Experiment 8 Report

Verification of KCL for AC Circuits

Course No: EEE 164

Experiment No: 08
Department: CSE
Section: B2

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1 Objectives

This experiment is designed to:

- Verify KCL for AC circuits.

Upon successful completion of this experiment, we should be able to:

- Construct RLC circuits.
- Understand the validity of analytical methods used in theory.

2 Apparatus

1. Function generator
2. Oscilloscope
3. Multimeter
4. Two 100 Ω resistors
5. One 120 Ω resistor
6. One 1 µF capacitor
7. Breadboard

The ratings of the equipment supplied were checked.

3 Experimental Setup

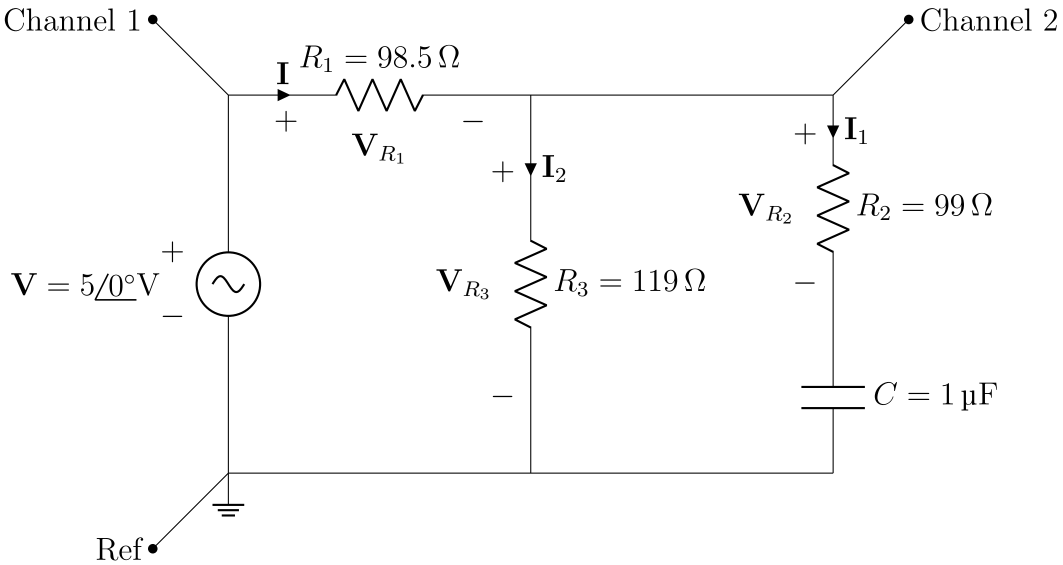

Fig 1: Circuit 1

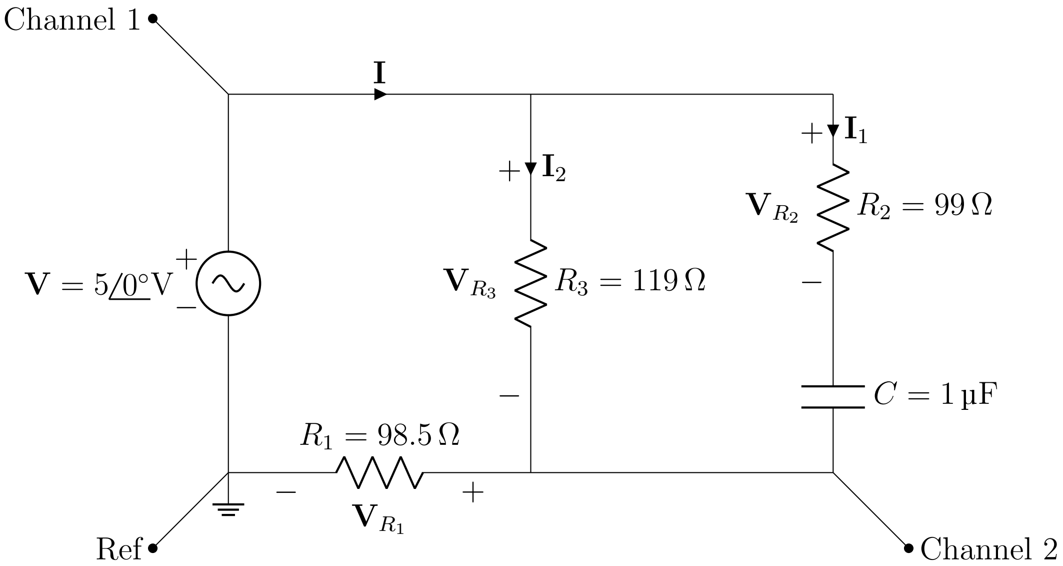

Fig 2: Circuit 2

4 Procedure

1. The resistance of the resistors was measured with the help of the multimeter and the values were recorded.

2. The frequency f of the function generator was set at 1 kHz. The power source was not turned on yet.
3. At first, circuit was setup as shown in Fig 1.
4. Then the magnitude and phase of the voltage $\mathbf{V}_{R_3}$ were determined using the multimeter and the oscilloscope respectively.
5. Then the phasor currents $\mathbf{I}_1 = \mathbf{I}_{R_2} = \mathbf{I}_C = \dfrac{\mathbf{V}_{R_3}}{Z_{RC}}$ and $\mathbf{I}_2 = \dfrac{\mathbf{V}_{R_3}}{R_3}$ were determined mathematically, where Z_{RC} is the equivalent impedance of R_2 and C.
6. Then the circuit was setup as shown in Fig 2.
7. Then the magnitude and phase of the voltage $\mathbf{V}_{R_1}$ were determined using the multimeter and the oscilloscope respectively.
8. Then the phasor current $\mathbf{I} = \mathbf{I}_{R_1} = \dfrac{\mathbf{V}_{R_1}}{R_1}$ was determined mathematically.
