IT 318 – SUPPLEMENTARY MATERIAL CHAPTER 2

Electronic Measuring Equipment

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Chapter 2: Electronic Measuring Equipment

Preview

Working with electricity and electrical circuits requires that we become familiar with test equipment which allows us to observe this otherwise invisible phenomenon. Measuring things always involves two very fundamental problems:

1. The very act of measuring something always changes what we are measuring. Sometimes the change is negligible, but sometimes it is not.
2. Measuring equipment is never perfect. Sometimes these imperfections in the measuring equipment are negligible, but sometimes they are not.

The primary types of measuring equipment in electronics are the DMM (digital multi-meter) and the oscilloscope (often just called a *scope*). The DMM consists of three primary tools (thus the term "multi"): a volt meter, a current meter (sometimes called an ammeter), and a resistance meter (usually called an Ohm meter). This gives us tools to measure the three basic parameters of electricity (voltage, current and resistance), plus the ability to see voltage change in time (with oscilloscopes).

2-1 Precision, Accuracy & Resolution

An ideal meter would always give exactly the same reading if measuring a value that never changes. Practical meters do not always give exactly the same reading, and the degree to which this reading varies is a function of the accuracy, precision, and resolution of the meter.

Precision is another word for repeatability. If a target shooter were to produce a 5-shot pattern as shown in Figure 2-1, we would say the shooter has very high repeatability, although they are not very close to the bullseye. Repeatability is calculated by finding the greatest deviation from the average of multiple measurements, then dividing by the average:

$$Precision = \frac{Max(abs(highest - average, lowest - average))}{average}$$

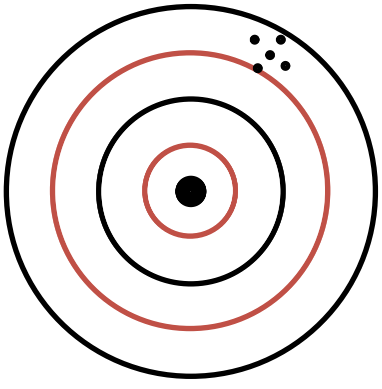

Figure 2-1: A target with five very repeatable shots, but which are not very close to the bullseye.

For example, let's say we took the following five measurements of the same 3.140 kΩ resistor:

1. 3.143 kΩ
2. 3.152 kΩ
3. 3.136 kΩ
4. 3.141 kΩ
5. 3.149 kΩ

We would calculate the repeatability of our meter as:

Precision = max(abs(3.152 kΩ – 3.1442 kΩ, 3.136 kΩ – 3.1442 kΩ) / 3.1442 kΩ
= max(abs(7.8 Ω, -8.2 Ω) / 3.1442 kΩ
= max(7.8 Ω, 8.2 Ω) / 3.1442 kΩ = 8.2 Ω / 3.1442 kΩ = **0.2608%**

Accuracy is defined as how close a given measurement is to the known or actual value. If a target shooter were to produce a 5-shot pattern as shown in Figure 2-2, we would say that the shooter, on average, is very accurate, but not very precise. Accuracy is calculated by finding the greatest deviation from the known or actual value, then dividing by the actual value:

$$Accuracy = \frac{\max(\text{abs}(highest - actual, lowest - actual))}{actual}$$

So given the same set of five measurements used previously, we would calculate the accuracy as:

Accuracy = max(abs(3.152 kΩ – 3.140 kΩ, 3.136 kΩ – 3.140 kΩ)) / 3.140 kΩ

= max(abs(12, -4)) / 3.140 kΩ

= max(12, 4) / 3.140 kΩ = 12 / 3.140 kΩ = **0.3822%**

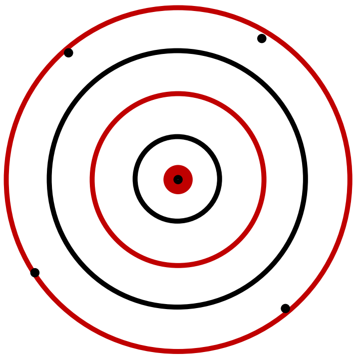

Figure 2-2: A target with five shots which are, on average, very accurate but not very repeatable.

