# *Electrical Engineering Fundamentals*

## *First class*

# AC & DC

# lab Experimental

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# Experiment No.1

# Resistor Color Code and Measurement of Resistance

## 1. Introduction

### 1.1 Objective:

This experiment aims to teach students how to use a multimeter and calculate the value of a resistor.

### 1.2 Components:

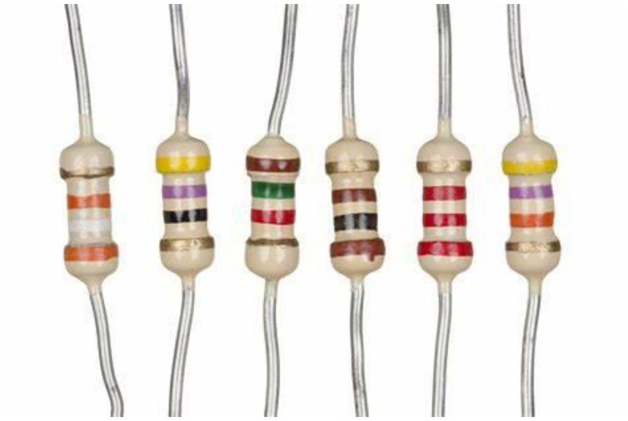
- Set of Resistors;
- Multimeter.

### 1.3 Theory

### 1.3.1. Resistor:

A passive electrical component with two terminals that are used for either limiting or regulating the flow of electric current in electrical circuits.

The main purpose of resistor is to reduce the current flow and to lower the voltage in any particular portion of the circuit. It is made of copper wires which are coiled around a ceramic rod and the outer part of the resistor is coated with an insulating paint.



Tolerance: Tolerance indicates how much the measured value of its **actual resistance** is different from its **theoretical value**, and it is calculated using percentages.

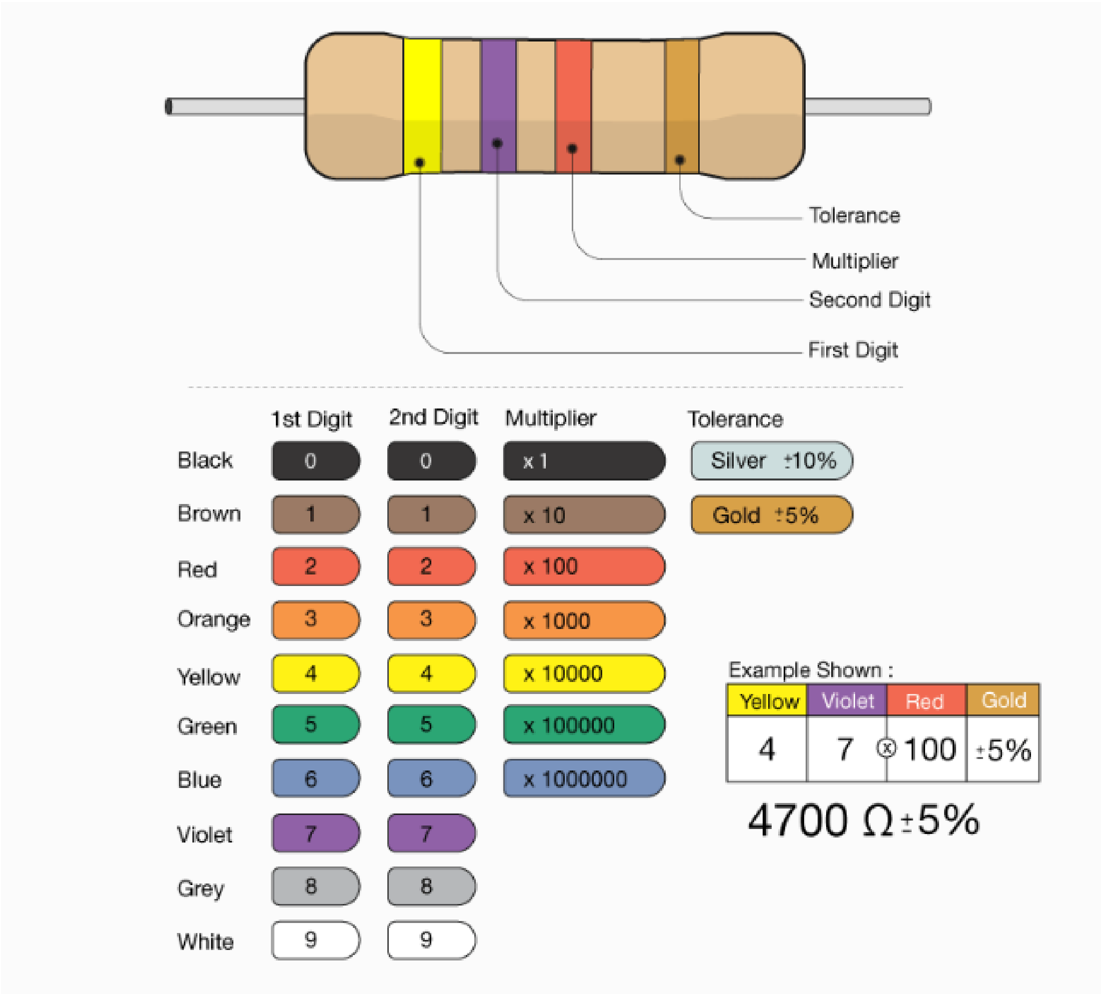
**Resistor Colour Table:**

| Colour | Digit | Multiplier | Tolerance |
|---|---|---|---|
| Black | 0 | 1 | |
| Browen | 1 | 10 | ±1% |
| Red | 2 | 100 | ±2% |
| Orange | 3 | 1000 | |
| Yellow | 4 | 10000 | |
| Green | 5 | 100000 | ±0.5% |
| Blue | 6 | 1000000 | ±0.25% |
| Violet | 7 | 10000000 | ±0.1% |
| Grey | 8 | | ±0.05% |
| White | 9 | | |
| Gold | | 0.1 | ±5% |
| Silver | | 0.01 | ±10% |

## How to Read Resistor Colour Code?

- To read them, hold the resistor such that the tolerance band is on your right. Thetolerance band is usually gold or silver in colour and is placed a little further away from the other bands.
- Starting from your left, note down all the colours of the bands and write them down in sequence.
- Next, use the table given below to see which digits they represent.
- The band just next to the tolerance band is the multiplier band. So if the colour of this band is Red (representing 2), the value given is $10^2$.

Example 1:



| | 1st Digit | 2nd Digit | Multiplier | Tolerance |
|---|---|---|---|---|
| Black | 0 | 0 | x 1 | Silver ±10% |
| Brown | 1 | 1 | x 10 | Gold ±5% |
| Red | 2 | 2 | x 100 | |
| Orange | 3 | 3 | x 1000 | |
| Yellow | 4 | 4 | x 10000 | |
| Green | 5 | 5 | x 100000 | |
| Blue | 6 | 6 | x 1000000 | |
| Violet | 7 | 7 | | |
| Grey | 8 | 8 | | |
| White | 9 | 9 | | |

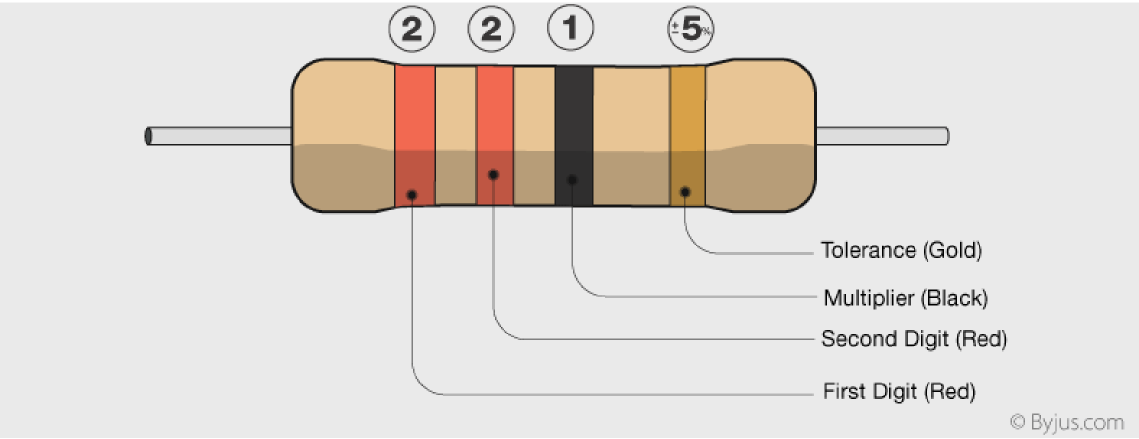
Example Shown :

| Yellow | Violet | Red | Gold |
|---|---|---|---|
| 4 | 7 | ⊗ 100 | ±5% |

4700 Ω ±5%

Example 2:

After learning about resistance colour codes, let us learn how to find resistor colour codes with an example. Here's an example to get you started:



The band colours for resistor colour code in the order:

| **Band colours in order** | ***RED*** | ***RED*** | ***BLACK*** | ***GOLD*** |
|---|---|---|---|---|
| **Digit representation** | 2 | 2 | $10^0 = 1$ | ±5% |
| **Value** | 22 Ω ±5 % | | | |

The tolerance values represent by how much the resistance can vary from its mean value in terms of percentage. A gold band represents the lowest variation, so be sure to buy these at the electronics store. The value of the given resistance is: 22 Ω ± 5%. The tolerance of the resistor can be calculated as follows:

***Tolerance=Value of resistor* × *value of tolerance band*** = 22 Ω × 5% = 1.1 Ω

This means that the 22 Ω resistor with a tolerance value of 1.1 Ω could range from the actual value as much as 23.1 Ω to as little as 20.9 Ω. It is important to note that the band next to the tolerance band represents the multiplier. All the bands to the left of this band represent thE significent digits. There can be more than two such bands.

### 1.3.2. Digital Multimeter:

A digital multimeter is a test tool used to measure two or more electrical values—principally voltage (volts), current (amps) and resistance (ohms). It is a standard diagnostic tool for technicians in the electrical/electronic industries.

Digital multimeters long ago replaced needle-based analog meters due to their ability to measure with greater accuracy, reliability and increased impedance. Fluke introduced its first digital multimeter in 1977.

How to use a multimeter

Digital multimeters combine the testing capabilities of single-task meters—the voltmeter (for measuring volts), ammeter (amps) and ohmmeter (ohms). Often, they include several additional specialized features or advanced options. Technicians with specific needs, therefore, can seek out a model targeted to meet their needs.

**The face of a multimeter typically includes four components:**

- Display: Where measurement readouts can be viewed.
- Buttons: For selecting various functions; the options vary by model.
- Dial (or rotary switch): For selecting primary measurement values (volts, amps, ohms).
- Input jacks: Where test leads are inserted.

