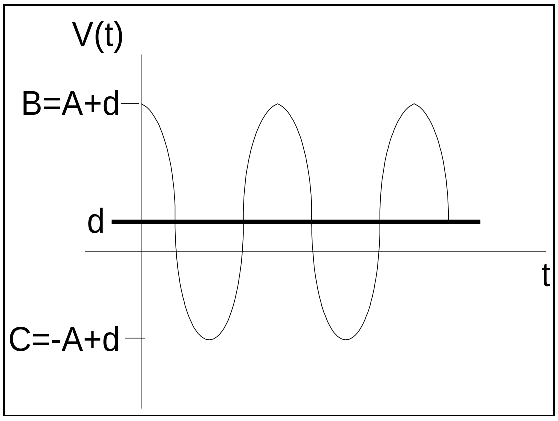


Fig. 5.7: A Sinusoidal Signal with DC-Offset

5.3 Procedure:

1. switch on the CRO and FG and allow some time to warm up.
2. With the DMM connected to the CRO probe, measure the input resistance for the DC and AC input couplings. Comment on this results.
3. Connect the OUTPUT jack of the FG to the CRO.
4. Adjust the FG to provide a triangle signal with $V_{pk\text{-}pk}$= 4 V and f= 60 KHz.
5. Measure the signal values from the CRO display, and plot it on a graph paper.
6. Obtain a square wave V_{pk}= 4V , f= 1MHz. Measure the rise time of this signal.
7. Obtain a square wave V_{pk}= 4V , f= 100 kHz.

8. Use dual mode to compare OUTPUT and TTL/CMOS outputs in amplitude, frequency, waveform , phase. Plot both signals in one graph paper using the same time scale.
9. Use the ADD function of the oscilloscope to get OUTPUT +TTL/CMOS. Set both channels to the same volts/div scale. Plot the resulting waveform.
10. Invert CH2 and get OUTPUT -TTL/CMOS, Plot the resulting waveform.
11. Obtain a sine wave with V_{pk-pk}= 8 V, f = 15KHz. Press the DC OFFSET button, increase the dc offset until the sine wave starts to be distorted.
12. Measure from the CRO the maximum value of DC offset at which an undistorted output is possible. Set the DMM to measure a DC voltage and measure the OUTPUT jack. Compare with the CRO results.

Experiment 6
Basic Laws onAC Circuits(I)

6.1 *Objectives*

- To introduce time varying and periodic signals.
- To implement Ohm Law, KVL, KCL for AC circuits.

6.2 *Basic information*

The Voltage-Current Characteristic of a Resistor

For a resistor, the relation between current and voltage is linear. It is given by *Ohm's law*:

$$v(t) = R \cdot i(t)$$

This relation does not change for the sinusoidal signal or any other signal. Therefore the *Ohm's law* can be expressed in the *phasor* form as following:

$$\mathbf{V} = \mathrm{R}\,\mathbf{I} \qquad V_m \angle\theta = R I_m \angle\theta$$

Clearly the voltage amplitude is merely the current amplitude multiplied by the constant R. A resistor does not introduce phase shift between the voltage across and the current through it. Furthermore the above relationships are independent of the frequency of the sinusoidal signal.

6.3 Equipment

FG, CRO, DMM, and several of components.

6.4 Procedure

6.4.1 Part A

1. Use the FG to generate a sinusoidal with amplitude of 10Vp-p, and frequency of 1.5KHz.
2. Implement the circuit in (figure 6.1) Check the source signal after connection.
3. Use the DMM to measure the current in the circuit I(t). Don't forget to switch the DMM to AC.
4. Observe and recorder the signal of CH1 on the CRT (oscilloscope).
5. Calculate the current in the circuit, its frequency and peak voltage across the resistor.
6. Write down the formulas for V(t), and I(t) as a function of time.

$$V(t) = V_m \sin(\omega t) \qquad I(t) = I_m \sin(\omega t) \qquad \omega = 2\pi f$$

7. Plot the signal V(t) and I(t) on the same graph paper using the same time scale.
8. Calculate Irms and compare this with the value measured by the ammeter. Calculate Vrms from the CRO display of V(t).
9. Verify that Ohm Law holds for RMS values.
10. Change the frequency of V(t) to 15KHz, repeat steps 2 till 9. Is Ohm Law frequency dependent?

