KVL and KCL rules govern every lumped electrical circuit regardless of its elements. In this experiment, you practically verify KCL and KVL rules.

MANDATORY EXPERIMENTS

Experiment 1

Build the circuit shown in Fig. 1 on a breadboard.

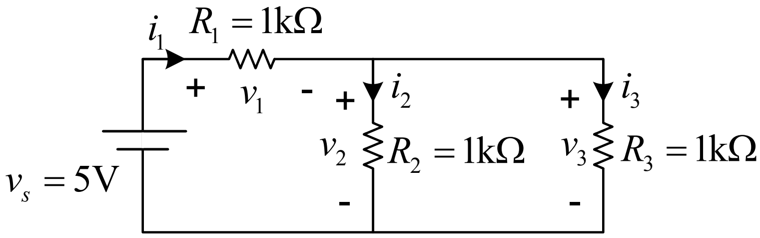

Figure 1: A resistive circuit.

(a) Measure the voltages of the circuit using a multimeter and verify the KVL $v_s = v_1 + v_2$.

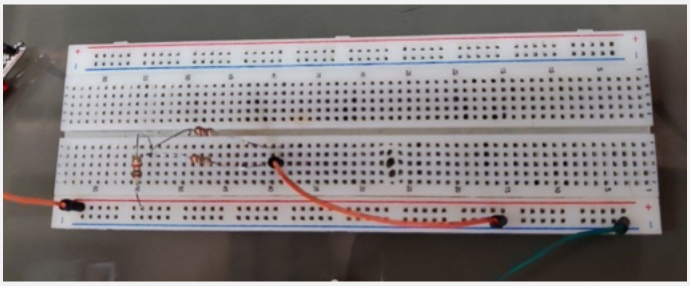

Figure 2: The circuit.

Figure 3: v_1 and v_2 measured by multimeter.

v_1 + v_2 = 3.35 + 1.67 = 5.02 V, compared to v_s = 5.00 V , the error is 0.02 V.

Experiment 1 continued on next page...

(b) Measure the currents of the circuit indirectly using a multimeter and verify the KCL $i_1 = i_2 + i_3$.

Figure 4: R_1, R_2 and R_3 for calculating i.

Since the current identifier of the multimeter is not working, we cannot measure the current directly. However, we can calculate it using Ohm's law.

$$i_1 = \frac{v_1}{R_1} = \frac{3.35}{1.012} = 3.31\,\text{mA}, \quad i_2 = \frac{v_2}{R_2} = \frac{1.67}{1.018} = 1.64\,\text{mA}, \quad i_3 = \frac{v_3}{R_3} = \frac{1.67}{1.016} = 1.64\,\text{mA}$$

So, we have $i_1 = i_2 + i_3 = 3.31\,\text{mA} = 1.64\,\text{mA} + 1.64\,\text{mA} = 3.28\,\text{mA}$. The error is 0.03 mA.

(c) Reverse the direction of the current i_2 *and the polarity of the voltage* v_3 *in Fig. 1 and repeat the previous parts.*

Figure 5: the direction of the polarity of the voltage v_3 reversed.

The results are the same as the previous parts. The error is 0.03 mA.

(d) Change the resistors to $10\ \text{k}\Omega$ *and repeat the previous parts.*

Figure 6: v_1 and v_2 measured by multimeter.

v_1 + v_2 = 3.35 + 1.67 = 5.02 V, compared to v_s = 5.00 V , the error is 0.02 V.

Figure 7: R_1, R_2 and R_3 for calculating i.

$$i_1 = \frac{v_1}{R_1} = \frac{3.35}{9.89} = 0.34\,\text{mA}, \quad i_2 = \frac{v_2}{R_2} = \frac{1.67}{9.80} = 0.17\,\text{mA}, \quad i_3 = \frac{v_3}{R_3} = \frac{1.67}{9.85} = 0.17\,\text{mA}$$

So, we have $i_1 = i_2 + i_3 = 0.34$ mA = 0.17 mA + 0.17 mA = 0.34 mA. The error is 0.00 mA.

Figure 8: the direction of the polarity of the voltage v_3 reversed.