Test leads are flexible, insulated wires (red for positive, black for negative) that plug into the DMM. They serve as the conductor from the item being tested to the multimeter. The probe tips on each lead are used for testing circuits.

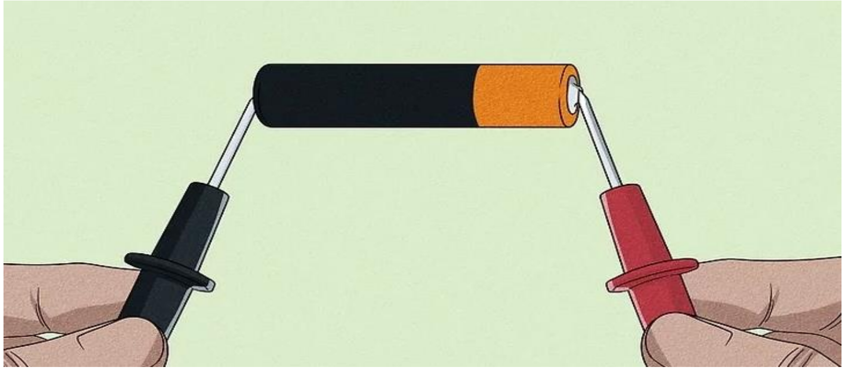
## Measuring Voltage

1- Plug the test leads into the COM and V terminals. Always plug the black test lead into the terminal that's labeled "COM" for "Common." Always plug the red test lead into the terminal labeled "V" for "Voltage," since this is what you're testing.

2- Move the dial to the voltage setting for AC or DC voltage. Turn the dial to V~, or the V with a wave sign next to it, if you're measuring AC voltage. Switch the dial to V⎓, or the V with a horizontal line next to it, to measure DC voltage.

3- Set the voltage range to a higher voltage than what's expected. If you set the voltage range too low, you won't get an accurate reading. Look at the numbers on the dial and choose the setting that's closest to the expected voltage of what you're measuring, while still being above that voltage.

4- Touch the probes to both sides of a load or power source. Put the tip of the black probe on the negative lead of a battery or into the right side of a wall socket, for example. Put the red probe on the positive end of a battery or into the positive side of a wall socket, for instance

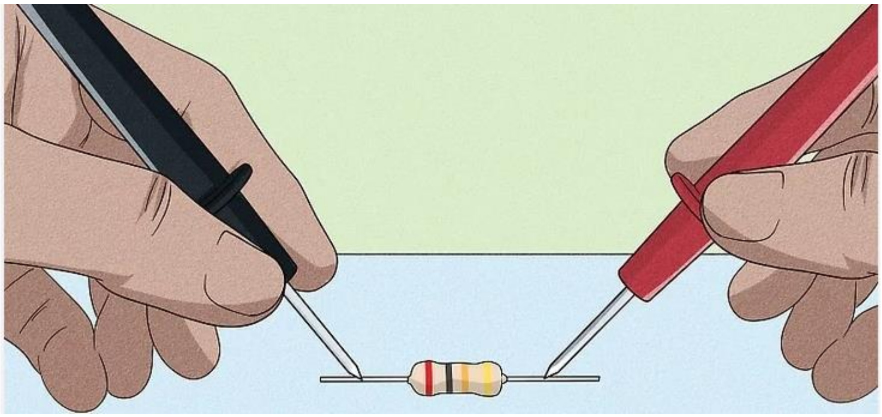


## Measuring Resistance:

1- Insert the black test lead in COM and the red test lead in the Ω terminal. Stick the black test lead's plug into the COM terminal. The red test lead's plug goes into the terminal labeled Ω, which is the symbol for ohms.

2- Set the dial to a number on the multimeter's resistance scale. Look for the Ω symbol on your multimeter's dial area. Twist the dial to a number close to the expected resistance in this section. If you aren't sure what the expected resistance is, set it to a number at the top of the scale.

3- Place the probes on the resistor and read the resistance. Touch the tips of the probes onto each end of the resistor. Look at the multimeter's digital screen to see the reading, which tells you the amount of resistance in ohms



**2. Experiment procedure:**

1- Choose randomly three different resistors.
2- Read the resisters value by using resistor colour code method.
3- Using the multimeter, read the resistors value (Measured value).
4- Write down all the measured and calculated values on the table below.

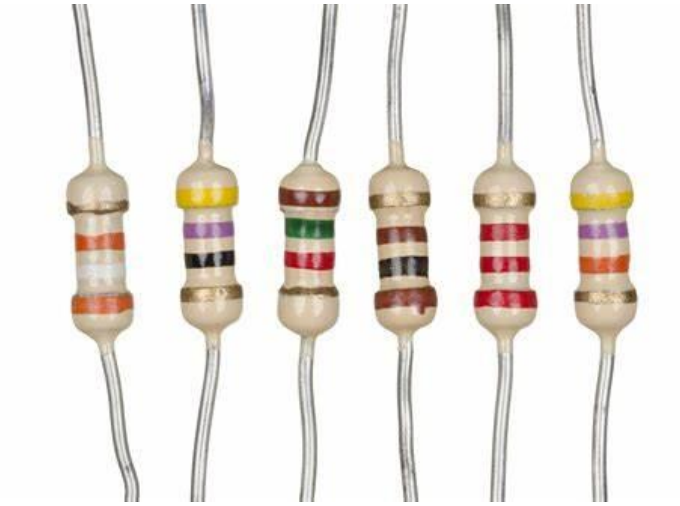
**Deviation = | ((R measured – R nominal)/ R nominal) | × 100%**

**Table 1**

| **Color Code Bands** | **Nominal** | **Tolerance** | **Minimum** | **Maximum** | **Measured** | **Deviation** |
|---|---|---|---|---|---|---|
| 1- | | | | | | |
| 2- | | | | | | |
| 3- | | | | | | |

## 3. Discussion:

1. What are the uses and main specifications of resistors in electrical circuits?
2. What is meant by color codes and tolerance values of resistors?
3. Determine and record the nominal value, tolerance and the minimum and maximum acceptable values of resistors shown in the following figure.



| Color Code Bands | Nominal | Tolerance | Minimum | Maximum |
|---|---|---|---|---|
| 1- | | | | |
| 2- | | | | |
| 3- | | | | |
| 4- | | | | |
| 5- | | | | |
| 6- | | | | |

**4.** Record four band resistor colors gave to its value in below:

| **Value** | **Four Band Resistor Color Codes** |
|---|---|
| 1- 390 ± 10 % | |
| 2- 680 ± 5 % | |
| 3- 1.5k ± 20 % | |
| 4- 10k ± 5 % | |
| 5- 820k ± 10 % | |
| 6- 2.2M ± 10 % | |

**5.** What is the function of a multimeter?

# Experiment No.2
# Ohm’s Law

## 1. Introduction

### 1.1 Objective:

This experiment aims to learn how o investigate Ohm's Law

### 1.2 Components:

- DC power supply.
- Electrical and electronic system trainer.
- Connecting wire.
- Multimeter.

### 1.3 Theory

In Fig.(1), the tungsten filament of the light bulb offers a considerable amount of opposition, or what is called ELECTRICAL RESISTANCE, to the passage of electric current through it. Because of the high resistance of the filament, the battery voltage V must be relatively high to produce the amount of current (I) required to heat the filament to incandescence.

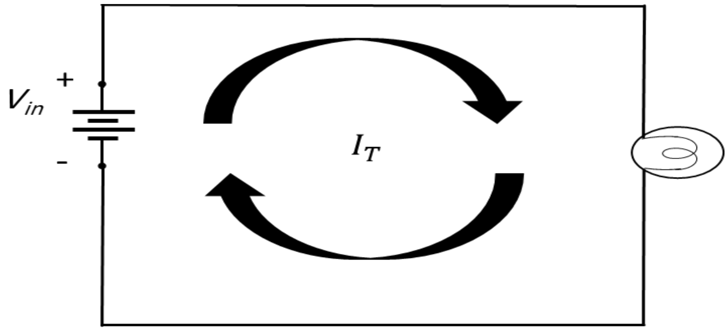


Figure 1

R denotes the amount of electrical resistance, and in electrical diagrams, the presence of resistance is represented by the symbol. Using this symbol, we have redrawn Fig.(1) as Fig.(2), in which R denotes the “electrical resistance” of the tungsten filament in the light bulb.

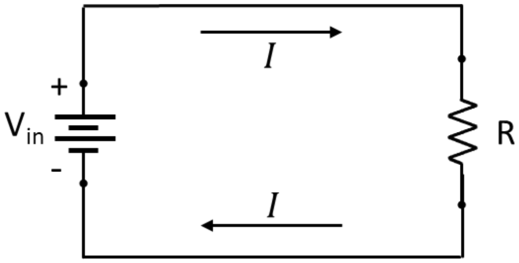


Figure 2

We have already learned that substances that offer little resistance to the passage of current is called “conductors,” while those that offer great resistance are called “insulators.”

The first comprehensive investigation into the nature and measurement of electrical resistance was made by the German physicist Ohm (as in “home”) around the year 1826. After a lengthy series of experiments, Ohm was able to report that

**"The current in a conductor is directly proportional to the potential difference between the terminals of the conductor and inversely proportional to the resistance of the conductor"**

The above constitutes are called OHM’S LAW. If we let
V = potential difference (emf) applied to the conductor,
I = current in the conductor,
R = resistance of the conductor

Therefore, if we express V in volts, I in amperes, and R in ohms, then the basic OHM’S LAW is R I V = The relationship between V & I can be represented in Fig.(3).

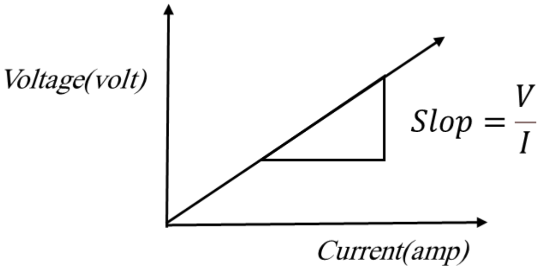


Figure 3

There are, of course, many grades of conductors (and insulators). Take, for example, two metals such as copper and tungsten. Both are classified as “conductors,” but a copper wire is a better conductor than a tungsten wire of the same length and diameter; Conductor: A material, which gives up free electrons early and offers little opposition to current flow and the unit of conductance, is (siemens). The inverse of resistance called conductance (G) where: $G = \frac{1}{R}$

## 2. Experiment procedure:

1. Connect the circuit as shown in Fig. 4

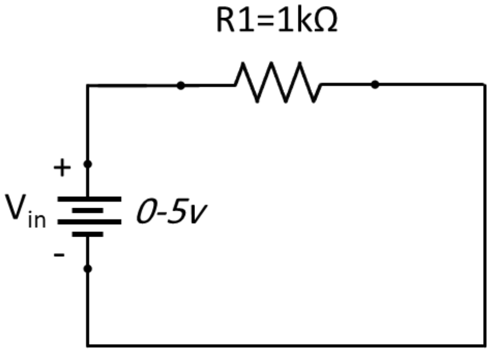


Figure 4

2. Increase the DC voltage from zero in steps of 1 V up to 5 V, and record the voltage across the variable resistor $R_1 = 1$ kΩ.
3. Tabulate your results in a table as shown in Table (1).

