

# EECE 2150 - Circuits and Signals: Biomedical Applications

## Lab 5

### Thevenin Equivalents of Lab Equipment

DiMarzio Section Only: **Prelab.** Read the lab instructions carefully.

(1) Draw a diagram in your notebook showing a voltage source with some internal series resistance,  $R_S$ , and an oscilloscope with input resistance,  $R_M$ , connected to each other through a resistor you add,  $R$ . Show how the voltages measured with different known values of  $R$  can be used to determine either  $R_S$  or  $R_M$ .

(2) What would happen if you put the voltmeter across the oscilloscope input while making these measurements?

### Introduction:

Equivalent circuits, most often Thevenin Equivalents, are used to make analysis of complex circuits tractable and understandable. The basic idea is to break a complex circuit, like the RF amplifier in a cell phone, into “subcircuits” which then can often be represented by a voltage source and a resistor, or more generally voltage source and a combination of a resistor and either a capacitor or an inductor (within a certain range of operating power, for example). From a system point of view we can say that the equivalent circuit has the same input/output relationship as the original circuit, and that is the sense in which it is “equivalent”. Note that when we say “input/output” that implies that we are defining what is considered input or output (so in a circuit, a pair of terminals), and “equivalence” always has to be understood in this context. Circuits are *equivalent only from the point of view that is at those terminals, outside* the part of the circuit for which an equivalent is substituted.

If we have this kind of subsystem relationship for each part of a complex circuit like a cell phone, we can analyze the relationships between the sub-circuits separately and then combine them to understand the overall behavior of the system. As pictured below in Figure 3-15 from a text by Ulaby that we used to use for this course, a cell phone is a complex system with many sub-circuits connected together. These sub-circuits are often designed by different people or different groups of people. The equivalent circuit model makes it possible to understand the behavior of the entire circuit as the parts are interconnected.

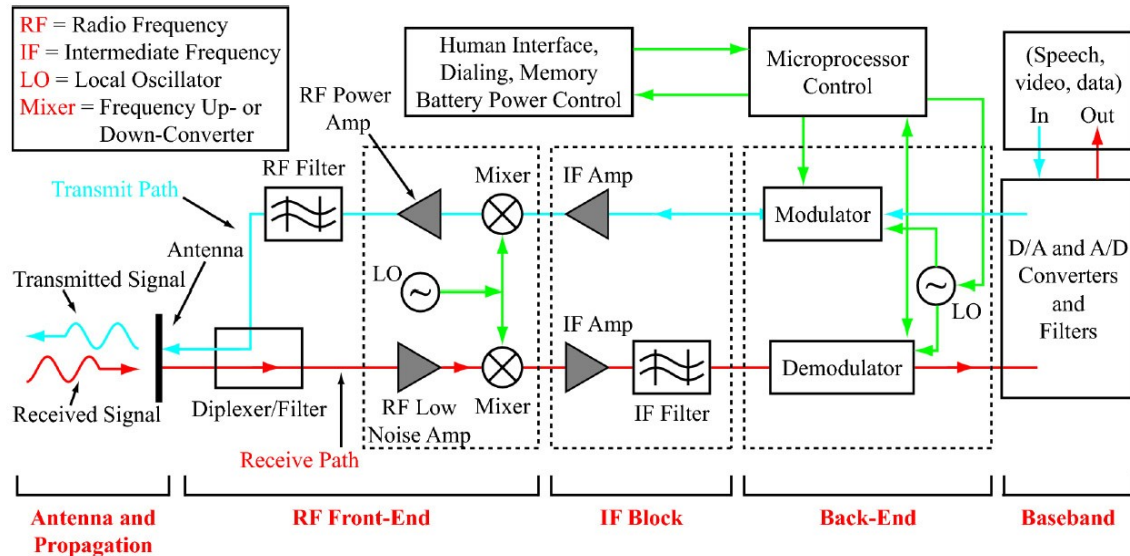


Figure 3-15: Cell-phone block diagram.