An ideal meter would always give the same reading for the same measurement, so the precision and accuracy of an ideal meter would be 0%. This seems strange, until we realize that the numbers calculated for precision and accuracy are actually how far they are from ideal – the lower the better – and 0 means they're right on. Thus, numbers given for precision and accuracy are actually specifying their imprecision and inaccuracy.

The resolution of a meter specifies the smallest part it can resolve, and is specified in %, ppm, ppb, or # of digits. The most common DMM on the market today gives readings from 0000 up to 1999, or 2000 different readings. This is generally specified to be a 3½-digit DMM, because the first digit can only be a 0 or 1, while the other three digits can range from 0-9. This same meter could be specified as having a resolution of 1 part out of 2000, which is:

1 / 2000 = 0.05% = 500 ppm

One of the highest-resolution DMMs on the market today is specified as having 7½ digits, which means it gives readings from 00000000 to 19999999, or 20,000,000 different readings. This same meter could be specified as having a resolution of 1 part out of 20,000,000, which is:

1 / 20,000,000 = 0.05 ppm = 50 ppb

2-2 Measuring Voltage

To measure a voltage, the meter must have the same voltage across it as the voltage being measured. Recalling section 1-5 on parallel circuits, we remember that all elements in a parallel circuit always have the same voltage drop. Thus, to measure a voltage, we must put the meter in parallel with the voltage to be measured, as shown in Figure 2-3.

One other thing we learned in section 1-5 is that as soon as we add ANY resistance in parallel with another resistance, the total resistance is decreased. For example, if we place a 500 kΩ resistor in parallel with another 500 kΩ resistor, the total resistance is only 250 kΩ resistance. Notice the voltmeter in Figure 2-3; it includes a resistance (more commonly referred to as its *input impedance*), which is a representation of what a real (as opposed to ideal) voltmeter consists of. Once this meter is added in parallel to the 50 Ω resistor of Figure 2-3, it will change (reduce) the resistance across which the voltage is being measured. This reduction will actually change the voltage being measured. In the Preview section above, we pointed out that sometimes effects like this are negligible, and sometimes they are not. Let's look at an example of each situation.

Most voltmeters have an input impedance (Z_i) of 10 MΩ. If we put one of these meters in parallel with the 50 Ω resistor of Figure 2-3, we get an effective resistance of:

Z_{eff} = 50 Ω || 10 MΩ = 49.9998 Ω

which is a change of only -5 ppm. Such a change is truly negligible in most cases.

But suppose R_2 of Figure 2-3 instead had a value of 10 MΩ. In this case, when we put our voltmeter in parallel with this resistance, we get an effective resistance of:

Z_{eff} = 10M Ω || 10 MΩ = 5.00 MΩ

which is a change of -50%! Such a change is not at all negligible, and will result in a very significant voltage measurement error.

Therefore, our rule of thumb in using voltmeters is that if we are measuring the voltage across a resistance of 1 MΩ or greater, we will need to take into account the *meter loading effect* – the measurement error due to the non-ideal 10 MΩ input impedance of our meter.

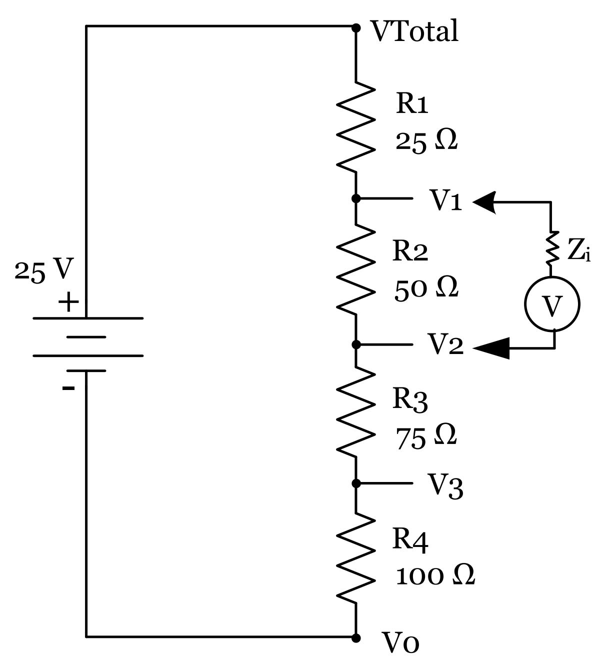

Figure 2-3: A voltmeter must be placed in <u>parallel</u> with the voltage being measured.