Table (1)

| Input voltage (Volt) | Measured Current (mA) | Calculated Current (mA) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |

4. Fix the input DC voltage to 2V, and change the variable resistor R1 from 1kΩ up to 5kΩ according to Table (2), and measure the current in each step.
5. Tabulate your results in a table as shown in Table (2).

Table (2)

| **Resistor (kΩ)** | **Measured Current (mA)** | **Calculated Current (mA)** |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |

## 3. Discussion:

1. Draw the relationship between V & I from the table in step 3.
2. Draw the relationship between R & I from the table in step 5.
3. What are the reasons behind the difference between the measured and calculated values of current in Tables 1 and 2?
4. Is it necessary that the relationship between V & I start with the original point (0, 0), and why?
5. For the table in step 5, find G in each step.
6. What do the slopes represent in V & I relationship?
7. Why should the graphic be a straight line in step (3)?

# Experiment No.3

# Series and Parallel Connection

## 1. Introduction

### 1.1 Objective:

To study the properties of series and parallel connection.

### 1.2 Components

1. DC circuit training system
2. Set of wires.
3. DC Power supply
4. Digital A.V.O. meter

### 1.3 Theory

### 1.3.1. The Series Circuit

A series circuit or ‘‘series-connected circuit’’ is a circuit having just one current path. Thus, Figure 1 is an example of a ‘‘series circuit’’ in which a battery of constant potential difference V volts, and three resistances, are all connected ‘‘in series

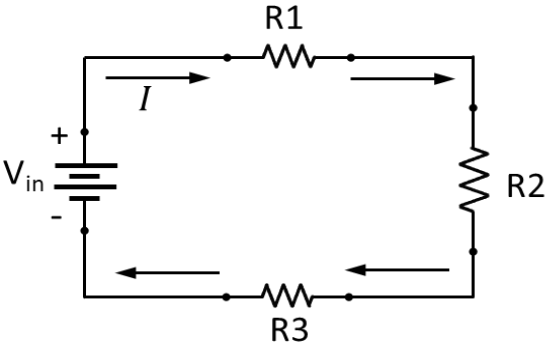


Figure 5

Since a series circuit has just one current path, it follows that all the components in a series circuit carry the same current I, a fact evident from inspection of Figure 1. The current I is assumed to be a flow of positive charge, and thus flows out of the positive terminal of the battery and around through the external circuit, re-entering the battery at the negative terminal. This is indicated by the arrows in Figure 1. In a series circuit, the total resistance, $R_T$, that the battery sees is equal to the SUM of the individual resistances. Thus, in the particular case of Figure 1 the battery sees a total resistance, $R_T = R_1 + R_2 + R_3$, while in the general case of "n" resistances connected in series the battery sees a total resistance of: $R_T = R_1 + R_2 + R_3 + \ldots R_n$

By Ohm's law, it follows that the current I in a series circuit is equal to;

$$\mathbf{I}= \frac{V_T}{R_T} = \frac{V_T}{R1+R2+R3+\cdots\ldots Rn}$$

On the other hand, consumes electrical energy, removing it from the circuit in the form of heat. Since resistance does not produce or generate electrical energy, it is a non-active or passive type of circuit element. The potential difference between the terminals of a resistor is called the voltage drop across the resistor, and, is equal to the current I times the resistance R; that is, the "voltage drop" across a resistance of R ohms carrying a current of I amperes is I×R volts

$$\mathbf{V=I}R_T$$

$$\mathbf{V=I(R_1+R_2+\ldots\ldots+R_n)}$$

$$\mathbf{V=IR_1+IR_2+\ldots\ldots\ldots+IR_n}$$

**In a series circuit, the applied voltage is equal to the sum of the voltage drops.**

We have the important fact that:

It should be pointed out that the voltage drop across a resistor is always from plus to minus in the direction of the current flow, a fact illustrated in Figure 2.

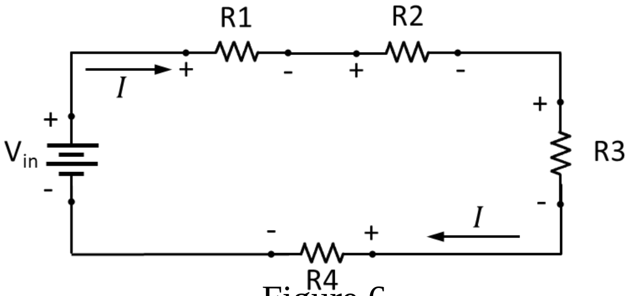


Figure 6

### 1.3.2. The Parallel Circuit

A parallel circuit is one in which the battery current divides into a number of ‘‘parallel paths.’’ This is shown in Figure 3, in which a battery, of constant V volts, delivers a current of I amperes to a load consisting of any number of n resistances connected ‘‘in parallel.’’

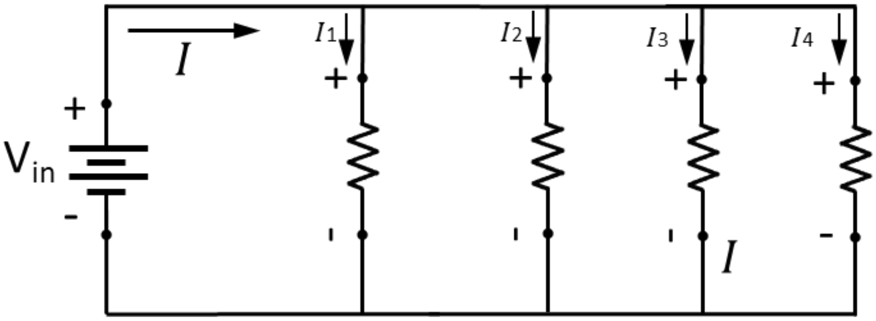


Figure 7

The currents in the individual resistances are called the ‘‘branch currents,’’ and the battery current I is often called the ‘‘line current.’’ From inspection of Figure 3 we see that, in a parallel circuit, the battery current I is equal to the sum of the branch currents

$$I_{T}=I_1+I_2+I_{3+\cdots\ldots I_n}$$

if the battery voltage V is applied equally to all n resistances; that is, the same voltage V is applied to all the parallel branches. Hence, by Ohm’s law, the individual branch currents in Figure 3 have the values:

$$I_1=V/R1 \qquad ,I_{2}=V/R2 \qquad ,I_{n}=V/Rn$$

Then, we have:

$$\mathbf{I=V(\frac{1}{R1}+\frac{1}{R2}+\cdots+\frac{1}{Rn})}$$

**Now let RT be the total resistance as seen by the battery in Fig.(3). Then, by Ohm's law, it has to be true that:**

$$\mathbf{I=\frac{V}{R_T}}$$

Since the left-hand sides of the last two equations are equal, the two righthand sides are also equal. Setting the two right-hand sides equal, then canceling the Vs, gives

## 2. Experiment procedure:

1. Using the DC circuit trainer, connect the circuit Shown in Figure 4, take VT =10V, and $R_1$= 1kΩ, $R_2$ = 470Ω, and $R_3$ =5kΩ.

2. Measured the voltage and current of "$R_1$, $R_2$, and $R_3$", then record it in table below

| | 1kΩ | 470kΩ | 5kΩ | |
|---|---|---|---|---|
| V (Volt) | | | | $V_T$(Volt)= |
| I(mA) | | | | $I_T$(mA)= |

3. By using ohm's law, Calculate the $R_T$

4. Disconnect the DC power supply, and then measured the equivalent resistance by using the AVO meter only.

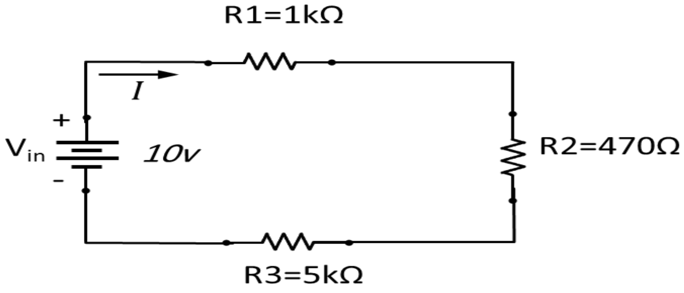


Figure 8

5. Using the DC circuit trainer, connect the circuit Shown in Figure 5, and take $V_T$ =10V, and $R_1$=1KΩ, $R_2$ = 470Ω and $R_3$ =5KΩ.

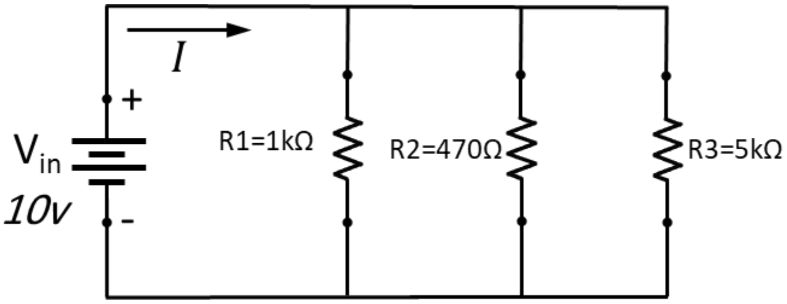


Figure 9

6. Measured the voltage and current of "$R_1$, $R_2$, and $R_3$", then record it in table below

| | 1kΩ | 470kΩ | 5kΩ | |
|---|---|---|---|---|
| V (Volt) | | | | $V_T$(Volt)= |
| I(mA) | | | | $I_T$(mA)= |

7. Disconnect the DC power supply, and then measured the equivalent resistance by using the AVO meter only.

## 3. Discussion:

1. Three resistors ($R_1$, $R_2$ and $R_3$) are connect in parallel, prove that

$$\boldsymbol{R_T = \frac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_1R_3}}$$

2. For the circuit shown in Figure 6, find $R_T$, $V_2$.

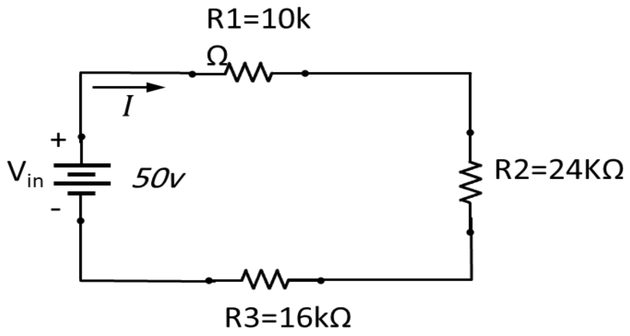


Figure 10

3. In Figure 7, the battery voltage is V = 60 volts, and the values of the resistances, in ohms, are 38, 17, and 27, as shown. Find:
   a) Total resistance seen by the battery
   b) Current measured by the ammeters shown in the figure,
   c) Power output of the battery,
   d) Power input to each resistor

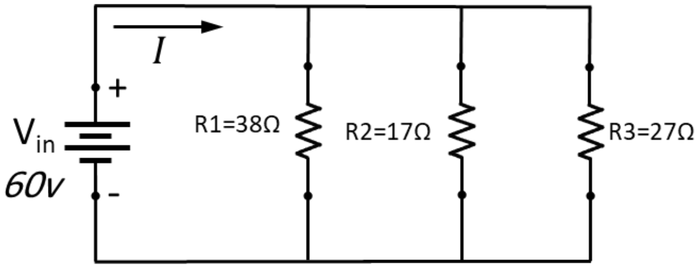


Figure 7

# Experiment No. 4

# Star – Delta Connection

## 1. introduction

### 1.1. Objective

Verify the equivalence between star connection and delta connection for the resistornetworks**.**

### 1.2. Components:

- DC power supply.
- Electrical and electronic system trainer.
- Connecting wire.
- Multimeter.