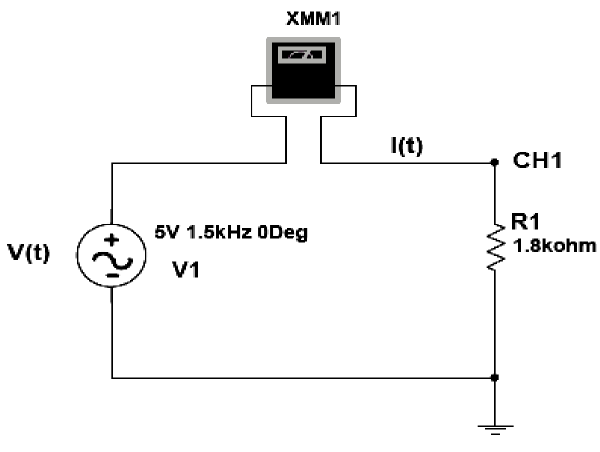


Figure 6.1

6.4.2 Part B

1 Generate V(t), a sinusoidal signal with Vp = 2V, ω = 15.7Krad/s.

2 Assemble the circuit in (fig 6.2). Where R1 =1.8KΩ, R2 = 1KΩ, R3 = 750Ω. Check and adjust, if necessary, the source signal after connection.

3 Use the CRT to display the signals V1(t), V2(t), V3(t), and draw them underneath each other on one sheet of graph paper using the same scale.

Important note: V1(t) cant be measured by placing the CRT probes directly across R1, as this will ground the resistors R2 and R3, invert CH2 display and add CH2 to CH1 to get CH1 – CH2 = V1(t).

4 Show that KVL applies to the time functions of voltages in this circuit.

5 Calculate the current in each one of the resistors. Dose KCL apply? Show that from your calculations.

6 Measure the RMS values of all currents and voltages in the circuit.

7 Calculate the above RMS value and compare with the measurements. Show that KVL & KCL apply to the RMS values.

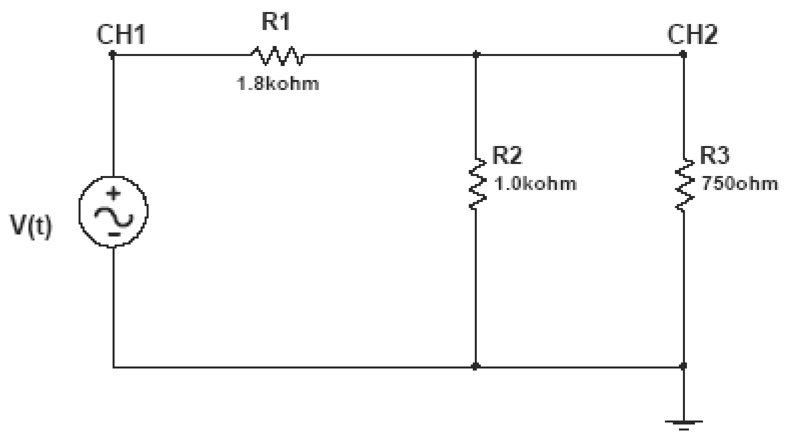


Figure 6.2

Experiment 7
Basic Laws on AC Circuits(II)

7.1 Objective

1. To introduce time varying and periodic signals.
2. To investigate the voltage-current relationship, and its dependence on frequency for resistors, capacitors, and inductors.
3. To implement Ohm's law, KVL and KCL for AC circuits.

7.2 Basic Information

7.2.1 The Voltage-Current Characteristic of a Capacitor

For a capacitor, the relation between current and voltage is:

$$v(t) = \frac{1}{C}\int i(t)\,dt$$

This relation does not change for the sinusoidal signal or any other signal. For sinusoidal signals, the phasor form is given by:

$$\mathbf{V} = \frac{1}{J\varpi C}\mathbf{I}$$

The voltage amplitude is the current amplitude divided by the constant C and the radian frequency ϖ. Therefore, the voltage amplitude is <u>inversely</u> related to the frequency. In addition the current <u>leads</u> the voltage by an angle of 90^0.

7.2.2 The Voltage-Current Characteristic of an Inductor

For an inductor, the relation between current and voltage is:

$$v(t) = L\frac{d}{dt}i(t)$$

This relation does not change for the sinusoidal signal or any other signal. For sinusoidal signals, the phasor form is given by:

$$\mathbf{V} = j\varpi L\,\mathbf{I}$$

The voltage amplitude is the current amplitude multiplied by the constant L and the radian frequency ω. Therefore, the voltage amplitude is <u>directly</u> related to the frequency. In addition, the current <u>lags</u> the voltage by an angle of 90^0.

