# ELE202: Electric Circuits

## Lab Manual

Prepared By

M. T. Ghorab & S. B. Prabhu

Revised By

A. Ye

Department of Electrical and Computer Engineering
Ryerson University
Toronto, Ontario


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# Contents:

**Experiment #1 Simple Direct-Current (DC) Circuits**

## 1.1 Introduction:

A circuit is a collection of interconnected electrical devices. The currents and the voltages at various places in an electric circuit are determined by two distinctly different types of constraints, namely:

1) **Device constraints,** whereby the relationship between the voltage **across** and current **through** each device is restricted by its own **i-v characteristic,** regardless of circuit connections, and
2) **Connection constraints,** whereby device voltages and currents are forced to behave in certain ways when the devices are interconnected to form a circuit. Connection constraints are based **only on the circuit connections** and not on specific devices in the circuit. The connections constraints are formulated as:
    a) **Kirchhoff"s voltage law (KVL)** which states that the **algebraic sum of voltages** around any loop is zero at every instant, and
    b) **Kirchhoff"s current law (KCL)** which states that the **algebraic sum of currents** into a node is zero at any instant.

This experiment examines the i-v characteristic of two-terminal devices such as resistors & diodes, and demonstrates the validity of Kirchhoff's voltage and current laws for basic circuit connections.

**Reference:** Text; Chapter two

## 1.2 Objectives:

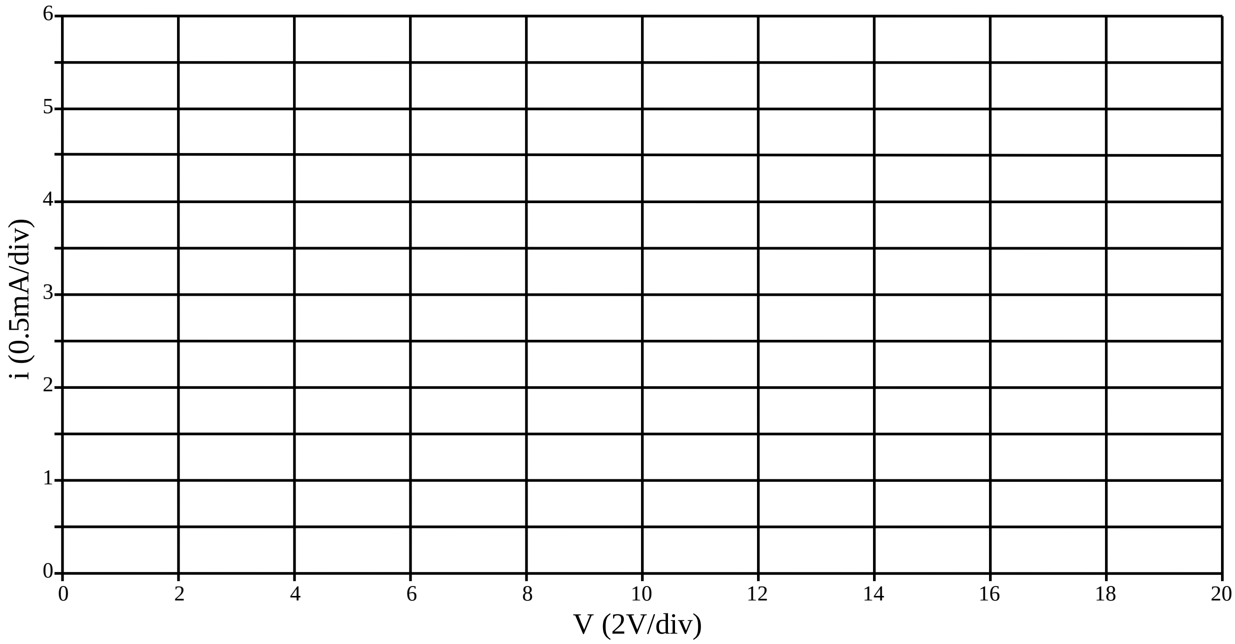
- To become familiar with the use of the digital multimeter **[DMM]** as a voltmeter & as an ammeter.
- To measure the i-v characteristic of two-terminal devices.
- To verify Kirchhoft"s voltage and current laws for basic circuit connections.

## 1.3 Prelab Assignment:

1- a) Use Graph (1.1) to plot the **i-v characteristic** of a **3.3 kΩ** resistor, and a **10 kΩ** resistor.
    b) Use your plots to find the **missing data** in the following table.

| Resistor | Voltage across (V) | Current through (mA) | Power absorbed (mW) |
|---|---|---|---|
| **3.3 kΩ** | **10** | | |
| **10 kΩ** | **10** | | |
| **3.3 kΩ** | | **1** | |
| **10 kΩ** | | **1** | |

c) Use Graph (1.1) to plot the **locus of all points** that correspond to **[p = v i] = 5mW.**




**Graph (1.1)**

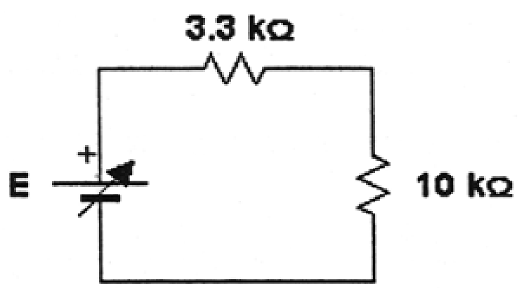



**Fig (1.1)**

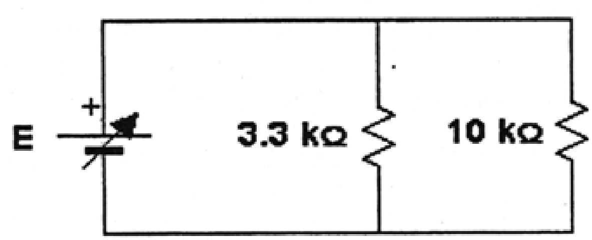



**Fig (1.2)**

2- Consider the simple series circuit shown in Fig (1.1).

a) Find the value of the voltage source "**E**" that is required to provide a **10V** across the **10kΩ** resistor. What are the values of **[$V_{10k}$/E]** and **[$V_{3.3k}$/$V_{10k}$]**?

b) Determine the amount of power supplied by the voltage source when **E = 20V.** What are the values of **[$P_{3.3k}$/$P_{10k}$]** and **[$P_{3.3k}$/$P_{supply}$]**?

3- Consider the simple parallel circuit shown in Fig (1.2).

a) Find the value of "**E**" that is required to provide a **2mA** current through the **10kΩ** resistor. What are the values of **[$I_{3.3k}$/$I_{10k}$]** and **[$I_{3.3k}$/$I_{supply}$]**?

b) Determine the amount of power supplied by the voltage source when the voltage across the **3.3 kΩ** resistor is **10V.** What are the values of **[$P_{3.3k}$/$P_{10k}$]** and **[$P_{3.3k}$/$P_{supply}$]**?

## 1.4 Procedure:

### Part I . The i-v Characteristics Of Linear & Nonlinear Devices

1- Construct the test circuit shown in Fig (1.3). The circuit consists of a variable dc-supply voltage-source in series with a **[current-limiting]** resistor of 2.7 kΩ. In addition, a DMM is used as an ammeter and another DMM is used as a voltmeter to measure the current through and the voltage across the **device-under-test [DUT]**, respectively. Use an unknown resistor as the DUT.

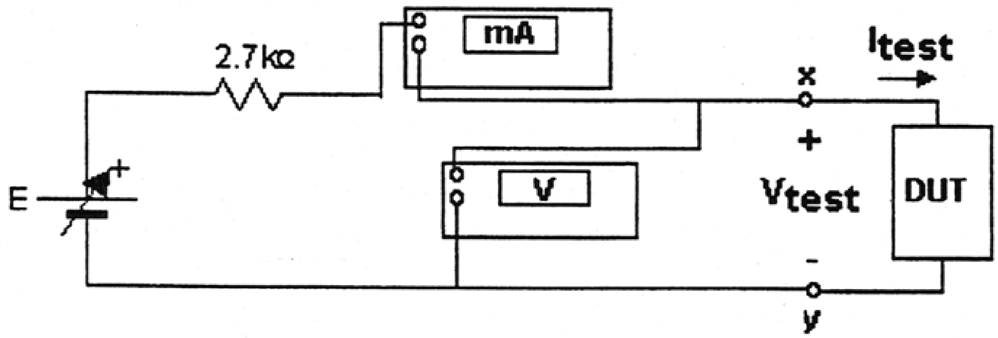


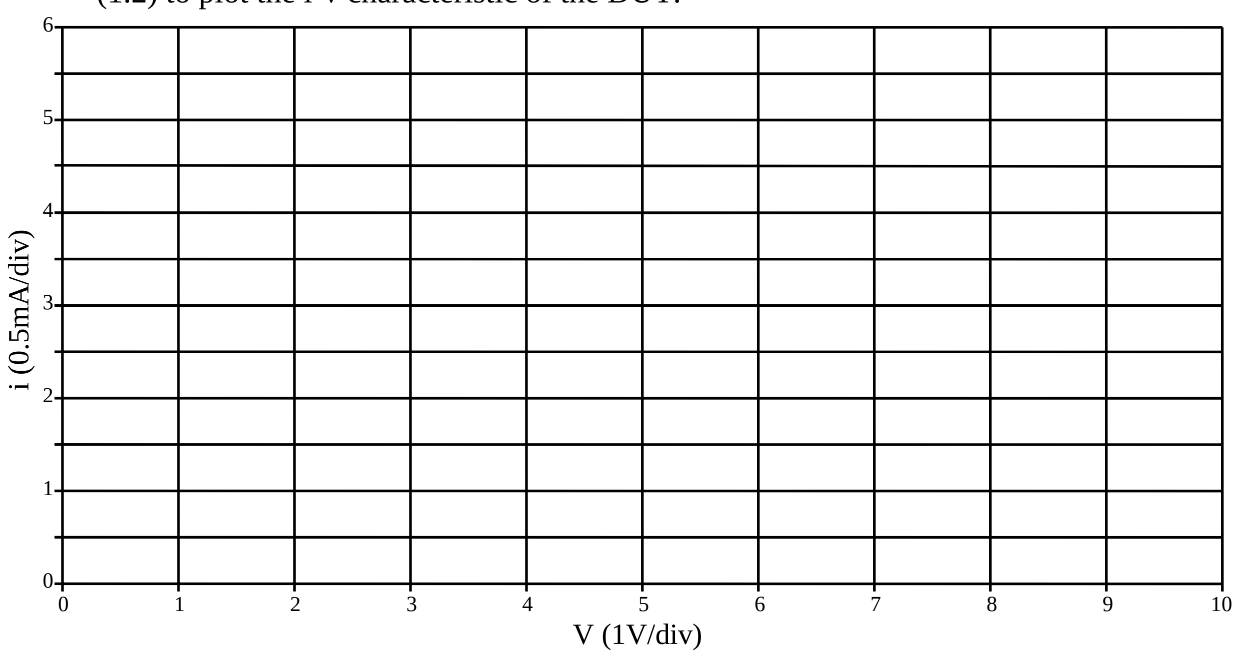

**Fig (1.3)**

2- Adjust the dc-supply voltage to set $\mathbf{V_{test}}$ @ each of the values shown in table (1.1); measure and tabulate the corresponding values for $I_{test}$.

**Table (1.1)**

| $\mathbf{V_{test}}$ **(V)** | **0.5** | **1** | **5** | **10** |
|---|---|---|---|---|
| $\mathbf{I_{test}}$ **(mA)** | | | | |

3- Reverse the DUT terminals and observe what happens as you repeat step #2 .Use Graph (1.2) to plot the i-v characteristic of the DUT.

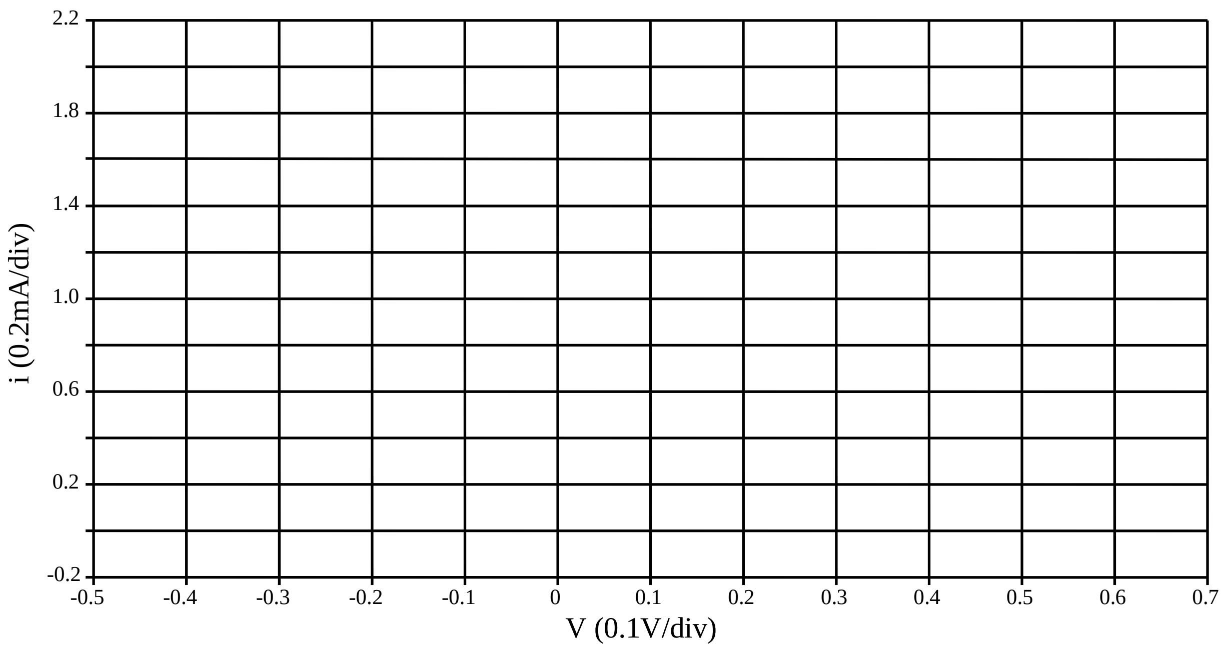



**Graph (1.2)**

4- Replace the unknown resistor with a forward-bias diode as the DUT. Repeat all the previous steps. Tabulate your results in table (1.2) and use Graph (1.3) to plot the i-v characteristic of the diode.

**Table (1.2)**

| $V_{test}$ (V) | 0.2 | 0.5 | 0.6 | 0.7 |
|---|---|---|---|---|
| $I_{test}$ (mA) | | | | |




**Graph (1.3)**

## Part II. Simple Series Circuit

5- Connect the circuit shown in Fig (1.1). Set the value of **"E"** @ 2**0V.** Use the DMMs to measure the voltage across and the current through each device in the circuit. Calculate the power absorbed by each device and record your results in table (1.3).

**Table (1.3)**

| Device | Voltage across (V) | Current through (mA) | Absorbed Power (mW) |
|---|---|---|---|
| **Source** | | | |
| **10 kΩ** | | | |
| **3.3kΩ** | | | |

6- Connect the simple parallel circuit shown in Fig (1.2) and repeat as in step #5. Record your results in table (1.4).

**Table (1.4)**

| Device | Voltage across (V) | Current through (mA) | Absorbed Power (mW) |
|---|---|---|---|
| **Source** | | | |
| **10 kΩ** | | | |
| **3.3kΩ** | | | |

## 1.5 Conclusion:

1- Use your plot for the i-v characteristic of the unknown resistor to formulate an expression for the current through “i” as a function of the voltage across “v” of the resistor.

2- How does the i-v characteristic of a diode differ from that of a resistor? Use two test points on Graph (1.3) to show if the diode satisfies the properties of superposition and homogeneity.

3- Use table (1.3) to derive the basic properties of a simple series circuit.

a)

b)

c)

d)

e)

4- Specify at least one practical application for connecting devices in a simple series form.

5- Use table (1.4) to derive the basic properties of a simple parallel circuit.

a)

b)

c)

d)

e)

6- Specify at least one parctical application for connecting devices in a simple parallel form.

# Experiment #2 General DC Circuits

## 2.1 Introduction:

In most practical circuits, devices are neither connected in simple series nor simple parallel form. Practical devices are connected in various circuit configurations that generally consist of combinations of both series and parallel forms. Some of these circuit connections have standard forms that are identified by such names as **ladder, lattice, tee, pi, wye,** and **delta** networks, to mention but a few. In the process of designing an electrical system, circuit designers try various circuit configurations, evaluate their performances, and select the one that meets or exceeds the design objectives at minimum cost.

This experiment examines the behavior of a general dc circuit, and deals with the design and performance-evaluation of a simple voltage-divider circuit.

**Reference:** Text; chapter three.

## 2.2 Objectives:

- To investigate the performance of a general dc circuit.
- To become familiar with the concept of circuit (reference point) ground.
- To design, construct, and test the performance of a simple voltage-divider circuit.

## 2.3 Prelab Assignment:

1- Consider the general dc circuit shown in Fig (2.1). Through measurements, it is found that the voltage of node # **3** [w.r.t. circuit ground] is **+6V.** Find all the missing data in the following table.