### 1.3. Theory

Circuit configurations are often encountered in which the resistors do not appear to be in series or parallel .1Jnder these conditions, it may be necessary to convert the circuit from one form to another. Two circuit configurations that often account for these difficulties are the vye (Y) interconnection because the interconnection can be shaped to look like theletter Y. The (Y) configuration also is referred to as tee (T) structure without disturbing the electrical equivalence of the two structures and delta (Δ)in which the interconnection looks like the Greek letter (Δ) . It also is referred to as pi (Π) interconnection without disturbing the electrical equivalence of the two configuration depicted in Figures 1 and 2.

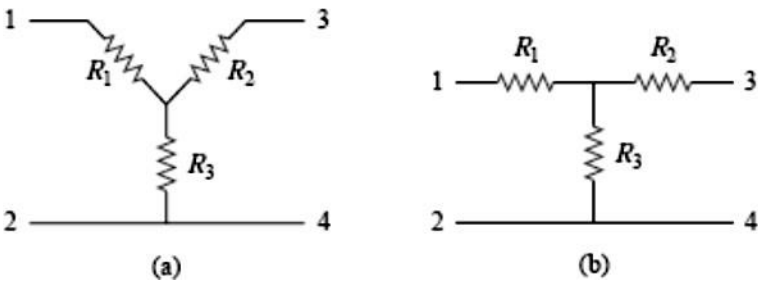


**Figure 1 Two forms of the same network: (a) Y, (b) T.**

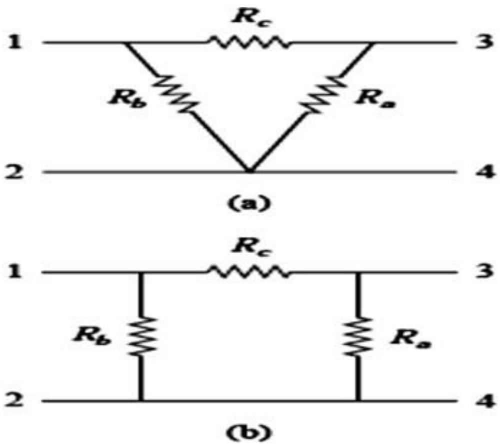


**Figure 2 Two forms of the same network: (a) Δ, (b) π.**

## Delta to Wye Conversion

Suppose it is more convenient to work with a **wye** network in a place where the circuit contains a delta configuration. We superimpose a **wye** network on the existing **delta** network and find the equivalent resistances in the **wye** network. For terminals 1 and 2 in **Figs. 1** and **2**

$$R_1 = \frac{R_b\ R_c}{R\ +R\ +R}$$

$$R_2 = \frac{R_c\ R_a}{R\ +R\ +R}$$

$$R_3 = \frac{R_a\ R_b}{R\ +R\ +R}$$

## Wye to Delta Conversion

Reversing the Δ-to-Y transformation also is possible. That is, we can start with the Y structure and replace it with an equivalent Δ structure. The expressions for the three Δ- connected resistors as functions of the three Y-connected resistors are

$$Ra = \frac{R1R2 + R2R3 + R3R1}{R1}$$

$$Rb = \frac{R1R2 + R2R3 + R3R1}{R2}$$

$$Rc = \frac{R1R2 + R2R3 + R3R1}{R3}$$

## 2. Experiment procedure:

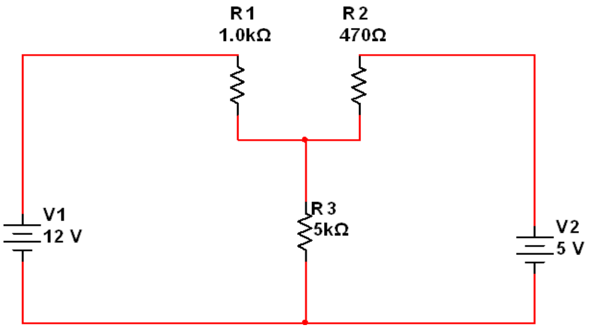


Fig. 3: Y circuit.

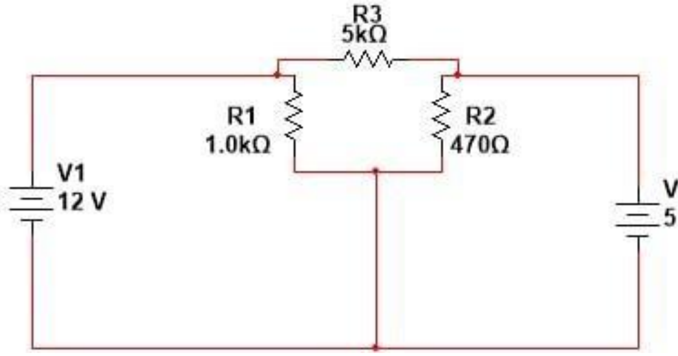
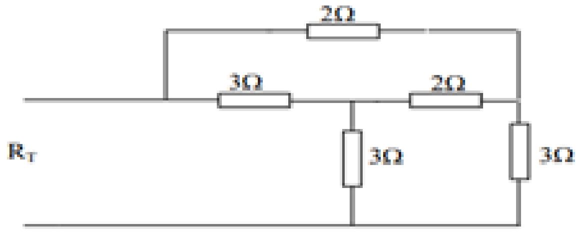


Fig. 4: Delta circuit.

1. Using the DC circuit trainer, connect the circuit shown in Fig. 3.
2. Use the multimeter to measure the currents in each branch.
3. Convert the Y circuit in Fig. 3 to delta connection theoretically.
4. Using the DC circuit trainer, connect the circuit shown in Fig. 4.
5. Repeat. step 2 and convert it to the equivalent Y circuit

## 3. Discussion

1. Why do we convert Wye to Delta or Delta to Wye?
2. What is the difference between delta and star-delta? And Which current is higher, Star or Delta?
3. Did the power delivered from (the DC power supply change after using the conversion from A to Y. Prove that?
4. Find RT for the circuit below in Fig.
5. Find IT for the circuit below in Fig. 6.



1. **Fig. 5**

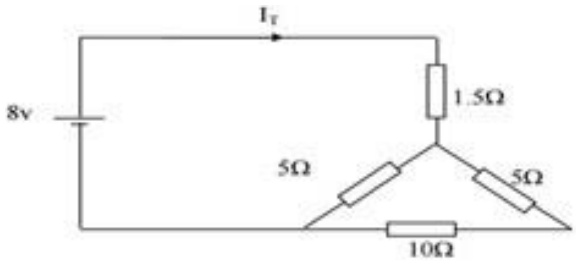


**Fig. 6**

# Experiment No. 5
# Kirchhoff's Laws

## 1. Introduction

### 1.1 Objective:

To verify Kirchhoff's current and voltage laws experimentally.

### 1.2 Components

1. DC circuit training system
2. Set of wires.
3. DC Power supply
4. Digital A.V.O. meter

### 1.3 Theory

Kirchhoff 's laws relate to the conservation of energy, which states that energy cannot be created or destroyed, only changed into different forms. This can be expanded to laws of conservation of voltage and current. In any circuit, the voltage across each series component (carrying the same current) can be added to find the total voltage. Similarly, the total current entering a junction in a circuit must equal the sum of current leaving the junction.

### 1.3.1 Kirchhoff's Current Law "KCL"

"current law" is based upon the fact that at any connecting point in a network the sum of the currents flowing toward the point is equal to the sum of the currents flowing away from the point. The law is illustrated in the examples in Fig.(1), where the arrows show the directions in which it is given that the currents are flowing. (The number alongside each arrow is the amount of current associated with that arrow.)

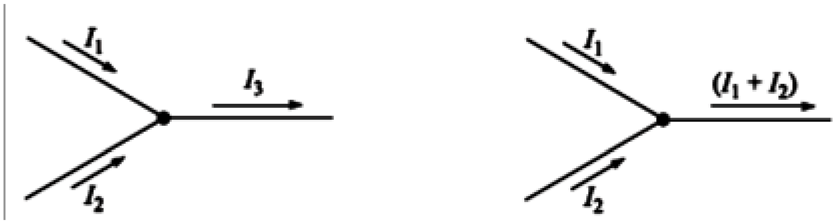


Fig.(1)

**The sum of the currents flowing TO a node point equals the sum of the currents flowing FROM that point.**

However, by Kirchhoff's current law, $\mathbf{I_3 = I_1 + I_2}$, and thus, as shown in Fig. (1), we need to use only two current designations. In other words, if we know any two of the three currents, we can then find the third current. In the same way, if there are, say, four branch currents entering and leaving a node point, and if we know any three of the currents, we can then find the fourth current, and so on.

$\boldsymbol{I_1+I_2=I_3}$

$\boldsymbol{I_1+I_2-I_3=0}$

The Kirchhoff's current law can be state in the form:

**The algebraic sum of the currents at a node (junction point) is equal to zero**

## 1.3.2. Kirchhoff's Voltage Law "KVL"

It states as follows;

The algebraic sum of the products of currents and resistance in each of the conductors in any closed path (or mesh) in a network plus the algebraic sum of the e.m.fs. in that path is zero.