What would it take for a voltmeter to have no meter loading effect? For this to happen, the input impedance of our voltmeter would need to be *infinite*. Such meters do not exist, so we have to be content to use the practical meters available in the market today, most of which have an input impedance of 10 MΩ.

2-3 Measuring Current

To measure a current, the meter <u>must</u> have the same current through it as the current being measured. Recalling section 1-4 on series circuits, we remember that all elements in a <u>series</u> circuit always have the same current. Thus, to measure a current, we must put the meter in <u>series</u> with the current to be measured, as shown in Figure 2-4.

As in the previous section, we see that the internal impedance of our ammeter has the potential to disturb the measurement. Let's consider the case of a negligible disturbance, followed by the case of a non-negligible disturbance.

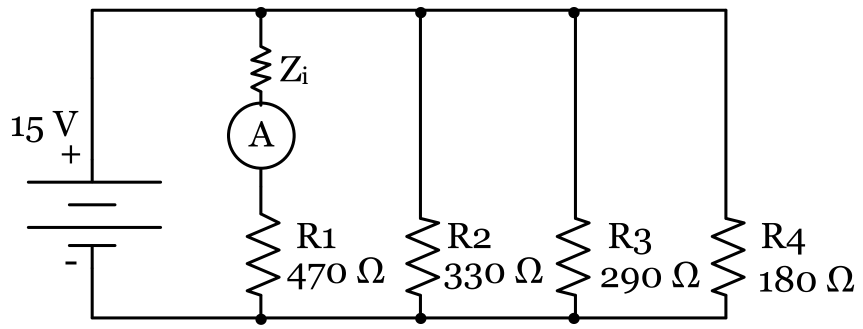

Figure 2-4: An ammeter (current meter) must be placed in <u>series</u> with the current being measured.

Most ammeters are pretty close to ideal, with an input impedance of about 10 mΩ. In Figure 2-4, this would change the combined resistance by 10 mΩ out of 470 Ω, a difference of only 21.28 ppm.

But suppose R_1 had a value of 10 mΩ? In this case, putting the ammeter in series with this resistance would change our combined resistance by 100%! Such a change is not at all negligible.

What would it take for an ammeter to have no meter loading effect when measuring current? For this to happen, the input impedance of the ammeter would need to be 0 Ω. Such meters do not exist, but an input impedance of only 10 mΩ is low enough that it is generally negligible.

At this point, we should mention that resistors in most circuits typically range from about 10 Ω up to 30 MΩ. Thus, we can see that most circuits will not be significantly affected by a current measurement, but it is very possible that they may be significantly affected by a voltage measurement.

2-4 Measuring Resistance

DMMs measure resistance by applying a known voltage to the unknown resistance, then displaying the resulting current as Ohms, according to Ohm's Law (R = E/I). This means that the resistor being measured must NOT have any other voltage applied to it (a fault condition shown in Figure 2-5), and that it must NOT be connected to other resistances or components (a fault condition shown in Figure 2-6).

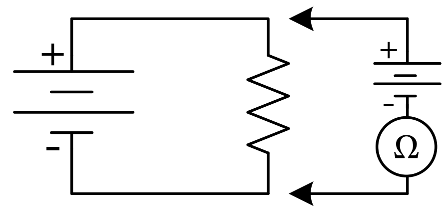

Figure 2-5: The fault condition (mistake) of measuring a resistor with a voltage applied to it.

In the first fault condition (Figure 2-5), it will result in an erroneous reading, and can also damage the DMM. In the second fault condition (Figure 2-6), it will simply result in an erroneous reading.

Most common DMMs can measure resistances ranging from 10 mΩ to 20 MΩ. Specialized DMMs can extend this range much further.