9. Then the phasor voltage $\mathbf{V}_{R_2}$ was determined mathematically.
10. The steps 3-9 were repeated for 0.5 kHz and 2 kHz source frequency.
11. The phasor values of $\mathbf{I}$, $\mathbf{I}_1$ and $\mathbf{I}_2$ were determined theoretically for the three frequencies and compared to the experimentally found values.

5 Data Collection

Measurements:

$R_1 = 98.5\,\Omega$ $\quad R_2 = 99\,\Omega$ $\quad R_3 = 119\,\Omega$

Table:

f(kHz)	$\mathbf{V}_{R_2}$(V)	$\mathbf{V}_{R_3}$(V)	$\mathbf{I}_1$(mA)	$\mathbf{I}_2$(mA)	$\mathbf{V}_{R_1}$(V)	$\mathbf{I}$(mA)	$\mathbf{I}_1+\mathbf{I}_2$(mA)
0.5	$0.55\angle 66.6^\circ$	$2.01\angle -6.12^\circ$	$6.03\angle 66.6^\circ$	$16.89\angle -6.12^\circ$	$1.89\angle 6.48^\circ$	$19.19\angle 6.48^\circ$	$19.55\angle 11.01^\circ$
1	$0.82\angle 50.9^\circ$	$1.72\angle -7.2^\circ$	$9.17\angle 50.9^\circ$	$14.45\angle -7.2^\circ$	$2.02\angle 7.2^\circ$	$20.5\angle 7.2^\circ$	$20.8\angle 14.77^\circ$
2	$1.02\angle 30.15^\circ$	$1.45\angle -8.64^\circ$	$11.4\angle 30.15^\circ$	$12.18\angle -8.66^\circ$	$2.09\angle 7.2^\circ$	$21.22\angle 7.2^\circ$	$22.24\angle 10.07^\circ$

Table 1: Experimental values

6 Report

6.1 Theoretically calculate all the values written in the table.

For $f = 0.5\,\text{kHz}$:

$\omega = 2\pi f = 3.141 \times 10^3\,\text{rad}\cdot\text{s}^{-1}$

$Z_C = -\dfrac{1}{\omega C}j = -318.310j\Omega$

$\therefore Z_{eq} = R_1 + ({R_3}^{-1} + (R_2 + Z_C)^{-1})^{-1} = 199.076\underline{/-8.75°}\Omega$

$\therefore \mathbf{I} = \dfrac{\mathbf{V}}{Z_{eq}} = 25.116\underline{/8.75°}\text{mA}$

Now using the current divider rule:

$\mathbf{I}_1 = \dfrac{R_3}{R_3 + R_2 + Z_C}\mathbf{I} = 7.747\underline{/64.34°}\text{mA}$, and

$\mathbf{I}_2 = \dfrac{R_2 + Z_C}{R_3 + R_2 + Z_C}\mathbf{I} = 21.701\underline{/-8.38°}\text{mA}$