7.2.3 Applaying KVL and

KVL and KCL are applicable to AC signals the same way they are for DC signals:

a- **KVL**: the algebraic sum of the voltages around any closed path in a circuit is zero.

$$\sum_{i=0}^{N} V_i = 0$$

Where N is the number of drop voltages around any closed loop.

b- **KCL**: the algebraic sum of the currents around entering any node is zero.

$$\sum_{i=0}^{N} I_i = 0$$

Where N is the number of entering currents through any node.

7.2.4 Measuring Current with CRO

To study the voltage-current characteristic of any component Z, it is necessary to observe both the voltage across and the current through this component. Since CROs display voltage only, an *indirect method* must be used to display current.

By placing a resistor R in series with the component Z(see figure7.1)the voltage drop across the resistor will be directly related to the current in Z, and this voltage can be observed on the CRO. By dividing the value of this voltage by the resistance value of R, we get a measure of the current in Z. The resistor R must be small to limit the voltage across it, and its power rating should be considered carefully to sustain the current in the circuit.

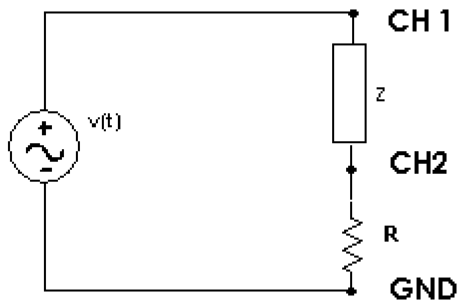


Figure7.1 Measuring Current with CRO.

7.2.5 Measuring Phase Shift with CRO

To measure the phase shift between two signals (see figure7.2) with the same shape and the same frequency. Observe the following procedure:

1. Connect the two signals to the two channels of the CRO. They must both have the same ground level.
2. Choose one of the signals as the reference.
3. Measure the number of horizontal divisions for one full cycle of the reference signal (the distance B).
4. Measure the number of horizontal divisions between two corresponding points of the wave forms (the distance A).
5. The phase shift is given by the formula:

$$\theta = \frac{A}{B} \times 360^o \text{ [in degrees]} \qquad \text{or} \qquad \theta = 2\pi f \times (\text{time/div}) \times A \text{ [in radians]}$$

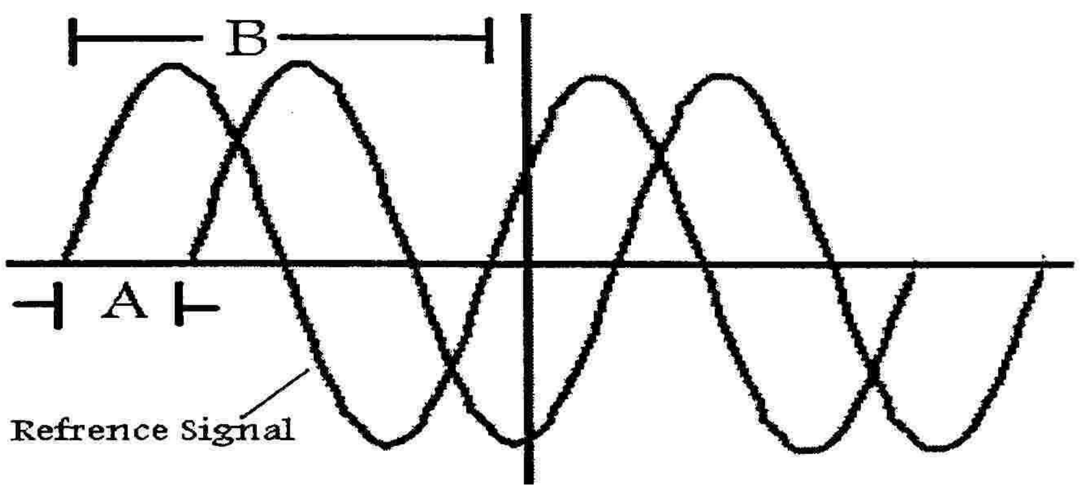


Figure7.2 Measuring Phase Shift with CRO.

7.3 Equipments

FG, CRO, DMM, and various components.

7.4 Procedure

7.4.1 Part A

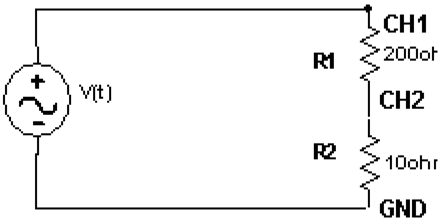


Figure 7.4: Circuit of Part B.

