Lab 1: Verification of KVL and KCL

A. Background

A.1. AC Sources:

An AC source is one in which the flow of charge periodically reverses direction. The symbol of an AC voltage source is shown in Figure A.1.1.

Figure A.1.1

Since the output of an AC source is time-variant, they are usually represented using sinusoids as functions of time. An example of an AC source can be:

$$V(t) = V_0 \sin(\omega t) \qquad \text{(Eq A.1.1)}$$

where the maximum value V is called the amplitude. The voltage varies between V_0 and $-V_0$ since a sine function varies between +1 and −1. A graph of voltage as a function of time is shown in Figure A.1.2

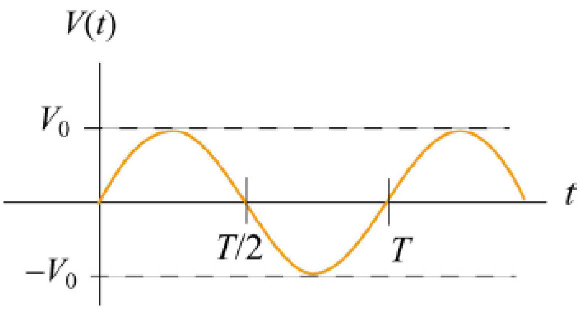

Figure A.1.2

The value of the voltage at time t will be exactly the same at a later time $t' = t + T$ where T is the period. The frequency, f, defined as $f = 1/T$, has the unit of inverse seconds (s^{-1}), or hertz (Hz). The angular frequency is defined to be $\omega = 2f\pi$.

A.2. Simple AC circuit with a purely resistive load

Consider a purely resistive circuit with a resistor connected to an AC source, as shown in Figure A.2.1:

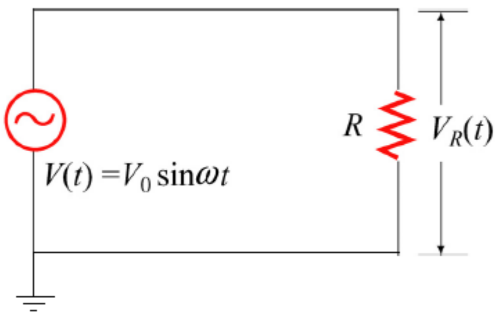

Figure A.2.1

An alternating current will flow in the circuit as a response to the driving voltage source. The current, written as

$$I(t) = I_0 \sin(\omega t - \varphi) \qquad \text{(Eq A.2.1)}$$

will oscillate with the same frequency as the voltage source, with an amplitude I_0 and phase φ that depends on the driving frequency.

The instantaneous current in the resistor is given by

$$I_R(t) = \frac{V_R(t)}{R} = \frac{V_{R0}\sin(\omega t)}{R} = I_{R0}\sin(\omega t) \qquad \text{(Eq A.2.2)}$$

where $V_{R0} = V_0$ and $I_{R0} = V_{R0} / R$ is the maximum current. Comparing Eq. B.2.1 with Eq. B.2.2, we find φ = 0, which means that $I_R(t)$ and $V_R(t)$ are in phase with each other, meaning that they reach their maximum or minimum values at the same time. The time dependence of the current and the voltage across the resistor is depicted in Figure B.2.2.