$\therefore \mathbf{V}_{R_1} = \mathbf{I}R_1 = 2.474\underline{/8.75°}\text{V}$

$\therefore \mathbf{V}_{R_2} = \mathbf{I_1}R_2 = 0.767\underline{/64.34°}\text{V}$

$\therefore \mathbf{V}_{R_3} = \mathbf{I_2}R_3 = 2.582\underline{/-8.38°}\text{V}$

For $f = 1\,\text{kHz}$:

$\omega = 2\pi f = 6.283 \times 10^3\,\text{rad}\cdot\text{s}^{-1}$

$Z_C = -\dfrac{1}{\omega C}j = -159.155j\Omega$

$\therefore Z_{eq} = R_1 + ({R_3}^{-1} + (R_2 + Z_C)^{-1})^{-1} = 177.835\underline{/-10.02°}\Omega$

$\therefore \mathbf{I} = \dfrac{\mathbf{V}}{Z_{eq}} = 28.116\underline{/10.02°}\text{mA}$

Now using the current divider rule:

$\mathbf{I}_1 = \dfrac{R_3}{R_3 + R_2 + Z_C}\mathbf{I} = 12.396\underline{/46.15°}\text{mA}$, and

$\mathbf{I}_2 = \dfrac{R_2 + Z_C}{R_3 + R_2 + Z_C}\mathbf{I} = 19.524\underline{/-11.97°}\text{mA}$

$\therefore \mathbf{V}_{R_1} = \mathbf{I}R_1 = 2.769\underline{/10.02°}\text{V}$

$\therefore \mathbf{V}_{R_2} = \mathbf{I_1}R_2 = 1.227\underline{/46.15°}\text{V}$

$\therefore \mathbf{V}_{R_3} = \mathbf{I_2} R_3 = 2.323\underline{/-11.97^\circ}\text{V}$

<u>For $f = 2\,\text{kHz}$:</u>

$\omega = 2\pi f = 1.257 \times 10^4\,\text{rad} \cdot \text{s}^{-1}$

$Z_C = -\dfrac{1}{\omega C} j = -79.577 j \Omega$

$\therefore Z_{eq} = R_1 + ({R_3}^{-1} + (R_2 + Z_C)^{-1})^{-1} = 161.54\underline{/-7.44^\circ}\Omega$

$\therefore \mathbf{I} = \dfrac{\mathbf{V}}{Z_{eq}} = 30.95\underline{/7.44^\circ}\text{mA}$

Now using the current divider rule:

$\mathbf{I}_1 = \dfrac{R_3}{R_3 + R_2 + Z_C}\mathbf{I} = 15.871\underline{/27.50^\circ}\text{mA}$, and

$\mathbf{I}_2 = \dfrac{R_2 + Z_C}{R_3 + R_2 + Z_C}\mathbf{I} = 16.941\underline{/-11.30^\circ}\text{mA}$

$\therefore \mathbf{V}_{R_1} = \mathbf{I} R_1 = 3.049\underline{/7.44^\circ}\text{V}$

$\therefore \mathbf{V}_{R_2} = \mathbf{I_1} R_2 = 1.571\underline{/27.50^\circ}\text{V}$

$\therefore \mathbf{V}_{R_3} = \mathbf{I_2} R_3 = 2.016\underline{/-11.30^\circ}\text{V}$

Table:

f(kHz)	$\mathbf{I}$(mA)	$\mathbf{I}_1$(mA)	$\mathbf{I}_2$(mA)	$\mathbf{V}_{R_1}$(V)	$\mathbf{V}_{R_2}$(V)	$\mathbf{V}_{R_3}$(V)
0.5	$25.116\underline{/8.75^\circ}$	$7.747\underline{/64.34^\circ}$	$21.701\underline{/-8.38^\circ}$	$2.474\underline{/8.75^\circ}$	$0.767\underline{/64.34^\circ}$	$2.582\underline{/-8.38^\circ}$
1	$28.116\underline{/10.02^\circ}$	$12.396\underline{/46.15^\circ}$	$19.524\underline{/-11.97^\circ}$	$2.769\underline{/10.02^\circ}$	$1.227\underline{/46.15^\circ}$	$2.323\underline{/-11.97^\circ}$
2	$30.95\underline{/7.44^\circ}$	$15.871\underline{/27.50^\circ}$	$16.941\underline{/-11.30^\circ}$	$3.049\underline{/7.44^\circ}$	$1.571\underline{/27.50^\circ}$	$2.016\underline{/-11.30^\circ}$

Table 2: Theoretical values

6.2 Draw the phasor diagrams for both the circuits of Fig 1 and Fig 2 for $f = 1\,\text{kHz}$ source frequency using the theoretical values. The diagrams should be drawn to scale on graph paper.

