California State University, Fresno
Department of Electrical and Computer Engineering

ECE 90L Principles of Electrical Circuits Laboratory
Experiment No. 4: Two-Terminal Networks

Objective

The objective of this experiment is to demonstrate the idea of a two-terminal network. This is done for both a DC resistive circuit and an AC resistive circuit.

Prelab

Two-Terminal Network

In a two-terminal network, it is advantageous to think in terms of the voltage v across the two terminals and the current i into one terminal. Figure 1 shows the sign conventions that we use for a two-terminal network. One terminal is marked positive and the other negative for the purpose of defining the voltage across the terminals. Either terminal may be marked positive, but once that selection is made, it determines the direction of positive current flow. The current is regarded as positive when it enters the two-terminal network at the positive terminal and leaves at the negative terminal. The magnitude of the current is the same at both terminals. (This is a consequence of the conservation of charge.)

When a two-terminal network consists only of resistors (and connections between the resistors), we can replace it with a single resistor between the two terminals. We call this the equivalent load resistor or, simply, the *load*. The equivalent load resistor may be determined, for example, by using formulas for resistors in parallel and resistors in series.

The relationship between v and i for a two-terminal network is exactly the same as Ohm's Law for the equivalent load resistor. Replacing a two-terminal resistive network with its equivalent load resistor has no effect on the outside world.
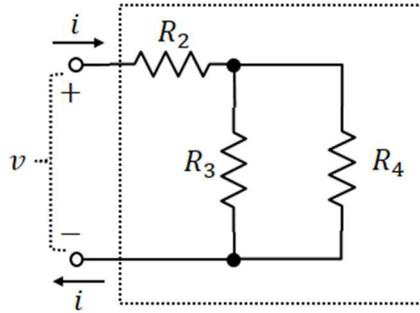
Figure 1: Sign conventions for a two-terminal network

Exercise: Calculate v and i for the DC circuit of Figure 2 with the resistor values of Table 2. Calculate the power dissipated in each resistor and the power delivered by the DC source.

Consider the two-terminal network of Figure 3. (The two-terminal network in that figure is the connected set of resistors R_2, R_3, and R_4.) Using the resistor values of Table 2, calculate the equivalent load resistance for this two-terminal network.

Calculate v and i for the circuit of Figure 4 with the resistor values of Table 2. Calculate the power dissipated in R_1 and the power dissipated in R_L. Calculate the power delivered by the DC source.

AC Circuit

The above remarks on two-terminal networks are applicable also when an AC source is applied to the network.

The average power P (watts) dissipated in a resistor can be calculated as

$$P = \frac{V_{\text{rms}}^2}{R}$$

The average power delivered by a source can be calculated as the rms voltage of the source times the rms current through the source.

Table 1 is a reminder of how the rms value, denoted X_{rms}, of an AC signal is related to the amplitude A of that signal.

Table 1: Relationship between X_{rms} and A

Waveform	X_{rms} (Exact)	X_{rms} (Approximate)
Sinewave	$A/\sqrt{2}$	$0.707A$
Square-wave	A	A
Triangle-wave	$A/\sqrt{3}$	$0.577A$

Decibels

Decibels (dB) are used to measure the power of one signal relative to another on a logarithmic scale,

$$\text{power ratio } P_1/P_2 \text{ in decibels} = 10 \log(P_1/P_2) \text{ dB}$$

where log is the common (base 10) logarithm. A logarithmic scale is useful when you have to compare powers that can range over several orders of magnitude. For example, when the signal power at a wireless receiver is only $1/100{,}000$ as large as the power that was broadcast by a wireless transmitter, we can say this (perhaps less awkwardly) like so: "the received power is -50 dB relative to the transmitted power".

It is common to compare a signal power to the reference value of 1 milliwatt (mW). When an rms voltage V_{rms} is placed across a load of R ohms, the average power dissipated in that load equals V_{rms}^2/R watts. Relative to one milliwatt, this is

$$10 \log\left(\frac{V_{\text{rms}}^2/R}{0.001}\right) \text{ dBm}$$

We can read dBm as "decibels relative to one milliwatt"; however, most engineers simply say "dBm". (That is, they spell it out loud.)

For example, when a sinewave of amplitude 1 V (and, therefore, an rms voltage of $1/\sqrt{2}$ V rms) is placed across a 75-Ω load, the dissipated average power is

$$10 \log\left[\frac{0.5/75}{0.001}\right] = 8.2 \text{ dBm}$$

It is important to note that this dBm value depends on the load. If the same sinewave is placed across a 50-Ω load, this would be 10.0 dBm. Thus, it is best to say "8.2 dBm for a 75-Ω load" or "10.0 dBm for a 50-Ω load".

