Contents

I. Lab 1: Basic Measurements and Oscilloscope Use

A. Introduction

In this lab you will learn how to take basic AC and DC measurement using a digital multimeter (DMM) and an oscilloscope, and also learn how to use a function generator and a DC power supply. You will also build a basic voltage divider, observe the rise time of a square wave, and measure the RMS voltage of various waveforms

1. Protoboards

In this class you will use a Global Industries PB-503 or PB-505A protoboard. They are very similar to each other. The PB-505A is shown in Figure I-1. The white panels in the center of the device are *breadboards.* To use a breadboard, you insert either the leads of your components or connecting wires into the holes. Often, you'll use premade wires referred to as *jumper wires.* If you use your own wires, it is best to use solid copper 22 gauge wire. Finer gauges might not make a reliable connection, and thicker gauges can damage the sockets. Besides the connections you add with wires, some of the breadboard sockets are also internally connected together.

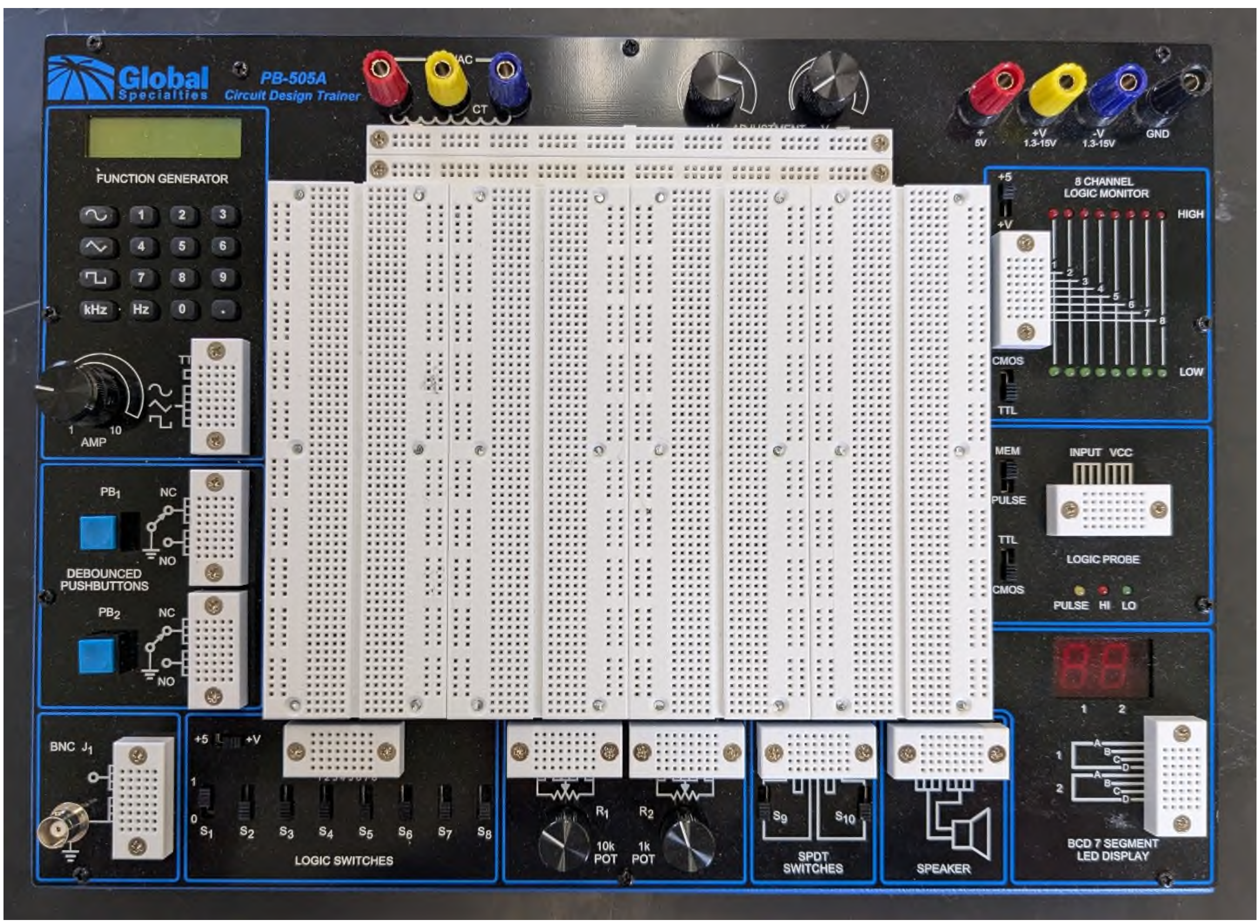

Figure I-1. PB-505A protoboard

As can be seen in Figure I-1, the protoboards also include a number of useful instruments and accessories such as a function generator, power supplies, switches, and indicator lights.