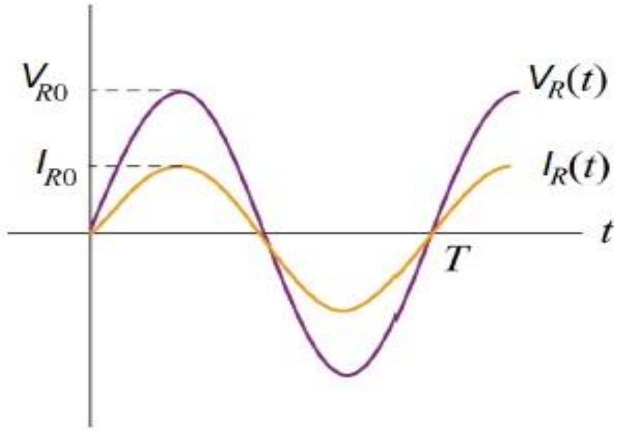

Figure A.2.2

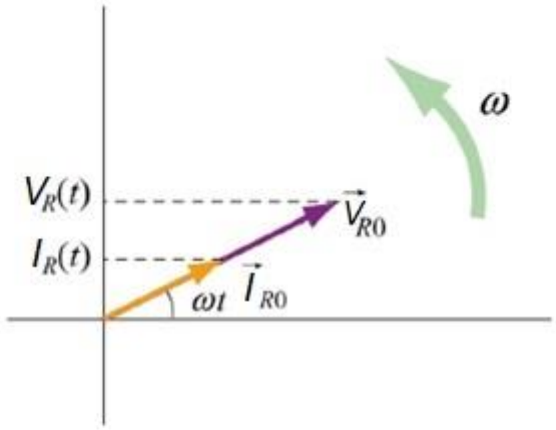

Figure A.2.3

The behavior of $I_R(t)$ and $V_R(t)$ can also be represented with a phasor diagram, as shown in Figure A.2.3. A phasor is a rotating vector having the following properties:

i. Length: the length corresponds to the amplitude.
ii. Angular speed: the vector rotates counterclockwise with an angular speed ω.
iii. Projection: the projection of the vector along the vertical axis corresponds to the value of the alternating quantity at time t.

We shall denote a phasor with an arrow above it. The phasor $\vec{V}_{R0}$ has a constant magnitude of V_{R0}. Its projection along the vertical direction is $V_{R0}\sin(\omega t)$, which is equal to $V_R(t)$, the voltage drops across the resistor at time t. A similar interpretation applies to I_{R0} for the current passing through the resistor. From the phasor diagram, we readily see that both the current and the voltage are in phase with each other.

A.3. RMS value

The RMS, or "Root Mean Square" value of an AC source is the constant or "DC" value that would cause the same physical effect as the actual time-varying waveform does, during one complete period. For a sinusoidal waveform:

$$V_{RMS} = \frac{V_P}{\sqrt{2}} = (0.707)V_P$$

Where V_P is the peak voltage.

Experiment 1: Verification of KVL

A.1 Objective

- To verify KVL for a purely resistive AC circuit.

B.1 Theory

Kirchhoff's Voltage Law states that, the net directed voltage drops and EMFs across a closed loop is zero. This rule is purely true for DC circuits. However, for AC circuits this rule is modified. In AC circuits, KVL is applicable for phasor quantities; that means the net phasor voltage drop and phasor EMFs across a closed loop is zero.

For purely resistive circuits, the voltage and current are in phase, hence the phase difference is zero. Thus only the peak amplitudes or RMS values are sufficient for its verification. So, for simplicity, we will measure the EMFs and voltage drop across a purely resistive series circuit and verify the KVL.

C.1 Apparatus

Components	Instruments
• Resistors: 1×5kΩ, 1×10kΩ, 1×15kΩ	• 1× Breadboard • 1× Function Generator • 1× Digital Storage Oscilloscope • 1× Digital Multi-meter (DMM) • Connecting wires and probes

D.1 Procedure

D.1.1 Measuring the practical value of circuit components

1. Measure the practical values of the circuit components (R1, R2, R3) shown in Fig.D.1.2.1 using DMM and note down in the Table 1.1.
2. Calculate the percentage of difference with respect to the nominal values.

D.1.2 Constructing the circuit

1. Construct the circuit shown Fig.D.1.2.1 on the bread board. Use minimal wires.
2. Set 2 kHz in Function Generator.
3. Connect Channel 1 of the oscilloscope across the source V_S (positive red port to node 'a' and negative black port to node '0' i.e. ground).
4. Observe the generated signal on the oscilloscope screen and fine tune the amplitude to 4V peak (8V peak to peak) and frequency of the input signal generated from the function generator to match the nominal values.