The results are the same as the previous parts. The error is 0.00 mA.

Experiment 2

Build the circuit shown in Fig. 9 on a breadboard and use two oscilloscopes to show the marked voltages. Use external triggering to synchronize the two oscilloscopes.

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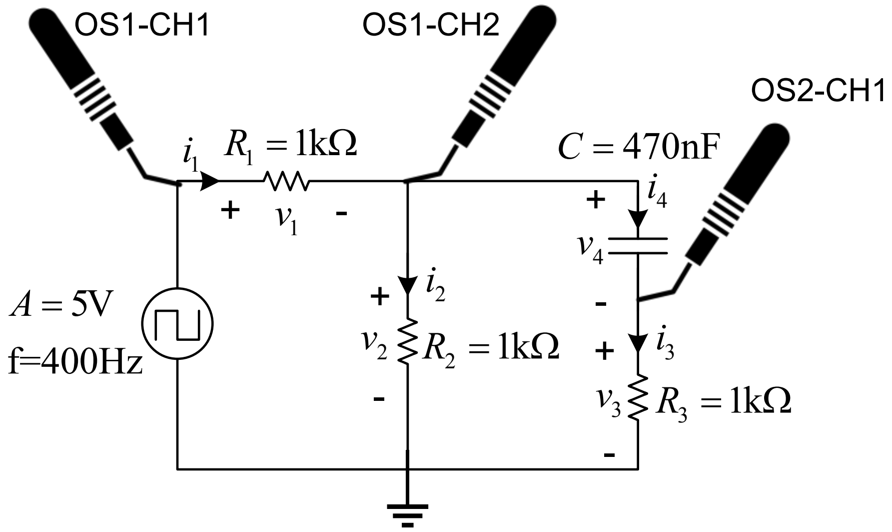

Figure 9: A sample circuit.

(a) *Verify the KCL $i_1 = i_2 + i_4$ graphically using the oscilloscopes.*

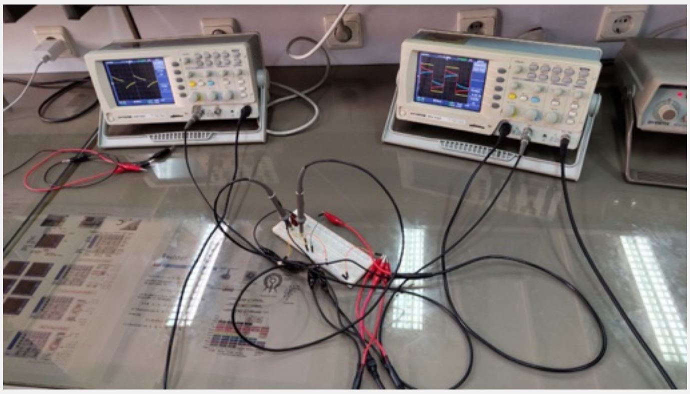

Figure 10: full setup.

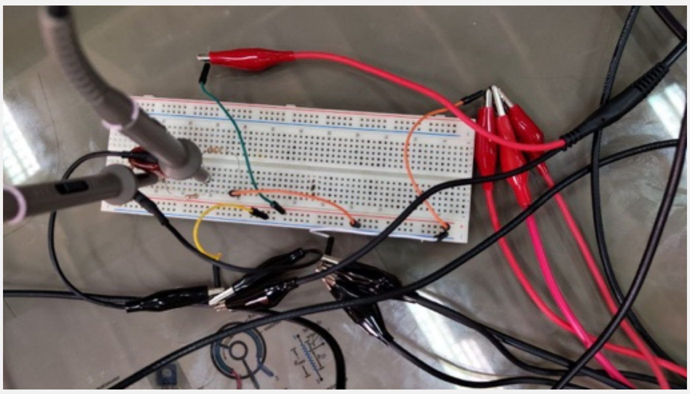

Figure 11: circuit.

Experiment 2 continued on next page...

Figure 12: oscilloscopes.

The red curve from left oscilloscope shows i_1 and the blue one shows i_2, The yellow curve from right oscilloscope is i_4.
as can be seen the KCL is verified graphically.