Figure 3-16 below (again from the Ulaby text) illustrates this idea. The input to the RF low-noise amplifier (in the RF front-end area above) receives a signal from the diplexer/filter. The diplexer/filter can be represented by an equivalent circuit (its Thevenin equivalent) consisting of a voltage source and an impedance. (The concept of impedance is just a generalization of resistance for circuits with capacitors and inductors.) The circuit being designed or analyzed is the RF low-noise amplifier. Finally the signal goes into the mixer, which is simply represented by an impedance (so in effect the “Thevenin voltage” for this last equivalent circuit is set to 0).

So to design the RF low-noise amplifier, we don’t have to know all the details of the diplexer/filter or the mixer, we just have to know the source voltage, the source impedance and the mixer input impedance and required voltage. Basically, we have reduced what we need to know about the rest of the circuit to what we can put on a spec sheet, and this makes it far easier to do our design and, in a realistic setting on a large project, interact with other design groups in a reliable and predictable way.

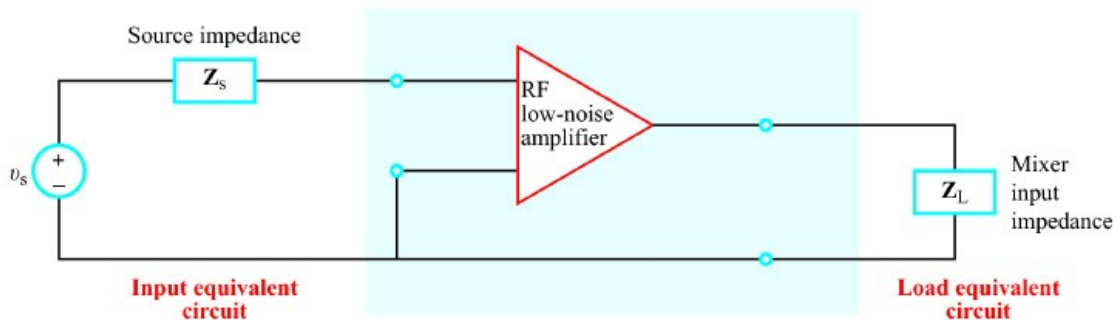
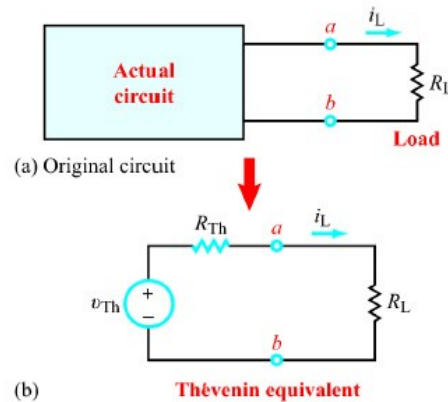


Figure 3-16: Input and output circuits as seen from the perspective of a Radio-Frequency amplifier circuit.

To summarize, the idea is to represent something like the diplexer/filter, which is a complicated circuit, as a voltage source and an impedance, as shown below in Figure 3-17 from Ulaby. Often, at the output of the circuit, the voltage source is zero and we can represent the following circuit simply by a resistor or resistor plus capacitor or inductor (the  $R_L$  below, or the  $Z_L$ , an impedance, above)



**Figure 3-17:** A circuit can be represented in terms of a Thévenin equivalent comprised of a voltage source  $v_{Th}$  in series with a resistance  $R_{Th}$ .