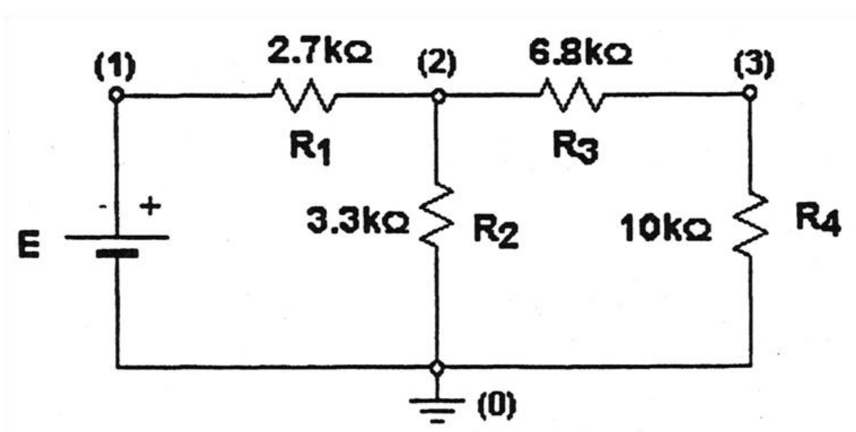



**Fig (2.1)**

| Device | Voltage across (V) | Current through (mA) | Absorbed Power (mW) |
|---|---|---|---|
| **Source** | | | |
| **$R_1$** | | | |
| **$R_2$** | | | |
| **$R_3$** | | | |
| **$R_4$** | **6** | | |

2- Given a circuit similar to that in Fig (2.1), but without any numerical values for its components. Use the symbols: "↑" for increase, "↓" for decrease, and "=" for no change, in the following table, to show the effects of an **increase in the value of $R_2$** on the voltage, current, and power of all devices.

| Device | Voltage across | Current through | Absorbed Power |
|---|---|---|---|
| **Source "="** | | | |
| **$R_1$ "="** | | | |
| **$R_2$ "↑"** | | | |
| **$R_3$ "="** | | | |
| **$R_4$ "="** | | | |

3- Fig (2.2) shows a **simple voltage-divider** connecting a dc voltage source to a **variable** resistive load. Design the voltage divider to provide a voltage of **about 5V (± 10 %)** across the variable load. The load-current demand varies in the range of **0 to 5mA,** and the available dc-supply voltage is **15V.**

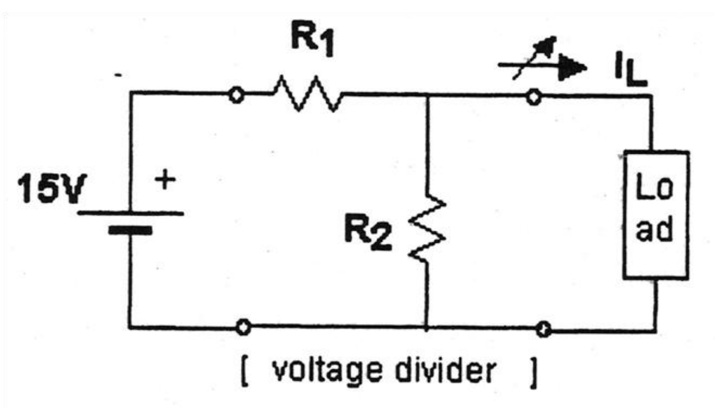



**Fig (2.2)**

## 2.4 Procedure:

### Part I. General DC Circuit

1- Construct the circuit shown in Fig (2.1). Adjust the value of the source voltage **"E"** to set the voltage of node #3 @ **6V.** Measure all node voltages **(w.r.t. the reference node)** and all branch currents. Calculate the voltage across and the power absorbed by each device, and record your results in table (2.1).

**Table (2.1)**

| Device | Voltage across (V) | Current through (mA) | Absorbed Power (mW) |
|---|---|---|---|
| **Source** | | | |
| **$R_1$** | | | |
| **$R_2$** | | | |
| **$R_3$** | | | |
| **$R_4$** | **6** | | |

2- Replace **$R_2$** with a **4.7 kΩ** resistor. Repeat step # 1 and record your results in table (2.2).

**Table (2.2)**

| Device | Voltage across (V) | Current through (mA) | Absorbed Power (mW) |
|---|---|---|---|
| **Source** | | | |
| **$R_1$** | | | |
| **$R_2$ =4.7k "↑"** | | | |
| **$R_3$** | | | |
| **$R_4$** | | | |

### Part II. Circuit Reference Point (Ground)

3- Connect the circuit shown in Fig (2.3). Select each node **(one at a time)** in the circuit as the reference point **(ground node).** Measure the voltages of all other nodes w.r.t. the ground node, and record your results in table (2.3).

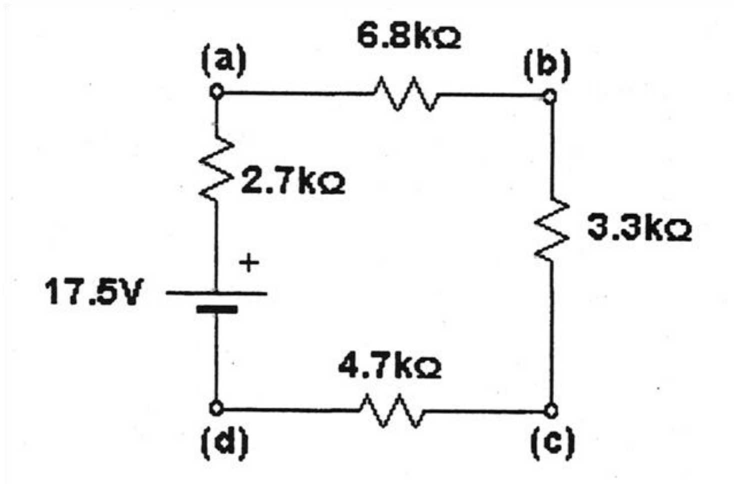



**Fig (2.3)**

**Table (2.3)** **[Voltage measured @ other nodes w.r.t. the selected ground node (V)]**

| Ground node # | $V_a$ | $V_b$ | $V_c$ | $V_d$ |
|---|---|---|---|---|
| **a** | **0.0** | | | |
| **b** | | **0.0** | | |
| **c** | | | **0.0** | |
| **d** | | | | **0.0** |

## Part II . Voltage-Divider

4- Connect your own **voltage-divider** circuit as shown in Fig (2.4); use a decade resistance box **(whose settings are at their maximum value)** as the variable resistive load.

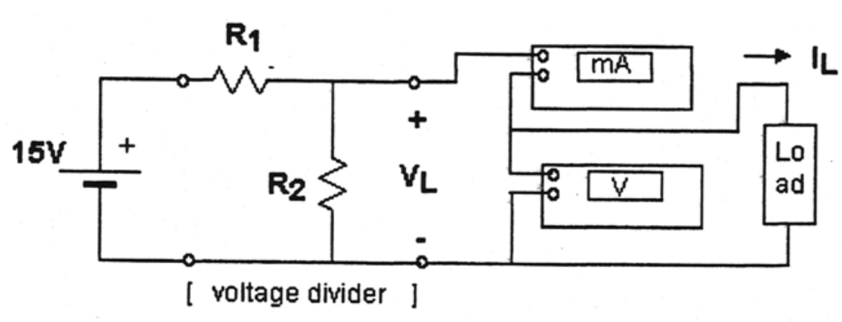
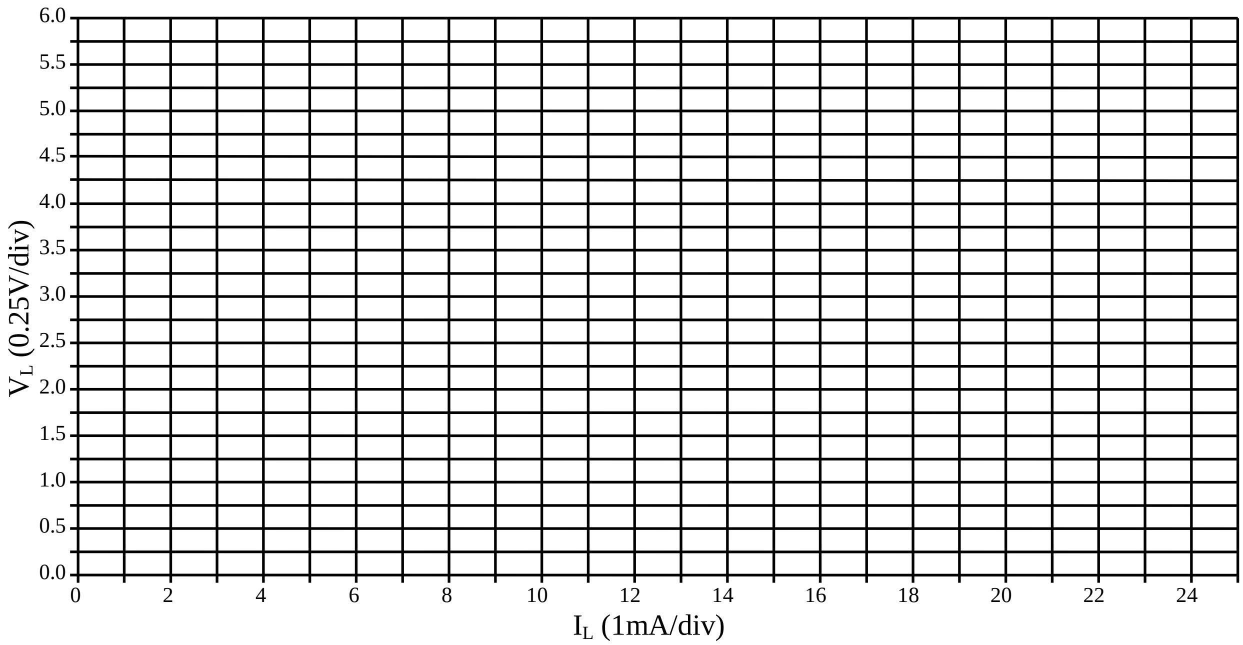



**Fig (2.4)**

5- With the decade resistance box open circuit; i.e., the load current $\mathbf{I_L = 0.0\ A}$**,** measure the value of the load voltage $\mathbf{V_L}$**.** Reconnect the decade box and adjust its resistance settings to provide each of the values of $\mathbf{I_L}$ shown in table (2.4). For each setting of $\mathbf{I_L}$ measure the corresponding value of $\mathbf{V_L}$**.**
Use Graph (2.1) to plot $\mathbf{V_L}$ vs $\mathbf{I_L}$ [which is known as the **load-regulation characteristic**] of your voltage-divider circuit.

**Table (2.4)**

| $\mathbf{I_L}$**(mA)** | **0** | **1** | **3** | **5** | **7** | **10** | **15** | **20** | **25** |
|---|---|---|---|---|---|---|---|---|---|
| $\mathbf{V_L}$**(V)** | | | | | | | | | |




**Graph (2.1)**

## 2.5 Conclusions:

1- Use your recorded data in table (2.1) to verify KVL for each loop and KCL at each node for the general dc circuit.
   Comment on the possible causes for any deviations from what you would expect theoretically.

2- Based on your observations from step # 3, design a dc circuit utilizing a **15V** voltage battery to provide the following node voltages: **+10V, +5V,** and **-5V** w.r.t. a circuit ground node. Select your resistors such that the maximum power demand on the battery does not exceed **1mA.**

3- Explain your observation of the **load-regulation characteristic** on Graph (2.1). Does your voltage-divider circuit meet the design objectives?

# Experiment #3 Thevenin's Equivalent Circuit & Maximum Power Transfer

## 3.1 Introduction:

Node-voltage and mesh-current methods are systematic ways of analyzing the behaviour of electric circuits. These methods provide a detailed description of the behaviour of each circuit-element. In many electrical and electronic applications, however, such a detailed description of circuit behaviour can be overwhelming as well as time consuming. For example, when we connect a **variable load** network to a **source network** [with constant elements], we are interested primarily in the resulting voltage & current at the load-network terminals (usually called the **source-load interface**), and have little or no interest in the voltages or the currents elsewhere in the circuit. Consequently, special analysis methods have been developed to handle such cases. These methods provide a technique by which the source network is replaced by a simple equivalent circuit consisting of either:

a) An ideal voltage-source in series with a resistive element [called the **Thevenin's equivalent circuit**], or
b) An ideal current source in parallel with a resistive element [called the **Norton's equivalent circuit**].

This experiment deals with the development of the Thevenin's equivalent circuit of a **two-terminal** source-network connected to a variable load, and examines the effects of load variations on the voltage, current, power, and power-transfer efficiency @ the source-load interface.

**Reference:** Text; chapter five.

## 3.2 Objectives:

- To develop, construct, and test the performance of the Thevenin's equivalent circuit of a two-terminal source network.
- To examine the effects of load variations on the voltage, current, power, and power-transfer efficiency @ the source-load interface.

## 3.3 Prelab Assignment:

Fig (3.1) depicts a two-terminal source network connected to a variable load $\mathbf{R_L}$.

1- Find the Thevenin's equivalent circuit of the source network.
2- Use this equivalent circuit to derive the expression for the load current $\mathbf{i_L}$ in terms of $\mathbf{V_{TH}}$, $\mathbf{R_{TH}}$, and the load voltage $\mathbf{v_L}$, independent of the value of the load resistance.

3- Use this expression to plot $\mathbf{i_L}$. vs $\mathbf{v_L}$ on Graph (3.1). This plot is referred to as the **load line;** it represents the source-network constraints @ the source-load interface.

4- Find the values of the voltage, current, power, and power-transfer efficiency @ the source-load interface for three different load values, namely: **2.2kΩ, 6.8kΩ,** and **22kΩ.**

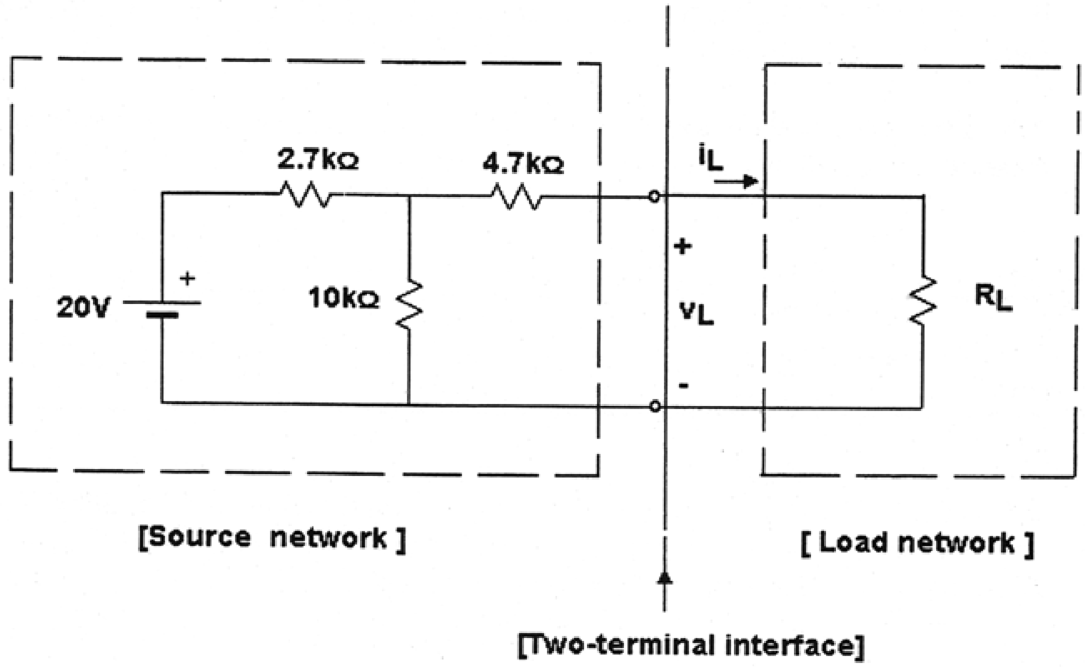
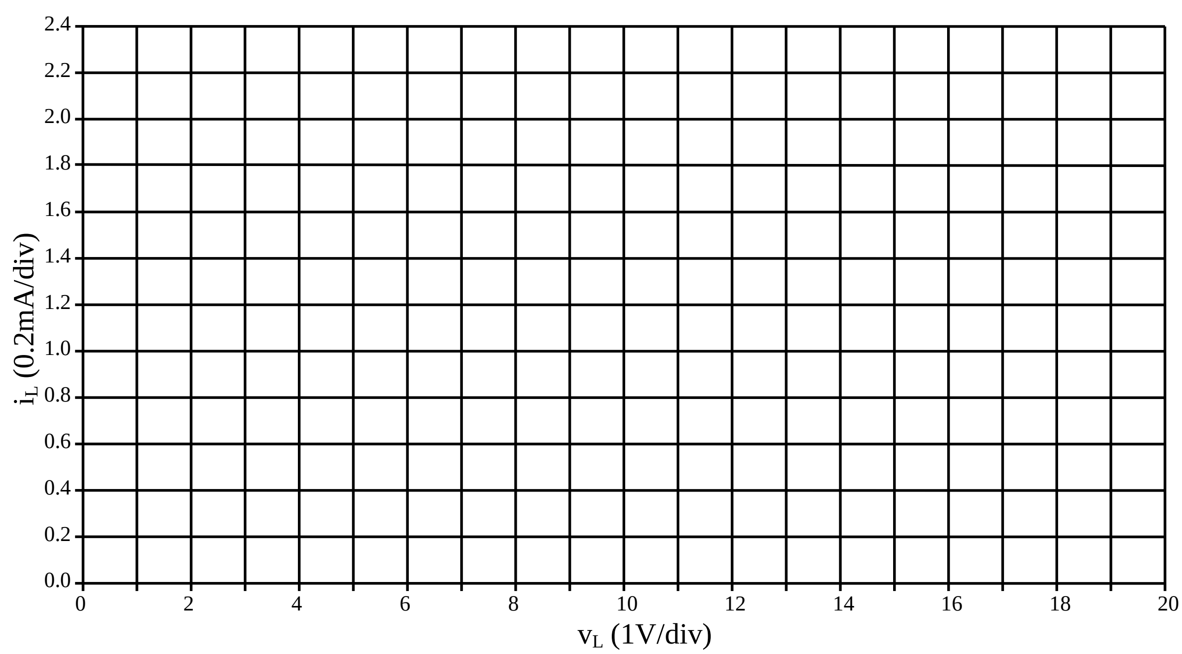



**Fig (3.1)**




**Graph (3.1)**

## 3.4 Procedure:

### Part I. Thevenin's Equivalent Circuit

1- Connect the circuit shown in Fig (3.1). Use a **decade-resistance box** as the variable load $\mathbf{R_L}$. Connect two DMM to the circuit: one to measure the load voltage $\mathbf{v_L}$, and the other to measure the load current $\mathbf{i_L}$.

Adjust the value of $\mathbf{R_L}$ to set the load voltage $\mathbf{v_L}$ at each of value listed in table (3.1); measure and record the corresponding value of $\mathbf{i_L}$.

**Table (3.1)**

| $v_L$(V) | 0 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|
| $i_L$(mA) | | | | | | |

2- Use the data in table (3.1) to plot $\mathbf{i_L}$ vs $\mathbf{v_L}$ (This is the **measured loadline** of the source network) on graph (3.1). Use this plot to evaluate the Thevenin's voltage $\mathbf{V_{TH}}$ & resistance $\mathbf{R_{TH}}$ for the equivalent circuit of the source network.

$\mathbf{V_{TH}}$ = V & $\mathbf{R_{TH}}$ = kΩ.

3- Replace the source network in your Circuit by its **Thevenin's equivalent circuit,** and repeat as in step # 1. Record your measurement in table (3.2).