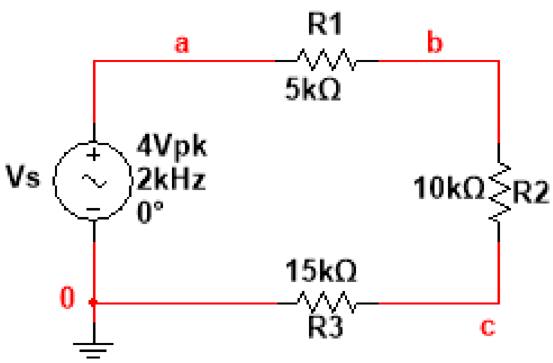

Fig.D.1.2.1: Circuit diagram of a purely resistive series AC circuit

D.1.3 Measuring the peak voltage drop across the resistors with the oscilloscope

1. Use the "measure" and "math" feature of the oscilloscope to find the peak to peak values of the voltage drop across the resistors R1, R2 and R3.

D.1.4 Measuring the peak voltage drop across the resistors with the DMM

1. Set the DMM to measure ac voltage.
2. Measure the source voltage and voltage drops across the resistors in RMS and note down in Table 1.2.
3. Set the DMM to measure the frequency, connect probes across the source, measure the frequency of the source and note down in Table 1.2.

D.1.5 Calculating the theoretical values with measured values of components

1. Use the measured value of the components from Table 1.1 in Fig.D.1.2.1 and show the full theoretical calculations in Box 1.1 for V_{R1}, V_{R2} and V_{R3}.

D.1.6 Comparing the practical values with the theoretical values

1. Fill up Table 1.3 with data from Table 1.2 and Box 1.1.
2. Calculate the percentage of error and note down in Table 1.3.

D.1.7 Calculating the theoretical values with the nominal values

1. Use the nominal values of the components in Fig.D.1.2.1 and show the full theoretical calculations in Box 1.2 for V_{R1}, V_{R2} and V_{R3}.

D.1.8 Drawing phasor diagram

1. Draw the Voltage Phasor diagram of the circuit in Fig.D.1.2.1 with the calculated values from Box 1.2 in Box 1.3.

F.1 Simulation

F.1.1 Measure Peak Voltage using Oscilloscope and RMS Voltage using Multi-meter in Multisim

1. Construct the circuit in Fig.D.1.2.1 and show the voltage drop across R1 on Oscilloscope screen and show the voltage drop across R2 on multi-meter screen
2. Attach the screen-shot of the simulation.

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F.1.2 Measure RMS Voltage drops across R1, R2 and R3 using Single Frequency Analysis in Multisim

1. Construct the circuit in Fig.D.1.2.1 and find the voltage drops across R1, R2 and R3 using single frequency ac analysis.
2. Export and attach the result of the simulation.

F.1.4 Measure Peak Voltage using Transient Analysis in Multisim

1. Construct the circuit in Fig.D.1.2.1 and show the voltage drop across R1, R2 and R3 using transient analysis.
2. Export and attach the result of the simulation.

G.1 Questions

1. From Table 1.2 can it be shown that KVL is applicable for only Peak to Peak voltage or RMS values? If so, then demonstrate. Is it a true for any AC circuits? Why or why not, explain briefly.
2. Oscilloscope or DMM, which device shows more accuracy in your experiment. Analyze Table 1.2 to support your claim.
3. Can you verify KVL for any series RLC circuit with AC source by using only a DMM? If ‘yes’ then state, the procedure. If ‘no’ then explain reason briefly.
4. For the circuit shown in Fig.D.1.2.1, can you measure the voltage drop across R1 by using only a single channel of the Oscilloscope? If so, explain how. Why did we use MATH function in our experiment, explain?
5. What are the key differences between an Oscilloscope and a DMM?
6. From Table 1.3 explain if the experimental result agrees with the theoretical calculation. What are the sources of error in this experiment, can those be eliminated, explain?

Experiment 2: Verification of KCL

A.2 Objective

- To verify KCL for a purely resistive AC circuit.

B.2 Theory

Kirchhoff's Current Law states that, the net directed current at a node is zero. This rule is purely true for DC circuits. However, for AC circuits this rule is modified. In AC circuits, KCL is applicable for phasor quantities; that means the net phasor currents at a node is zero.

For purely resistive circuits, the voltage and current are in phase, hence the phase difference is zero. Thus only the peak amplitudes or RMS values are sufficient for its verification. So, for simplicity, we will measure the currents at node of a purely resistive series-parallel circuit and verify the KCL.