2. Digital multimeter

Figure I-2. BK precision model 388B multimeter.

In this class you'll also use a digital multimeter (DMM). For this lab we have BK Precision model 388B multimeters, as shown in Figure I-2. To measure the voltage across two points, you connect one probe to the COM input and the other probe to the VΩ input and select one of the voltage (V) ranges. You take your measurement *across* the two points whose voltage difference you want to measure, as shown in Figure I-3. You can switch between measuring DC volts and AC volts with the DC/AC switch. When the meter is set up this way, its impedance is very high and it draws very little current. That is so that the load of the meter doesn't affect the voltage being measured.

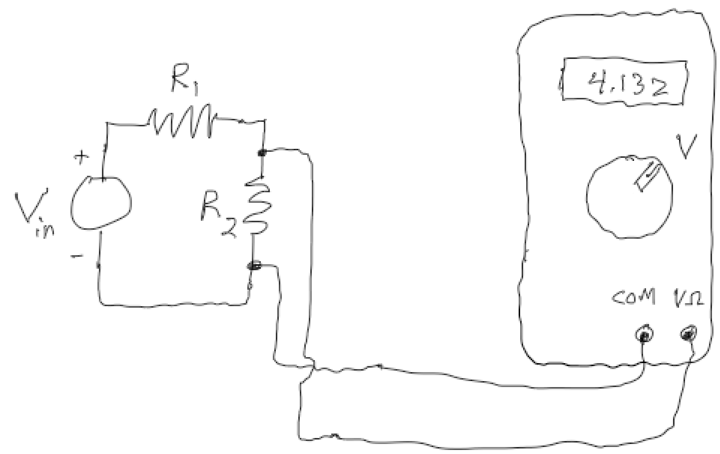

Figure I-3. Arrangement for measuring the voltage across R_2 in a circuit.

To measure resistance with this meter, you also connect your probes to the COM and VΩ inputs, and select one of the resistance (Ω) ranges.

To measure current with this meter, you connect one probe to the COM input and the other probe to either the 20 A input or the μAmA input. You measure current *through* a component. To do this, you have to break into the circuit and put your meter in series with the component, as shown in Figure I-4. Again, you can select measurements of DC or AC current with the AC/DC switch. If you connect to the 20 A input, the meter can measure up to 10 A (for continuous currents). If you connect to the μAmA input, the meter can measure up to 2 A currents. The μAmA input will display currents with higher resolution, but you will burn out the fuse in the meter if you put much more than 2 A into it. When the meter is set-up this way, its impedance is very low. That is so that its impedance does not affect the current you are trying to measure.

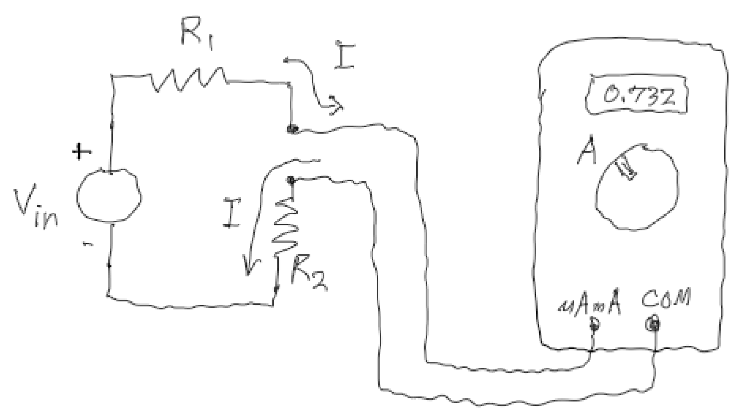

Figure I-4. Arrangement for measuring the current through R_2 in a circuit.

This model of multimeter can also test diodes, test for continuity, and measure capacitance, frequency, logic voltage levels, and transistor gain. For instructions on how to use these functions, refer to the multimeter manual, which you can easily find online.

3. Function generator

In this class, you'll make use of the BK Precision 4010A *function generator.* A function generator is a device that can ouput a periodic voltage waveform of adjustable amplitude and frequency. Our function generators can output a sine wave, a square wave, or a triangle wave using the switches on the upper right. The coarse adjustment of the frequency is made with the row of pushbuttons below "RANGE". The fine adjustment is made with the dial. The output amplitude can be adjusted with the knob on the lower right. The DC offset of the waveform (an added DC potential) can be adjusted with the knob next to that. The waveform is output from the BNC connector labelled "OUTPUT." The connector labelled "TTL/CMOS" outputs a square wave that is synchronized with the waveform at the output. It is normally used for triggering an oscilloscope as discussed below. The amplitude depends on whether the CMOS level switch is engaged. If it is not, the amplitude is in the range of a logical 1 for TTL logic. If it is engaged, then the output amplitude can be adjusted with the CMOS level knob.