**Table (3.2)**

| $v_L$(V) | 0 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|
| $i_L$(mA) | | | | | | |

## Part II. Effects of Load Variations

4- Adjust the settings of the decade-resistance-box $\mathbf{R_L}$ to provide each of the resistance ratios shown in table (3.3). For each setting measure the load voltage $\mathbf{v_L}$ & current $\mathbf{i_L}$, and evaluate the load power $\mathbf{P_L}$ the source power $\mathbf{P_S}$, and the efficiency of power transfer [**η%**], where

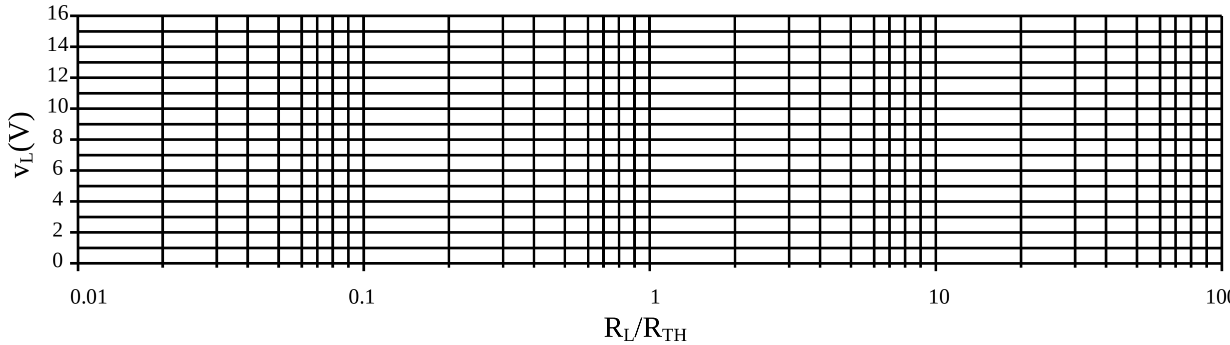
$$\eta\% = [P_L / P_S] \times 100$$

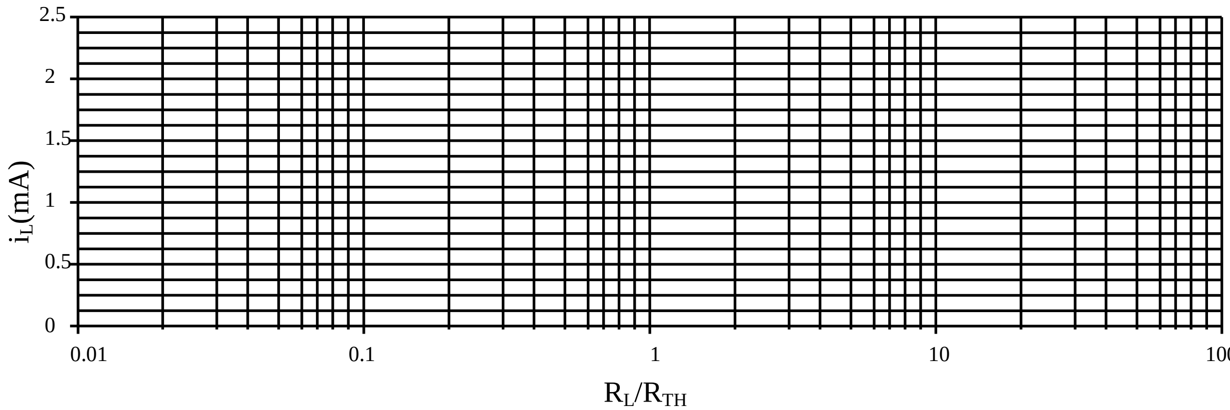
Record your results in table (3.3).

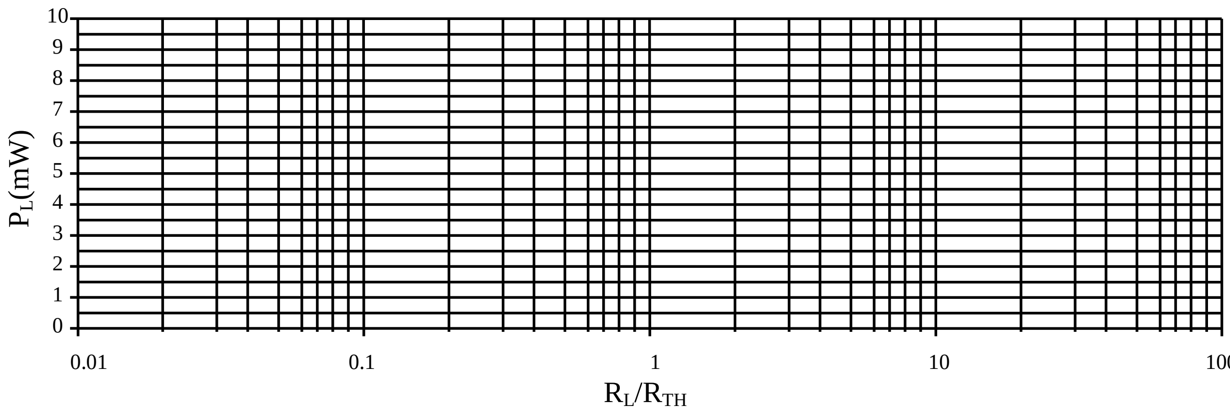
**Table (3.3)**

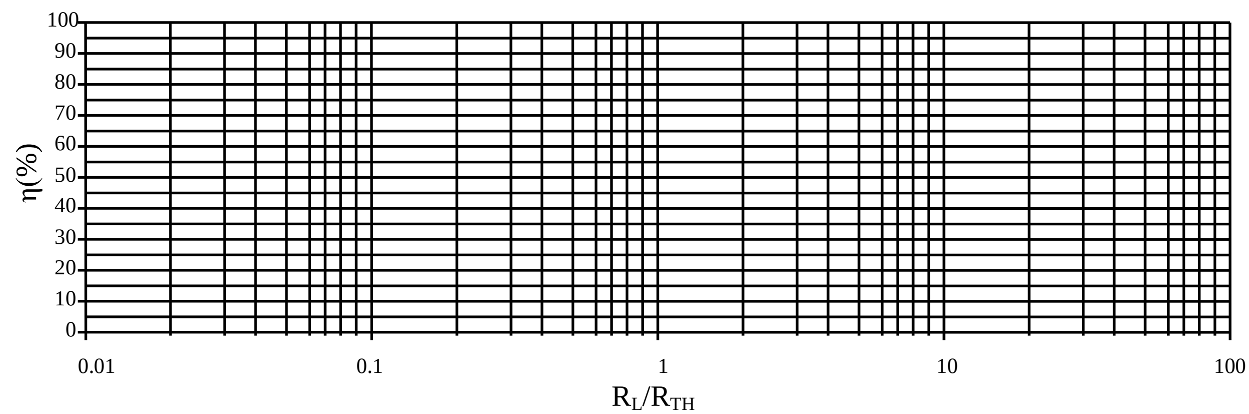
| $R_L/R_{TH}$ | 0.05 | 0.1 | 0.2 | 0.5 | 1.0 | 2 | 5 | 10 | 50 |
|---|---|---|---|---|---|---|---|---|---|
| $v_L$(V) | | | | | | | | | |
| $i_L$(mA) | | | | | | | | | |
| $P_L$(mW) | | | | | | | | | |
| $P_S$(mW) | | | | | | | | | |
| η% | | | | | | | | | |

5- Use the data in table (3.3) to plot $\mathbf{v_L}$ vs $\mathbf{[R_L/R_{TH}]}$, $\mathbf{i_L}$ vs $\mathbf{[R_L/R_{TH}]}$, $\mathbf{P_L}$ vs $\mathbf{[R_L/R_{TH}]}$, and **η%** vs $\mathbf{[R_L/R_{TH}]}$ on graphs (3.2), (3.3), (3.4), and (3.5).




**Graphs (3.2), (3.3), (3.4) & (3.5)**

## 3.5 Conclusion:

1- Comment on how the "measured" load line [on Graph (3.1)] compare with its theoretical version. Discuss the causes of any discrepancies.

2- Discuss what you observed from the corresponding data recorded in tables (3.l) & (3.2).

3- Discuss what you observed from the plots on Graph (3.2), (3.3), (3.4) & (3.5).

4- What is the range of values for **[$R_L/R_{TH}$]** that provide a combination of "almost" optimum power transfer to the load at a reasonably high power-transfer efficiency?

**Experiment #4 Introduction to Digital Multimeters, Oscilloscopes & Function Generators**

## 4.1 Introduction:

At each station in our electric-circuits laboratories a standard set of instruments is available to enable you to conduct your investigations of circuit behaviour. These instruments are capable of providing the following:

a) Generate test signals such as sinusoidal, triangular, and square waveforms with adjustable amplitude and frequency. These signals can be level-shifted [up or down] with the addition of a dc-offset component,
b) Measure dc and/or ac voltage & current, resistance, and frequency, and
c) Display voltage waveforms on a CRT.

This experiment introduces these instruments and demonstrates their capabilities and limitations.

## 4.2 Prelab Assignment:

Read the Appendix-section associated with this experiment and familiarize yourself with the various controls of each instrument.

## 4.3 Procedure:

1- Connect the dc-circuit shown in Fig (4.1). Set the oscilloscope controls as follows: Signal Coupling (<u>**CHx MENU**</u>→<u>*Coupling*</u>) ☛ **dc,** Y-Position (VERTICAL <u>**POSITION**</u> knobs) ☛ **screen centre,** and Vertical Sensitivity (<u>**VOLTS/DIV**</u> knobs) ☛ **1V/div** for both channels **"1"** & **"2".**
   Connect channels "1" & "2" to display the voltage waveforms @ nodes **(1) & (2)** respectively.

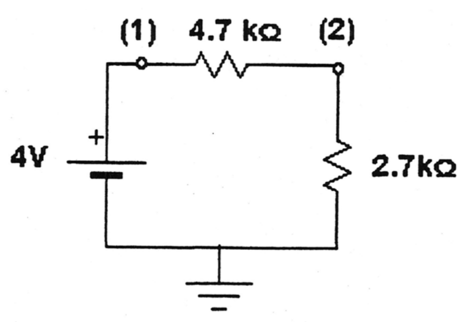



**Fig (4.1)**

2- Use the oscilloscope to measure the voltages @ nodes **(1) & (2).**

$\mathbf{V_{(1)}=}$ **V** **&** $\mathbf{V_{(2)}=}$ **V**

3- Use the DMM to measure the voltages @ nodes **(1) & (2).**

**$V_{(1)}$=                    V      &      $V_{(2)}$=                    V**

4- With the oscilloscope connected as in step #1, set the following additional controls as: Horizontal Sensitivity (**SEC/DIV** knob) ☛ **0.2 msec/div,** Trigger Source (**TRIG MENU**→*Source*) ☛ **CH1,** and Trigger Slope (**TRIG MENU**→*Slope*) ☛ **Rising.**

Replace the dc-source in the circuit of Fig (4.1) with the **function generator.** Set the controls of the function generator to provide a **sinusoidal** voltage of **2V (peak)** with a frequency of about **1kHz** @ node **(1).**
Use the DMM to measure the **voltage** & **frequency** [*using the dual display of the DMM*] of the signal @ node **(1).** Adjust the frequency of the function generator to exactly **1kHz.**

**[DMM readings: Frequency =                    Hz & $V_{(1)}$ =                    V.]**

5- Set the **"waveform-select"** control of the function generator to **square wave,** and use the DMM to measure the voltage & frequency @ node **(1).**

**[DMM readings: Frequency =                    Hz & $V_{(1)}$ =                    V.]**

6- Set the waveform-select control of the function generator to **triangular wave,** and use the DMM to measure the voltage & frequency @ node **(1).**

**[DMM readings: Frequency =                    Hz & $V_{(1)}$ =                    V.]**

7- Use the **"dc-offset"** control of the function generator to provide a **triangular** wave of **4V (peak-to-peak)** with an **average value of 2V** at a frequency of **1kHz** @ node **(1).** Note that the amplitude of the waveform is now fluctuating in the voltage range: **0.0V to 4V** @ 1kHz. Use the DMM to measure each of the following voltage entities @ node **(1):**

a) The dc-component…… **$V_{(1)}$ [dc-value]**          =          V,
b) The ac-component…… **$V_{(1)}$ [ac-value]**          =          V, and
c) The [ac + dc]-value… **$V_{(1)}$ [ac+dc-value]**          =          V.

8- Set the controls of the function generator [with the help of the oscilloscope] to provide a sinusoidal signal of **20mV (peak)** with an average value of **2V** at a frequency of **1kHz** @ node **(1).**
***{Note that the present settings of the oscilloscope controls will not enable you to perform the above step !!}***

[Hint: Use the **dc/ac**-coupling & Vertical (Voltage) Sensitivity controls of Channel **"1"** to separately set accurately the dc & ac components of the desired signal]

Use the DMM to measure the dc & ac components of the voltage @ node (1), and record your measurements in table (4.1).

9- Set the "frequency" control of function generator to each of the values listed in table (4.1), and repeat the above step.

**Table (4.1) [DMM measurements]**

| **Frequency (kHz)** | **DC Component (V)** | **AC Component (mV)** |
|---|---|---|
| **1.0** | | |
| **10.0** | | |
| **100.0** | | |
| **1000.0** | | |

10- Connect the circuit shown in Fig (4.2). Connect channels **"1"** & **"2"** of the oscilloscope to node **(1) & (2),** respectively. Note Channel 2 will now display a scaled-up version of the current = **(10,000)** × **i (t).** Set the oscilloscope controls as follows:
Signal Coupling (**CHx MENU**→*Coupling*) ☛ **ac,** Y-Position (VERTICAL **POSITION** knobs) ☛ **screen centre,** and Vertical Sensitivity (**VOLTS/DIV** knobs) ☛ **1V/div** for both channels **"1"** & **"2",** Horizontal Sensitivity (**SEC/DIV** knob) ☛ **0.1 msec/div,** Trigger Source (**TRIG MENU**→*Source*) ☛ **CH1,** and Trigger Slope (**TRIG MENU**→*Slope*) ☛ **Rising.**
Set the controls of the function generator to provide a **sinusoidal** voltage of **4V (peak)** with a frequency of about **1kHz** @ node **(1).**
Note the displays of the waveforms of $\mathbf{V_{(1)}(t)}$ and **i(t)** are both sinusoids with the same frequency, but with a different magnitude and phase angle.

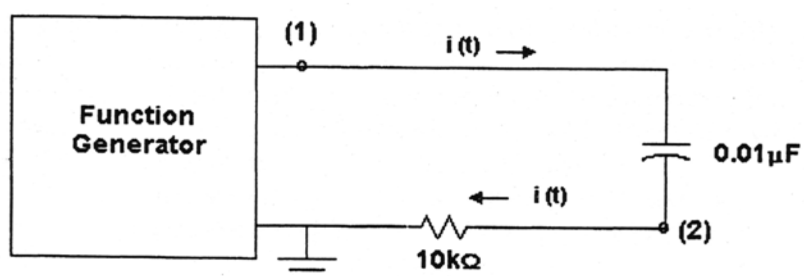



**Fig (4.2)**

11- Use the oscilloscope to measure the phase angle **(θ°)** of **i(t)** relative to $\mathbf{V_{(1)}(t)}$**.** This measurement can be performed in **one-out-of-two** ways depending on the mode of operation of the oscilloscope [**(Y-Time)** or **(X-Y)** mode]:

## Phase Measurement

### A) With The Oscilloscope In The Y-Time Display Mode:

Proceed by setting the oscilloscope controls as follows:

**First:** Set the Y-Position (VERTICAL **POSITION** knobs) for both “1” & “2” ☛ **screen centre,** and Horizontal Sensitivity (**SEC/DIV** knob) to display about **one period** of the **Channel 1** display. Adjust Trigger Level (**LEVEL** knob) to trigger the **Channel 1** display @ the positive-going **zero crossing** instant, and move this point (with **X-Position** (HORIZONTAL **POSITION** knob) adjustment) to the left end of the display.

**Second:** Using Horizontal Controls (**HORIZ MENU**→*Window Zone*) to set **one-half period** of the **Channel 1** display to occupy **exactly nine divisions** along the x-axis.

[***The x-axis is now calibrated for phase-angle measurements with a scale of 20°/div.***]

Measure the phase angle **(θ°)** and record your result in table (4.2).

### B) With The Oscilloscope In The X-Y Display Mode:

Proceed by setting the oscilloscope controls as follows:

Set Display Format (**DISPLAY**→*Format*) of the oscilloscope to **XY** mode. Note that the oscilloscope is now using the signal from Channel 1 to control the X coordinate and the signal from Channel 2 to control the Y coordinate. The oscilloscope is now operating in the X-Y display mode.

The vertical deflection is now controlled by the current **i(t),** and the horizontal deflection is controlled by the voltage $\mathbf{V_{(1)}(t)}$.
Generally, the X-Y display [usually called a **“Lissajous pattern”**] is an ellipse; the ratio of [its intersection with the Y-axis ($y_0$)]-to-[its maximum vertical deflection ($y_m$)] is used to find the phase angle **(θ°)** as indicated in Fig (4.3).
Measure the phase angle **(θ°)** and record your result in table (4.2)

**(Table 4.2)** [Phase angle **(θ°)** of **i(t)** wrt $\mathbf{V_{(1)}(t)}$]

| Y-Time-display mode | X-Y-dispaly mode |
|---|---|
| | |

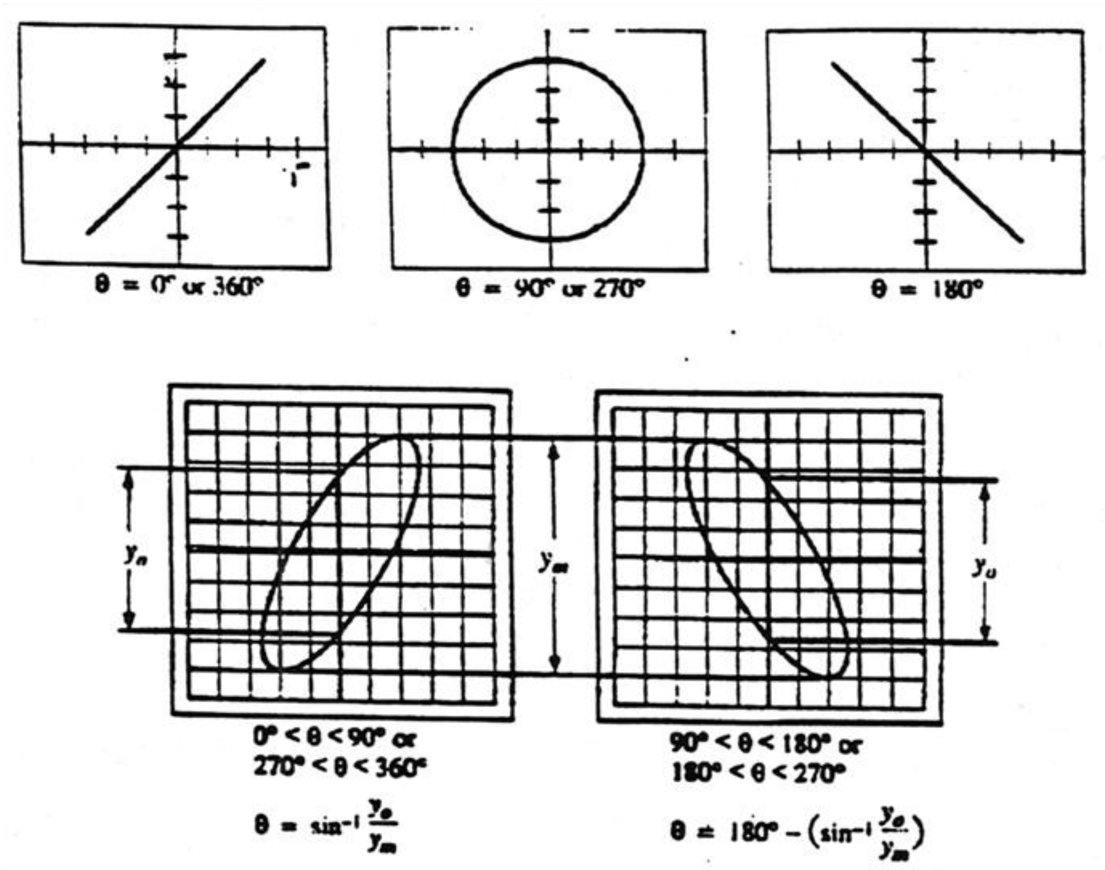



**Fig (4.3)**

## 4.4 Conclusion:

1- Compare your measurements from steps #2 & 3. Which set of measurements would you consider to be more accurate, and why?