C.2 Apparatus

Components	Instruments
• Resistors: 1×5kΩ, 1×10kΩ, 1×15kΩ	• 1× Trainer Board • 1× Function Generator • 1× Dual Channel Oscilloscope • 1× Digital Multi-meter (DMM) • Connecting wires and probes

D.2 Procedure

D.2.1 Measuring the practical value of circuit components

1. Measure the practical values of the circuit components (R1, R2, R3) shown in Fig.D.2.2.1 using DMM and note down in the Table 2.1.
2. Calculate the percentage of difference with respect to the nominal values.

D.2.2 Constructing the circuit

1. Construct the circuit shown Fig.D.2.2.1 on the bread board. Use minimal wires.
2. Set the input voltage in the Function Generator to $5V_{rms}$ using the multimeter. Set the input frequency to 10kHz.
3. Set DMM to measure the frequency of the signal and fine tune the frequency to nominal 10kHz.
4. Set DMM to measure AC voltage and measure the source voltage.
4. Observe the amplitude of generated signal on DMM screen and fine tune the amplitude of the function generator to match the $5V_{rms}$ nominal value.

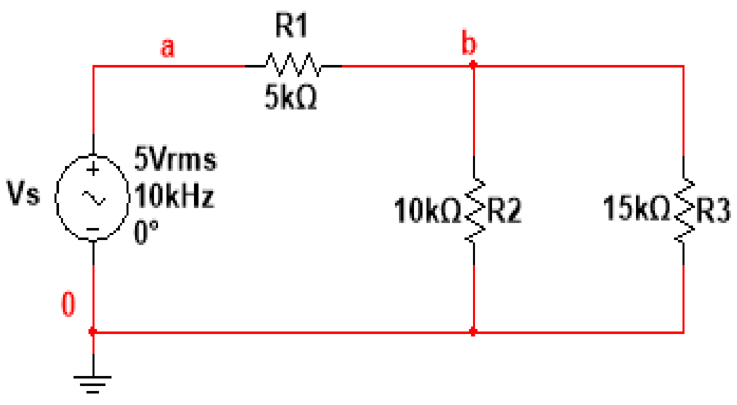


Fig.D.2.2.1: Circuit diagram of a purely resistive series-parallel AC circuit

D.2.3 Measuring the node currents using DMM

1. Set DMM to measure the AC current.
2. Measure the node currents I_{R1} (=I_S), I_{R2} and I_{R3} at node 'b' and note down the values in Table 2.2.

D.2.4 Measuring the node currents using the Oscilloscope

1. Use the "measure" and "math" feature of the oscilloscope to measure the voltage drop across the resistance R1, R2, R3.
2. Use the measured values of R1, R2, R3 from Table 2.1 and calculate the node current I_{R1} (=I_S), I_{R2} and I_{R3} in Table 2.2.
3. Calculate the percentage of errors and percentage of differences in Table 2.2.

D.2.5 Calculating the theoretical values with measured values of components

1. Use the measured value of the components from Table 2.1 in Fig.D.2.2.1 and show the full theoretical calculations in Box 2.1 for I_{R1}, I_{R2} and I_{R3}.

D.2.6 Comparing the practical values with the theoretical values

1. Fill up Table 2.3 with data from Table 2.2 and Box 2.1.
2. Calculate the percentage of error in Table 2.3.

D.2.7 Calculating the theoretical values with the nominal values

1. Use the nominal values of the components in Fig.D.2.2.1 and show the full theoretical calculations in Box 2.2 for I_{R1}, I_{R2} and I_{R3}.

D.2.8 Drawing phasor diagram

1. Draw the Current Phasor diagram of the circuit in Fig.D.2.2.1 with the calculated values from Box 2.2 in Box 2.3.

F.2 Simulation

F.2.1 Measure Peak Voltage using Oscilloscope and RMS Current using Multi-meter in Multisim

1. Construct the circuit in Fig.D.2.2.1 and show the source voltage VS and node voltage V_b on Oscilloscope screen and show the branch current I_{R2} on multi-meter screen.
2. Attach the screen-shot of the simulation.