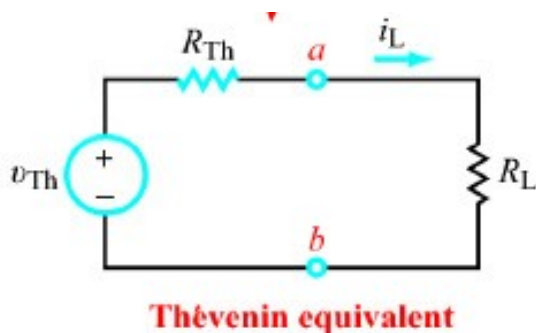
The very same idea can be applied to a topic central to this course, the design of an ECG amplifier. The actual electrical sources in the heart are often modeled as current sources, so we can conceptualize the heart sources in the body (itself treated as a passive conductor, in other words a kind of generalized resistance) as a current source in parallel with a resistor (what is known as a Norton equivalent). Doing so allows us to approximate, for instance, what range of voltage differences will be measured on the body surface, and thus how much gain (or amplification) our ECG amplifier will need to supply in order to make the range of the amplifier output signals big enough to convert to a computerized signal. At the same time, knowing the equivalent model for the amplifier (specifically, its impedance as seen from where it is attached to the body) allows us to determine if the amplifier will draw enough current to substantially change the ECG signal we want to measure. As with the cell phone amplifier, this process of 1) reducing complex systems to a sequence of interconnected subsystems, 2) modeling each subsystem with its own simplified (equivalent) model, and then 3) understanding the effects of each subsystem on the other systems it connects to, can be applied all along the way from heart itself to an ECG display on a computer (or phone) screen, and at different levels of detail in each stage of the process. (For example, as we will talk about later, we can use a similar approach to understand the relationship between the specifics of cardiac electrical activity and the voltage differences between locations on the body surface that result.)

## Part I

- Find the input resistance of the oscilloscope using your ohmmeter (make sure the oscilloscope is set for DC coupling!). What is the input resistance measured by the ohmmeter?
- Find the DC input resistance of the oscilloscope by using a DC power supply, a resistor, and voltage division. Use a resistor that is comparable to the resistance of the oscilloscope ( $300\text{ k}\Omega$ - $3\text{M}\Omega$ ). Note that the equivalent circuit for the oscilloscope is just a resistor! Hint: Use the oscilloscope to measure the voltage across itself. (For the best precision, press the cursor button in the measurements area of the front panel, select the y-direction cursors from the menu at the bottom of the screen, and then Y1 (or Y2) from the same menu, and then move the cursor to the middle of the line showing the voltage. The cursor reading is the voltage relative to ground, which is what you want.

## Part II

- Find the Thevenin equivalent of the signal generator at  $1\text{ kHz}/1\text{ V p-p}$  using the signal generator, an oscilloscope (to measure voltage – you can treat it as an ideal voltmeter here), and a  $100\ \Omega$  resistor. You can again use the Y-direction cursors, to measure the top and bottom of the sine wave. Measure the open circuit voltage, then the voltage with a  $100\ \Omega R_L$ , and then calculate the Thevenin resistance.  $V_{Th}$  and  $R_{Th}$  represent the internal circuitry of the signal generator and  $R_L$  is your  $100\ \Omega$  resistor. Remember that  $V_{oc}=V_{Th}$ .



- Connect a  $50\ \Omega$  load resistance ( $R_L$ ) to the output of the signal generator. Set the signal generator for a  $1\text{ V p-p}$  signal. What voltage do you observe on the oscilloscope? Now, continue observing the signal on the oscilloscope and disconnect the  $50\ \Omega$  resistor. What happens? **Q1:** Does this agree with your Thevenin equivalent circuit determined in a? (Think voltage division!)

### Part III

- a. Theory question: **Q2:** If you connect the oscilloscope to the signal generator, by what percentage will the open circuit output voltage change (again use voltage division)?
- b. Theory question: **Q3:** If we don't want connecting a voltmeter or oscilloscope to have an affect on the voltage being measured in a circuit more than one percent of the true value, what is the condition on the input resistance of the meter or oscilloscope relative to the Thevenin equivalent resistance of the circuit?

### Part IV – Instructions For the Lab Reflection

The lab reflection for this lab is due as per the instructions on Blackboard.

DiMarzio Section Only: There is no submission for this lab. Answer the questions in your notebook and be sure it is signed.

#### **IMPORTANT: BEFORE YOU LEAVE THE LAB:**

- (a) Turn off all of the equipment you have used on your workbench.**
- (b) Make sure you return your protoboard, the equipment wires and your reusable container to the front window.**
- (c) Make sure to have your notebook signed by an instructor before you leave the lab.**

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Last updated: 9/23/16, D. Brooks, 2/1/16, N. McGruer.