EECE 2150 - CIRCUITS AND SIGNALS: BIOMEDICAL APPLICATIONS

LAB 5, THEVENIN EQUIVALENTS OF LAB EQUIPMENT

Introduction:

Equivalent circuits, most often Thevenin Equivalents, are used to make analysis of complex circuits tractable and understandable. The basic idea is that a complex circuit, like the RF amplifier in a cell phone, can often be represented by a voltage source and a resistor, or more generally 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".

If we can do this 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 the Ulaby text, 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 various parts are interconnected.

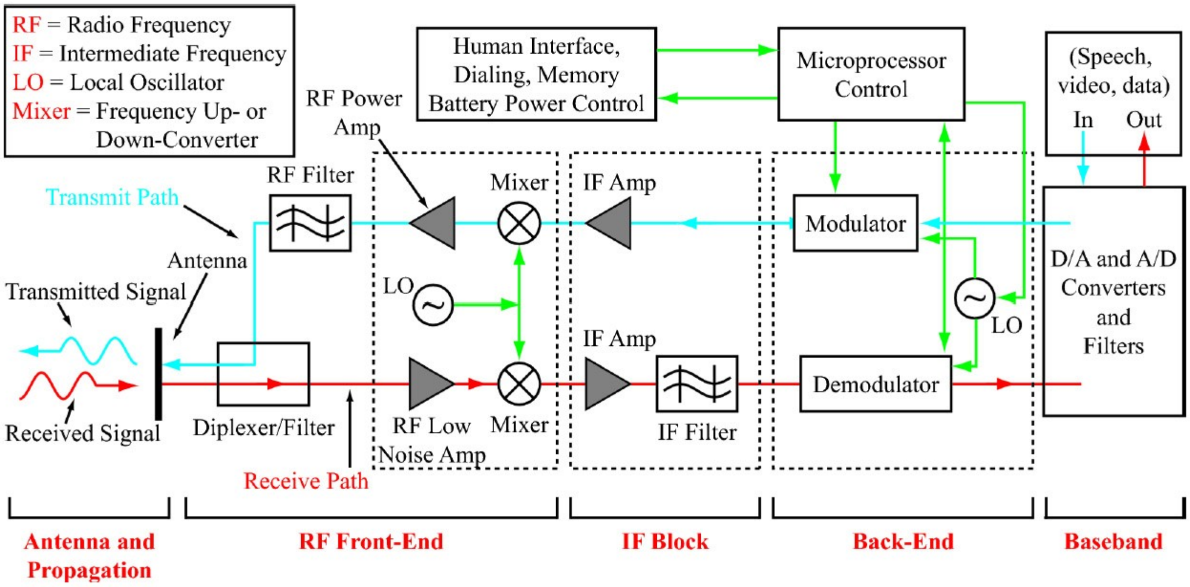


Figure 3-15: Cell-phone block diagram.

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. (Note that 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 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.

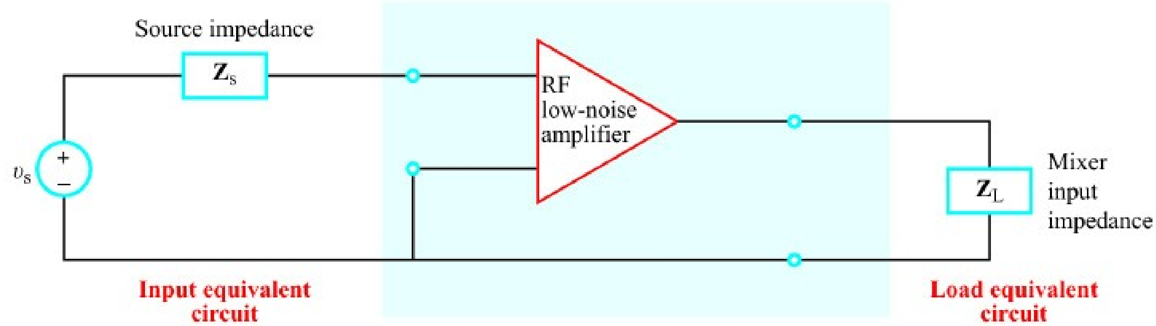
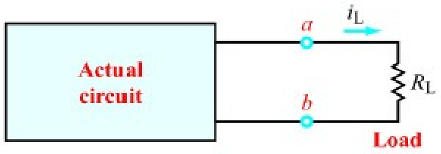
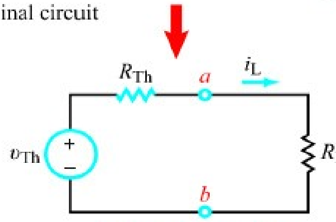


Figure 3-16: Input and output circuits as seen from the perspective of a Radio-Frequency amplifier circuit.