3

The resistance R that we use in this calculation is called the "reference resistance" (or "reference impedance"). We use different reference resistances under different circumstances. For the transmission of video, the standard impedance is 75 Ω. For radio-frequency circuits, the standard impedance is 50 Ω. For some audio and instrumentation applications, 600 Ω is used. In this experiment, we will use 75 Ω for R.

You might think that dBm is a poorly chosen notation. (Maybe dBmW would be better?) But dBm is the standard notation.

Exercise: Complete the following table.

| Sinewave Amplitude (V)	Power Delivered to a 75-Ω load, Relative to 1 mW (dBm)
1	
5	
10	

Procedure

You will use decade boxes for the resistors in this experiment. For each resistor, select a decade box. Set the correct resistance for each decade box in accord with Table 2. Measure and record the actual resistance for each.
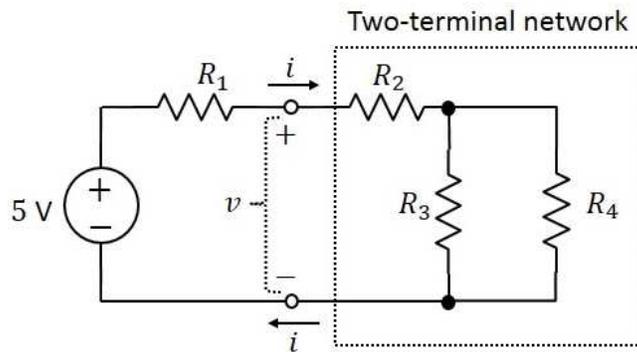
Table 2: Resistor values

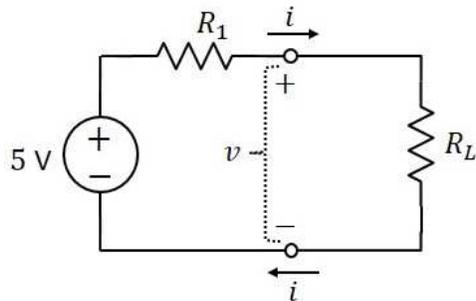| Resistor	Value
R_1	3.0 kΩ
R_2	1.0 kΩ
R_3	2.5 kΩ
R_4	2.0 kΩ

DC Circuit

Construct the DC circuit of Figure 2 with the resistances of Table 2. Use CH1 of the Siglent power supply. Set the current limit to 0.2 A.
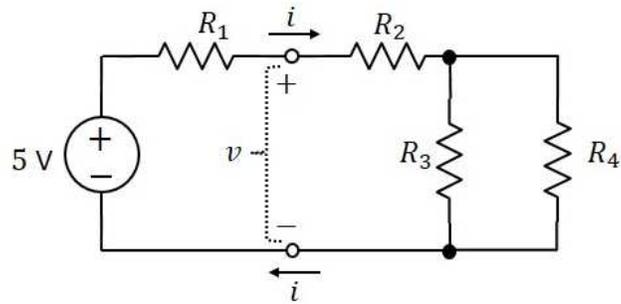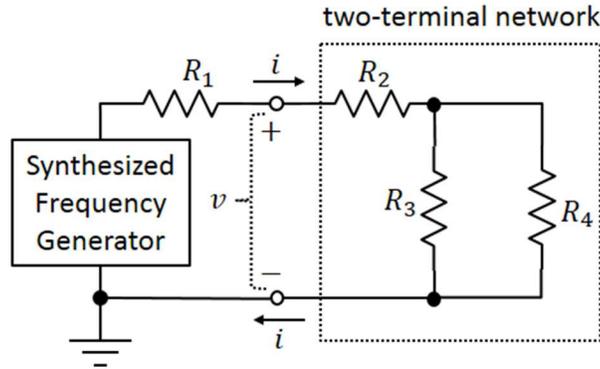
Figure 2: DC circuit

Figure 3: Two-terminal network defined

Figure 4: Equivalent load for DC circuit

Using the multimeter, measure v, i, and the voltage across each of the resistors R_2, R_3, and R_4. From these measurements, calculate the power dissipated in each of the resistors R_2, R_3, and R_4. Calculate the power delivered to the two-terminal network.

Replace the two-terminal network of Figure 3 with the equivalent load resistor (as calculated in the Prelab). The resulting circuit should look like Figure 4. Measure v and i. From these measurements, calculate the power dissipated in R_L.

5

Figure 5: AC circuit

AC Circuit

In the circuit of Figure 2, replace the DC source with the synthesized frequency generator, as shown in Figure 5.