F.2.3 Measure RMS branch current through R1, R2 and R3 using Single Frequency Analysis in Multisim

1. Construct the circuit in Fig.D.2.2.1 and find the branch current through R1, R2 and R3 using single frequency ac analysis.
2. Export and attach the result of the simulation.

F.2.4 Measure Peak Current using Transient Analysis in Multisim

1. Construct the circuit in Fig.D.2.2.1 and show the branch current through R1, R2 and R3 using transient analysis.
2. Export and attach the result of the simulation.

G.2 Questions

1. From Table 2.2 can it be shown that KCL is applicable for only Peak to Peak voltage or RMS values? If so, then demonstrate. Is it also true for series RL/RC/RLC circuits? Why or why not, explain briefly.
2. Oscilloscope or DMM, which device shows more accuracy in your experiment. Analyze Table 2.2 to support your claim.
3. Can you verify KCL for a series RLC circuit with AC source by only using a DMM? If 'Yes' then describe the procedure. If 'No' then explain the reason briefly.
4. Explain how we can measure the current through a circuit element using the oscilloscope.
5. From Table 2.3 explain if the experimental result agrees with the theoretical calculation. What are the sources of error in this experiment, can those be eliminated, explain?

E.1 Data Sheet: Lab 1, Experiment 1

Date:	Points:
Remarks:	

Signature of the Instructor

Student Information

Section:	Group:	Status:

E.1.1 Table 1.1: Components' measurements

Components	Nominal Value (n)	Measured Value (m)	% of difference[$\frac{(n-m)}{m} \times 100$]
R1	5kΩ		
R2	10kΩ		
R3	15kΩ		

E.1.2 Table 1.2: Verification of KVL

Components	Measured with Oscilloscope		Measured with DMM		% of difference $\frac{(a-b)}{a} \times 100$
	Peak to Peak Voltage, V_{pp}	(a) Peak Voltage, V_m [$V_{pp}/2$]	RMS Voltage, V_{rms}	(b) Peak Voltage, V_m [$V_{rms} \times \sqrt{2}$]	
Vs	**8V**	**4V**			
V_{R1}					
V_{R2}					
V_{R3}					
$V_T=V_{R1}+V_{R2}+V_{R3}$					
% of Error $\frac{V_S - V_T}{V_S} \times 100$					
Frequency					

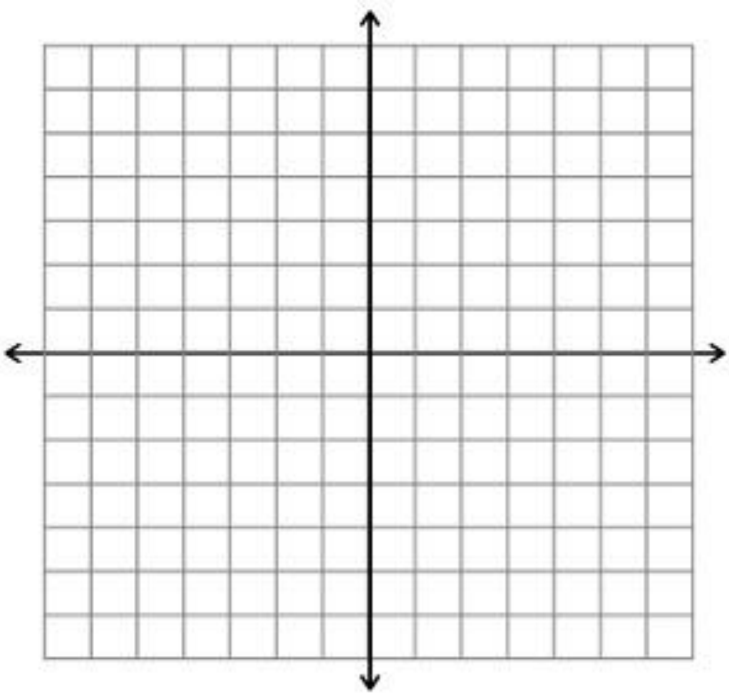
E.1.3 Box 1.1: Theoretical calculations with the measured values of the components

