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Network theorems can facilitate circuit analysis and design. In this experiment, you practically verify various network theorems including superposition, Thevenin-Norton equivalency, and maximum power transfer.

MANDATORY EXPERIMENTS

Experiment 1

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

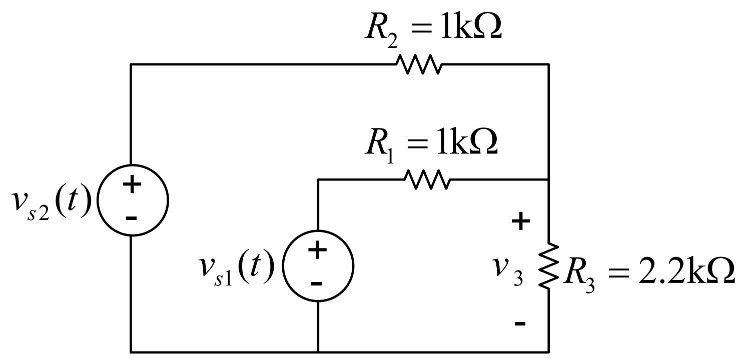

Figure 1: A circuit with two voltage sources.

(a) Connect $v_{s1}(t)$ and $v_{s2}(t)$ to a 5V and 10V DC voltage source, respectively.

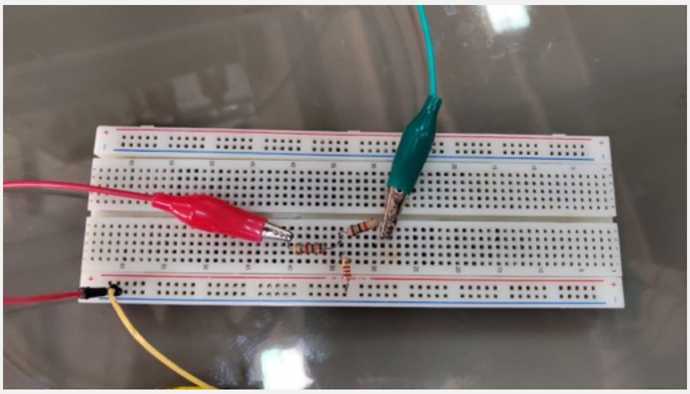

Figure 2: The circuit.

Experiment 1 continued on next page...

Figure 3: The DC power supply.

(b) Measure v_3 using a multimeter when $v_{s1}(t)$ is on and $v_{s2}(t)$ is off. Make sure that $v_{s2}(t)$ acts like short circuit when it is off.

(c) Measure v_3 using a multimeter when $v_{s2}(t)$ is on and $v_{s1}(t)$ is off. Make sure that $v_{s1}(t)$ acts like short circuit when it is off.

Experiment 1 continued on next page...

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(d) Measure v_3 using a multimeter when both $v_{s1}(t)$ and $v_{s2}(t)$ are on. Verify the superposition theorem.

to verify the superposition theorem, we can use the following equation:

$$v_3 = v_{s1} + v_{s2} = 2.10 + 4.07 = 6.07\ \text{V}$$

the direct measure of v_3 shows $6.15V$. So superposition is held in this case, but there is about 1.3% error in the measurement.

(e) Connect $v_{s1}(t)$ and $v_{s2}(t)$ to a 5V DC voltage source and a 2V 1KHz sine voltage source, respectively. Verify the superposition theorem by suitable measurements using a multimeter. Repeat this part while seeing v_3 using an oscilloscope.

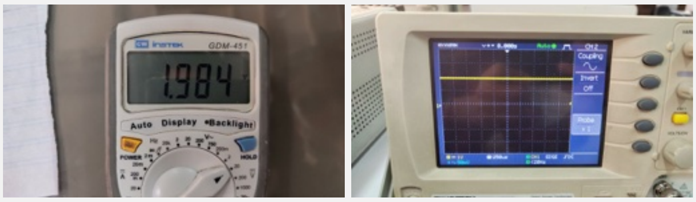

Figure 4: v_{s1} on and $v_{s2}(t)$ off.