In other words, $\sum IR + \sum e.m.f. = 0$ round a mesh

Let us now write the equation for Fig. (2) in accordance with Kirchhoff's voltage law. To do this, we start at any point, such as A, and move completely around the circuit (we will assume in the CW sense here), listing the "voltage drops" and the "voltage rises" as we go. (In doing this, remember that we have defined that going from "minus to plus" constitutes a RISE in voltage and going from "plus to minus" constitutes a DROP in voltage.) Thus, if we agree to list all "voltage drops" on the left-hand sides of our equations and all the "voltage rises" on the right-hand sides, the Kirchhoff voltage equation for Fig. (2) is:

$$\mathbf{R_1 I + R_2\, I + V_2 = V_1}$$

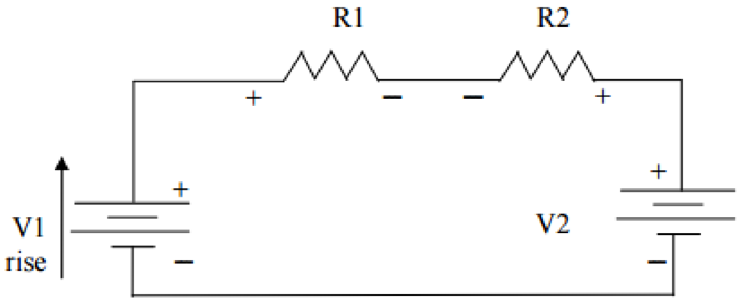


Fig. (2)

Note that V2 appears as a voltage drop, because we go through that battery from plus to minus ( + to -). Alternatively, putting all the battery voltages on the righthand side, the above equation becomes

$$R_1 I + R_2 \mathrm{I} = V_1 - V_2$$

**Hence** $\mathbf{I = \frac{V1-V2}{R1+R2}}$.

## 2. Experiment procedure:

1. Using the DC circuit trainer, connect the circuit shown in Fig. (3)

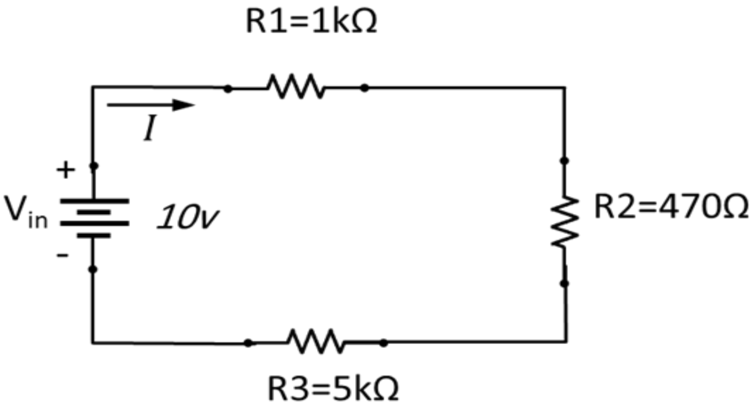


Fig. (3)

2. Using The Avometer to measure the values of voltage of each resistor in circuit and record it in the table below.

| | 1kΩ | 470Ω | 5kΩ |
|---|---|---|---|
| V (Volt) | | | |

3. Using the DC circuit trainer, connect the circuit shown in Fig. (4)

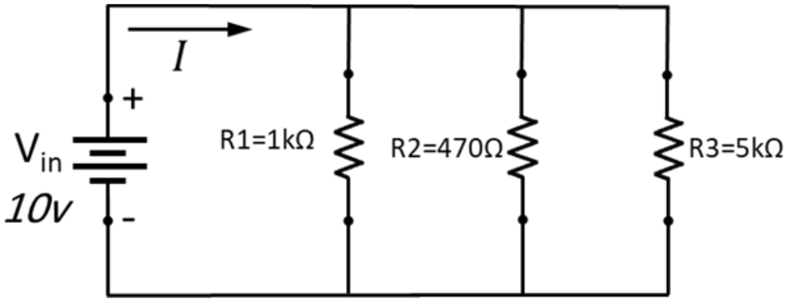


Fig. (4)

4. Using The multimeter to measure the values of current of each resistor in circuit and record it in the table below.

| | 1kΩ | 470Ω | 5kΩ |
|---|---|---|---|
| I (mA) | | | |

## 3. Discussion:

1. How do you verify Kirchhoff's law experiment?
2. Discuss the obtained measured results and compare it with the theoretical analysis.
3- Using Kirchhoff’s laws, determine the voltages of resistors and the current in each branch for the circuit shown in Fig. (5)

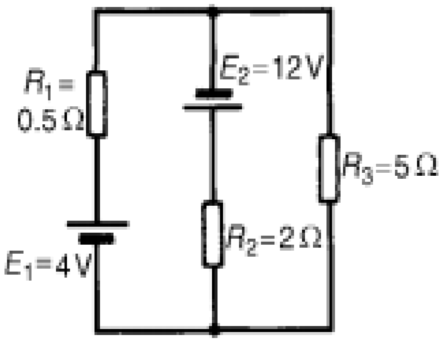


**Fig. (5)**

# Experiment No. 6
# Nodal Analysis

## 1. Introduction

### 1.1 Objective:

To measure the voltages and currents present in the circuit using Nodal analysis.

### 1.2 Components

1. DC circuit training system
2. Set of wires.
3. DC Power supply
4. Digital A.V.O. meter

### 1.3 Theory

A node is defined as a junction of two or more branches. If we now define one node of any network as a reference (that is, a point of zero potential or ground), the remaining nodes of the network will all have a fixed potential relative to this reference. For a network of N nodes, therefore, there will exist (N-1) nodes with a fixed potential relative to the assigned reference node. Equations relating these nodal voltages can be written by applying Kirchhoff's current law at each of the (N-1) nodes. To obtain the complete solution of a network, these nodal voltages are then evaluated in the same manner in which loop currents were found in loop analysis. The nodal analysis method is applied as follows:

1. Determine the number of nodes within the network.

2. Pick a reference node, and label each remaining node with a subscripted value of voltage: V1, V2, and so on

3. Apply Kirchhoff's current law at each node except the reference.

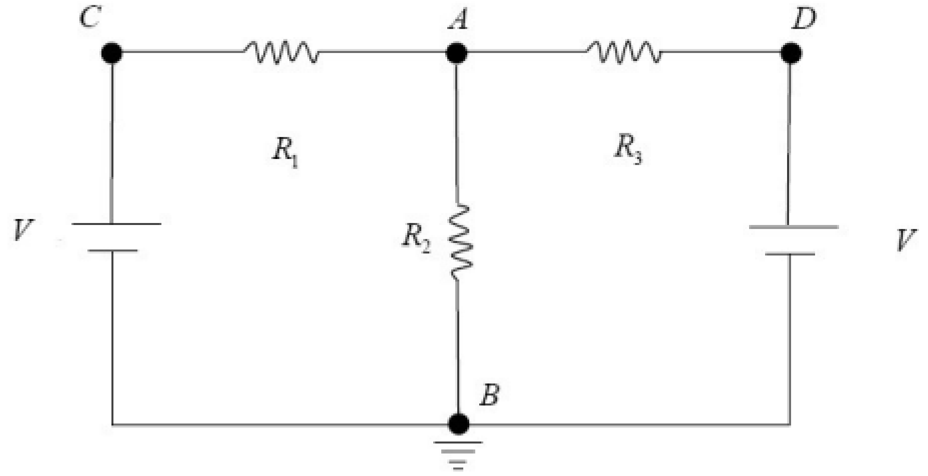
Assume that all unknown currents leave the node for each application of Kirchhoff's current law. In other words, for each node, don't be influenced by the direction that an unknown current for another node may have had. Each node is to be treated as a separate entity, independent of the application of Kirchhoff's current law to the other nodes

4. Solve the resulting equations for the nodal voltages. A few examples will clarify the procedure defined by step 3. It will initially take some practice writing the equations for Kirchhoff's current law correctly, but in time the advantage of assuming that all the currents leave a node rather than identifying a specific direction for each branch will become obvious.

## 2. Experiment procedure:

1. Using the DC circuit trainer, Connect the circuit shown below in figure(1)

Take V1= 6 volt , V2= 9 volt. R1= 81kΩ , R2= 470Ω , R3= 5Ω



**Figure(1)**

2. Using the multimeter to measure the values of current of each resistor in circuit and record it in the table below.

| | 1kΩ | 470Ω | 5kΩ |
|---|---|---|---|
| I (mA) | | | |

3.Using the avometer to Measured the voltage to each node and record it in the table below

| | Vab | Vac | Vad |
|---|---|---|---|
| V (Volt) | | | |

## 3. Discussion:

1. Discuss the obtained measured results and compare it with the theoretical analysis.

2.Why KCL is used in nodal analysis?

3. In the network of Figure( 3) use nodal analysis to determine :

(a) the voltage at nodes b and c

(b) the current in the 1.5k Ω resistance

(c) the magnitude of the active power dissipated in the 820 Ω resistance.

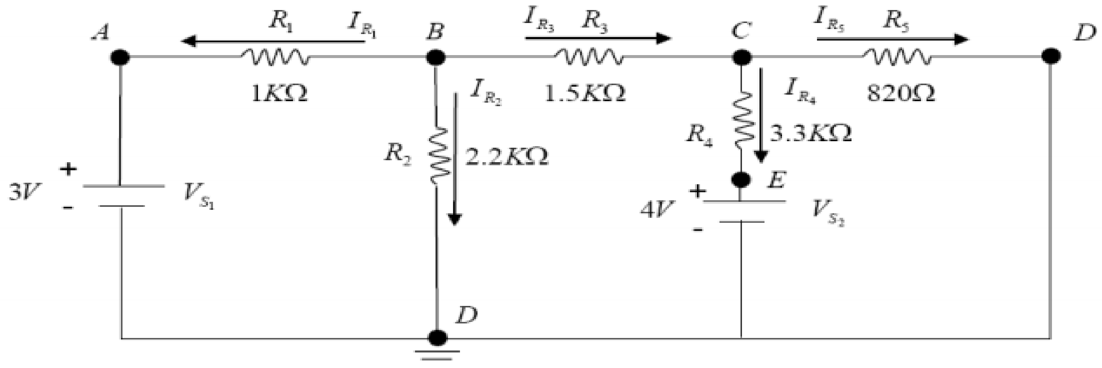


**Figure (2)**

# Experiment No. 7
# Properties of AC Signals

## 1. Introduction

### 1.1 Objective:

The aim of this experiment is to study the basic properties ofAlternating Current (AC) waveforms.

### 1.2 Components:

- Oscilloscope: is an instrument used to display and analyze the electrical signals variation over the time, that enables to study its amplitude, period, frequency, and phase angle.
- Function generator: is an equipment to generate input functions foryour circuit. It can generate sinewaves, square waves, triangular waves.
- Electrical and electronic system trainer.


(A) (B)

Figure 1. (A) Oscilloscope, (B) Function Generator.

The AC waveforms may be sine wave, square wave, triangular wave as wellas sawtooth wave. These different waveforms are illustrated in Figure 2.