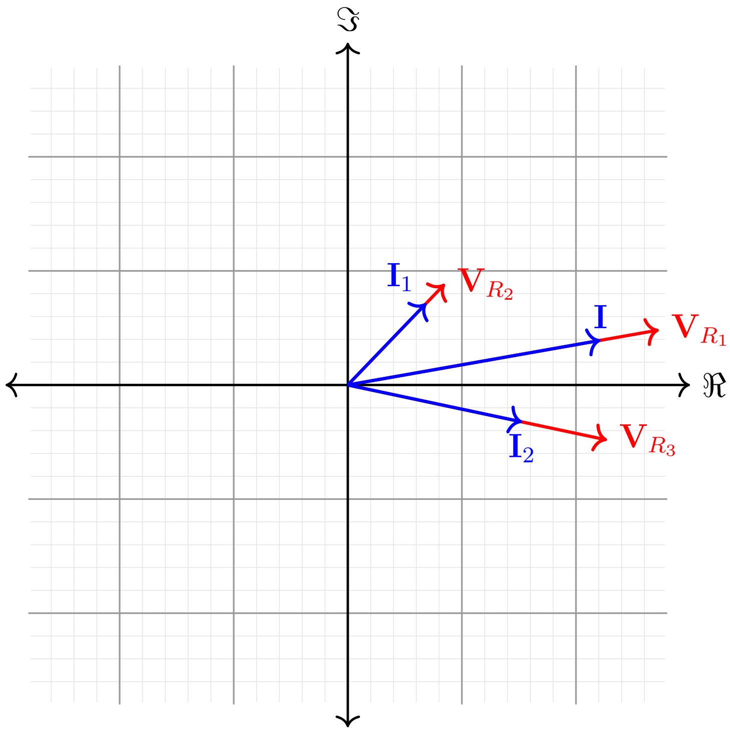

Fig 3: Phasor Diagram for Circuit 1 and Circuit 2 at $f = 1\,\text{kHz}$

The phasor diagram for Circuit 1 and Circuit 2 is the same, because the circuits are essentially the same.

6.3 From the phasor diagram, express the voltages and the currents as phasors and compare those with the values in table 1 for $f = 1\,\text{kHz}$.

From the phasor diagram, the voltages and currents at $f = 1\,\text{kHz}$ are:

- $\mathbf{V}_{R_1} = 2.769\underline{/10.02^\circ}$ V
- $\mathbf{V}_{R_2} = 1.227\underline{/46.15^\circ}$ V
- $\mathbf{V}_{R_3} = 2.323\underline{/-11.97^\circ}$ V
- $\mathbf{I} = 28.116\underline{/10.02^\circ}$ mA
- $\mathbf{I}_1 = 12.396\underline{/46.15^\circ}$ mA

- $\mathbf{I}_2 = 19.524\underline{/-11.97^\circ}$ mA

Comparing these theoretical phasor values with the experimental values in Table 1 for $f = 1\,\text{kHz}$:

	$\mathbf{V}_{R_1}$ (V)	$\mathbf{V}_{R_2}$ (V)	$\mathbf{V}_{R_3}$ (V)	$\mathbf{I}$ (mA)	$\mathbf{I}_1$ (mA)	$\mathbf{I}_2$ (mA)
Theoretical	$2.769\underline{/10.02^\circ}$	$1.227\underline{/46.15^\circ}$	$2.323\underline{/-11.97^\circ}$	$28.116\underline{/10.02^\circ}$	$12.396\underline{/46.15^\circ}$	$19.524\underline{/-11.97^\circ}$
Experimental	$2.02\underline{/7.2^\circ}$	$0.82\underline{/50.9^\circ}$	$1.72\underline{/-7.2^\circ}$	$20.5\underline{/7.2^\circ}$	$9.17\underline{/50.9^\circ}$	$14.45\underline{/-7.2^\circ}$

Table 3: Comparison of Theoretical and Experimental Values at $f = 1\,\text{kHz}$

The experimental values are close to the theoretical values, with some differences due to measurement errors, non-ideal components, and faulty apparatus. Regardless, they confirm the validity of the theoretical analysis.