For each of the following three waveforms, you will display v on the oscilloscope and measure its peak-to-peak value. You will also measure and record v as an rms voltage (V_{rms}) and i as an rms current (I_{rms}). When making AC measurements with the multimeter, connect its COM terminal to ground in the circuit under test. (For example, when measuring i, insert the ammeter into the path between the lower terminal of Figure 5 and ground.)

1. The AC source is a 2-kHz *sinewave* with an amplitude of 5.0 V.

2. The AC source is a 2-kHz *square-wave* with an amplitude of 5.0 V.

3. The AC source is a 2-kHz *triangle-wave* with an amplitude of 5.0 V.

For each of these three waveforms, calculate the power delivered to the two-terminal network ($V_{rms} \cdot I_{rms}$) and the ratio V_{rms}/I_{rms}.

Replace the two-terminal network of Figure 5 with the equivalent load resistor (as calculated in the Prelab). The resulting circuit should look like Figure 6. For each of the following three waveforms, you will display v on the oscilloscope and measure its peak-to-peak value. You will also measure and record v as an rms voltage and i as an rms current.
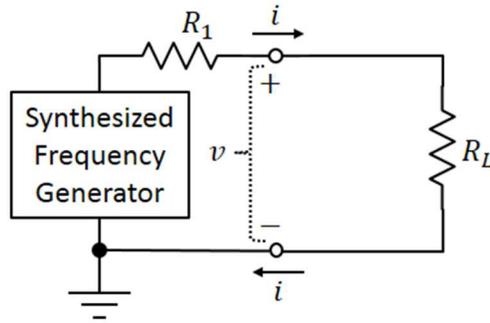
Figure 6: Equivalent load for AC circuit

1. The AC source is a 2-kHz *sinewave* with an amplitude of 5.0 V.

2. The AC source is a 2-kHz *square-wave* with an amplitude of 5.0 V.

3. The AC source is a 2-kHz *triangle-wave* with an amplitude of 5.0 V.

For each of these three waveforms, calculate the power delivered to R_L.

Decibels

On the multimeter, you can request that a signal level be displayed in units of dBm. For an AC signal, set the multimeter initially to AC voltmeter mode (using the top red terminal and pushing the AC V button). Connect the multimeter, in AC voltmeter mode, across the voltage to be measured. You will get the best accuracy if the COM terminal of the multimeter is connected to ground. The multimeter will now display the rms voltage.

Now we want to select dBm. We do this with the Shift button:

(Shift) → (⚹)

After selecting dBm on the multimeter, the reference resistance will be displayed. You can change the reference resistance that the multimeter uses. But in this experiment, we will use the default value of 75 Ω. So when we see that the reference resistance is already 75 Ω, we press the Auto button to accept that value. (If you want to change the reference resistance, you can do that with the arrow buttons.)

The signal level in dBm should now be displayed. You can return to a display of the rms voltage by pressing the same button combination that brought us to the dBm display:

(Shift) → (⚹)

In other words, this button combination is a toggle between dBm mode and AC V mode.

Please note that there is no actual 75-Ω load in the multimeter: it is a fiction. We are asking the hypothetical question: "What power *would be* delivered to a 75-Ω load, *if* this voltage *were* connected across it?" This hypothetical question is a standard way of characterizing signal level on a logarithmic scale.

Connect the output of the synthesized frequency generator to the multimeter in AC V mode. Set the signal generator to produce a 5-kHz sinewave. Set the signal amplitude to each of the following values, one after the other: 1 V, 5 V, and 10 V. For each of these amplitudes, measure the rms voltage with the multimeter and then have the multimeter display the signal level in dBm.

Lab Report

For the DC circuit, you can (and should) calculate the power delivered to the two-terminal network by two different methods. You can calculate $v \cdot i$, or you can add the powers dissipated in the resistors R_2, R_3, and R_4. Do you get approximately the same result with both calculations?

Are v and i that you measured for the DC circuit of Figure 2 approximately equal to the v and i that you measured for Figure 4?

Is the power delivered to the two-terminal network in Figure 2 approximately the same as the power delivered to the load in Figure 4?

Are V_{rms} and I_{rms} that you measured for the AC circuit of Figure 5 approximately equal to the V_{rms} and I_{rms} that you measured for Figure 6?

Is the power delivered to the two-terminal network in Figure 5 approximately equal to the power delivered to the load in Figure 6?

Is the ratio $V_{\mathrm{rms}}/I_{\mathrm{rms}}$ for the AC circuit of Figure 5 approximately equal to the equivalent load resistance R_L?