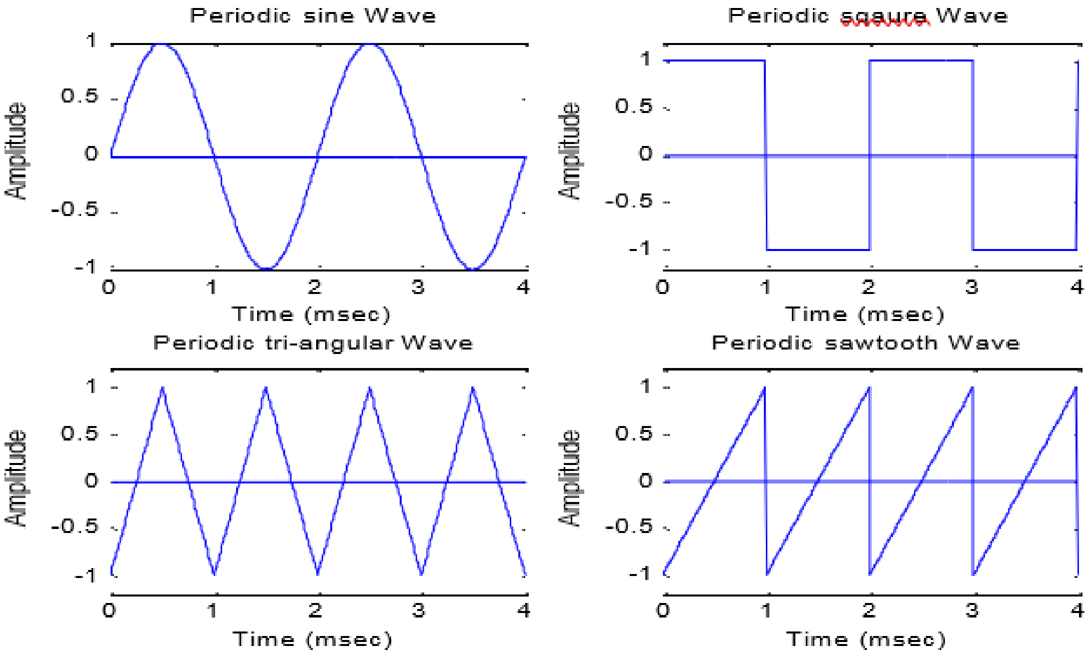


Figure 2. Different Types of Waveforms.

Alternating current changes its direction of flow continuously, in contrast to direct current (DC), which always flows always in same direction.

The basic parameters of the AC waveform that will be studied in this experiment are the peak amplitude, Root-Mean-Square (RMS), period, and frequency of the sinusoidal waveform.

Since the sinusoidal waveform is the most commonly used waveform in electrical systems, the theory in this experiment will be briefly reviewed for sinusoidal wave form which is expressed mathematically by

$$v(t) = v_p \sin(\omega_0 t + \theta_v)$$

$$i(t) = i_p \sin(\omega_0 t + \theta_i)$$

Where $v_p$ is the peak amplitude of the voltage waveform, $i_p$ is the peak amplitude of the current waveform, $\omega_o$ is the angular frequency, $\theta_v$ is the phase of the voltage wave and $\theta_i$ is the phase of the current wave. A sinusoidalvoltage waveform is plotted in Figure 3.

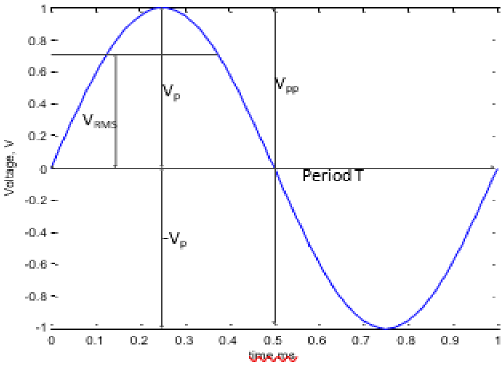


Figure 3. Sinusoidal Waveform.

The peak amplitude of AC signal can be measured directly by using the oscilloscope. However, the digital voltmeter can be used to measure the RMSvalue of the signal. In order to convert the measured RMS voltage into peak amplitude we can use the following equation

$$\boldsymbol{v_p} = \sqrt{\mathbf{2}} \times \boldsymbol{V_{RMS}}$$

that the frequency and the period and the wave form are related by

$$\boldsymbol{f} = \frac{\mathbf{1}}{\boldsymbol{T}}$$

Also the angular frequency is related to the frequency of the wave form by

$$m_{\mathbf{0}} = \mathbf{2}\boldsymbol{\pi f}$$

By Ohm’s law the current is given by

$$\boldsymbol{i} = \frac{\boldsymbol{v}}{\boldsymbol{R}} = \frac{\boldsymbol{v}}{\mathbf{1}} = \boldsymbol{v}$$

**Phase Difference Equation**

$$\boldsymbol{A}(\boldsymbol{t}) = \boldsymbol{Amax} * \mathbf{sin}(\ \square\boldsymbol{t} \pm \emptyset)$$

Where:

- $A_m$: is the amplitude of the waveform
- ω: is the angular frequency of the waveform in radian/sec.
- Ø (phi): is the phase angle in degrees or radians that the waveform hasshifted either left or right from the reference point.

### Phase Relationship of a Sinusoidal Waveform

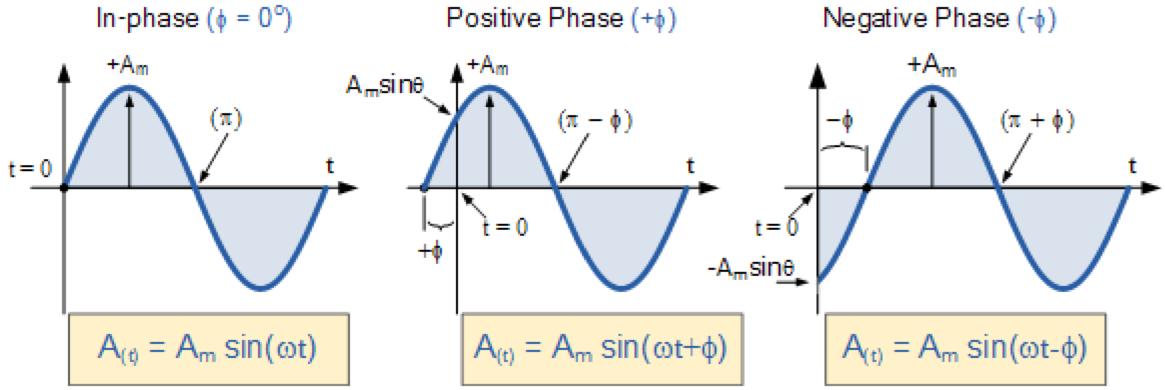


Figure 4. Phase Relationship

### Two Sinusoidal Waveforms – "in-phase"

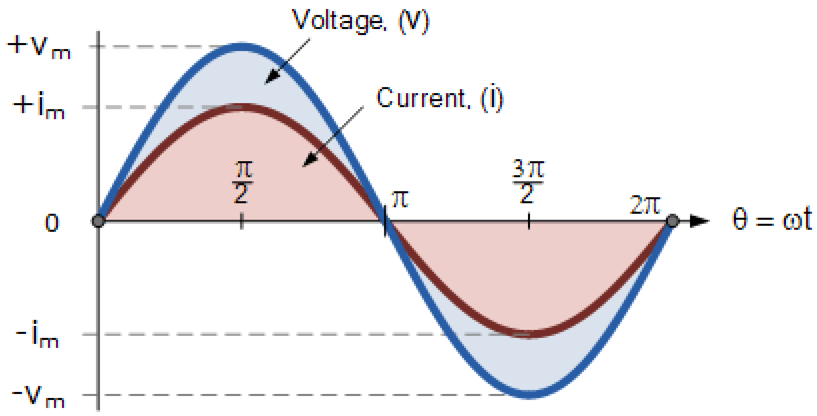


Figure 5. Two Sinusoidal Waveforms – in-phase.

## Phase Difference of a Sinusoidal Waveform

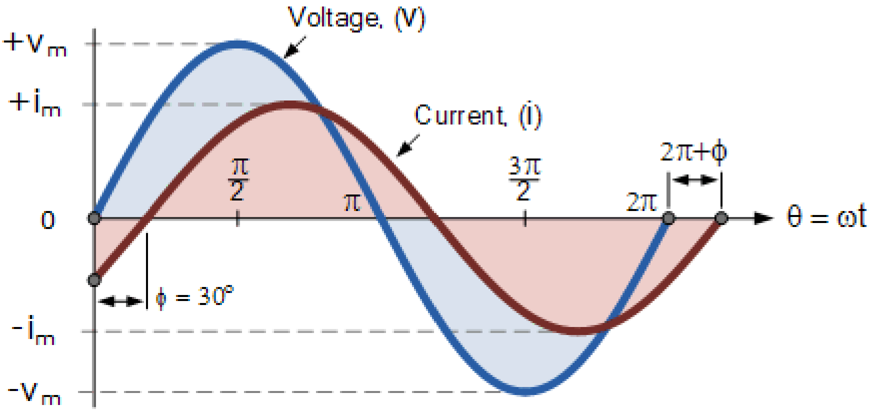


Figure 6. Two Sinusoidal Waveforms – Phase Difference.

The current waveform can also be said to be "lagging" behind the voltage waveform by the phase angle, Φ. Then in our example above the two waveforms have a **Lagging Phase Difference** so the expression for both the voltage and current above will be given as.

$$v\ (t) = Vm\ \sin \omega t$$

$$i(t) = Im\ \sin(\omega t - \varnothing)$$

Where current, i "lags" voltage, v by phase angle Φ

Likewise, if the current, i has a positive value and crosses the reference axis reaching its maximum peak and zero values at some time before the voltage, v then the current waveform will be "leading" the voltage by some phase angle. Then the two waveforms are said to have a **Leading Phase Difference** and the expression for both the voltage and the current will be.

$$v(t) = Vm\ \sin \omega t$$

$$i\ (t) = Im\ \sin(\omega t + \varnothing)$$

Where current, i "leads" the voltage v by phase angle Φ

The phase angle of a sine wave can be used to describe the relationship of onesine wave to another by using the terms “Leading” and “Lagging” to indicate the relationship between two sinusoidal waveforms of the same frequency, plotted onto the same reference axis. In our example above the two waveformsare *out-of-phase* by 30°. So we can correctly say that i lags v or we can say that v leads i by 30° depending upon which one we choose as our reference.

## 2. Procedure:

1. Connect the circuit as shown in Figure 7.

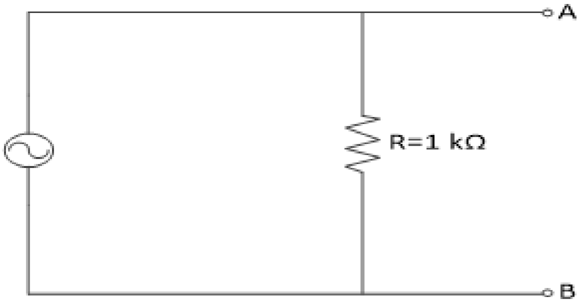


Figure 7. Simple AC Circuit.