E.1.4 Table 1.3: Comparison of theoretical and practical values

Components	Calculated Theoretical Values	Measured with Oscilloscope	% of Error
	Peak to Peak Voltage (a)	Peak to Peak Voltage (b)	$\frac{(a-b)}{a} \times 100$
Vs	**8V**	**8V**	**0**
V_{R1}			
V_{R2}			
V_{R3}			
$V_T=V_{R1}+V_{R2}+V_{R3}$			
% of Error $\frac{V_S - V_T}{V_S} \times 100$			

E.1.5 Box 1.2: Theoretical calculations with the nominal values of the components

E.1.6 Box 1.3: Voltage Phasor diagram of the circuit in Fig.D.1.2.1



X-axis unit =

Y-axis unit =

E.2 Data Sheet: Lab 1, Experiment 2

Date:	Points:
Remarks:	

Signature of the Instructor

Student Information

Section:	Group:	Status:

E.2.1 Table 2.1: Components' measurements

Components	Nominal Value (n)	Measured Value (m)	% of difference[$\frac{(n-m)}{m} \times 100$]
R1	5kΩ		
R2	10kΩ		
R3	15kΩ		

E.2.2 Table 2.2: Verification of KCL

Components (V_{rms}=5V)	Measured with DMM	Measured with Oscilloscope		% of difference $\frac{(a-b)}{a} \times 100$
	(a) RMS Current, I_{rms}	Peak to Peak Voltage, V_{pp} [Volts/Div × Div]	(b) RMS Current, I_{rms} [$\frac{V_{pp}}{R2\sqrt{2}}$]	
$I_S = I_{R1}$	mA			
I_{R2}				
I_{R3}				
$I_T=I_{R2}+I_{R3}$				
% of Error $\frac{I_S - I_T}{I_S} \times 100$				
Frequency				

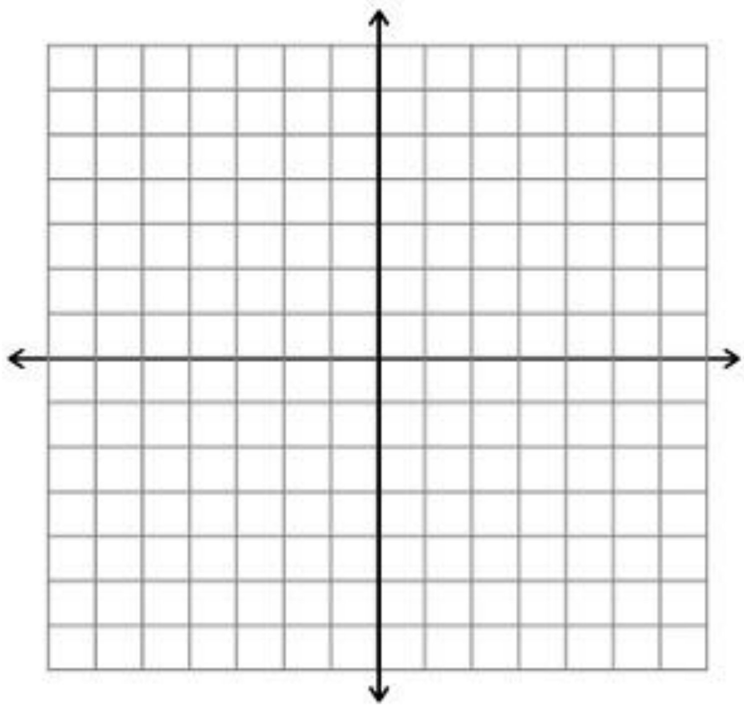
E.2.3 Box 2.1: Theoretical calculations with the measured values of the components

E.2.4 Table 2.3: Comparison of theoretical and practical values

Components	Calculated Theoretical Values	Measured with DMM	% of Error
	RMS Current (a)	RMS Current (b)	$\frac{(a-b)}{a} \times 100$
$I_S=I_{R1}$	**mA**	**mA**	**0**
I_{R2}			
I_{R3}			
$I_T=I_{R2}+I_{R3}$			
% of Error $\frac{I_S - I_T}{I_S} \times 100$			

E.2.5 Box 2.2: Theoretical calculations with the nominal values of the components

E.2.6 Draw the Current Phasor diagram



X-axis unit =

Y-axis unit =