Figure I-5. BK Precision 4010A function generator.

4. Oscilloscope.

In this class you'll use the Tektronix TBS1052C oscilloscope shown in Figure I-6.

An oscilloscope is used to create a display of voltage *vs*. time. Our oscilloscopes have two channels, channel 1 and channel 2. Either or both channels can be displayed. They also have an "auxiliary" input. The timing of the scope display is adjusted by "triggering" the oscilloscope. This means that the signal is displayed such that the time at which the signal crosses a triggering voltage level occurs at a specific point on the display. The scope can be triggered from channel 1, channel 2, or the aux or trigger input.

The operating procedure for the oscilloscope is too involved to summarize further here. We do go over some of the basics of operation in the procedure below. If you need additional help in operating the oscilloscope, please refer to the manual (readily available online) or ask your instructor or TA for help.

Figure I-6. Tektronix TBS1052C oscilloscope.

B. Procedure

For your report, please be sure to include a copy of the diagrams of the circuits you make, the results of all measurements you take on those circuits, and copies of any calculations or derivations that you do.

1. Wiring inside the breadboard

Using a few wires and the multimeter, determine the overall layout of the connections within the breadboard. You can plug the wires into the holes and use the multimeter on the buzzer setting. It looks like this:  Whenever there is a connection between the leads of the multimeter in this setting, it buzzes. For your report: make a diagram of the connections inside the breadboard.

2. Output impedance

a) <u>Open circuit voltage.</u>

On your breadboard, construct the open circuit shown in Figure I-7. Figure I-7(a) and (b) are just two ways of representing the same circuit. The “gap” down in both diagrams represents the absence of a wire or any other circuit element. The circuit is *open* in the sense that it is not completed and no current flows through it. Set V_{in} to be +5 V using the red (+) terminal of either the power supply on your protoboard, or one of the bench power supplies in the lab. The black $(-)$ terminal with serve as the circuit GND. Measure the open circuit output voltage by measuring the voltage difference between V_{out} and GND. (Make sure your multimeter is not is

AC mode.) Keep in mind that your voltage meter has a very large impedance in voltage mode, so touching its leads to V_{out} and GND will not affect the "openness" of the circuit.

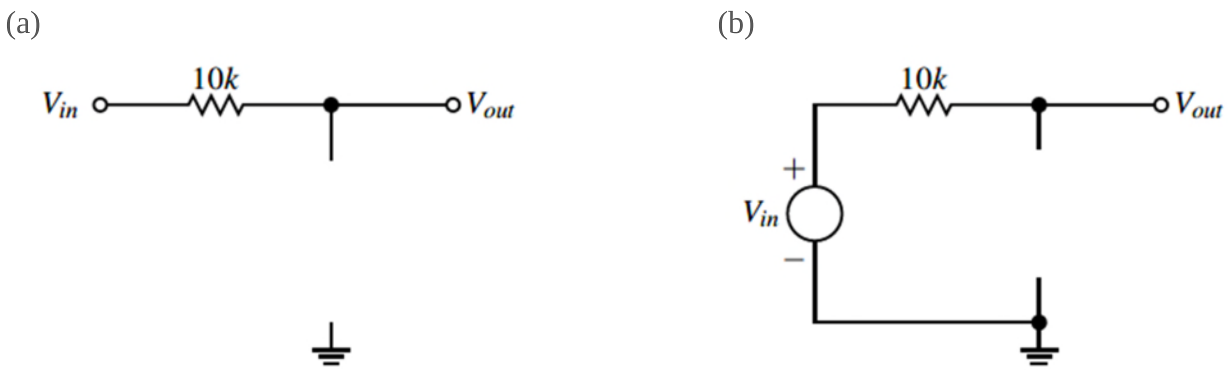

Figure I-7. (a) Open circuit. (b) Another way of drawing the same open circuit.

b) Closed circuit current.

Construct the "closed" circuit shown in Figure I-8. (We again show two different ways to draw this circuit. From now on, we may draw circuits using either of these conventions.) Measure the short circuit output current by measuring the current flowing through the wire connected between V_{out} and GND. Keep in mind that an ammeter has a very tiny impedance, so it "takes the place" of a wire between V_{out} and GND. It will not affect the "shortness" of the circuit.