2- The DMM ac-reading is called the **“root-mean-square (RMS)”** value of the signal (voltage or current) waveform. For standard waveforms, such as sinusoid, square, and triangular, the RMS-value is related to the peak-value of the signal as follows:

| Type of waveform | [RMS-value] /[peak-value] |
|---|---|
| **Sinusoid** | $[2]^{-0.5}$ |
| **Square** | **1** |
| **Triangular** | $[3]^{-0.5}$ |

Use the above table to check whether your measurements from steps #4, 5, and 6 are accurate enough.

Sinusoid:

Square:

Triangular:

3- Under which conditions would you set the oscilloscope coupling-control to **ac**?

4- Discuss the results of your measurements listed in table (4.1).

5- In comparing the two methods of phase measurement [step #11], which one do you think is more accurate, and why?

# Appendix

## 4.A FLUKE DUAL-DISPLAY DIGITAL MULTIMETER:

You have already gained experience in using DC power supply and the multimeter in measuring DC voltages and currents. Some of the additional features available and require your learning are listed below:

Refer to Figure 1A and 1B for various controls and operations.

Dual Display:

This feature allows to display two properties of an input signal at the same time. e.g.: ac voltage or current as one display and the frequency of the input signal as another display simultaneously.

To obtain the dual display, select any measurement function on modifier for the primary display such as [V~] or [A~] to select ac voltage or current function. Press [2 nd], then press [FREQ] to select the frequency function in the secondary function. Display can be interchanged, i.e. Frequency in Primary display and voltage or current as Secondary display.

AC RMS Values of the Signals:

Pressing [V~] or [A~] displays the magnitude of true rms value of ac voltage or current signal. To obtain the true rms value of a combined waveform (AC+DC), press [V~] & [V≈] or [A~] & [A≈] simultaneously. The meter will alternately take a dc and an ac measurement then calculate & display the rms value given by:

$$\text{RMS value} = \sqrt{(\text{ac rms value})^2 + (\text{dc})^2}$$

(The meter will show significant errors when reading rate is fast.)
[DC + AC] rms measurements can only be made in the primary display.

Function Modifier Buttons:

Selection of the function modifier causes the meter to perform an action on an input; e.g., convert to decibels or compare to another value.

- REL (Relative readings) modifier:

In this feature, the reading on the primary display is always between the relative base and an input measurement. For example, if the relative base is 10.0 volts and the present reading is 9.53 volts, the display will show -0.47. When this feature is selected, the last valid reading is stored as the relative base, the primary display zeroes out and "REL" is shown in the primary display.

- dB (Decibels and Audio power) modifier:

This modifier takes a voltage measurement, converts it to dBm (measure of decibels relative to one milliwatt), and displays the result on the primary display.
Decibels can be selected only when a voltage function is selected on the primary display (volts ac, volts dc, volts ac + dc). A voltage measurement is converted to dBm using the following formula:

$$\text{dBm} = 10\log_{10}\left[\frac{1000(\text{measured value})^2}{\text{Reference impedance}}\right]$$

The reference impedance values can be set to any of 21 values from 2Ω to 8000Ω. (Refer the manual to select the value). The default value is 600Ω.

- HOLD (Touch hold) modifier:

This allows you to take a measurement and "hold" that measurement on the display. This feature can be advantageous in difficult or hazardous circumstances when you might have to keep the eyes fixed on the probes, and read the display when it is safe to do so.

- MNMX (Minimum Maximum) modifier:

The selection of this feature causes the meter to store and display the minimum and maximum inputs measured.

The meter allows you to use multiple function modifiers simultaneously and evaluated in the order HOLD, dB, MNMX and REL.

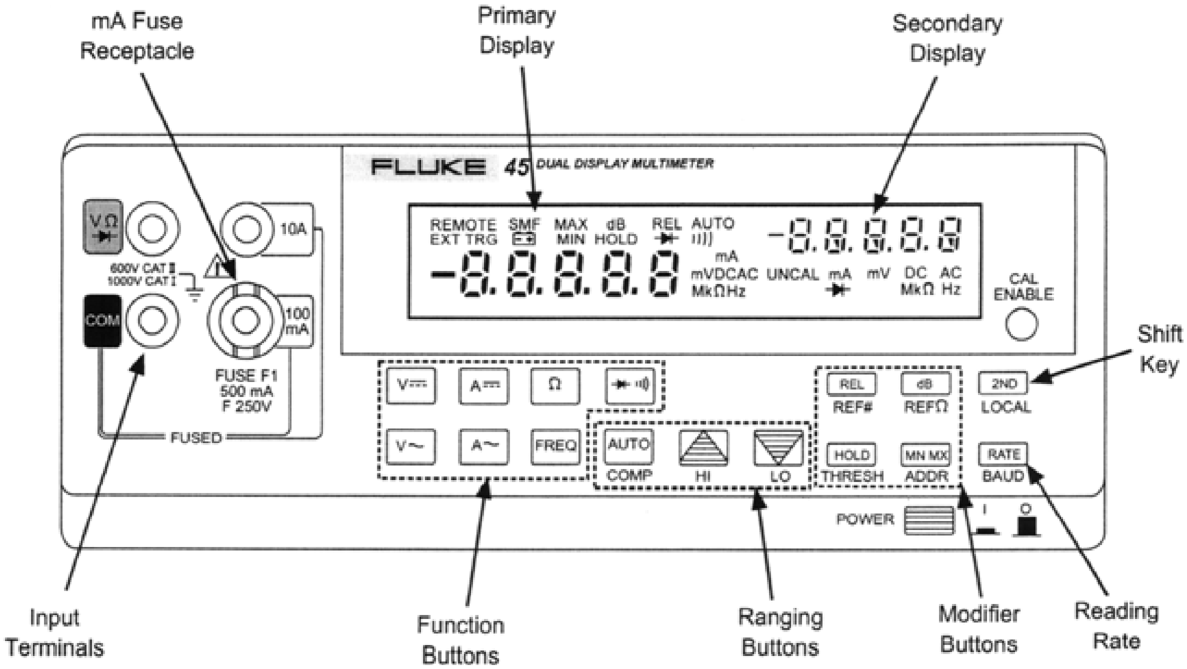

mA Fuse
Receptacle
Primary
Display
Secondary
Display
FLUKE 45 DUAL DISPLAY MULTIMETER
REMOTE
EXT TRG
SMF
MAX
MIN
dB
HOLD
REL
AUTO
mA
mVDCAC
MkΩHz
UNCAL
mA
mV
DC
MkΩ
AC
Hz
CAL
ENABLE
10A
100
mA
COM
600V CAT II
1000V CAT I
FUSE F1
500 mA
F 250V
FUSED
Shift
Key
REL
REF#
dB
REFΩ
2ND
LOCAL
V⎓
A⎓
Ω
V~
A~
FREQ
AUTO
COMP
HI
LO
HOLD
THRESH
MN MX
ADDR
RATE
BAUD
POWER
Input
Terminals
Function
Buttons
Ranging
Buttons
Modifier
Buttons
Reading
Rate

**Figure 1A**

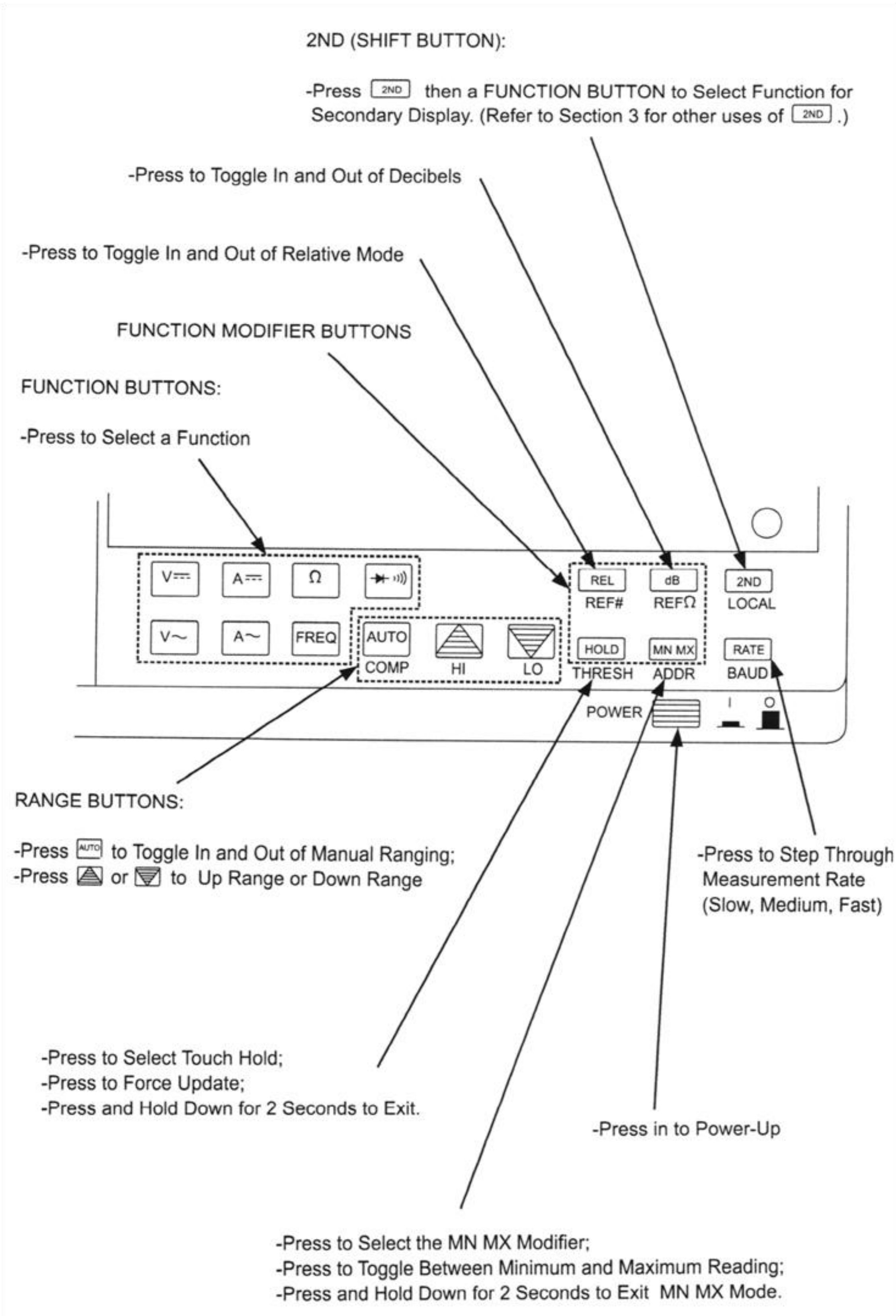

2ND (SHIFT BUTTON):
-Press 2ND then a FUNCTION BUTTON to Select Function for Secondary Display. (Refer to Section 3 for other uses of 2ND.)
-Press to Toggle In and Out of Decibels
-Press to Toggle In and Out of Relative Mode
FUNCTION MODIFIER BUTTONS
FUNCTION BUTTONS:
-Press to Select a Function
V⎓
A⎓
Ω
V~
A~
FREQ
AUTO
COMP
HI
LO
REL
REF#
dB
REFΩ
HOLD
THRESH
MN MX
ADDR
2ND
LOCAL
RATE
BAUD
POWER
I
O
RANGE BUTTONS:
-Press AUTO to Toggle In and Out of Manual Ranging;
-Press or to Up Range or Down Range
-Press to Step Through Measurement Rate (Slow, Medium, Fast)
-Press to Select Touch Hold;
-Press to Force Update;
-Press and Hold Down for 2 Seconds to Exit.
-Press in to Power-Up
-Press to Select the MN MX Modifier;
-Press to Toggle Between Minimum and Maximum Reading;
-Press and Hold Down for 2 Seconds to Exit MN MX Mode.

**Figure 1B**

## 4.B FUNCTION GENERATOR:

The function generator is used to generate AC signals. The GwINSTEK GFG-8216A function generator can produce sine, triangular and square waves.

Controls on front of the generator provide means of controlling frequency (f) and amplitude ($V_m$) of the ac signal, and the DC offset ($V_{avg}$). For example, the sine wave with the DC offset is described by

$$v(\mathrm{t}) = V_m \sin(\omega t + \emptyset) + V_{avg}$$


**Figure 2: Controls and connectors**

- Function Selector: Press one of the three push buttons to select the desired output waveform.

- Frequency Range Selector: To select the required frequency range by pressing the relevant push button.

- Frequency Adjustment: Press and turn clockwise the knob for MAX frequency and invert for MIN frequency.

- Output Amplitude Control: Turn clockwise for MAX output and invert for a -20dB output. Pull the knob out for an additional 20dB output attenuation. Press the knob to adjust a -20dB output.

- DC Offset Control: Pull out the knob to select any DC level of the waveform between ±10V, turn clockwise to set a positive DC level waveform and invert for a negative DC level waveform.

## 4.C OSCILLOSCOPE:

Oscilloscopes are scientific instruments that create graphical representations of electrical signals. Figure 3 shows the front panel control of the Tektronix TDS1002B Oscilloscope.

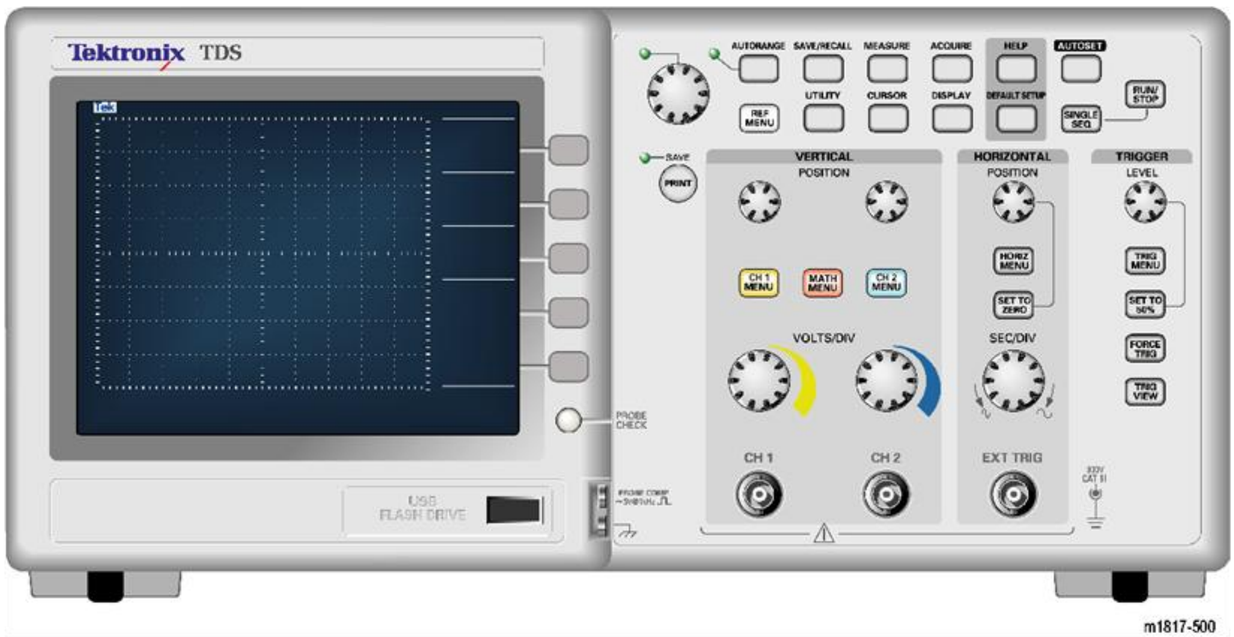



**Figure 3: Front Panel controls**

The y-axis of the oscilloscope display can be used to represent the magnitude of the voltages from the two input channels (Channel 1 and Channel 2). The x-axis of the display can be used to represent either the time or the magnitude of the voltage from input Channel 2.

The panel includes a set of controls that determine the precise behaviour of the x and y axes. It also includes controls that determine the conditions (called the trigger conditions) that must be met before the oscilloscope saves and plots a new set of data on the display. Each set of these controls are described in turn.

## Display

Push the **DISPLAY** button to choose how waveforms are presented and to change the appearance of the entire display.

| Options | Settings | Comments |
|---|---|---|
| Type | Vectors, Dots | Vectors fill the space between adjacent sample points in the display<br>Dots display only the sample points |
| Persist | OFF, 1 sec,<br>2 sec, 5 sec,<br>Infinite | Sets the length of time each displayed sample point remains displayed |

| | | |
|---|---|---|
| Format | YT, XY | YT format displays the vertical voltage in relation to time (horizontal scale)<br>XY format displays a dot each time a sample is acquired on channel 1 and channel 2<br>Channel 1 voltage or current determines the X coordinate of the dot (horizontal) and the channel 2 voltage or current determines the Y coordinate (vertical) |
| Contrast | | Makes it easier to distinguish a channel waveform from persistence |

## Horizontal

You can use the horizontal controls to set up two views of a waveform, each with their own horizontal scale and position. The horizontal position readout shows the time represented by the centre of the screen, using the time of the trigger as zero. When you change the horizontal scale, the waveform will expand or contract around the screen centre.