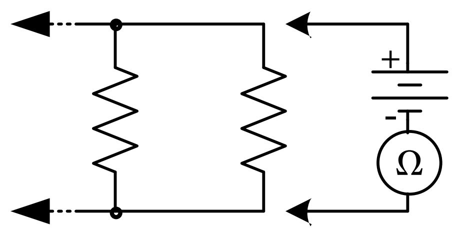

Figure 2-6: The fault condition (mistake) of measuring a resistor which is connected to other resistor(s).

2-5 Oscilloscopes

An oscilloscope has one primary function, and that is to display voltages which change in time. By seeing how a time-varying voltage looks, we can learn a great deal about the circuit that produces the voltage.

The primary sections of an oscilloscope are the display, the vertical amplifier, the horizontal time base, and the triggering. We will cover each of these in that order. Figure 2-7 shows a shot of one of the oscilloscopes used in the IT program, each of which is actually a computer-based program combined with a set of probes.

The vertical amplifier section is used to set the vertical amplitude of the signal being displayed. The measurements are in Volts or milliVolts.

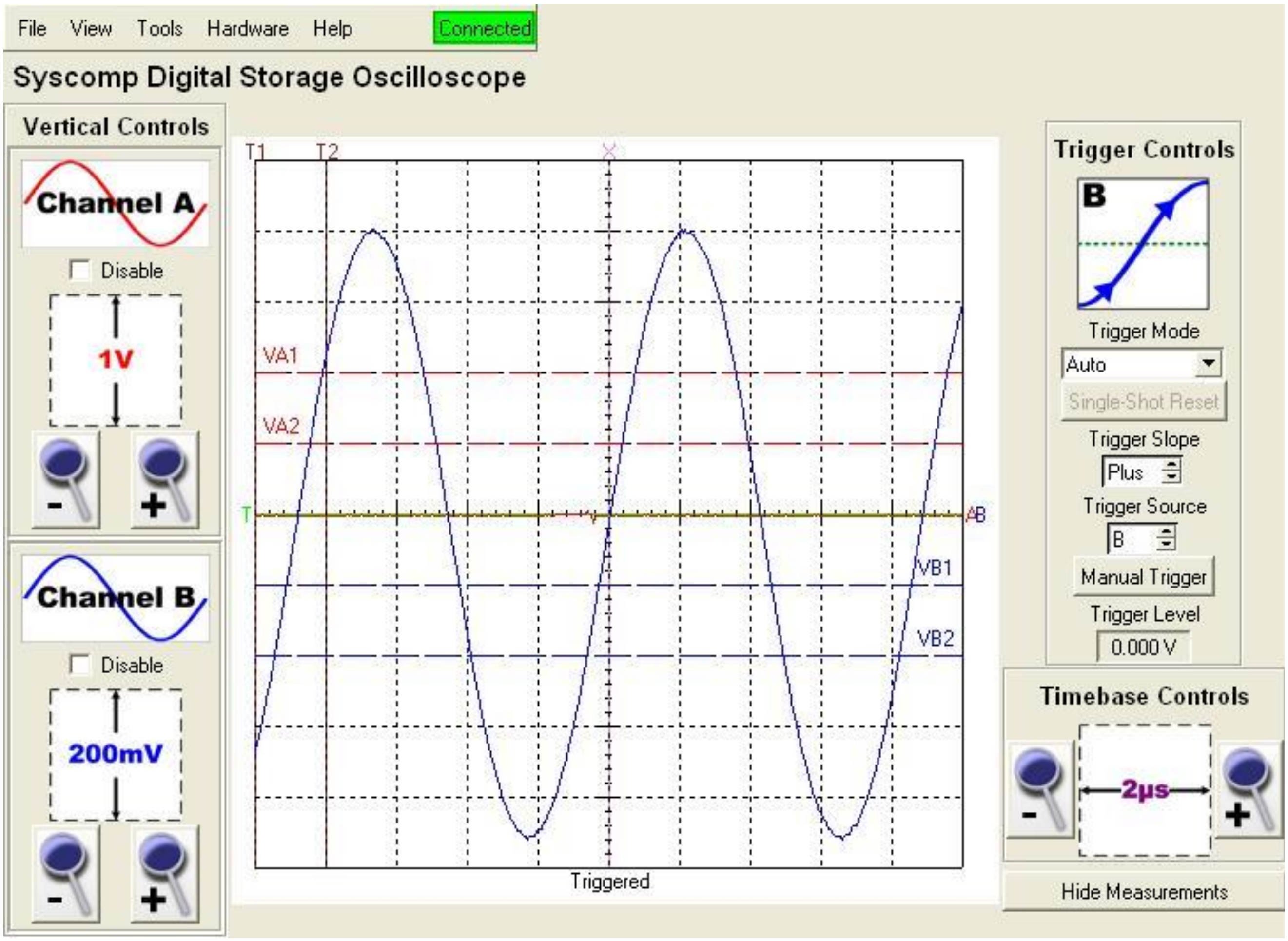

Figure 2-7: The oscilloscope used in the IT program, consisting of the Vertical Controls (vertical amplifier section), the screen, the Trigger Controls (trigger section), and the Timebase Controls (horizontal timebase).

The horizontal time base controls the horizontal axis, whose units are time (usually ms, μs, or ns). If the user wishes to see more or fewer cycles on the screen, this is the section that should be adjusted.

The trigger section is usually the most difficult to understand, but it is one of the most important. This section is what allows a stable signal to be displayed on the screen. If the signal on the screen is constantly changing, it is almost always because something in this section needs to be adjusted. If you are looking at only one signal, and you're looking at it on Channel B, make sure the Trigger Controls show B as the Trigger Source (as shown in Figure 2-7). Conversely, if you are looking at only one signal, and you're looking at it on Channel A, make sure the Trigger Controls show A as the Trigger Source. The Trigger Slope should generally be Plus, but Minus (or Negative) generally works also. The Trigger Mode should generally be Auto. The Trigger Level does not generally need to be adjusted.