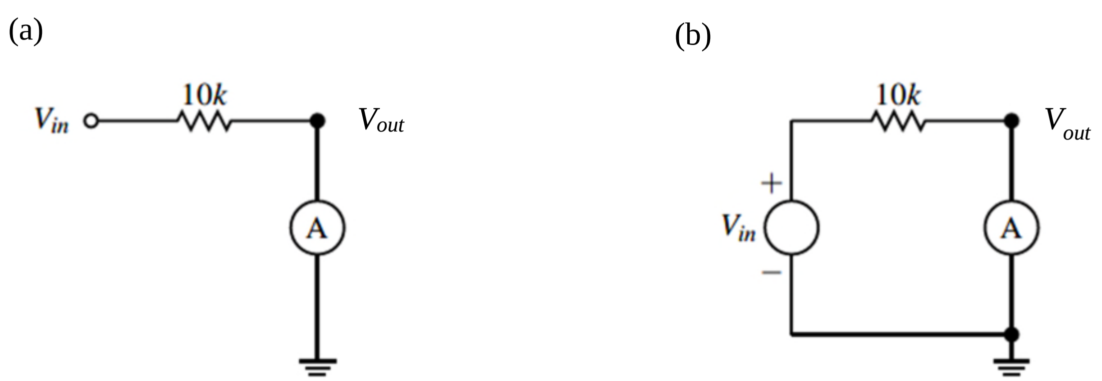

Figure I-8. (a) A closed circuit. (b) Another way of showing the same circuit.

c) Output impedance.

The output impedance of a circuit is defined as the ratio of the open circuit output voltage to the short circuit output current. Using your measurements from parts (a) and (b), determine the output impedance of this circuit. Does this value make sense when you look back at your circuit?

3. Voltage divider

a) Voltage divider circuit.

Construct the voltage divider circuit shown in Figure I-9, again using $V_{in} = 5$ V. Measure V_{out}. Calculate what V_{out} should be using the voltage divider formula. How close are your calculated and measured values for V_{out}?

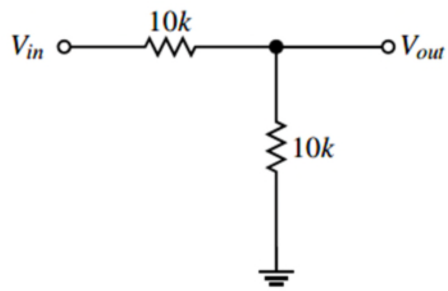

Figure I-9. Voltage divider, both resistors equal.

b) General case voltage divider.

Derive the expression for V_{out} for the general case voltage divider shown in Figure I-10. Consider two limiting cases: $R_2 >> R_1$ and $R_2 << R_1$. In each case, what does V_{out} become?

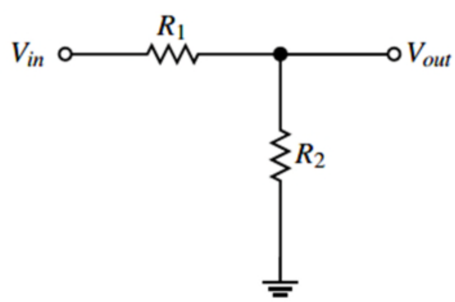

Figure I-10. Voltage divider, general case.

4. Measuring voltage waveforms with an oscilloscope

a) Measuring the waveform from a function generator.

Turn your oscilloscope on and press “Default Setup.” This will set the oscilloscope to a known condition to start from. There is one default setting that we don’t want. To see this, press the “1” button. You will see that “Probe set-up” says 10x. What this means is that the oscilloscope is set to use a scope probe that attenuates the voltage by a factor of 10. In the 10x setting the scope multiplies the channel 1 voltage by 10 to make up for the 10x attenuation. But we’re not using a scope probe so we don’t want that. To correct this setting, click on the button right beside “Probe set-up.” Rotate the Multipurpose knob to highlight “Attenuation.” Click on the multipurpose knob and rotate it until the attenuation reads 1x. Then click on the multipurpose knob again, and finally click on “Menu on/off.” This sets the attenuation to 1x, which is what we want.

Next, plug in your function generator and turn it on. Connect the output of the function generator to channel 1 of the oscilloscope with a BNC cable. The signal is sent through the inner wire of the BNC cable, and the outer cylinder is GND. Set the output waveform from the function generator to be a 1kHz sine wave (Range 2k, knob set to 1.0). Look for the sine wave on your oscilloscope. You will need to adjust the horizontal scale and the vertical scale to see it clearly.