2. Connect channel one of the oscilloscope to point A in the circuit. Adjustthe voltage and time scales of the oscilloscope to display one cycle ofthe sinusoidal waveform.
3. Sketch the signal as it appears on the screen of the oscilloscope
4. From the signal shown on the oscilloscope screen, determine thequantities listed in **Error! Reference source not found.**
5. To demonstrate how the oscilloscope can be used to measure current,connect the circuit as shown in Figure 7.
6. On channel Ch1 measure the voltage across $R_1$.

Table 1. Experiment Results

| oltage Vp-p | Vrms | | Current |
|---|---|---|---|
| | Measured | Calculated | |
| 1V | | | |
| 2V | | | |
| 5V | | | |
| 10V | | | |

## Discussion:

**1** What is the difference between the AC and DC signal?
2 What is the function of the oscilloscope and the function generator?
3 What is the difference between the Vp and the Vp-p?
4 What is the phase difference?
5 Discuss the difference between the theoretical and practical results inTable 1.

# Experiment No. 8

# RC Series Circuit

## 1. Introduction

### 1.1. Objectives:

The aim of the experiment to:

- Investigate the electrical characteristics of a series RC circuit;
- Study the relation between the input frequency $f$ and the circuit impedance $XC$.

### 1.2. Components:

- Function generator;
- Oscilloscope;
- Digital Multimeter;
- Resistor;
- Connection wires;
- Capacitor.

### 1.3. Theory:

A resistor-capacitor circuit (RC circuit), or called RC filter / RC network, is an electrical circuit composed of resistors and capacitors driven by a voltage or current source. The RC circuit can be used as a **low pass filter** to remove the higher frequency signals. Allowing the low-frequency signals to pass, the signals measured across the capacitor and have frequencies higher than the cut-off frequency will be removed. The RC circuit can also be used as a **high pass filter**, If the resistor and capacitor are switched, in their position. And the output signal across the resistor can be measured. A high pass filter is used to pass the high-frequency signals and removes the low-frequency signals. When an Ac voltage is applied to a resistor and a capacitor in series, as shown in Fig. 1, the capacitor will constantly charge and discharge as the input voltage (Vin) is constantly changing.

A **capacitor** $C$ is formed whenever two conductors are separated by an insulating material.

Consider the simple example of two parallel conducting plates separated by a small gap that is filled with an insulating material (vacuum, air, glass, or another dielectric). If a potential difference exists between the two plates, then an electric field exists between them, and opposite electric charges will be attracted to the two plates. The ability to store that electric charge is a fundamental property of capacitors. The larger the plates, the more charge can be stored. The closer the plates, the more charge can be stored…at least until the charges leap the gap and the dielectric breaks down. If a voltage source is connected across a capacitor, a charge will flow in the external circuit until the voltage across the capacitor is equal to the applied voltage. The charge that flows is proportional to the size of the capacitor its "capacitance" and to the applied voltage. The relationship is given by the equation

$$Q=CV \qquad (1)$$

Where $Q$ is the charge in coulombs, C is the capacitance in farads, and $V$ is the applied voltage in volts.

In an *RC* circuit, the capacitive impedance *Xc* decreases as the frequency of the input voltage increases, and current *I* flow through the circuit is proportionally increased. i.e., as that frequency increases, the capacitor will act as a short circuit to the high-frequency current in its path. At low frequencies, the capacitor tends to block current flow. However, the change of the input frequency will not change the value of the resistor *R*.

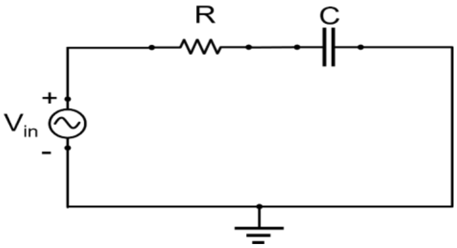


Figure 1: Schematic diagram illustrae an *RC* circuit connected in series.

Reactance is a characteristic exhibited by capacitors and inductors in circuits with time-varying voltages and currents, such as common sinusoidal AC circuits. Like resistance, reactance opposes the flow of electric current and is measured in ohms. Capacitive reactance XC can be found by the equation:

$$X_c = \frac{1}{2\pi f C} \qquad (2)$$

Where *f* is the frequency of the applied voltage or current and C is the capacitance in farads. As with resistance, the capacitor reactance obeys Ohm’s law:

$$X_c = \frac{V_c}{I_c} \qquad (3)$$

If a sinusoidal voltage is applied across a purely resistive circuit, it produces a sine wave (sinusoidal) current. Both waveforms attain their peak values at the same time, and pass through zero at the same time. Voltage and current, in a purely resistive circuit, are therefore said to be "IN PHASE" with each other.

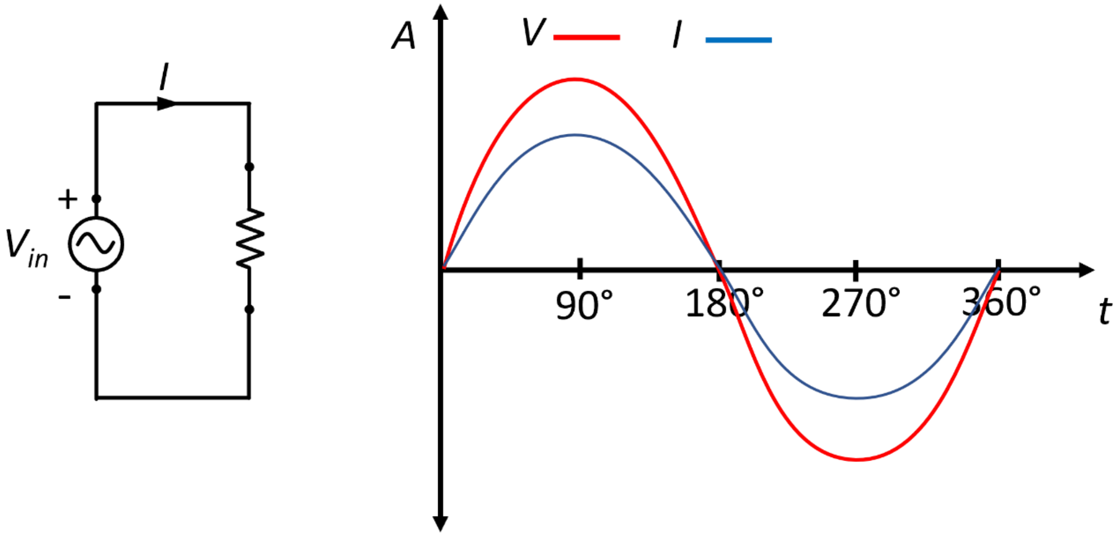


Figure 2: illustrate that the voltage and current wave are in phase in purely resistive load.

In a purely capacitive circuit, the voltage and current waveforms are not in phase. Capacitance has the property of delaying changes in voltage. The applied voltage reaches steady state only after a time dictated by the time constant. In AC circuits, the voltage and current are changing continuously, and in a purely capacitive AC circuit, the peak value of the voltage waveform occurs a quarter of a cycle after the peak value of the current. Therefore, a phase shift is occurring in the capacitor, the amount of phase shift between voltage and current is +90° for a purely capacitive circuit, with the current LEADING the voltage as shown in Fig. 3. The opposite phase shift to an inductive circuit.

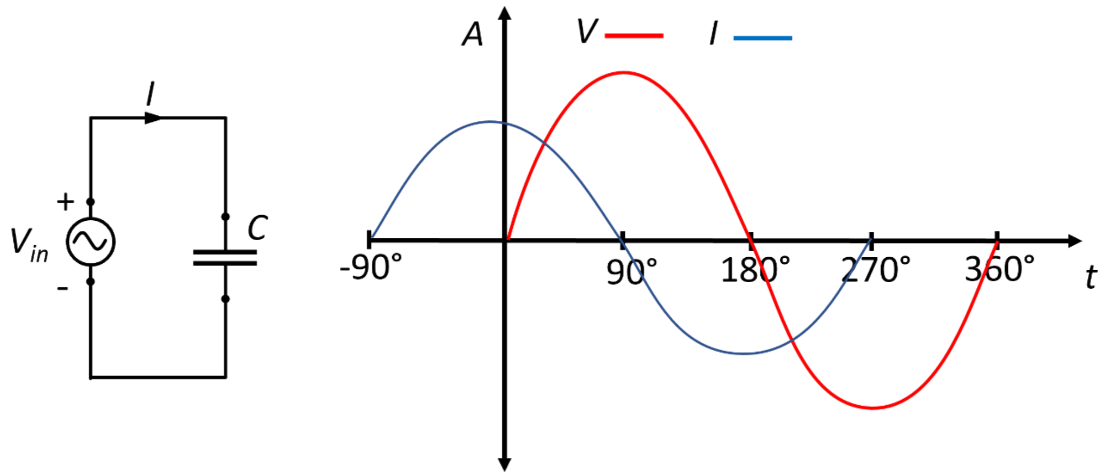


Figure 3: illustrate the voltage and current phase shift in a purely capacitive load.

In an *RC* circuit, a phase shift occurs as well between the voltage across the capacitor *VC* and the current *I*. As the circuit is a resistive-capacitive load, the current leads the voltage, as shown in Fig. 4. The phase shift can be calculated using equation 5.

$$\theta = \tan^{-1}\frac{-V_C}{V_R} \qquad (5)$$

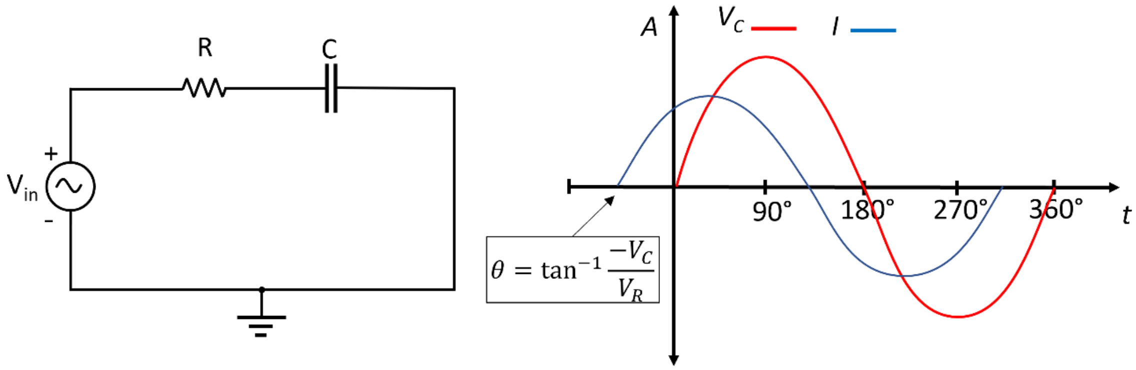


Figure 4: illustrate the voltage and current phase shift of a resistive-capacitive load.