Since an oscilloscope measures voltage, it is important to remember that it must be connected in parallel with the voltage being measured. The input impedance of most oscilloscopes is the same as that of most DMMs: 10 MΩ.

2-6 Summary

1. The most common measurement devices in electronics are the DMM, which measures voltage, current and resistance, and the oscilloscope, which measures and displays a time-varying voltage.
2. No DMM or oscilloscope is ideal, and it is important to know the limitations of your DMM and oscilloscope.
3. DMMs and oscilloscopes are commonly specified in terms of their precision, accuracy, and resolution.
4. A voltmeter must be connected in parallel with the voltage being measured. Its input impedance is usually 10 MΩ.
5. An ammeter must be connected in series with the current being measured. Its input impedance is usually 10 mΩ.
6. An ohmmeter must not be used to measure the resistance of a resistor which is connected to a voltage or to another resistor.
7. Oscilloscopes are very useful for looking at time-varying (AC) voltages. Their input impedance is usually 10 MΩ.

Problems

1. Describe both quantitatively and qualitatively the effects of using a voltmeter to measure the voltage across a 35 kΩ resistor if the voltmeter has an input impedance of 20 kΩ. Assume the 35 kΩ resistor is in series with another 35 kΩ resistor. (5 points)

2. Describe the difference between accuracy and precision in measurements. (5 points)

3. A certain Ohmmeter gave the following measurements of a known 3,175.000 Ω resistor. Give the accuracy, precision, and resolution of the Ohmmeter. (15 points)

Measurement 1 = 3.170 kΩ
Measurement 2 = 3.180 kΩ
Measurement 3 = 3.175 kΩ
Measurement 4 = 3.172 kΩ
Measurement 5 = 3.179 kΩ

4. Describe in your own words the function of each of the four sections of an oscilloscope. (20 points)

Answers to Chapter 2 Numerical Problems

1. Quantitatively: If the applied voltage is 10 Volts, you should measure 5.0 Volts across each resistor, but you actually would measure 2.667 Volts.
3. Accuracy = 0.1575%
   Precision = 0.1638 %
   Resolution = 4½ digits, or 0.005%, or 50 ppm