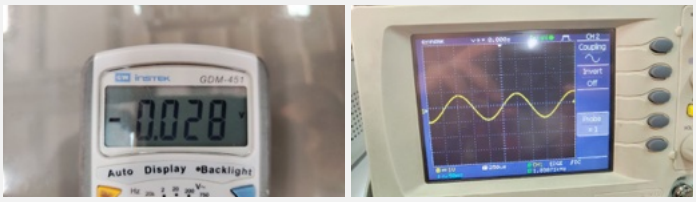

Figure 5: v_{s1} off and $v_{s2}(t)$ on.

Experiment 1 continued on next page...

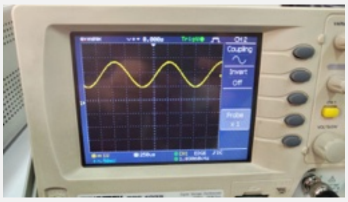

Figure 6: v_{s1} on and $v_{s2}(t)$ on.

to verfy superposition, we can use the following equation:

$$v_3 = v_{s1} + v_{s2} = 1.98 - 0.02 = 1.96 \text{ V}$$

the direct measure of v_3 shows $1.95V$. So superposition is held in this case, but there is about 0.5% error in the measurement.

(f) Connect $v_{s1}(t)$ and $v_{s2}(t)$ to a 5 V and 10 V DC voltage source, respectively, and replace R_1 and R_2 with two diodes such that the positive leg of each diode connects to the positive side of the corresponding voltage source. Check if the superposition is held or not. Discuss the results.

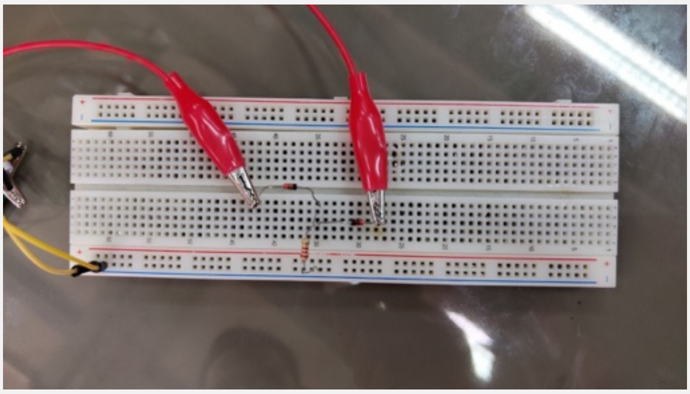

Figure 7: The circuit.

Figure 8: v_{s1} on and $v_{s2}(t)$ off.

Figure 9: v_{s1} off and $v_{s2}(t)$ on.

Figure 10: v_{s1} on and $v_{s2}(t)$ on.

Since diode is considered as a non-linear element, the superposition theorem is not held in this case and v_3 is not equal to the sum of v_{s1} and v_{s2}.

Experiment 2

Build the circuit shown in Fig. 11 on a breadboard.

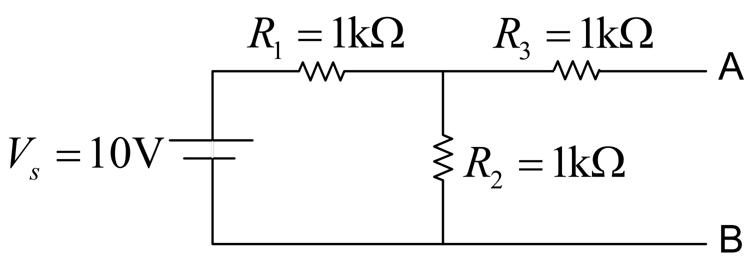

Figure 11: A linear circuit.

Experiment 2 continued on next page...

(a) Measure the open circuit voltage V_{oc} of the circuit.

(b) Connect an $R_L = 2.2$ kΩ resistor to the port AB and measure its voltage V_L.

(c) Can you obtain the corresponding Thevenin equivalent circuit using the measured values of V_{oc} and V_L.