Table 1 shows important equations required to theoretically calculate $VR$, $VC$, $V_S$, $R$, $XC$, and Z.

Table 1: Important equations

| **For voltages** | **For impedance** |
|---|---|
| $\lvert V_R\rvert = \lvert V_S\rvert \times \cos(\theta)$ | $R = \lvert Z\rvert \times \cos(\theta)$ |
| $\lvert V_C\rvert = \lvert V_S\rvert \times \sin(\theta)$ | $\lvert X_C\rvert = \lvert Z\rvert \times \sin(\theta)$ |
| $\lvert V_s\rvert = \sqrt{\lvert V_R\rvert^2 + \lvert V_C\rvert^2}$ | $\lvert Z\rvert = \sqrt{R^2 + \lvert X_C\rvert^2}$ |

## Experiment procedure

- Connect the circuit shown in Fig. 1 using a 1 kΩ resistor and a 0.1 µF capacitor.
- Set the input voltage at 5V and frequency at 1 kHz.
- Using the Oscilloscope, read the voltage across the 1kΩ resistor and the 0.1µF capacitor.
- Change the input voltage from 5 to 10, 15, and 20 volts.
- Repeat step 3, measuring the voltage across the 1kΩ resistor and the 0.1 µF capacitor.
- Based on the experimental measurement, Calculate the phase shift ($\theta$) between $V_R$ and $V_C$ theoretically using equation 5.
- Write down all the measured and calculated values.

## Discussion

1 What are the applications of the RC circuit?
2 Why is there a phase shift ($\theta$) between the measured voltage VC and current I?
3 If we increase the input frequency from 1 kHz to 5 kHz, what is the phase shift ($\theta$) between the voltage VC and current I?

# Experimental No. 9
# RL Series Circuit

## 1. Introduction

A resistor-inductor circuit (also known as an RL filter) is defined as an electrical circuit consisting of the passive circuit elements of a resistor (R) and an inductor (L) connected, in series, driven by a voltage source or current source.

## 1.1 Objectives

The experiment aims to study the electrical characteristics of an RL circuit in series. Also, to study the relation between the input frequency $f$ and the circuit impedance $X_L$.

## 1.2 Components

- Function generator;
- Oscilloscope;
- Digital Multimeter;
- Resistor;
- Inductor;
- Connection wires.

## 1.3 Theory:

Consider a simple RL circuit in which resistor, R, and inductor, L are connected in series with a voltage supply of $Vin$. The current flowing in the circuit is $I$ and the current through resistor R and inductor L is $IR$ and $IL$, respectively. However, the resistor and inductor are connected in series, that's why the current passing through both elements is the same. i.e.,

$$I_L = I_R = I \qquad (1)$$

The voltages VR and VL are the voltage drop across the resistor and inductor By applying the Kirchhoff voltage law (The summation of the drop voltages across R and L equal to the input voltage Vin) to this circuit, we get:

$$V_{in} = V_R + V_L \ (2)$$

Before drawing the phasor diagram of a series RL circuit, one should know the relationshipbetween voltage and current in the case of resistor and inductor.

In the case of the resistor R, the voltage and current are in the same phase, or we can say that the phase angle difference $\theta$ between voltage and current is zero.

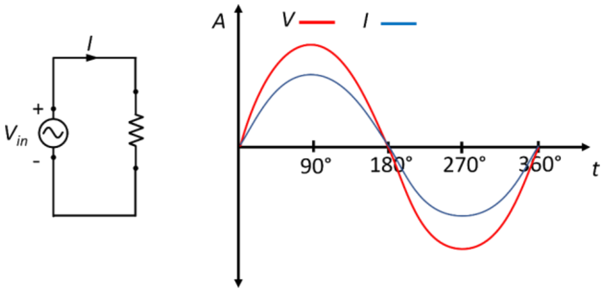


**Figure 1** :illustrate that the voltage and current wave are in phase in purely resistive load

In the case of the inductor L, the voltage and current are not in phase. The voltage leads the current by 90°.

This means the voltage reaches its maximum when the current attains the zero value.

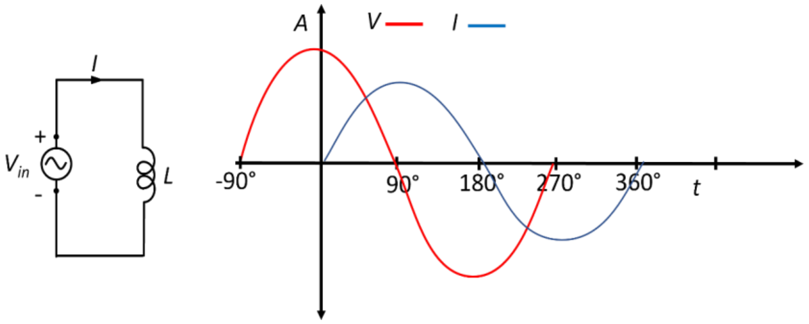


**Figure 2:** illustrate the voltage and current phase shift in a purely inductive load

**Inductor** (also named as a choke) is basically a coil or loops of wire that are either woundaround a hollow tube former (air cored) or wound around some ferromagnetic material likeiron core to increase their inductive value (inductance).

The inductor stores its energy in the form of a magnetic field that is created when a voltageis applied across an inductor. The growth of the current flowing through the inductor is notinstant but is determined by the inductors own self-induced or back emf value. Then for an inductor coil, his back emf voltage $VL$ is proportional to the rate of change of the current flowing through it.

In an AC circuit, the opposition to the current flowing through the coils not only depends upon the inductance of the coil but also the frequency f of the applied voltage waveform as it varies from its positive to negative values.

The actual opposition to the current flowing through a coil in an AC circuit is determined by the AC Resistance of the coil with this AC resistance being represented by a complex number. But to distinguish a DC resistance value from an AC resistance value, which is also known as Impedance, the term Reactance is used. Like resistance, reactance is measured in Ohm's but is given the symbol X to distinguish it from a purely resistive "R" value and as the component in question is an inductor, the reactance of an inductor is called Inductive Reactance, XL and is measured in Ohms. Its value can be found from the formula.

$$X_L = 2\pi f L \qquad (3)$$

Where $XL$ is inductive reactance in (Ω), π is the numeric constant of 3.142, $f$ is the frequency in Hz, and $L$ = inductance in H

Whenever a sinusoidal voltage is applied to an inductor, the back emf opposes the rise and fall of the current flowing through the coil and in a purely inductive coil which has zero resistance, this impedance (which can be a complex number) is equal to its inductive reactance. Also, reactance is represented by a vector as it has both a magnitude and a direction (angle). See Fig. 3.

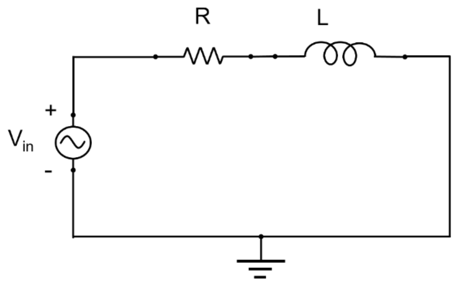


**Figure 3:** Schematic diagram illustrate an RC circuit connected in series

This simple circuit above consists of a pure inductance of $L$ Henries (H), connected inseries with a resistor $R$ (Ohm) and a sinusoidal voltage given by the expression:

$$V_{in} = V_{max} sine\ wt \qquad (4)$$

This sinusoidal voltage will cause a current to flow and rise from zero to its maximumvalue. This rise or change in the current will induce a magnetic field within the coil whichin turn will oppose or restrict this change in the current.

But before the current has had time to reach its maximum value as it would in a DC circuit,the voltage changes polarity causing the current to change direction. This change in the other direction once again being delayed by the self-induced back emf in the coil, and in acircuit containing a pure inductance only, the current is delayed by 90°.

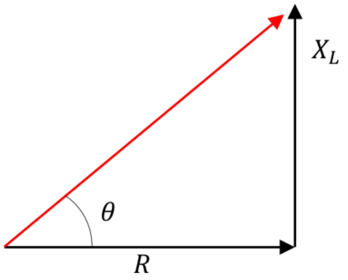


**Figure 4:** RL circuit, $\theta$ depend on the values of the R and XL

In an *RL* circuit, a phase shift occurs as well between the voltage across the inductor $VL$and the current *I*. As the circuit is a resistive-inductive load, the voltage *V* leads the current*I*, as shown in Fig. 4. The phase shift can also be calculated using equation

$$\theta = \tan^{-1}\frac{VL}{VR} \qquad (5)$$

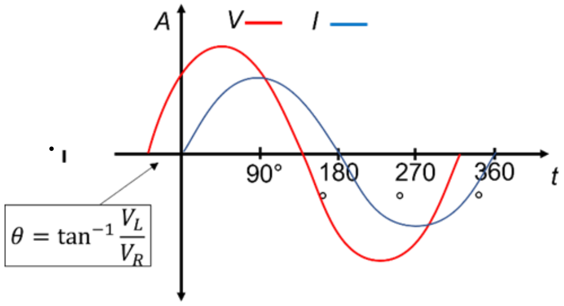


**Figure 5:** illustrate the voltage and current phase shift of a resistive-capacitive load.

Table 1, shows important equations required to theoretically calculate $VR$, $VL$, $V_S$, $R$, $XL$, and Z.

**Table 1:** Important equations

| For voltages | For impedance |
|---|---|
| $\lvert V_R\rvert = \lvert V_S\rvert \times \cos(\theta)$ | $R = \lvert Z\rvert \times \cos(\theta)$ |
| $\lvert V_L\rvert = \lvert V_S\rvert \times \sin(\theta)$ | $\lvert X_L\rvert = \lvert Z\rvert \times \sin(\theta)$ |
| $\lvert V_s\rvert = \sqrt{\lvert V_R\rvert^2 + \lvert V_L\rvert^2}$ | $\lvert Z\rvert = \sqrt{R^2 + \lvert X_L\rvert^2}$ |

## 2. Procedure

1- Connect the circuit shown in Fig. 1 using a 1 kΩ resistor and a 100 mH inductor.

2- Set the input voltage at 5 V and frequency at 500 Hz.

3- Using the Oscilloscope, read the voltage across the 1 kΩ resistor and the 100 mHinductor.

4- Change the input frequency from 500 to 1 kHz, 1.5 kHz 2 kHz 2.5 kHz and 3 kHz.

5- Repeat step 3, measuring the voltage across the 1 kΩ resistor and the 100 mH inductor.

6- Based on the experimental measurement, Calculate the phase shift ($\theta$) between $VR$ and $VL$ theoretically using equation 5.

7- Write down all the measured and calculated values.

## 3. Discussion

1. What are the applications of the RL circuit?
2. Why there is a phase shift ($\theta$) between the measured voltage $VL$ and current $I$?
3. If we increase the input frequency from 1kHz to 5 kHz, what is the phase shift ($\theta$) between the voltage $VC$ and current $I$?