(a) Original circuit



(b)

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}.

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)

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 a heart source in the body can be treated as an ideal current source in parallel with a resistor (or a Norton equivalent). Doing so allows us to approximate, for instance, the level of voltage difference that 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 Norton model, along with the Thevenin 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 subsystems it connects to, can be applied all along the way from acquiring a signal from the heart to displaying the signal on a computer (or phone) screen, and at different levels of detail in each stage of the process.

PART I

a. 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?

b. Find the DC input resistance of the oscilloscope by using a DC power supply, a resistor, and voltage division, see Figure 4. Use a resistor that is comparable to the resistance of the oscilloscope $(300\,k\Omega - 3\,M\Omega)$. The equivalent circuit for the oscilloscope is just a resistor!
Hints: 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.

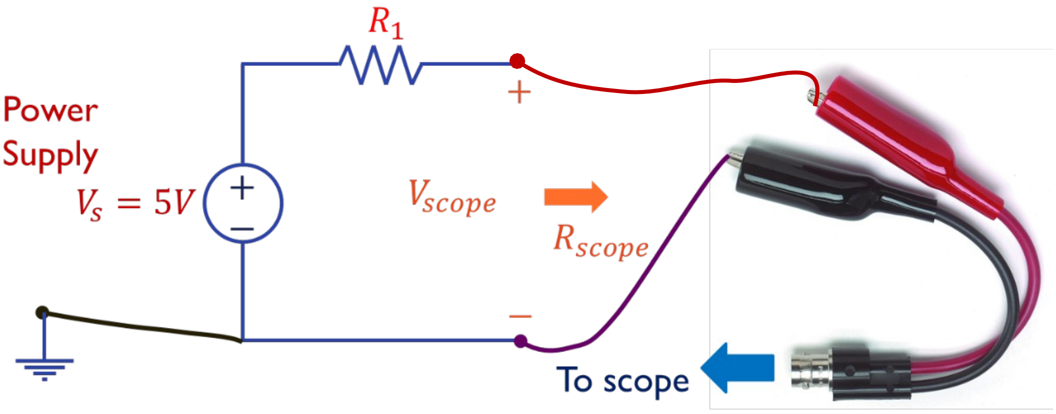


Figure 4, Setup for measuring the Thevenin's equivalent resistance of the oscilloscope

PART II

a. Find the Thevenin equivalent of the signal generator at $1\,kHz / 1\,V\,pp$ using the signal generator, an oscilloscope (to measure voltage – you can treat it as an ideal voltmeter here. Make sure the signal generator is set to High Z mode. To set it to the high Z mode, press the function key ‘Utility’, then press the soft key, ‘Output Setup’, then toggle the left soft key to change to High Z mode 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 Ω 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 $V_{oc}=V_{TH}$

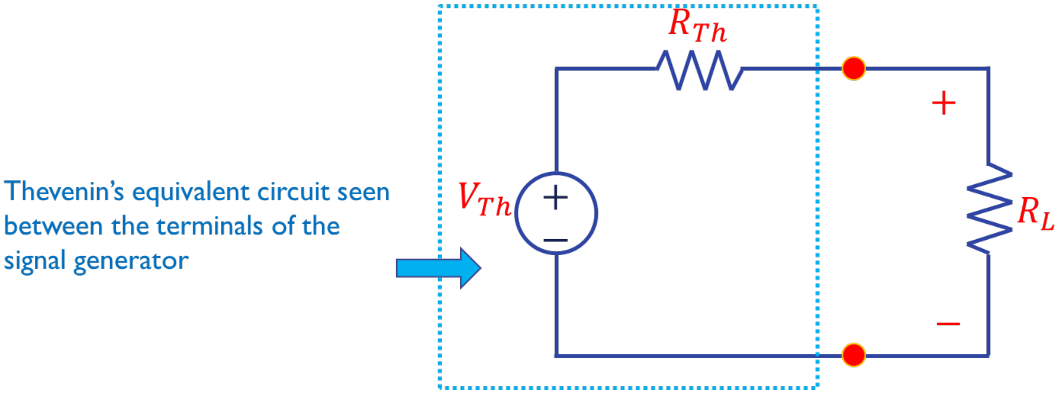

Thevenin’s equivalent circuit seen between the terminals of the signal generator

Figure 5, Measuring the Thevenin’s equivalent circuit of the signal generator

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

PART III

a. Theory question: 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: If we want a voltmeter or oscilloscope to not affect the voltage in a circuit under test more than one percent, what is the condition on the input resistance of the meter or oscilloscope relative to the Thevenin equivalent resistance of the circuit?

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