Considering a series circuit which contains voltage source V_{oc} , R_{eq} and R_L, the relation between variables of this circuit and the original circuit is:

$$V_{oc} = V_1 \quad V_L = \frac{R_L}{R_{eq} + R_L} \times V_{oc} \quad I_{sc} = \frac{V_{oc}}{R_{eq}}$$

Using the equations, since $V_{oc} = 5.14$ V and $V_L = 3.02$ V and $R_L = 2.2$ kΩ, we can find R_{eq} as:

$$R_{eq} = 1.56 \text{ k}\Omega$$

So the Thevenin equivalent circuit is a voltage source with $V_{oc} = 5.14$ V and a resistor with $R_{eq} = 1.56$ kΩ.

(d) Build the Thevenin equivalent circuit on the breadboard. Connect a same load resistor to both circuits and measure its voltage. Interpret the results.

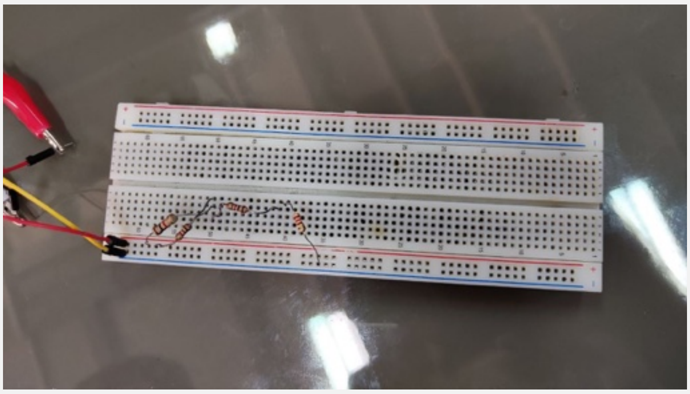

Figure 12: The circuit.

Figure 13: Voltage of the load resistor.

The voltage of the load resistor is 3.00 V which has a 0.7% error. This can be due to tolerances of the components (like resistors).

Experiment 3

Build the circuit shown in Fig. 14 on a breadboard.

Experiment 3 continued on next page...

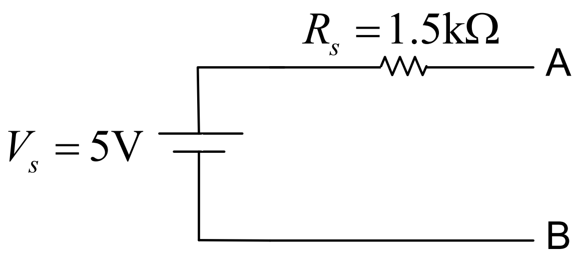

Figure 14: A simple resistive circuit.

(a) Calculate the load resistor R_L drawing the maximum power from the source. Connect it to the port AB and measure the consumed power.

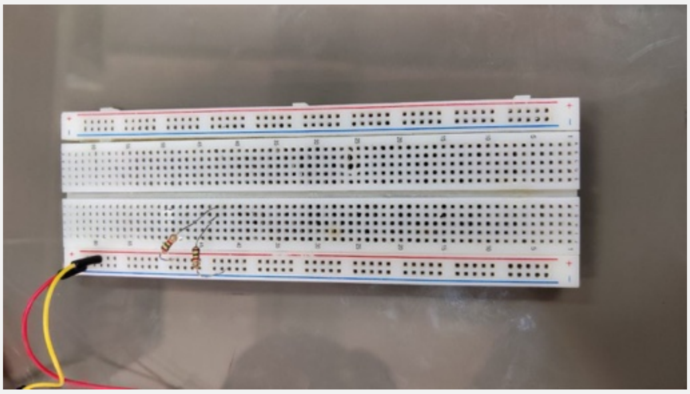

Figure 15: The circuit.

Figure 16: The exact value of R.

Figure 17: The exact value of v of R.

The power consumed will be maximum when $R_L = R_{eq} = 1.45$ kΩ. Using $\frac{V^2}{R}$ for calculation of power, we will have:

$$P = \frac{v^2}{R} = \frac{2.51^2}{1.45} = 4.35 \text{ W}$$

(b) Connect a 1 kΩ and a 2.2 kΩ resistor to the port and measure the corresponding consumed powers. Discuss the results and verify the maximum power transfer theorem.

Figure 18: The exact value of R.

Figure 19: The exact value of v of $R = 0.98k$.