Push the **HORIZ MENU** button to get the following options:

| **Options** | **Comments** |
|---|---|
| Main | The main horizontal time base setting is used to display the waveform |
| Window Zone | Two cursors define a window zone<br>Adjust the Window Zone with the Horizontal Position and SEC/DIV controls |
| Window | Changes the display to show the waveform segment (expanded to screen width) within the window zone |
| Set Holdoff | Displays the holdoff value; push the option button and use the multipurpose knob to adjust |

**Knobs and Other Buttons**

HORIZONTAL **POSITION** Knob. Use to control the position of the trigger relative to the center of the screen.

The trigger point can be set to the left or the right of the center of the screen. The maximum number of divisions to the left depends on the Horizontal Scale (time base) setting. For most scales, the maximum is at least 100 divisions. Placing the trigger point off the screen to the left is called Delayed Sweep.

**SET TO ZERO** Button. Use to set the horizontal position to zero.

**SEC/DIV** Knob (Horizontal Scale). Use to change the horizontal time scale to magnify or compress the waveform.

## Vertical Controls

You can use the vertical controls to display and remove waveforms, adjust vertical scale and position, set input parameters.

Push the **CH1 MENU** or **CH2 MENU** button to get the following options:

| Options | Settings | Comments |
| --- | --- | --- |
| Coupling | DC, AC, Ground | DC passes both AC and DC components of the input signal<br>AC blocks the DC component of the input signal and attenuates signals below 10 Hz<br>Ground disconnects the input signal |
| BW Limit | 20 MHz, Off | Limits the bandwidth to reduce display noise; filters the signal to reduce noise and other unwanted high frequency components |
| Volts/Div | Coarse, Fine | Selects the resolution of the Volts/Div knob<br>Coarse defines a 1-2-5 sequence.<br>Fine changes the resolution to small steps between the coarse settings |
| Probe | | Push to adjust Probe options |
| Invert | On, Off | Inverts (flips) the waveform with respect to the reference level |

**Knobs**

VERTICAL **POSITION** Knobs. Use the VERTICAL POSITION knobs to move the channel waveforms up or down on the screen.

**VOLTS/DIV** Knobs. Use the VOLTS/DIV knobs to control how the oscilloscope amplifies or attenuates the source signal of channel waveforms. When you turn a VOLTS/DIV knob, the oscilloscope increases or decreases the vertical size of the waveform on the screen. Waveforms that extend beyond the screen (overrange) and display a ? in the measurement readout indicates an invalid value. Adjust the vertical scaling to ensure the readout is valid.

## Trigger Controls

You can define the trigger through the Trigger Menu (**TRIG MENU** button) and front-panel controls.

### Trigger Types

Three types of triggering are available: Edge, Video, and Pulse Width. A different set of options are displayed for each type of trigger. The Edge Trigger menu is summarized in detail here. Please refer to the manual for the other two trigger types.

| **Option** | **Details** |
|---|---|
| Edge (default) | Triggers the oscilloscope on the rising or falling edge of the input signal when it crosses the trigger level (threshold) |
| Video | Displays NTSC or PAL/SECAM standard composite video waveforms; you trigger on fields or lines of video signals. |
| Pulse | Triggers on aberrant pulses. |

### Edge Trigger

Use Edge triggering to trigger on the edge of the oscilloscope input signal at the trigger threshold.

| **Options** | **Settings** | **Comments** |
|---|---|---|
| Edge | | With Edge highlighted, the rising or falling edge of the input signal is used for the trigger |
| Source | CH1, CH2, CH3, CH4, Ext, Ext/5, AC Line | Select the input source as the trigger signal |
| Slope | Rising, Falling | Select to trigger on either the rising or falling edge of the signal |
| Mode | Auto, Normal | Select the type of triggering |
| Coupling | AC, DC, Noise Reject, HF Reject, LF Reject | Selects the components of the trigger signal applied to the trigger circuitry |

### Knobs and Other Buttons

**LEVEL** Knob. Use to control the Trigger Level.

**<u>SET TO 50%</u>** Button. Use the SET TO 50% button to quickly stabilize a waveform. The oscilloscope automatically sets the Trigger Level to be about halfway between the minimum and maximum voltage levels. This is useful when you connect a signal to the EXT TRIG BNC and set the trigger source to Ext, or Ext/5.

**<u>FORCE TRIG</u>** Button. Use the FORCE TRIG button to complete the waveform acquisition whether or not the oscilloscope detects a trigger. This is useful for SINGLE SEQ acquisitions and Normal trigger mode. (In Auto trigger mode, the oscilloscope automatically forces triggers periodically if it does not detect a trigger.)

**<u>TRIG VIEW</u>** Button. Use the Trigger View mode to display the conditioned trigger signal on the oscilloscope. You can use this mode to see the following types of information:

- Effects of the Trigger Coupling option
- AC Line trigger source (Edge Trigger only)
- Signal connected to the EXT TRIG BNC

# Experiment #5 Pulse Response of Simple RC & RL Circuits

## 5.1 Introduction:

In addition to sources and resistors, many circuits also contain capacitors and inductors. Unlike sources and resistors, these elements neither produce nor dissipate power. **Capacitors** and **inductors** are instead **energy-storage** elements, and as a result, they exhibit electrical **“memory”** effects in the sense that energy stored at an earlier time may contribute to the present value of the voltage across (for capacitors) or current through (for inductors). Thus, when a sudden change occurs in a circuit, such as opening or closing a switch, both the voltage across a capacitor and the current through an inductor cannot change instantaneously, as the stored energy would require some time to readjust to the new conditions.

This experiment investigates the dynamic response of circuits [containing one energy-storage element, either a capacitor or an inductor] as a result of a pulse-train excitation.

**Reference:** Text , chapter seven

## 5.2 Objectives:

- To measure the internal (output) resistance of a function generator.
- To investigate the dynamic response of simple R-C circuits due to a pulse excitation.
- To investigate the dynamic response of simple R-L circuits due to a pulse excitation.

## 5.3 Prelab Assignment:

1- Consider the circuit shown in Fig (5.1). The switch S was in position (a) for a long time and then moved to position (b) at time t = 0.

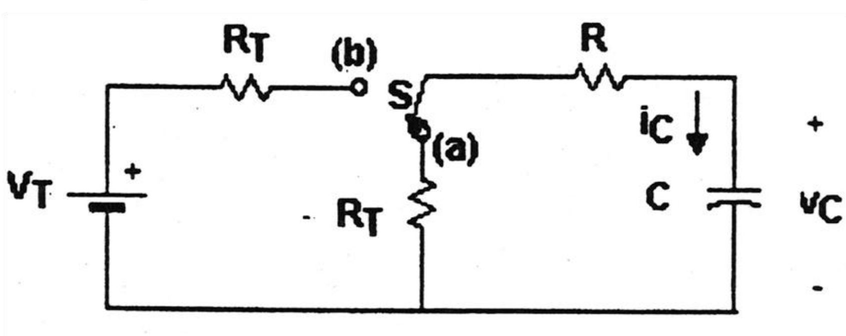



**Fig (5.1)**

a) Derive the equations for the voltage $\mathbf{v_C(t)}$ and the current $\mathbf{i_C(t)}$ for $\mathbf{t \geq 0}$.
b) Fill in the missing values (or expressions) in Table (5.1).

**Table (5.1)**

| | At $t(0^-)$ | At $t(0^+)$ | At $t = \infty$ |
|---|---|---|---|
| $v_C(t)$ (V) | | | |
| $i_C(t)$ (μA) | | | |

c) For the values of R and C shown below in Table (5.2) determine the charging time-constant ($\tau_C$) and initial charging current $\mathbf{i_C(0^+)}$. Assume $R_T = 600\ \Omega$ & $V_T = 6V$.

**Table (5.2)**

| R(kΩ) | C(μF) | $\tau_C$ | $i_C(0^+)$ |
|---|---|---|---|
| 1 | 0.01 | | |
| 6.8 | 0.01 | | |

2- Consider the circuit of Fig (5.2). The switch S was in position (a) for a long time and then moved to position (b) at time t = 0.

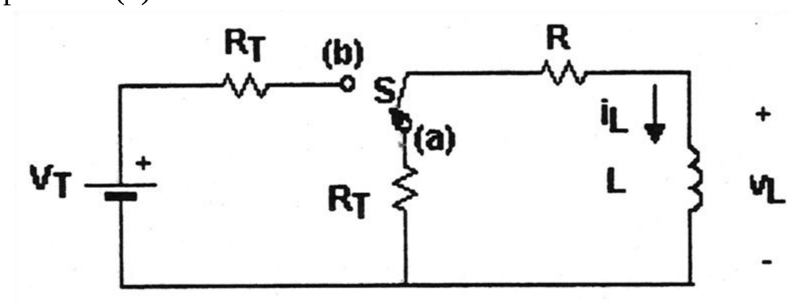



**Fig (5.2)**

a) Derive the equations for current $\mathbf{i_L(t)}$ and voltage $\mathbf{v_L(t)}$ for $\mathbf{t \geq 0}$.
b) Fill in the missing values (or expressions) in Table (5.3).

**Table (5.3)**

| | At $t(0^-)$ | At $t(0^+)$ | At $t = \infty$ |
|---|---|---|---|
| $i_L(t)$ (mA) | | | |
| $v_L(t)$ (V) | | | |

c) For the values of R and L shown below in Table (5.4) determine the time constants and the initial voltage across the inductor.

**Table (5.4)**

| R(kΩ) | L(mH) | $\tau_L$ | $v_L(0^+)$ |
|---|---|---|---|
| 1 | 50 | | |
| 1 | 150 | | |

Assume $R_T = 600\Omega$ & $V_T = 6V$.

## 5.4 Procedure:

### Part I: The Internal (Output) Resistance of The Function Generator

1- Connect the oscilloscope across the output terminals of the function generator. Set the controls of the function generator to provide a **squarewave** signal of **2V (peak)** and zero average value @ **1kHz.** Note that this **(open circuit)** output voltage represents the value of $\mathbf{V_{TH}}$ of the Thevenin's equivalent circuit of the function generator **for the present setting.**

2- Connect a decade resistance box $\mathbf{R_L}$ across the output terminals of the function generator. Adjust $\mathbf{R_L}$ until the output voltage drops to **1V (peak).** The value of $\mathbf{R_L}$ now is equal to $\mathbf{R_{TH}}$ of the Thevenin's equivalent circuit of the generator, which is also referred to as the **internal** (or **output**) resistance of the generator.

The **internal (output)** resistance of the function generator = $\mathbf{R_{TH}}$ **=** **Ω**

3- Prove to yourself that the value of $\mathbf{R_{TH}}$ of the function generator remains the same regardless of the magnitude and waveshape of the output signal of the generator.

### Part II. The RC- Circuit Pulse Response

4- Set the oscilloscope controls as follows:

- Channel **"1":** Signal Coupling @ **dc,** Y-Position @ **screen bottom,** and Vertical Sensitivity @ **1V/div.**
- Channel **"2":** Signal Coupling @ **dc,** Y-Position @ **screen centre,** and Vertical Sensitivity @ **20mV/div.**
- Horizontal Sensitivity @ **0.1msec/div,** Trigger Source @ **Channel 1,** and Trigger Slope @ **Rising.**

Connect channel **"1"** across the output terminals of the function generator and set the controls of the function generator to provide a **squarewave** signal of **3V (peak)** and **3V** average value @ **1kHz.** (Note that the signal is actually a **positive-pulse train** with a height of **6V** and a duration of **500µsec.** Adjust the **"X-Position"** of the scope to set the beginning of the pulse @ the **left end** of the display.

5- Connect the circuit shown in Fig (5.3). Note that the **20Ω** resistor is a **current-sampling** resistor that provides a voltage across = $\mathbf{(20\Omega) \times i_C(t)}$**.**
Connect channel **"1"** of the oscilloscope to node "A" in order to display (approximately) the voltage waveform across the capacitor $\mathbf{v_C(t)}$ & channel **"2"** to node "B" to display the **(scaled up)** current waveform $\mathbf{20 \times i_C(t)}$**. [*Use "X-Position" & "Trigger Level" to set the begining of the pulse in the* $v_C(t)$ *@ the left end of the display.*]**

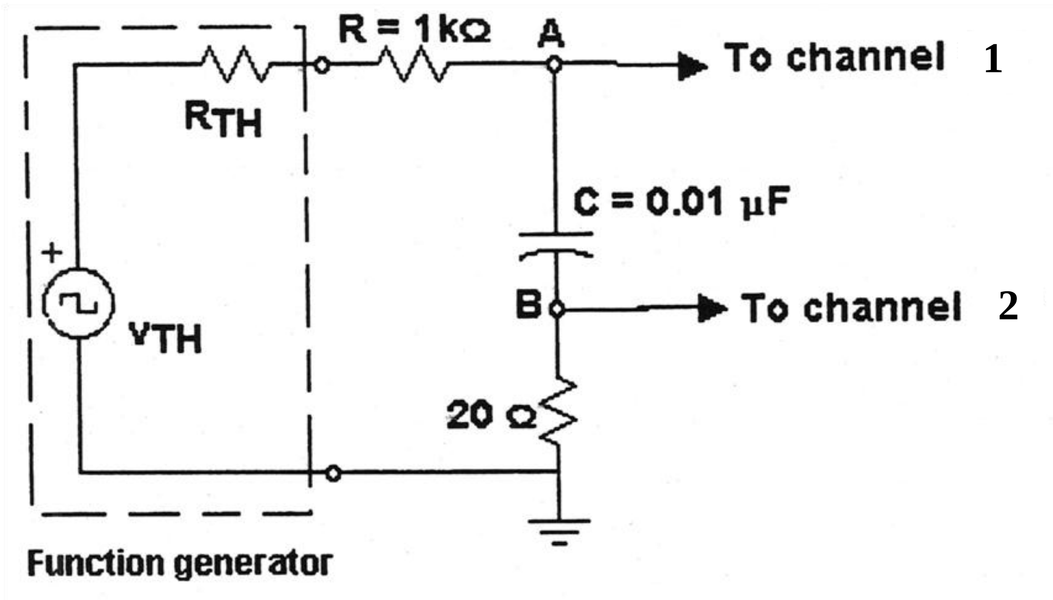
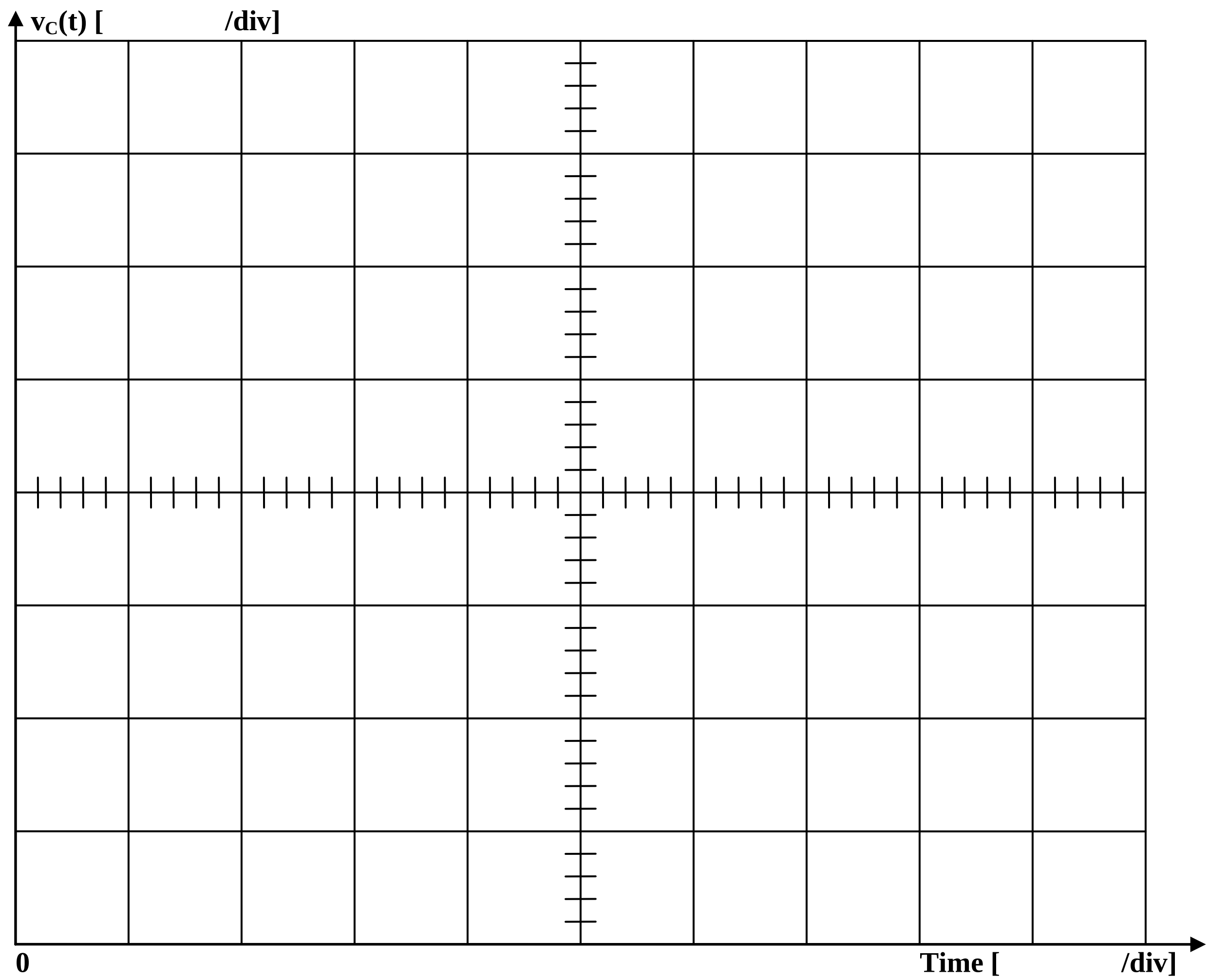