(b) Change the square wave to sine wave and repeat the previous part.

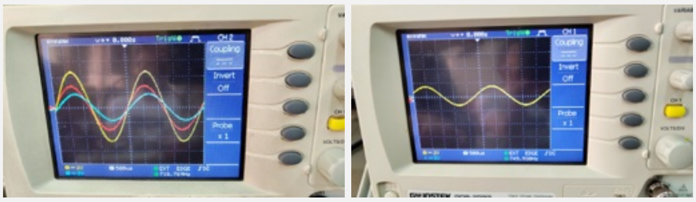

Figure 13: oscilloscopes.

as can be seen the KCL is verified graphically.

(c) Redo the previous parts when the capacitor is replaced with a diode.

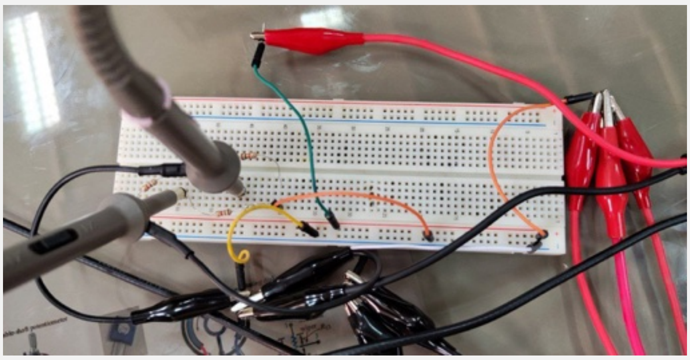

Figure 14: circuit.

Experiment 2 continued on next page...

Figure 15: oscilloscopes with square wave.

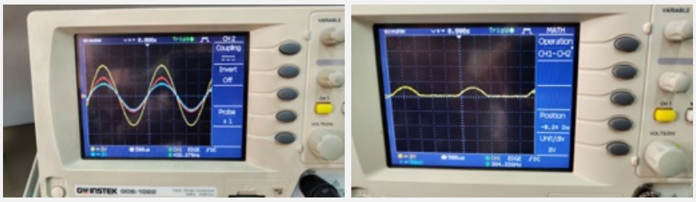

Figure 16: oscilloscopes with sine wave.

BONUS EXPERIMENTS

Experiment 3

Write a MATLAB/Python code that receives the data set $(x_i, y_i), i = 1, \cdots, n$ and determines the optimal coefficients of the linear curve $y = ax + b$ that fits the data set with the least square error $\epsilon = \sum_{i=1}^{n}(y_i - ax_i - b)^2$.

```
% Entries
V = [ .. ,  ..];
I = [.. , ..];

I = I / 1000;

[a, b] = fitLinearCurve(I, V);

fprintf('The resistance of the resistor is %.2f Ohms\n', a);


figure;
plot(I, V, 'bo'); % data --> blue circles
hold on;
plot(I, a*I + b, 'r-'); % fit --> red line
```

Experiment 3 continued on next page...

```
xlabel('Current (A)');
ylabel('Voltage (V)');
title('Voltage vs. Current and Linear Fit');
legend('Data', 'Linear Fit');
grid on;

function [a, b] = fitLinearCurve(x, y)
    coefficients = polyfit(x, y, 1);
    a = coefficients(1);
    b = coefficients(2);
end
```

Experiment 4

Tab. 1 includes the measured voltage and current pairs for an unknown LTI resistor. Use linear curve fitting to estimate the characteristic curve of the resistor and its resistance.

Voltage (V)	02.03	04.12	06.25	08.65	10.00	14.26	16.76	17.56	19.75	21.28
Current (mA)	00.97	01.90	03.18	03.94	05.41	05.61	06.66	07.43	08.34	10.73
Voltage (V)	26.13	25.70	26.37	32.52	32.27	33.38	36.68	36.40	38.72	47.89
Current (mA)	11.17	12.11	12.07	14.98	15.36	15.52	17.04	17.64	17.38	18.95

Table 1: Measured voltages and currents for an LTI resistor.