Figure 20: The exact value of R.

Figure 21: The exact value of v of $R = 2.15k$.

calculating the power for these two resistors, we have:

$$P_{1k} = \frac{v^2}{R} = \frac{2.06^2}{0.98} = 4.32 \text{ W}$$

$$P_{2.2k} = \frac{v^2}{R} = \frac{2.97^2}{2.15} = 4.11 \text{ W}$$

Experiment 3 continued on next page...

as can be seen, the power consumed by the $1\ \text{k}\Omega$ resistor is 4.32 W and the power consumed by the $2.2\ \text{k}\Omega$ resistor is 4.11 W which both are less than the maximum power of 4.35 W. So the maximum power transfer theorem is verified.

BONUS EXPERIMENTS

Experiment 4

A Zener diode is a special type of diode designed to reliably allow current to flow backwards when a certain set reverse voltage, known as the Zener voltage, is reached. The characteristic curve of a typical Zener diode is shown in Fig. 22. Explain how a Zener diode can be used as a voltage source. Is there any practical or analytical limitation on a voltage source created by a Zener diode?

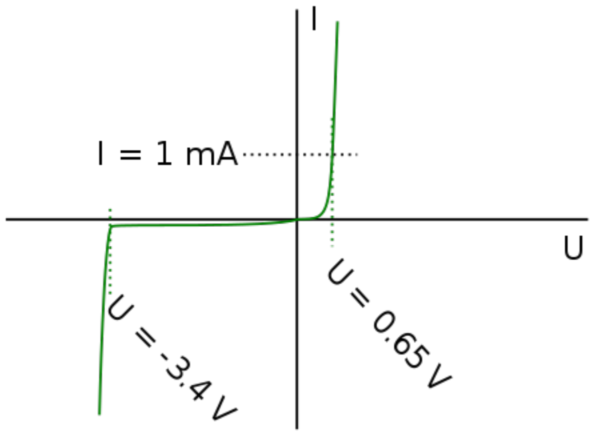

Figure 22: Typical characteristic of a Zener diode.

The Zener diode can be used as a voltage regulator to provide a stable reference voltage. This is achieved by operating the Zener diode in its reverse breakdown region. When the reverse voltage applied to the Zener diode exceeds the Zener breakdown voltage V_Z, the diode conducts and maintains a constant voltage V_Z across its terminals. Consider a circuit where a Zener diode is connected in parallel with the load resistor R_L and a series resistor R_s is placed between the supply voltage V_s and the Zener diode. The supply voltage V_s must be greater than the Zener voltage V_Z for the Zener diode to regulate the voltage. The current through the series resistor R_s is given by:

$$I_s = \frac{V_s - V_Z}{R_s}$$

The current through the load resistor R_L is:

Experiment 4 continued on next page...

$$I_L = \frac{V_Z}{R_L}$$

The Zener current I_Z, which is the current flowing through the Zener diode, is:

$$I_Z = I_s - I_L = \frac{V_s - V_Z}{R_s} - \frac{V_Z}{R_L}$$

For proper operation, the Zener current I_Z must be within the specified limits of the Zener diode. The Zener diode will maintain a constant voltage V_Z as long as I_Z remains within these limits.
There are several practical and analytical limitations to consider when using a Zener diode as a voltage source:
1. **Power Dissipation:** The Zener diode must be able to dissipate the power generated by the Zener current. The power dissipated by the Zener diode P_Z is:

$$P_Z = V_Z \cdot I_Z$$

Ensure that P_Z does not exceed the maximum power rating of the Zener diode.
2. **Current Limitations:** The series resistor R_s must be chosen to ensure that the Zener current I_Z remains within the specified operating range of the Zener diode. If the Zener current is too low, the Zener diode may not maintain the voltage regulation. If the Zener current is too high, the diode may overheat and fail.
3. **Supply Voltage and Load Variations:** The supply voltage V_s must be sufficiently higher than the Zener voltage V_Z to maintain regulation. Variations in V_s can affect the current through the Zener diode and potentially impact voltage regulation.
4. **Load Variations:** Changes in the load resistance R_L will affect the load current I_L. The series resistor R_s must be sized to accommodate the expected range of load variations while keeping the Zener current I_Z within the safe operating region.