**Figure (5.3)**

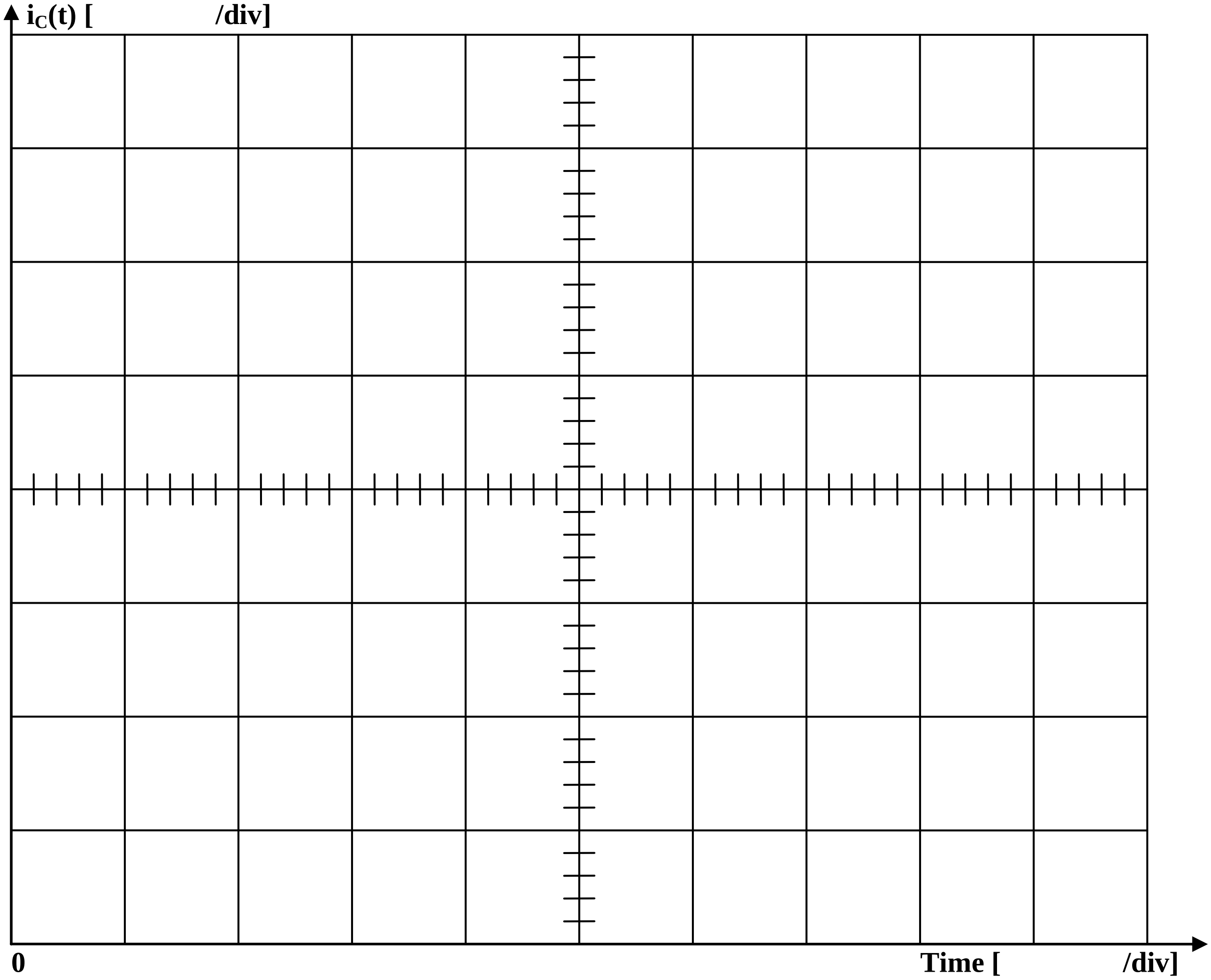
6- Use Graphs (5.1) & (5.2) to plot the waveforms of $\mathbf{v_C(t)}$ & $\mathbf{i_C(t)}$, respectively.

7- Use the $\mathbf{v_C(t)}$ to measure the time constant $\boldsymbol{\tau_C}$ as accurately as possible [your instructor will show you how it is done]. Record your results in table (5.5).

8- Replace the resistor **"R"** in Fig (5.3) with another value of **6.8kΩ,** and repeat the above step.




**Graph (5.1)**




**Graph (5.2)**

**Table (5.5)**

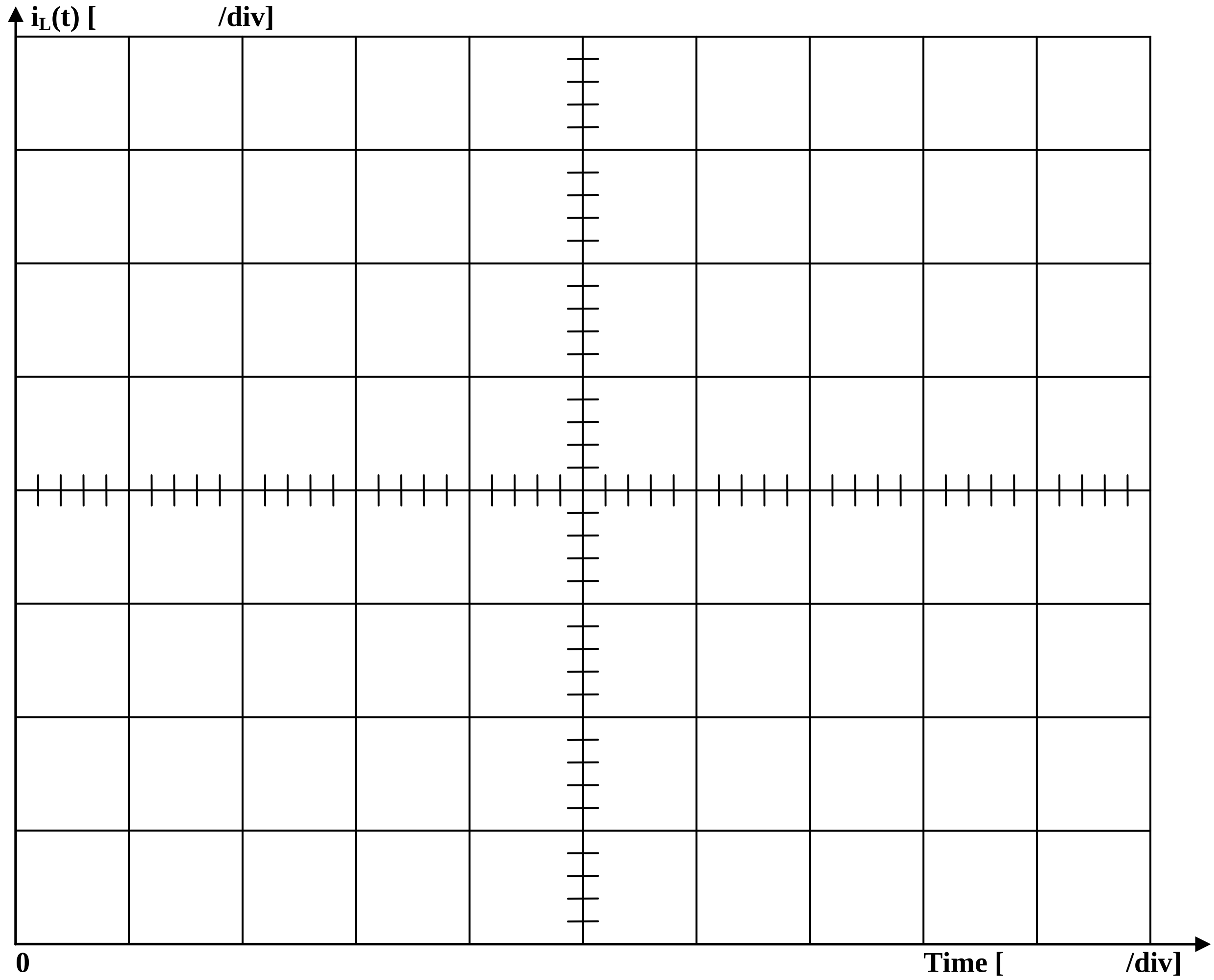
| R(kΩ) | $R_{total}$(kΩ) | Time Constant (μsec) | $i_C$ (max) (mA) |
|---|---|---|---|
| **1** | | | |
| **6.8** | | | |

## Part II. The RL- Circuit Pulse Response

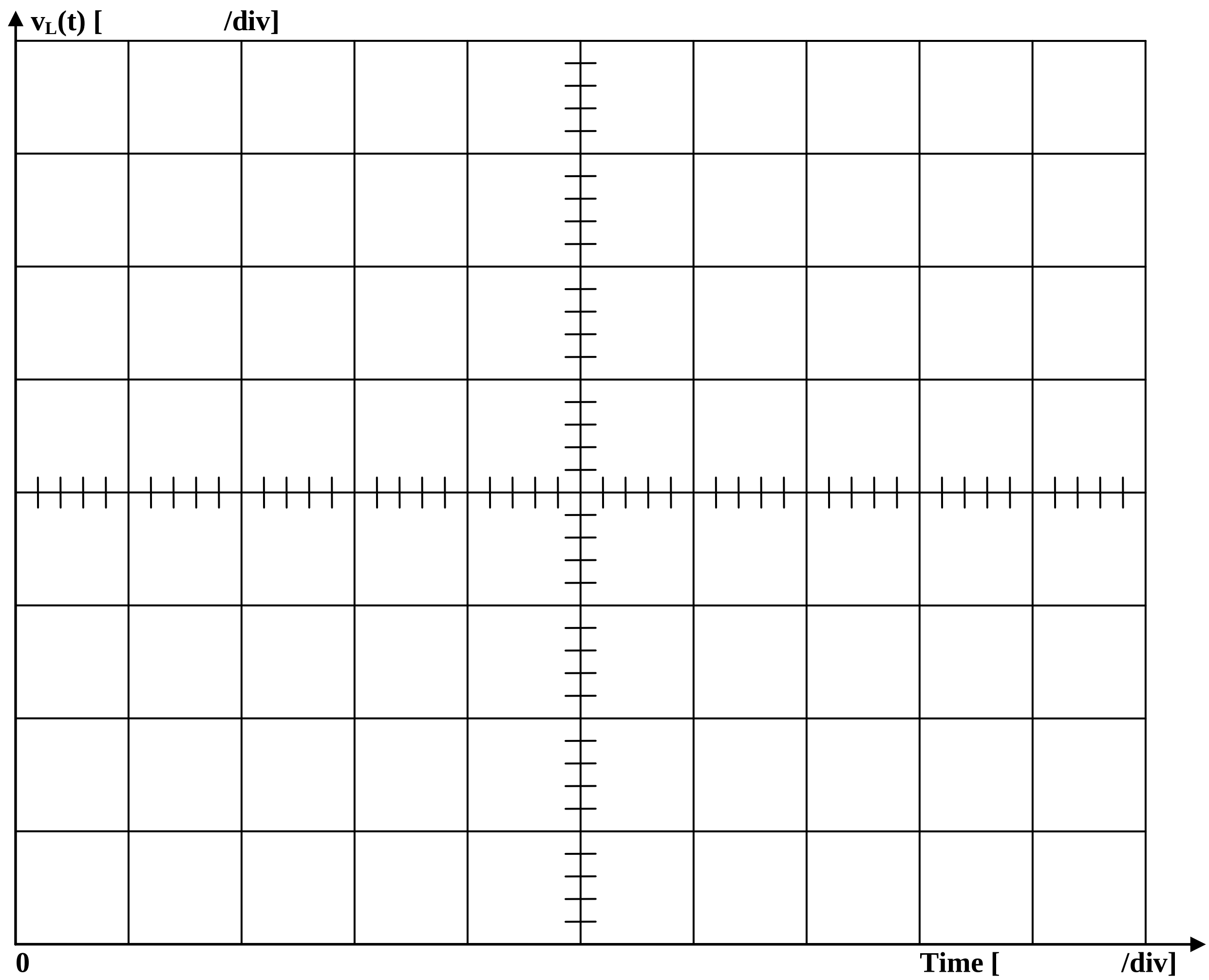
9- Replace the capacitor in your circuit with a decade inductance box with **L = 50mH** inductor, and let **R = 1kΩ:** Modify the positions of the oscilloscope-controls as:

- Channel **"1":** Y-Position @ **screen centre,** and sensitivity @ **2V/div.**
- Channel **"2":** Y-Position @ **screen bottom,** and sensitivity @ **l0mV/div.**

Channel "1" now displays (approximately) the inductor's voltage waveform **$v_L(t)$,** and channel "2" displays the (scaled-up) current **(20Ω) × $i_L(t)$.** Repeat as in steps **#4 to 7.** Use Graphs (5.3) & (5.4) for your plots of the current and voltage waveforms **$i_L(t)$ & $v_L(t)$,** respectively. [***Use "X-Position" & "Trigger level" to set the beginning of the pulse in the $i_L(t)$ @ the left end of the display.***]




**Graph (5.3)**




**Graph (5.4)**

10- Adjust the decade inductance box to 150mH , and repeat the above step.

**Table(5.6)**

| L(mH) | $R_{total}$(kΩ) | Time Constant (μsec) | $v_C$ (max) (V) |
|---|---|---|---|
| 50 | | | |
| 150 | | | |

## 5.5 Conclusion:

1- Compare the corresponding data recorded in tables (5.2) & (5.5). Comment on the possible causes for any deviations from your expectations.

2- Discuss what you have observed from the plots on Graph (5.1) & (5.2).

3- Compare the corresponding data recorded in tables (5.4) & (5.6). Comment on the possible causes for any deviations from your expectations.

4- Discuss what you have observed from the plots on Graph (5.3) & (5.4).

5- Explain briefly the differences in the dynamic responses to pulse excitation of RL- and RC- circuits.

6- What is the **“inherent”** error in our procedure for displaying both $\mathbf{v_C(t)}$ & $\mathbf{v_L(t)}$? How would you go about reducing the effect of this error?

# Experiment #6 Sinusoidal-Steady-State Response of RC & RL Circuits

## 6.1 Introduction:

The dynamic response of a **stable linear** circuit consists of two components:

a) A natural (usually called **transient**) component that eventually vanishes; its time duration is determined by the circuit composition, and
b) A forced (usually called a **steady-state**) response which is the sustained component caused by the driving excitation source.

When the **excitation** source is a **sinusoid,** the **steady-state response** is also a **sinusoid,** with the **same frequency** as the excitation, but with a **different amplitude and phase angle.**

The sinusoidal-steady-state (SSS) behaviour of circuits is an important area of study for several reasons:

a) The generation, transmission, and consumption of electrical energy occur under essentially SSS conditions,
b) An understanding of SSS behaviour of circuits makes it possible to predict the behavior of circuits with **nonsinusoidal** excitation, and
c) SSS behaviour often simplifies the design of electrical systems.

This experiment examines the sinusoidal-steady-state behaviour of simple-series RC & RL circuits.

**Reference:** Text , chapter 10.

## 6.2 Objectives:

- To examine the sinusoidal-steady-state response of simple-series RC & RL circuits.
- To investigate the effect of frequency variations on the amplitude and phase angle of the SSS response of the RC & RL circuits.

## 6.3 Prelab Assignment:

1- Consider the circuit shown in Fig (6.1). The sinusoidal signal source has a Thevenin's equivalent voltage: $\mathbf{v_{TH}(t) = 5\sin[(2\pi)\times 1000t]}$ volts, and a Thevenin's equivalent resistance: $\mathbf{R_{TH} = 600\Omega}$.

a) Find the **SSS expression** for the capacitor current $\mathbf{i_C(t)}$.

b) Suppose that the frequency of $\mathbf{v_{TH}(t)}$ is varied as listed in table (6.1), find the magnitude and phase angle of the impedance **Z,** where $\mathbf{Z = |Z|\angle\theta°_Z}$, and the peak value of the capacitor current $\mathbf{|I_C|}$, for each frequency setting. [Hint: set up the expressions for $\mathbf{|Z|}$, $\mathbf{\theta°_Z}$, and $\mathbf{|I_C|}$ in terms of the frequency variable **"f",** enter each expression in your calculator, and then enter the values of **"f"** (one at a time) to get the corresponding results.]

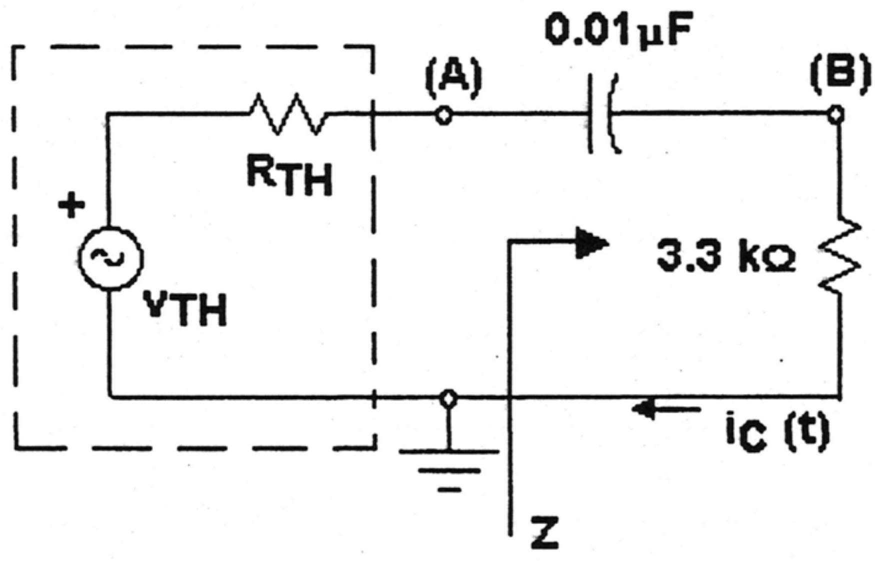



**Fig (6.1)**

**Table (6.1)**

| **Frequency (kHz)** | **\|Z\| (kΩ)** | **$\theta°_Z$** | **$\|I_C\|$ (mA)** |
|---|---|---|---|
| **0.5** | | | |
| **1** | | | |
| **2** | | | |
| **5** | | | |
| **10** | | | |
| **20** | | | |
| **50** | | | |

2- Suppose that the capacitor in Fig (6.1) is replaced with a **"practical"** inductor whose equivalent circuit consists of a series combination of an inductive element of **0.5H** and a resistive element of **700Ω.**

a) Find the **SSS expression** for the inductor current $\mathbf{i_L(t)}$**.**

b) Suppose that the frequency of $\mathbf{v_{TH}(t)}$ is varied as listed in table (6.2), find the magnitude and phase angle of the impedance **Z,** where $\mathbf{Z = |Z|\angle\theta°_Z}$**,** and the peak value of the inductor current $\mathbf{|I_L|}$**,** for each frequency setting.