Here is the estimated characteristic curve of the resistor and its resistance:
The resistance of the resistor is 2218.80 Ohms (code output).

Experiment 4 continued on next page...

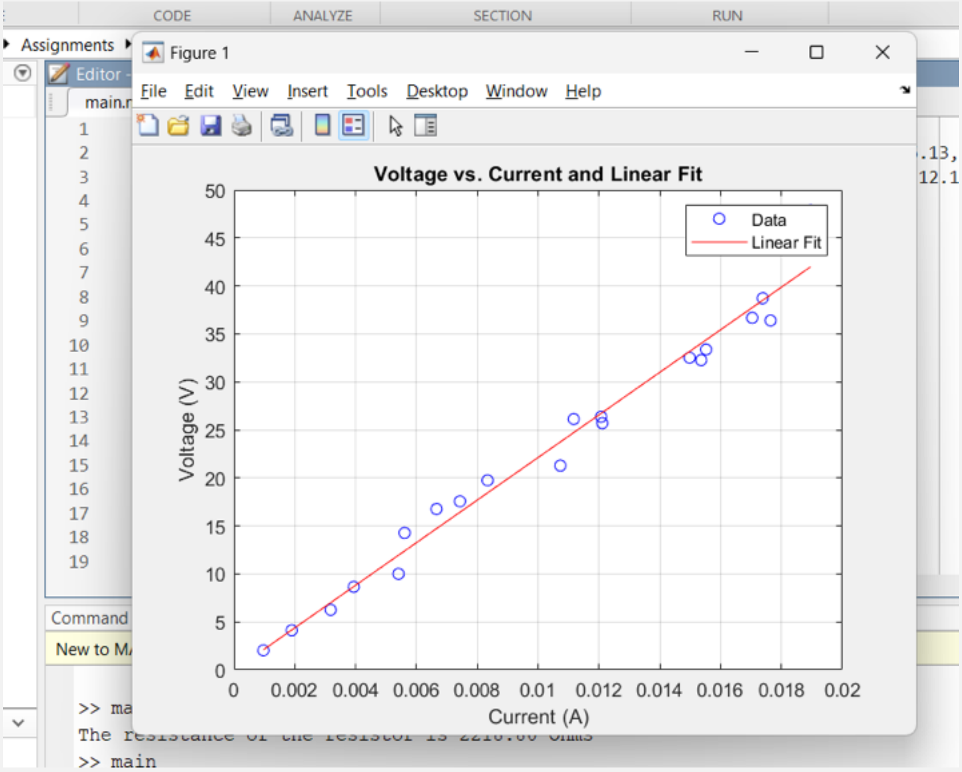

Figure 17: The characteristic curve of the resistor.

The Matlab code used to estimate the characteristic curve of the resistor and its resistance is as follows:

```
% Entries
V = [2.03, 4.12, 6.25, 8.65, 10.00, 14.26, 16.76, 17.56,
    19.75, 21.28, 26.13, 25.70, 26.37, 32.52, 32.27, 33.38,
    36.68, 36.40, 38.72, 47.89];
I = [0.97, 1.90, 3.18, 3.94, 5.41, 5.61, 6.66, 7.43, 8.34,
    10.73, 11.17, 12.11, 12.07, 14.98, 15.36, 15.52, 17.04,
    17.64, 17.38, 18.95];

I = I / 1000;

[a, b] = fitLinearCurve(I, V);

fprintf('The resistance of the resistor is %.2f Ohms\n', a);


figure;
plot(I, V, 'bo'); % data --> blue circles
hold on;
plot(I, a*I + b, 'r-'); % fit --> red line
xlabel('Current (A)');
ylabel('Voltage (V)');
```

```
title('Voltage vs. Current and Linear Fit');
legend('Data', 'Linear Fit');
grid on;

function [a, b] = fitLinearCurve(x, y)
    coefficients = polyfit(x, y, 1);
    a = coefficients(1);
    b = coefficients(2);
end
```

Experiment 5

Return your work report by filling the LaTeXtemplate of the manual. Include useful and high-quality images to make the report more readable and understandable.