Thevenin Equivalence and Oscilloscopes

EK307 Lab

Learning objectives: Circuit simplification with Thevenin equivalent sources, maximum power transfer; how to use a function generator and oscilloscope.

Prelab:

1) Draw a schematic of a Thevenin source where the Thevenin voltage is the present hour of the day and the resistance is 100 multiplied by the current minute of the hour. (Don’t use zero, round up to 1!). For example 4:05 AM results in a $V_{Th}$ of 4 and $R_{Th}$ of 500. The circuit in figure 1 is a Thevenin source with a load resistor connected to its output.

2) Add a load resistor across your source. Assume the load resistor $R_{Load}$ across your equivalent circuit is equal to $R_{Th}$. Calculate the voltage across, current through, and power dissipated by the load resistor and Thevenin resistor. Next change the load resistance to a value that is double $R_{Th}$ and redo the calculations. Finally change the load resistance to a value 5 times smaller than $R_{Th}$ and calculate the power dissipation in each resistor. Draw a table that compares and communicates the results of all three scenarios. It can be hand drawn or electronic. What is the voltage across and resistance of the load in the scenario that maximizes power dissipated in the load?

3) What is the period of a 100 Hz square wave? The period is the time in seconds for a complete cycle of the waveform to occur before it repeats.

![Figure 1: A Thevenin source connected to a load resistor. The load resistor is inside the dashed box. $V_{out}$ is the voltage across the load resistor](image-url)
Introduction:

Many times a circuit is designed and constructed without prior knowledge of how it will interface other circuits. A common example is an audio amplifier connected to a loudspeaker. A user might have and amplifier and speaker from different manufactures. When they are connected together will the system work? Will the speaker overload the amplifier? Is the maximum power from the amplifier being delivered to the speaker?

To answer this question one can connect both the device schematics and analyze them as one. Often this is very complicated or not time efficient. Luckily many circuits can be simplified using Thevenin equivalent models. The parameters of the model (Thevenin voltage and resistance) can be determined by measuring the circuit with test equipment and the results can be applied to real world scenarios.

Introduction to the Function Generator:

The function generator (FG) is a signal source. It can produce sine, triangle, square waves, and a few others. The parameters such as frequency and amplitude are adjustable with the front panel controls. The waveform is outputted from a BNC connector on the front panel. A common use of a function generator is to test a circuit. One feeds the (FG) signal into the circuit to be measured. The signal type (sine, square, etc) is chosen depending on what one is trying to measure.

Introduction to the Oscilloscope:

To observe how the circuit is responding to the FG input an oscilloscope (scope) can be used. The scope is an instrument that displays voltage vs. time on its screen. Oscilloscopes are notoriously complicated instruments. Luckily there are only a few knobs and buttons you need to know to get started using them. The other controls are convenience features that you can learn later. The main reason you turn the knobs and push the buttons is to adjust the scale and position of the waveform being measured and displayed to make it readable on the screen. A similar situation happens when you are using a camera. You move the camera up, down, and side to side to place the object in the field of view. Then you adjust the zoom to the amount of detail you want to see. The difference is on a scope the scales of the horizontal and vertical axes are adjusted independently.
Lab exercise (complete both levels 1 and 2 for level 2 credit):

Level 1:

You will use the oscilloscope and a few resistors to determine the Thevenin equivalent resistance of the function generator.

a) Obtain a BNC to BNC cable, a BNC tee, and a BNC to clip cable from the bench. Obtain 10Ω, 50Ω, 470Ω, and 1kΩ resistors from the parts bench. Note that you probably can’t find an exact 50Ω resistor. Can you make one using series or parallel resistors?

b) Power up the function generator and oscilloscope.

c) Connect the output of the function generator to the tee. Connect one branch of the tee to the channel 1 or channel A on the scope. The BNC makes two wire connections simultaneously (figure 3).

d) Draw a diagram of the connections you just made in your lab notebook. Draw the FG as an AC voltage source symbol. How is the resistor connected to the source terminals? Use figure 3 as a hint. The oscilloscope can be drawn as a rectangle with a screen. Similar to a cartoon TV. See figure 4 for a sample scope cartoon.

![Figure 3: When you make a BNC connection you are connecting two conductors. The center pin is the signal wire. The outer metal shell is the ground wire. The cable has these two wires inside. On the BNC to clip cables the two wires are 'broken out' into the two clips. Red is always the signal wire. Black is always ground.]

![Figure 4: Oscilloscope cartoon. Note the signal (red) and ground (black) wires are broken out at the end of the cable]

e) Setup the function generator to produce a 1 Volt peak to peak (1 Vp-p) sine wave with a frequency of 100Hz. Peak to peak means minimum to maximum or peak to trough. See figure 5 for an example. To do this you will need to set the waveform to sine, adjust the frequency, and amplitude.

f) The expression “seeing is believing” is relevant when using these instruments. You want to verify the waveform is indeed a 1Vp-p 100Hz sine wave. To do this, observe the waveform on the oscilloscope. Follow the abbreviated scope setup procedure below…

g) Push the restore to default button on the scope. This will put it in a standard state.
h) Verify which scope channel you are plugged into. We usually connect to channel 1. Adjust the vertical scale by turning the vertical knob until your scale is 200mV/division. The scale setting is visible on the screen. A division is the distance between the approximately 1cm vertical distance between the horizontal grid lines on the screen.