**Table (6.2)**

| Frequency (kHz) | $\lvert Z \rvert$ (kΩ) | $\theta°_Z$ | $\lvert I_L \rvert$ (mA) |
|---|---|---|---|
| **0.1** | | | |
| **0.2** | | | |
| **0.5** | | | |
| **1** | | | |
| **2** | | | |
| **5** | | | |
| **10** | | | |

## 6.4 Procedure:

### Part I: The Sinusoidal-Steady-State Behaviour of An RC Circuit

1- Connect channel **"1"** of the oscilloscope across the output terminals of the function generator. Set the controls of the function generator to provide an **"open-circuit"** sinusoidal voltage of **5V (peak)** @ a frequency **(f)** of **500Hz.**

Connect the circuit shown in Fig (6.1). Set the oscilloscope for **ac-coupling, Y-Positions** @ **screen centre, Trigger Source** @ **Channel 1,** and **Trigger Slope** @ **Rising.** Connect channel **"1"** of the oscilloscope to display the voltage waveform @ node (A), and channel **"2"** to display the voltage waveform @ node (B). [*The "2" display now represents the (scaled-up) current waveform (3300)* $i_C(t)$.]

2- Measure the peak-value of $\mathbf{v_A(t)}$ and $\mathbf{v_B(t)}$, and record in table (6.3) under $\lvert \mathbf{V_A} \rvert$ & $\lvert \mathbf{V_B} \rvert$, respectively. Evaluate the peak value of the current $\lvert \mathbf{I_C} \rvert$.

**Phase-Angle Measurement**

To measure the phase angle **θ°** [which is defined here as the phase angle of $\mathbf{v_B(t)}$ relative to $\mathbf{v_A(t)}$] as accurately as possible, proceed by setting the oscilloscope controls as follows:

**First:** Set **Horizontal Sensitivity** to display about **one period** of the **"1"** display. Adjust **Trigger Level** to trigger the **"1"** display @ the positive-going **zero crossing** instant, and move this point (with **"X-Position"** adjustment) to the left end of the screen.

**Second:** Adjust the **Horizontal Controls** to set **one-half period** of the **“1”** display to occupy **<u>exactly nine divisions</u>** along the x-axis.

***The x-axis is now calibrated for phase-angle measurements with a scale of 20°/div.***

**Third: <u>Remember to repeat the above settings each time you change the frequency of the sinusoidal excitation.</u>**

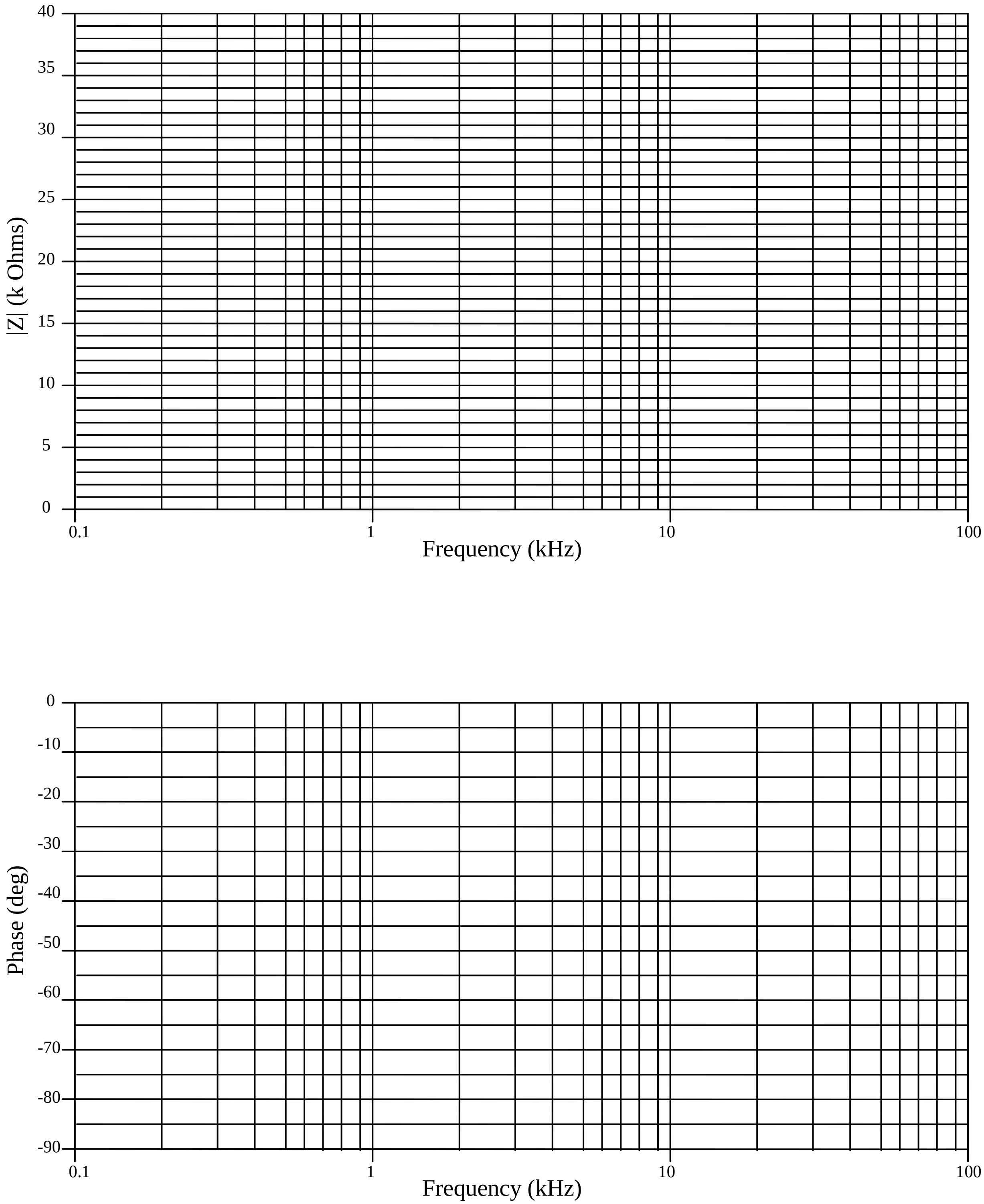
3- Measure the phase angle **θ°,** and evaluate the magnitude **|Z|** & phase angle $\theta°_Z$ of the impedance **Z.** Record your results in table (6.3).

4- Repeat the above steps for each frequency setting in table (6.3).

5- Use the semi-logarithmic graph (6.1) to plot **|Z|** & $\theta°_Z$ vs. frequency.

**Table (6.3)**

| Frequency (kHz) | $\lvert V_A \rvert$ (V) | $\lvert V_B \rvert$ (V) | $\lvert I_C \rvert$ (mA) | $\lvert Z \rvert$ (kΩ) | $\theta°_Z$ |
|---|---|---|---|---|---|
| **0.5** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **5** | | | | | |
| **10** | | | | | |
| **20** | | | | | |
| **50** | | | | | |


40
35
30
25
20
15
10
5
0
|Z| (k Ohms)
0.1
1
10
100
Frequency (kHz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Phase (deg)
0.1
1
10
100
Frequency (kHz)

**Graph (6.1)**

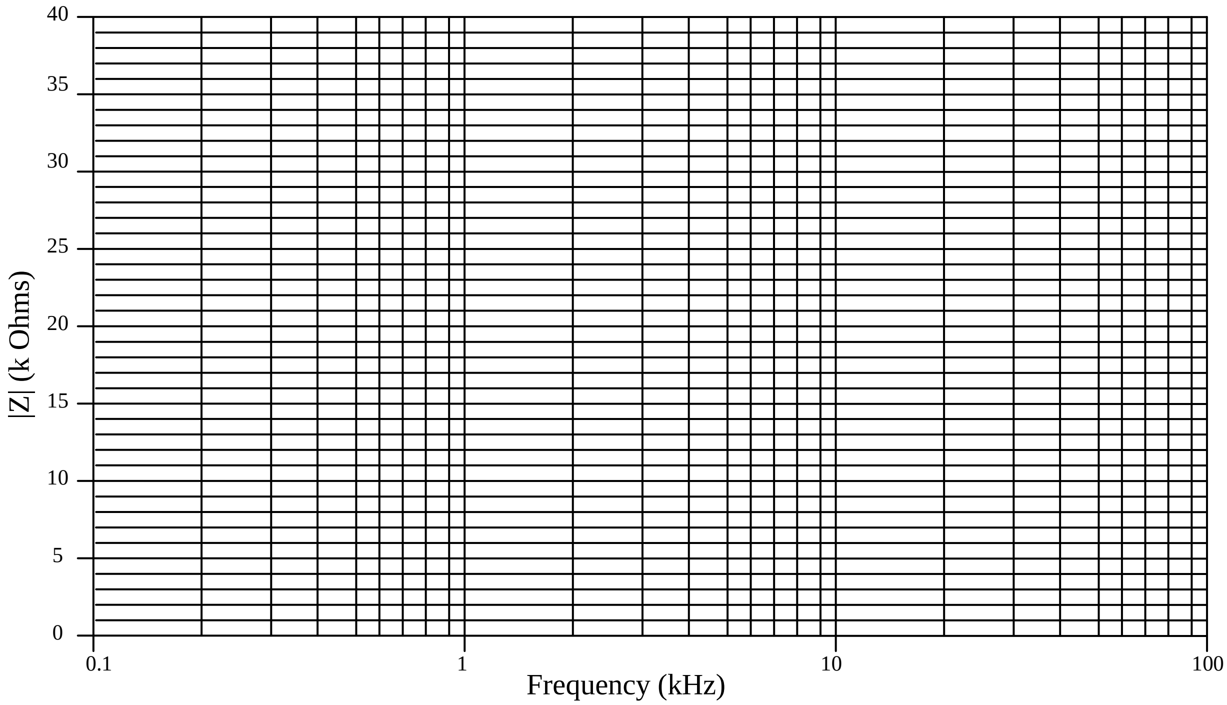
## Part II: The Sinusoidal-Steady-State Behavior of An RL Circuit

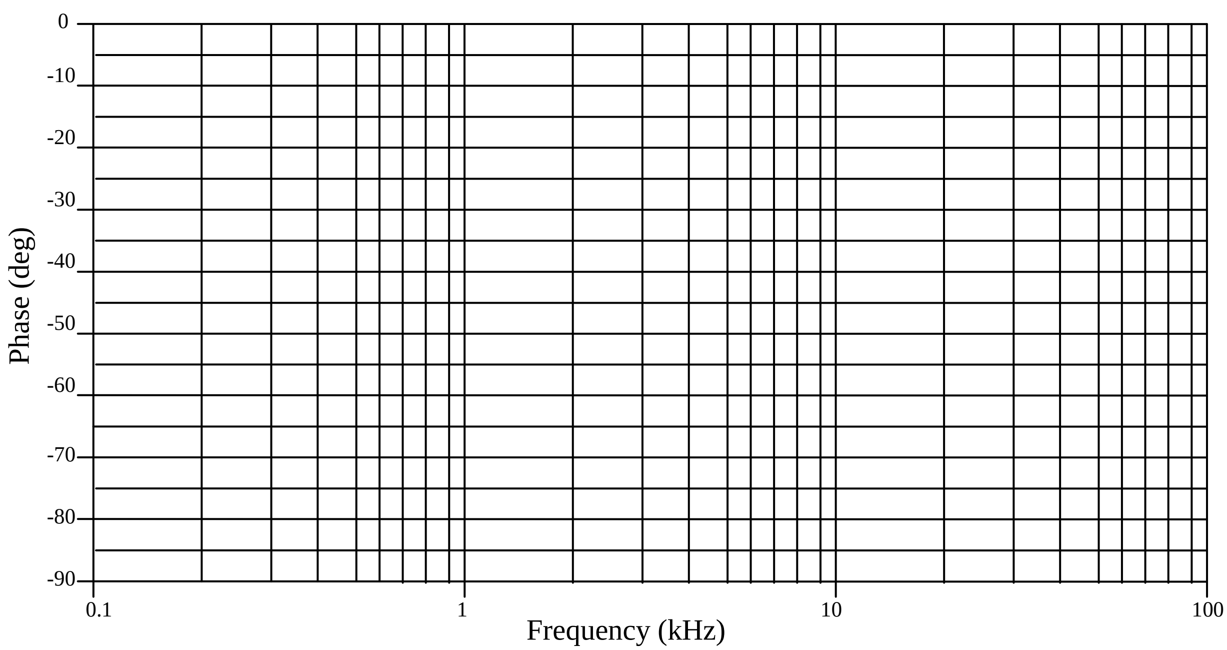
6- Replace the capacitor in your circuit with the decade-inductance box **(L = 0.5H).** Use the oscilloscope to measure **$|V_A|$, $|V_B|$** & **$\theta°$** for each frequency listed in table (6.4). Evaluate **$|I_L|$,** and the magnitude **$|Z|$** & phase angle **$\theta°_Z$** of the impedance **Z.**

7- Use the semi-logarithmic graph (6.1) to plot **$|Z|$** & **$\theta°_Z$** vs. frequency.

**Table (6.4)**

| **Frequency (kHz)** | **$\|V_A\|$ (V)** | **$\|V_B\|$ (V)** | **$\|I_L\|$ (mA)** | **$\|Z\|$ (kΩ)** | **$\theta°_Z$** |
|---|---|---|---|---|---|
| **0.1** | | | | | |
| **0.2** | | | | | |
| **0.5** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **5** | | | | | |
| **10** | | | | | |


40
35
30
25
20
15
10
5
0
|Z| (k Ohms)
0.1
1
10
100
Frequency (kHz)


0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Phase (deg)
0.1
1
10
100
Frequency (kHz)

**Graph (6.2)**

## 6.4 Conclusion:

1- Discuss what you have observed from the plots of **|Z|** & $\boldsymbol{\theta°_Z}$ vs. frequency on Graph (6.1). At which frequency range is the impedance of the series RC-circuit: a) predominantly **capacitive,** and b) predominantly **resistive**? Find the frequency at which both capacitive and resistive effects are equal.

2- Suppose that R & C in Fig (6.1) were, instead, connected in parallel. Sketch the corresponding plots for **|Z|** & $\boldsymbol{\theta°_Z}$ vs. frequency. At which frequency range is the impedance of the parallel RC-circuit: a) predominantly **capacitive,** and b) predominantly **resistive**?

3- Discuss what you have observed from the plots of **|Z|** & $\boldsymbol{\theta°_Z}$ vs. frequency on Graph (6.2). At which frequency range is the impedance of the series RL-circuit: a) predominantly **inductive,** and b) predominantly **resistive**? Find the frequency at which both inductive and resistive effects are equal.

4- Suppose that R & L in Fig (6.2) were, instead, connected in parallel. Sketch the corresponding plots of **|Z|** & $\boldsymbol{\theta°_Z}$ vs. frequency? At which frequency range is the impedance of the parallel RL-circuit: a) predominantly **inductive,** and b) predominantly **resistive**?

5- Use Graph (6.1) to find the expression for the voltage across the series RC-circuit $\mathbf{v_{RC}(t)}$, when the current $\mathbf{i_C(t)}$ is given as:

a) $\mathbf{i_C(t) = 4\cos(2\pi \times 2000\,t + 20°)}$ mA, and

b) $\mathbf{i_C(t) = 3\sin(2\pi \times 5000\,t - 30°)}$ mA.

6- Use Graph (6.1) to find the expression for $\mathbf{i_L(t)}$ when the voltage across the series RL-circuit $\mathbf{v_{RL}(t)}$ is given as:

a) $\mathbf{v_{RL}(t) = 4\cos(2\pi \times 2000\,t + 20°)}$ volts, and

b) $\mathbf{v_{RL}(t) = 3\sin(2\pi \times 5000\,t - 30°)}$ volts.

## Experiment #7 The Frequency Response of a Simple RLC Circuit

## 7.1 Introduction

The sinusoidal-steady-state (SSS) response of a linear circuit is solely determined by the type, value, and interconnections of its elements. If a circuit consists entirely of resistive elements, its SSS response will be the same, regardless of the value of the frequency of the sinusoidal excitation. Having capacitive and/or inductive elements in a circuit, however, will result in a SSS response that is a function of frequency. The magnitude and phase variations (as a function of frequency) of a circuit variable are usually referred to as the **"frequency response"** of the circuit.

The frequency response of a linear circuit is usually determined by transforming the circuit into the so-called **"frequency domain",** where every variable (voltage or current) is transformed into a corresponding **phasor,** and every element in the circuit is transformed into a corresponding **impedance.**

This experiment examines the frequency response of a simple RLC circuit.

**Reference:** Text, chapter 10.

## 7.2 Objectives:

- To examine the frequency response of a simple RLC circuit.

## 7.3 Prelab Assignment:

The circuit in Fig (7.1) consists of a sinusoidal voltage excitation connected in series with a practical inductor **($L = 0.5H$ & $r_L = 700\Omega$)** and a capacitor of **$0.01\mu F$.** In addition, a **current-sampling** resistor of **$47\Omega$** is added to the circuit.

1- Find the expression of the impedance **$Z = V_A / I = |Z|\angle\theta°_Z$.** Determine the frequency at which: i) **$|Z|$** is minimum, ii) **$\theta°_Z = +45°$,** and iii) **$\theta°_Z = -45°$.**
2- Find the expressions for the magnitude & phase of the voltage ratio **$V_C / V_A$.** Determine the values of the magnitude & phase @ **f = 1.6k, 2.2k, and 3kHz.**

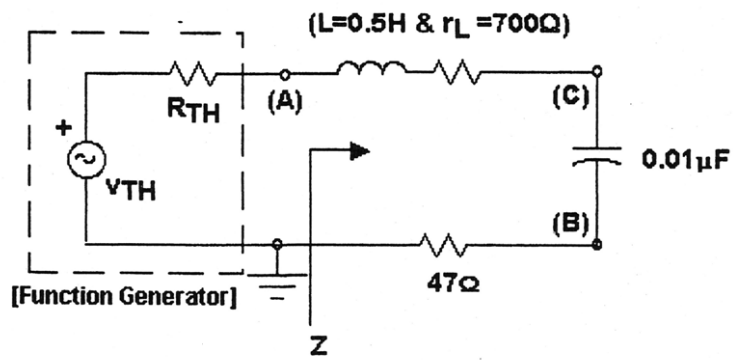



**Fig (7.1)**

## 7.4 Procedure:

### Part I The Frequency Response of The Input Impedance

1- Connect the circuit shown in Fig (7.1). Connect channels **"1" & "2"** of the oscilloscope to display the voltages of node **(A) & (B),** respectively. Set the oscilloscope for **ac-coupling,** Y-Positions @ **screen centre,** Trigger Source @ **Channel 1,** and Trigger Slope @ **Rising.** Note that the "2" display represents a scaled-up current **= (47Ω) × i(t).**
Set the function generator to provide a **sinusoidal** waveform of **5V (peak)** @ a frequency of **1.6 kHz.** Measure the phase angle $\theta°_Z$, which is the phase angle of the "2" sinusoid relative to the "1" signal. [Hint: **follow the phase-angle procedure of Exp #6**].