It's also important to point Zener effect.The Zener effect is a type of electrical breakdown that occurs in a reverse biased p-n junction when the electric field enables tunneling of electrons from the valence to the conduction band of a semiconductor, leading to numerous free minority carriers. When the reverse voltage applied to the Zener diode reaches the Zener voltage, these carriers are accelerated enough to create additional carriers through collisions with bound electrons, causing a rapid increase in current, while the voltage across the diode remains approximately constant. This constant voltage, even in the face of large changes in current, is what makes the Zener diode useful as a voltage regulator.

In summary, a Zener diode can be effectively used as a voltage source to provide a stable reference voltage, but it is essential to consider power dissipation, current limitations, and variations in supply voltage and load to ensure reliable operation.

Experiment 5

Consider the typical characteristic curve of a Zener diode.

(a) Propose a piecewise linear approximation for the characteristic curve using vertical and/or horizontal lines. The forward and (Zener) breakdown voltages should be included in the approximation.

To propose a piecewise linear approximation for the characteristic curve of a Zener diode, we can approximate the curve using vertical and horizontal lines that represent the forward and breakdown voltages. The key points to consider are the forward voltage V_F and the Zener breakdown voltage V_Z.
1. **Forward Bias Region:** - For $U > V_F$, the diode conducts and we approximate it with a horizontal line at the forward voltage V_F (typically 0.7V for a silicon diode).
2. **Reverse Breakdown Region:** - For $U < -V_Z$, the Zener diode enters breakdown and we approximate it with a horizontal line at the Zener voltage V_Z (e.g., -10V).
3. **Non-Conducting Region:** - For $-V_Z < U < V_F$, the diode does not conduct, and we approximate it with a vertical line at zero current.
The piecewise linear approximation can be expressed as:

$$I(U) = \begin{cases} I_F & \text{for } U \geq V_F \\ 0 & \text{for } -V_Z < U < V_F \\ -I_Z & \text{for } U \leq -V_Z \end{cases}$$

Where I_F is the current in the forward bias and I_Z is the Zener current in breakdown.

(b) Use the proposed piecewise linear approximation to suggest a model for the Zener diode. You may use ideal diodes, independent sources, or passive LTI resistors in your model.

Using the piecewise linear approximation from part (a), we can suggest a model for the Zener diode using ideal diodes, independent sources, and passive LTI resistors.
1. **Forward Bias Model:** - An ideal diode in series with a voltage source V_F (0.7V) represents the forward bias region.
2. **Reverse Breakdown Model:** - An ideal diode in series with a voltage source V_Z (-10V) represents the breakdown region. This series combination is placed in parallel with the forward bias model.
3. **Non-Conducting Region:** - This region is represented by an open circuit (no current flow).
The equivalent circuit model for the Zener diode is thus composed of: - An ideal diode D_1 in series with a voltage source V_F. - A second ideal diode D_2 in series with a voltage source V_Z placed in reverse bias.
The model can be represented as:

$$\begin{cases} D_1 + V_F & \text{for forward bias} \\ D_2 + V_Z & \text{for reverse breakdown} \end{cases}$$

Where D_1 and D_2 are ideal diodes.

(c) Use PSpice simulation to verify the accuracy of the suggested model for D02CZ10 zener diode with the forward and breakdown voltages around 0.7 and -10 V.

To verify the accuracy of the suggested model for the D02CZ10 Zener diode with forward and breakdown voltages around 0.7V and -10V, respectively, we can use PSpice simulation. The model in PSpice looks like:

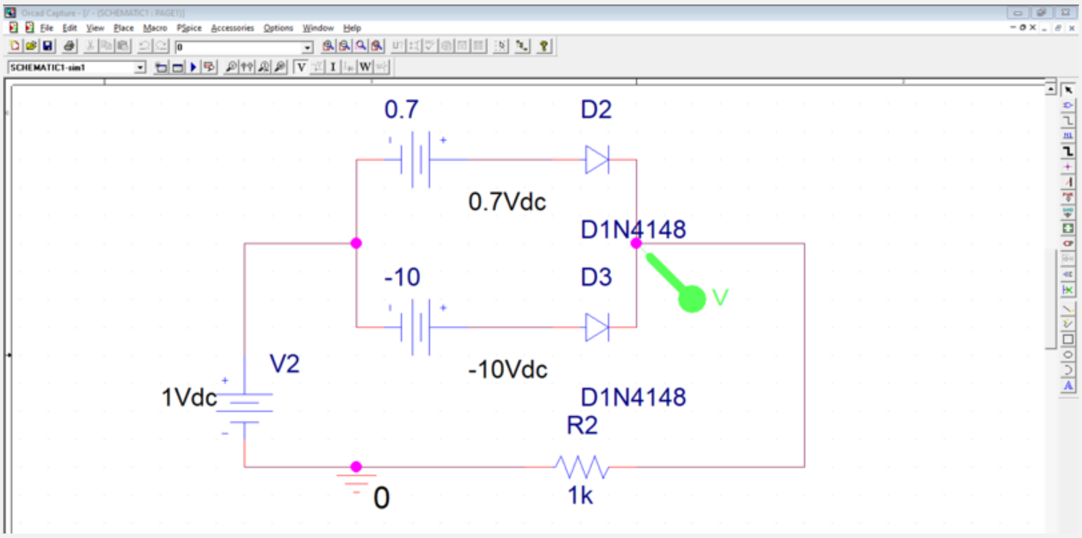

Figure 23: circuit in PSpice

and here is the output of the simulation:

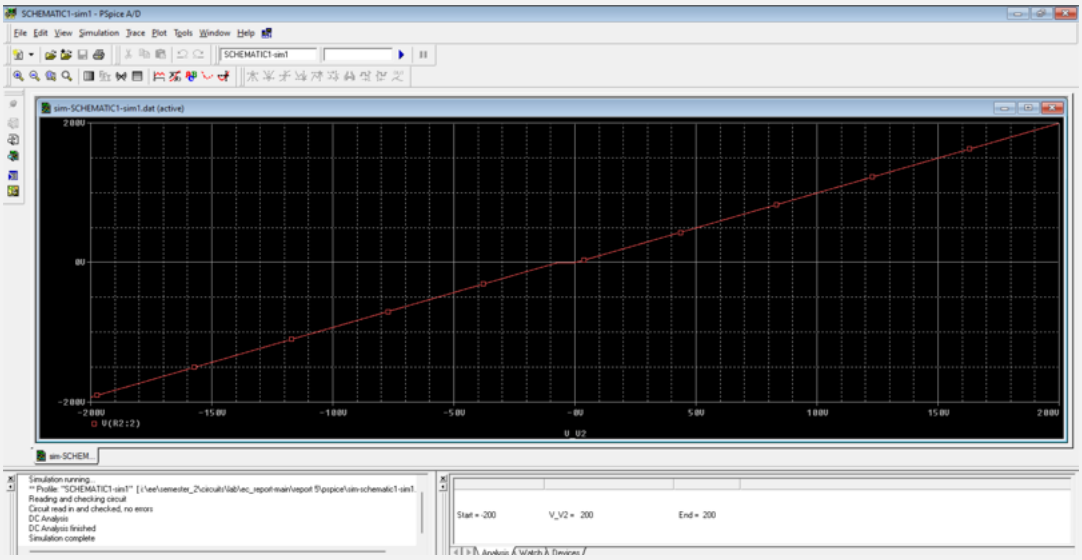

Figure 24: simulation results

Also, here is the desired Matlab code for the simulation:

```
U = linspace(-15, 1, 1000);
I = zeros(size(U));
```

Experiment 5 continued on next page...

```
V_Z = -10;
V_F = 0.7;

for k = 1:length(U)
if U(k) >= V_F
I(k) = 1; % Forward current
elseif U(k) <= V_Z
I(k) = -1; % Zener breakdown current
else
I(k) = 0; % Non-conducting region
end
end

figure;
plot(U, I, 'LineWidth', 2);
xlabel('Voltage (U)');
ylabel('Current (I)');
title('Piecewise Linear Approximation of Zener Diode');
grid on;
```

Experiment 6

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.