1. Use the FG to generate a sinusoid of 8 V_{PK-PK} at 500 Hz.
2. Implement the circuit in figure7.4. Check the source signal after assembly.
3. Observe and record the signals of CH1 and CH2. Measure the amplitude and the phase shift of the current..
4. Plot the signals v(t) and i(t) on the same graph paper.
5. Change the frequency of v(t) to 5 KHz and repeat steps 2 till 4

Parameter	***Unit***	***Calculated value***	***Measured value***	***% error***
I (500 Hz)	A			
θ_I (500 Hz)	^{o}			
I (5 KHz)	A			
θ_I (5 KHz)	^{o}			

7.4.2 Part B

1. Use the FG to generate a sinusoid of 8 V_{PK-PK} at 500 Hz.
2. Implement the circuit in figure 7.5. Check the source signal after assembly.
3. Observe and record the signals of CH1 and CH2. Measure the amplitude and the phase shift of the current..
4. Plot the signals v(t) and i(t) on the same graph paper.
5. Change the frequency of v(t) to 5 KHz and repeat steps 2 till 4.

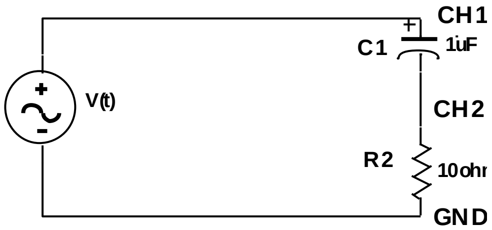


Figure 7.5 :Circuit of Part C.

Parameter	***Unit***	***Calculated value***	***Measured value***	***% error***
I (500 Hz)	A			
θ_I (500 Hz)	^{o}			
I (5 KHz)	A			
θ_I (5 KHz)	^{o}			

7.4.3 Part C

1. Use the FG to generate a sinusoid of 8 V_{PK-PK} at 5 KHz.
2. Measure the resistance of the inductor, add this resistance to the value of R2. Assemble the circuit in figure 6. Check the source signal after connecting.
3. Repeat the steps 3 till 5 of part B.

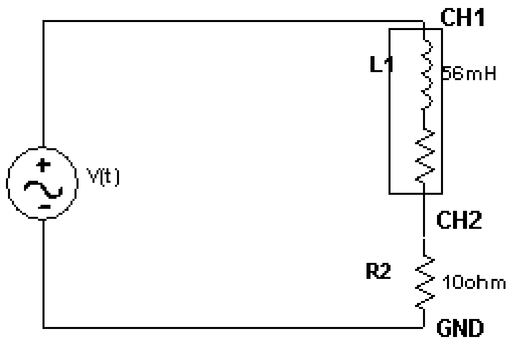


Figure 7.6: Circuit of Part D

Parameter	***Unit***	***Calculated value***	***Measured value***	***% error***
I (500 Hz)	A			
θ_I (500 Hz)	^{o}			
I (5 KHz)	A			
θ_I (5 KHz)	^{o}			

7.5 Calculations and Questions:

Part A:

Note: Answer questions for both frequencies 500 Hz and 5 KHz**.**

For the circuit shown in figure 7.4:

1. Calculate the amplitude of the current I .
2. Calculate the angle of the current θ_I .
3. Write v(t) and i(t) as functions of time. Is there a phase shift between v(t) and i(t)?
4. Verify (using obtained results) that Ohm’s law holds in pharos form.
6. Is the relation between current and voltage in this circuit affected by changes in frequency?

Part B:

For the circuit shown in figure 7.5:

Note: Answer questions for both frequencies 500 Hz and 5 KHz.

1. Calculate the amplitude of the current I .
2. Calculate the angle of the current θ_I .
3. Write v(t) and i(t) as functions of time. Is there a phase shift between v(t) and i(t)?
4. Verify (using obtained results) that Ohm’s law holds in phasor form.
5. Is the relation between current and voltage in this circuit affected by changes in frequency? How?

Part C:

For the circuit shown in figure 7.6**:**

Note: Answer questions for both frequencies 500 Hz and 5 KHz.

1. Calculate the amplitude of the current I .
2. Calculate the angle of the current θ_I .
3. Write v(t) and i(t) as functions of time. Is there a phase shift between v(t) and i(t)?
4. Verify (using obtained results) that Ohm’s law holds in phasor form.
5. Is the relation between current and voltage in this circuit affected by changes in frequency? How?