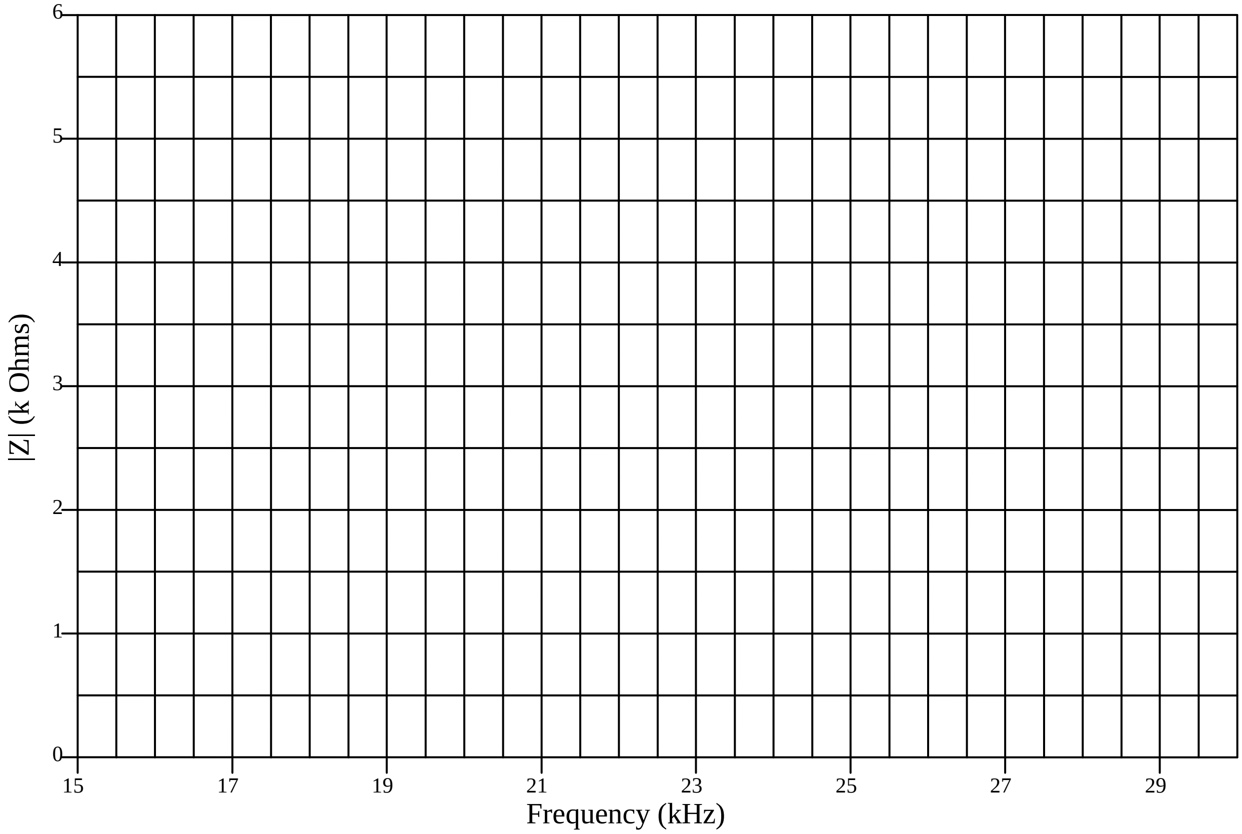
2- Connect the DMM to measure [*in the following sequence*]: i) The frequency of $V_A$, ii) The magnitude of $V_A$, and iii) The magnitude of $V_B$. Evaluate the RMS-value of the current and **|Z|.** Record your measurements in table (7.1).
***The DMM voltage-reading is an RMS-value of the measured voltage-waveform; for sinusoidal voltage, the RMS-value = (0.707) (peak-value).***

3- Repeat the above steps for each frequency setting in table (7.1)

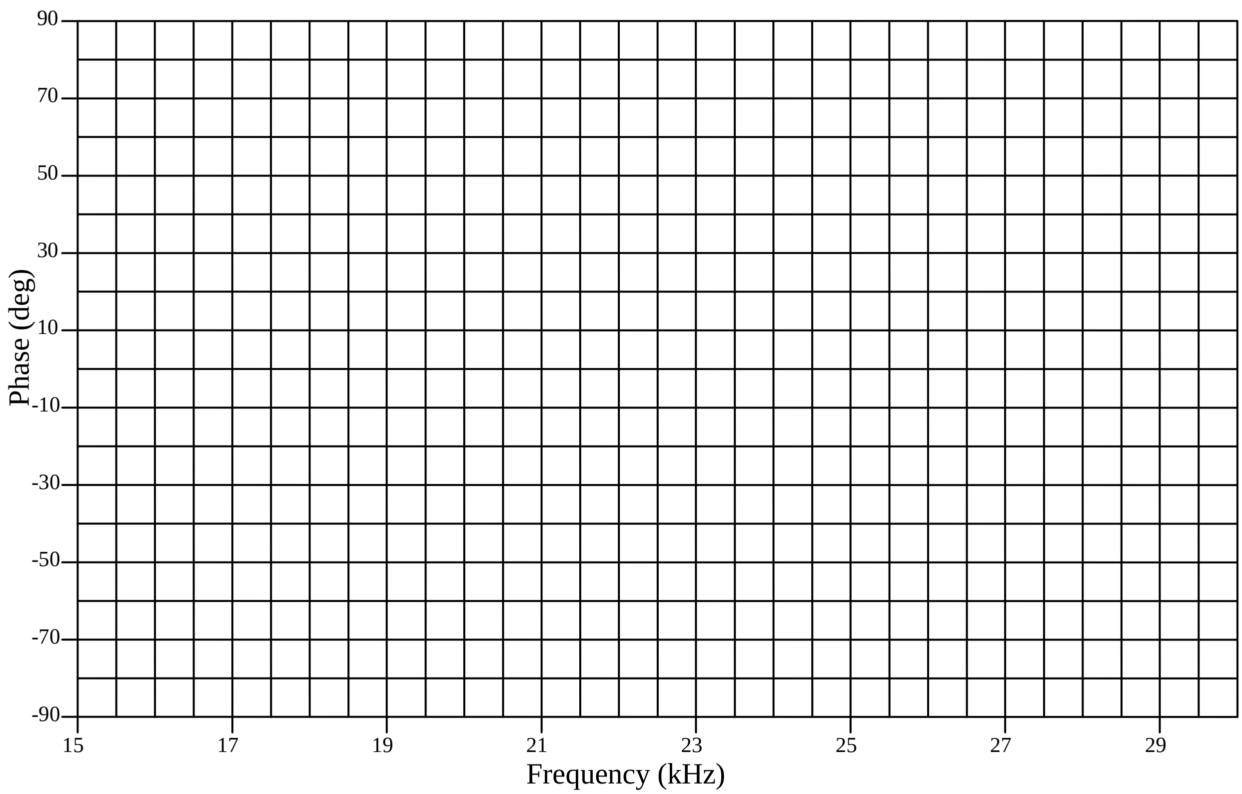
**Table (7.1)**

| Frequency (kHz) | $V_A$ (RMS) (V) | $V_B$ (RMS) (mV) | I (RMS) (mA) | \|Z\| (kΩ) | $\theta°_Z$ (Degrees) |
|---|---|---|---|---|---|
| 1.6 | | | | | |
| 1.8 | | | | | |
| 2.0 | | | | | |
| 2.1 | | | | | |
| 2.2 | | | | | |
| 2.3 | | | | | |
| 2.4 | | | | | |
| 2.6 | | | | | |
| 2.8 | | | | | |
| 3.0 | | | | | |

4- Use Graph (7.1) to plot the **frequency response of the input impedance [$Z=V_A/I$];** i.e., plot **|Z| &** $\theta°_Z$ vs. **frequency.**



6
5
4
3
2
1
0
|Z| (k Ohms)
15
17
19
21
23
25
27
29
Frequency (kHz)

90
70
50
30
10
-10
-30
-50
-70
-90
Phase (deg)
15
17
19
21
23
25
27
29
Frequency (kHz)


**Graph (7.1)**

## Part II The Frequency Response of a Voltage-Transfer Function

5- Connect channel **"2"** of the oscilloscope to display the voltage @ node **(C),** instead of **(B).**

6- Use the DMM to adjust the frequency to each setting in table (7.2), and measure the RMS-values of $\mathbf{V_A}$ & $\mathbf{V_C}$**.** Evaluate the magnitude of the voltage ratio $\mathbf{[V_C / V_A]}$**,** which is usually referred to as the **voltage transfer function** (from node **#A** to node **#C**) of the circuit.

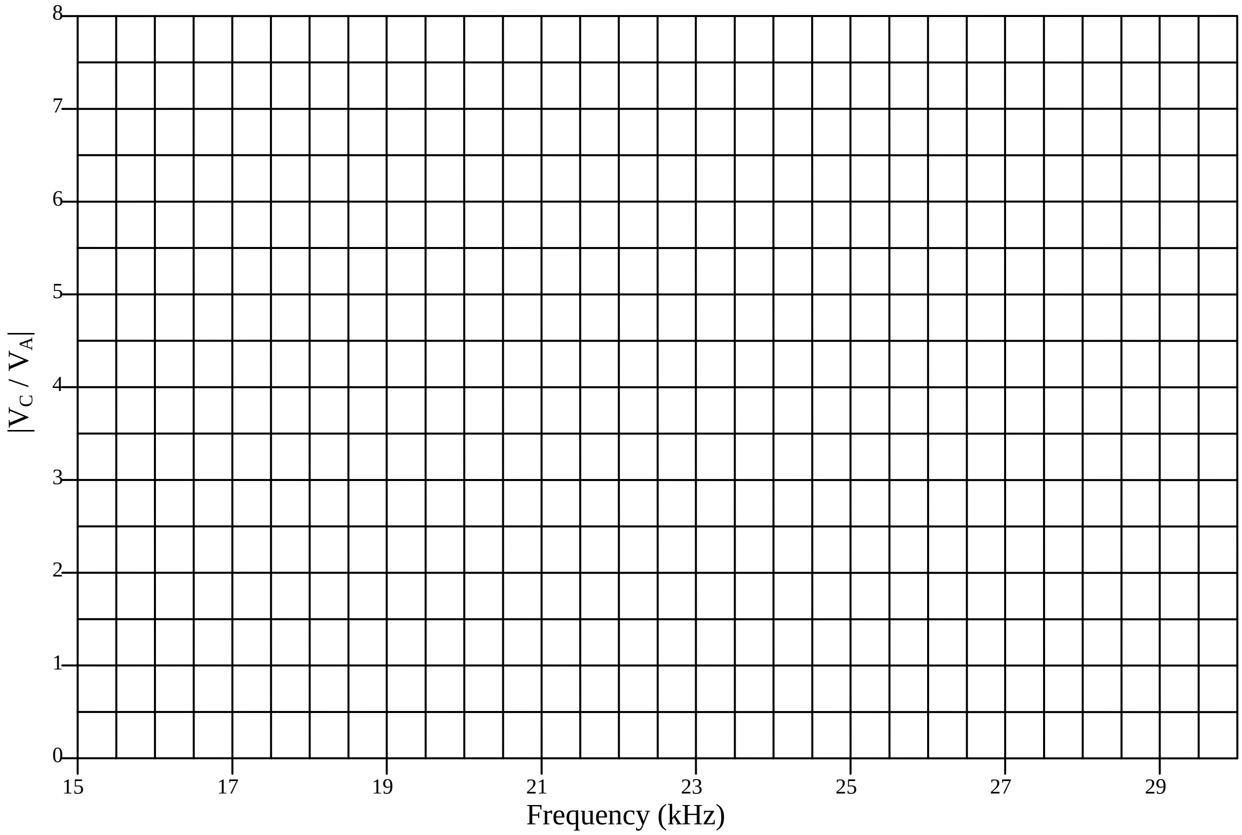
[***The term "function" refers to the fact that the voltage ratio is, in general a function of frequency.***]

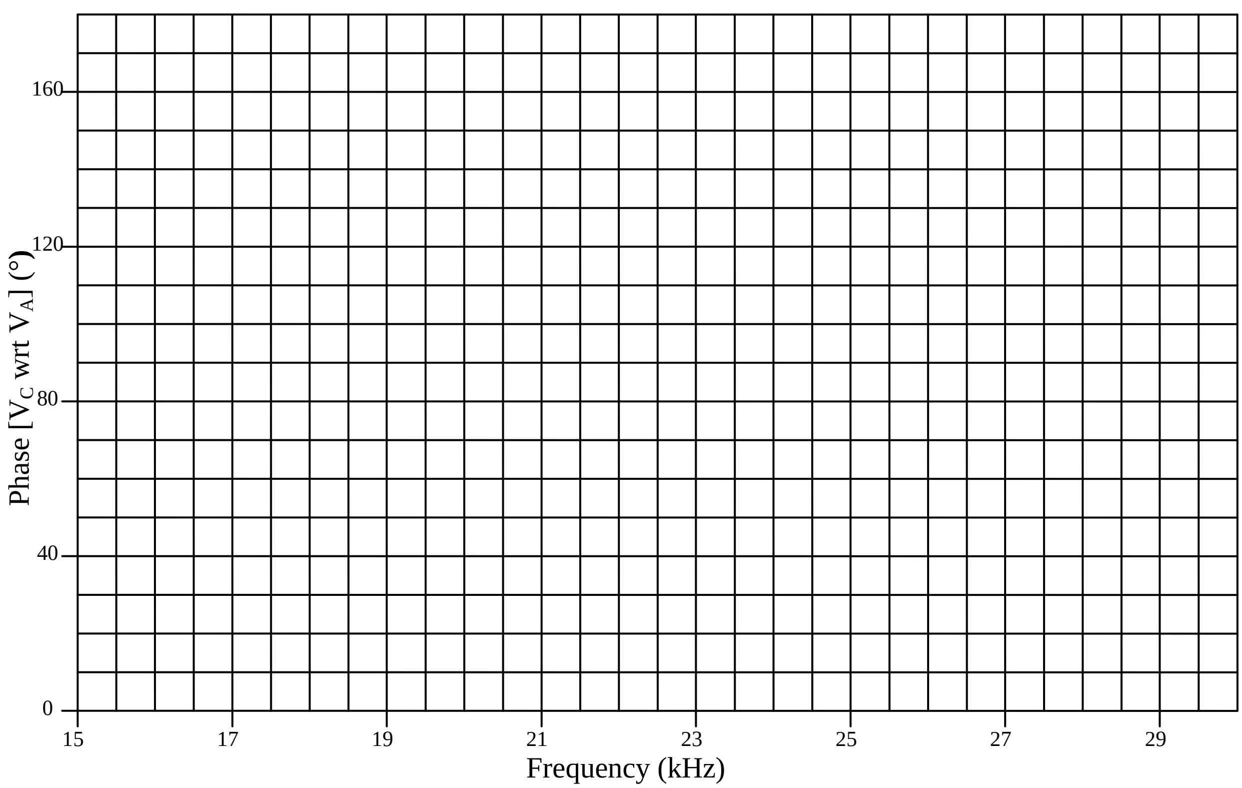
Use the oscilloscope to measure the phase angle $\mathbf{(\theta°_{CA})}$ of the voltage-transfer function for each frequency setting, and record your results in table (7.2).

**Table (7.2)**

| **Frequency (kHz)** | $\mathbf{V_A}$ **(RMS) (V)** | $\mathbf{V_C}$ **(RMS) (V)** | $\mathbf{\lvert V_C/V_A \rvert}$ | $\mathbf{\theta°_{CA}}$ **(Degrees)** |
|---|---|---|---|---|
| **1.6** | | | | |
| **1.8** | | | | |
| **2.0** | | | | |
| **2.1** | | | | |
| **2.2** | | | | |
| **2.3** | | | | |
| **2.4** | | | | |
| **2.6** | | | | |
| **2.8** | | | | |
| **3.0** | | | | |

7- Use Graph (7.2) to plot the **frequency response of the voltage transfer function** $\mathbf{[V_C / V_A]}$**;** i.e., plot $\mathbf{\lvert V_C / V_A \rvert}$ & $\mathbf{\theta°_{CA}}$ vs. **frequency.**


8
7
6
5
4
3
2
1
0
|V_C / V_A|
15
17
19
21
23
25
27
29
Frequency (kHz)


160
120
80
40
0
Phase [V_C wrt V_A] (°)
15
17
19
21
23
25
27
29
Frequency (kHz)

**Graph (7.2)**

## 7.5 Conclusion:

1- Discuss what you have observed from the plots on Graph (7.1).

2- Use the frequency-response plot of the input impedance [on Graph(7.1)] to find the time-domain expression for the voltage waveform $\mathbf{v_A(t)}$ when the circuit current **i(t)** is given as:

a) $\mathbf{i(t) = 4\cos[2\pi(1800)t + 10°]}$ mA
b) $\mathbf{i(t) = 3\sin[2\pi(2200)t - 40°]}$ mA, and
c) $\mathbf{i(t) = 2\cos[2\pi(3000)t + 60°]}$ mA.

3- Discuss what you have observed from the plots on Graph (7.2).

4- Use the frequency-response plot for the voltage-transfer function [on Graph(7.2)] to find the time-domain expression for the voltage waveform $\mathbf{v_C(t)}$ when the voltage waveform $\mathbf{v_A(t)}$ is given as:

a) $\mathbf{v_A(t) = 4 \cos [2\pi (1800)\, t + 100°]}$ volts,
b) $\mathbf{v_A(t) = 3 \sin [2\pi (2200)\, t - 40°]}$ volts, and
c) $\mathbf{v_A(t) = 2 \cos [2\pi (3000)\, t + 60°]}$ volts.

5- Suppose that the value of the capacitor in the circuit was reduced to **2.5nF,** how would that change affect:

a) the plot of $|\mathbf{Z}|$ vs. frequency?
b) the plot of $|\mathbf{V_C} / \mathbf{V_A}|$ vs. frequency?

Sketch the plots before & after the change of the capacitor value.