Lecture 06.01 Instrumentation for electricity measurement

At a high level, let's survey the measurement of electricity. We begin with electricity because nearly every modern measurement device has an electronic stage, so electronic measurement is fundamental for measuring most quantities. Although many modern measurement devices are digital—that is, sampled—we first consider analog measurement techniques, the principles of which still apply to digital measurement, and which are still in practical use in some cases.

The fundamental quantities to be measured are current, voltage, and resistance. Quick, one-off measurements of these quantities can be performed with a handheld *multimeter*, which can be either analog or digital. A multimeter has different modes for measuring a current, voltage, or resistance. To measure voltage or resistance between two nodes in a circuit, the multimeter's two probes are simultaneously contacted with them. To measure the current through a circuit element, the multimeter itself must be placed in the circuit such that current flows through it. In the former case, it is best for the multimeter to have *high* input resistance such that it draws as little as possible current through itself (and thereby affecting the measurement). In the latter case of current measurement, it is preferable for the multimeter to have *low* input resistance such that it drops the voltage across itself as little as possible (and thereby affecting the measurement).

multimeter

Figure 06.1: a Fluke multimeter from the SMU Robotics lab.

Precision, (typically) benchtop multimeters are available that can reduce the uncertainty in one-off measurements.

Specific aspects of an AC electronic signal can be measured with a multimeter; most commonly, just the root-mean-square (RMS) voltage or current can be measured. However, these measurements have significant limitations, including their effective frequency bandwidth, (typical) inability to indicate the signal frequency, and lack of information about the signal's

Figure 06.2: a Tektronix oscilloscope from the SMU Robotics lab.

noise. The multimeter's wheelhouse is the DC signal and the standard 60 Hz AC power transmission signal.

oscilloscope

Time-varying analog and digital voltage signals—including, DC, AC, and, to some extent, "other"—can be viewed effectively on an *oscilloscope* (or "scope"), a photo of which is shown in Figure 06.2 . These devices effectively show a trace of a signal across a time-window. If the window is properly "triggered," such that the window starts at the same point in a periodic signal, it will trace approximately the same path across the window. This gives the illusion of "zooming in" in time and viewing the signal across a viewing window of, say a couple milliseconds. Oscilloscopes are mostly practical for debugging and one-off measurements. But they are super fun.

digital data acquisition
analog-to-digital conversion
microcontrollers

For repeated, continuous, stored measurements of signals—DC, AC, and "other"—it is now standard practice to use a *digital data acquisition* device that includes *analog-to-digital conversion* (ADC). A plethora of *microcontrollers* (μCs) are now available for such measurements, ranging from inexpensive and inaccurate to accurate and expensive, as usual. Dedicated data acquisition boards can be very expensive (six figures), but highly flexible and accurate.

sensor

It is notable that most data acquisition boards have analog inputs configured to measure *voltage only*. Therefore, if one wishes to measure current or resistance, a separate *sensor* is required. The crudest current sensor is simply a resistor with a known resistance placed in series with the element through which one would like to measure the current. Measuring the voltage across it and hitting the result with your autOhmatic reveals the current.

This resistor-as-current-sensor has two distinct disadvantages: (1) like with the multimeter, one must "break" the circuit in order to flow current through the resistor/sensor and (2) the resistor's inclusion in the circuit will affect it by (assuming its not fighting a controlled current source) reducing the current flow and dropping the voltage. Much better current sensors exist, such as the *Hall effect sensor*. This is typically an integrated circuit (microchip) with a current pass-through that sees less than a mΩ of resistance! It outputs an analog voltage approximately linearly proportional to the current, ready for a data acquisition board analog input. Other current sensors exist that can be clamped around a wire to measure the current through it.

Hall effect sensor

There are several ways to measure resistance with a data acquisition board. Probably the easiest way is to put the unknown resistance in a voltage-divider with a known resistance and backing-out the unknown resistance value from the known input and output voltages and the known resistance. Another is to measure the voltage across and the current through (using, say, a Hall effect sensor) the unknown resistance, then letting the Ohm-g regulate. However, a much better way—with a *Wheatstone bridge circuit*—is described in detail in Lecture 06.02.

Wheatstone bridge circuit

There are also these special devices, typically benchtop and expensive, that are like the alter-ego of oscilloscopes: *spectrum analyzers*. These show "real-time" (quickly-updating) fast (discrete) Fourier transforms of signals on a screen. More band-limited spectrum analyzing functionality has relatively recently become available in higher-end oscilloscopes. I think it's reasonable to assume this label coinage will stick: *spectroscilloscopes*.[1] Ohmg.

spectrum analyzers

spectroscilloscopes

[1]I googled it 5 December 2017 and there were no results. Watch it grow.