6.4 Show that the currents noted in table 1 satisfy KCL for all three frequencies.

We can verify KCL by checking if the sum of the currents entering a node equals the sum of the currents leaving that node. Which means we need to check if $\mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2$ holds true.

<u>For $f = 0.5\,\text{kHz}$:</u>

From Table 1, we have: $\mathbf{I} = 19.19\underline{/6.48^\circ}$ mA

$\mathbf{I}_1 + \mathbf{I}_2 = 19.55\underline{/11.01^\circ}$ mA

$\therefore \mathbf{I} \approx \mathbf{I}_1 + \mathbf{I}_2$

<u>For $f = 1\,\text{kHz}$:</u>

From Table 1, we have: $\mathbf{I} = 20.5\underline{/7.2^\circ}$ mA

$\mathbf{I}_1 + \mathbf{I}_2 = 20.8\underline{/14.77^\circ}$ mA

$\therefore \mathbf{I} \approx \mathbf{I}_1 + \mathbf{I}_2$

<u>For $f = 2\,\text{kHz}$:</u>

From Table 1, we have: $\mathbf{I} = 21.22\underline{/7.2^\circ}$ mA

$\mathbf{I}_1 + \mathbf{I}_2 = 22.24\underline{/10.07^\circ}$ mA

$\therefore \mathbf{I} \approx \mathbf{I}_1 + \mathbf{I}_2$

It can be seen that the currents satisfy KCL for all three frequencies, as the sum of the currents entering the node is approximately equal to the sum of the currents leaving the node.

6.5 Explain why we couldn't measure all the voltages with the circuit shown in fig 1. Why it was essential to setup the circuit shown in fig 2?

If we were to measure the voltage $\mathbf{V}_{R_1}$ with the circuit shown in Fig 1, we would have needed to connect the channel 2 probe where the channel 1 probe is connected, and the channel 2 reference probe at node A as shown in Fig 4. This would have caused a short circuit, as the reference probe is grounded by default in the oscilloscope. Therefore, the circuit would have altered and the voltage $\mathbf{V}_{R_1}$ would not have been measured correctly. However, by setting up the circuit shown in Fig 2, we changed the position of R_1 effectively not changing the circuit, but allowing us to measure $\mathbf{V}_{R_1}$ without causing a short circuit. This is why, it was essential to setup the circuit shown in Fig 2.

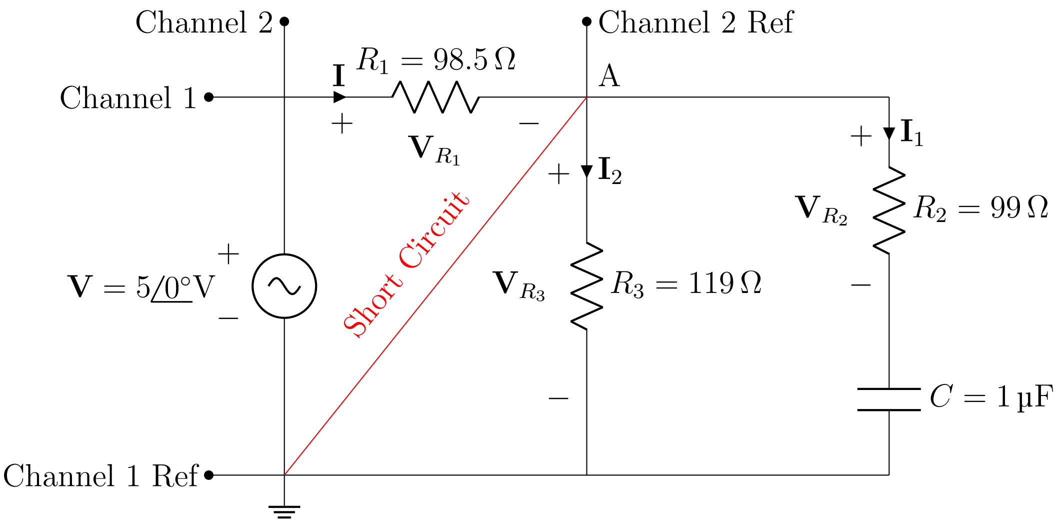

Fig 4: Measuring $\mathbf{V}_{R_1}$ with Circuit 1