![Oscilloscope Image]

**Figure 5: Oscilloscope with 1Vp-p 100Hz sine wave connected to channel 1. Adjust vertical and horizontal scales to see a few cycles of the waveform. Set trigger value to a voltage within the range of the wave.**

i) Adjust the horizontal scale. In the mode we are using the horizontal axis is time. The scale units are the same per division as the vertical scale. The horizontal scale is seconds/division. Set the scale to 5milliseconds/division. The setting will be visible on the screen. At this point your sine wave should be visible on the screen. If it is not verify the cables are connected and then ask for help.

j) If you have a 1Vp-p sine wave input to the scope you should see a sine waveform on the screen that has a range of 5 divisions. You set each division to represent 200mV. Multiplying the number of divisions by the volts/division will give you a voltage value. \(5 \times 200mV = 1000mV = 1V\). The period of a 100Hz sine wave is 10ms. If your horizontal scale is set to 5ms/division each sine wave cycle should have a period of 2 divisions. \(2 \times 5ms = 10ms\). Verify that you are measuring these values. If you are measuring a Vp-p double what you expect, there is most likely a configuration issue with the function generator. Ask a TA for help.

k) The scope has a trigger setting. Proper use of the trigger will make a periodic waveform appear to stand still on the screen. What is happening is the scope is redrawing the screen at the time the waveform voltage crosses the trigger voltage. If the waveform is periodic and not changing amplitude it will appear...
to stand still because of the synchrony between the waveform and the scope. Find the trigger knob. As you turn it back and forth watch the screen for a trigger symbol or voltage value that is changing as you turn the knob. Once you find the trigger voltage set it within the range of your signal voltage. If you have a 1Vp-p waveform on the screen the trigger can be anywhere between +0.3volts. If the waveform is not appearing stationary after this setting then find the trigger menu and make sure the trigger is set to normal and is triggering on the channel you are using. At this point your waveform should be similar to the figure 5 screen. If it isn’t try to adjust the settings and/or ask for help. The scope is complicated and usually takes a few sessions to get comfortable with.

l) Although you can use the scale to measure the voltage of your sine wave, the scopes in the lab are capable of measuring the peak to peak voltage directly and giving you a number. Each brand and model is different. There will be a measurement button. Push that and see what the options are. You want to make a peak to peak voltage measurement on the channel your input is connected to. I’m sure one can find the exact procedure to make a measurement on the Internet if you search for the model scope. The teaching staff is also available to help.

m) Once you get the scope figured out you will use it to explore Thevenin equivalence.

n) Make a table of the measured voltage at the oscilloscope as a function of load resistance. This is the same as the voltage at the function generator. Currently there is no load resistor connected therefore the load is infinite resistance.

o) Connect the 1kΩ resistor across the function generator output by adding a BNC to clip cable to the tee connector. Measure the voltage across this resistor. Calculate the current through the resistor.

p) Repeat this voltage measurement for the other resistors: (10Ω, 50Ω, 470Ω) add the results to your table.

q) Calculate the power dissipated in each of the different resistors. Plot the resistance vs. Power on a graph.

r) The resistor that has the maximum power dissipated across it is the closest value to the Thevenin resistance of the source. Which resistor is it? In this case you just measured the Thevenin resistance of the function generator.

------ END of LEVEL 1 ------

Level 2: (complete in addition to level 1)

Characterize the Thevenin equivalent of an unknown circuit: Obtain a four-terminal “Thévenin” box from the parts counter. Connect the box to the DC power supply on by your lab bench using the connections shown below. The 6-V external voltage source is to be considered an integral part of the mystery box.
** The behavior of your mystery box, as observed between terminals A and B, can be modeled by the “Thévenin Equivalent Circuit” shown below. If you were to build the simple network to the right with properly chosen values of $V_{Th}$ and $R_{Th}$, it would behave in all respects exactly like the circuit inside the mystery box. **

Devise an experiment to determine the values of $V_{Th}$ and $R_{Th}$ for your mystery box. (Hints: Apply at least two different resistive test loads between A and B and measure the resulting decrease in $V_{AB}$. Plot these results on a current vs. voltage graph. The negative reciprocal of the slope will be $R_{Th}$. Or use the open circuit voltage- short circuit current method.

------- END of LEVEL 2 ------
Appendix: Thévenin Equivalence

Leon Thévenin was a French telegraph engineer in the late 1800’s to whom the theorem is attributed. Thévenin’s theorem states that the behavior of a linear circuit as seen from any two nodes of the circuit (considered as “terminals”) can be represented by an equivalent circuit comprising a voltage source and a resistance, as shown in Figure 2. A resistive circuit is considered linear if it is made only from voltage sources, current sources, and resistors.

One parameter of a linear resistive circuit that is easily measured is its open circuit voltage, that is, the value of $v_X$ when $i_X = 0$. Another might be the short circuit current, that is, the current $i_X$ that flows when $v_X = 0$. These two quantities are, in fact, the axes intercepts in the plot shown below.

The behavior of a Thévenin circuit can be described by the equation: $v_X = V_{Th} - i_X R_{Th}$