Measure the frequency and peak-to-peak voltage of your sine wave using the oscilloscope. The peak-to-peak voltage is the difference between the highest and lowest voltage reached by the sine wave, and is equal to twice its amplitude. The simplest way to measure the frequency and peak-to-peak voltage of your signal is to click on “Measure.” Then the measurement menu will pop up, and you should see “Ch1” and “frequency” highlighted in blue. If you click on the multipurpose knob while on this screen, it will begin a measurement of the highlighted quantity. So, click the multipurpose knob and then click “Menu on/off.” You should see a new entry on your screen, which is the measured frequency of the waveform input to channel 1. Check that this frequency corresponds approximately to the frequency setting on the function generator. Next, click “Measure” again. Rotate the multipurpose knob until “Peak-to-Peak” is highlighted. Then click the multipurpose knob and the Menu on/off button again. You will see that a new measurement window has opened up to tell you what the peak-to-peak amplitude is.

Go ahead and use your oscilloscope to more precisely set the output frequency to 1 kHz and the peak-to-peak voltage to 2 Volts.

Next, connect a BNC tee to input 1 of your oscilloscope. Connect the function generator to one side of the tee and a 50Ω terminator to the other. The terminator is a resistor that connects the inner wire to the outer. For your report: reproduce your observed waveforms with and without the terminator. The best way to include the waveforms is to download them from the oscilloscope to a USB drive and then onto your computer. But since we only have a few USB drives available, for this week it is acceptable to either take a cell phone photo of the display or to make a careful sketch of the display. Make a circuit diagram for the function generator, scope and terminator. Explain the difference between your two observed waveforms. Should you think of the scope as a volt meter or an ammeter?

b) <u>Scope triggering.</u>

Use the same setup as in the measurements above but without the terminator. On the scope, press “1” to bring up the vertical menu, and the press the button next to “more.” Make sure “Coupling” is set to DC. Next press “Menu” under “Trigger.” Click on the button next to “More”. Make sure that “Mode” is set to “Auto.”

Twist the trigger level knob on the scope and observe the display of the waveform. (Leave the scope triggering set to “auto”.) Take note of what happens when you move the trigger level outside the range of the displayed signal. Also, push in the DC offset button on the function generator, and twist the offset knob to move the signal completely above and completely below the trigger level. Take note of what happens in this case too. For your report: sketch a few waveforms to show how the trigger level affects the display of the waveform. Explain what happens when the trigger level is outside the range of the displayed signal.

Next, use another BNC to connect the TTL output of the function generator (which is just to the left of the main output) to Channel 2 of the scope. Hit Trigger Menu, and adjust the "Source" to CH 2. The scope should now be triggering on the TTL output. Now adjust the trigger level and take note of the displayed sine wave. Also take note of what happens when the trigger level is above or below the displayed sine wave, either by moving the trigger level or adjusting the DC offset. For your report: sketch what you observe now when you adjust the trigger level up and down. Include what happens when the trigger level is outside the range of the displayed sine wave. Is there an advantage to triggering on the TTL output?

c) Square wave.

Now go back to using only the main output of the function generator, Trigger on it, and switch it to a square wave. Adjust the DC offset knob on the function generator. Switch back and forth between AC and DC mode of the scope (reminder: you can do this by going to Vertical Menu, Coupling). Note where GND is on the scope by adjusting the vertical position. FYR: sketch what you observe when you adjust the DC offset in each mode. What is the difference between the two?

d) Function generator output impedance.

The function generator has its own internal output impedance just like that in part 2. Using a load resistor across the output of the function generator, make a voltage divider as shown in Figure I-11. Using a given amplitude V, use the scope to measure V_{out} for 10 different values of R_{Load}. Include one or two resistors with resistance of 50 to 100 Ohms in your values. It may help to order your resistors in increasing resistance before taking measurements.

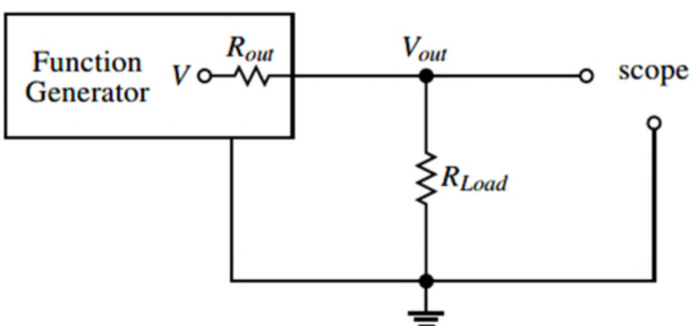

Figure I-11. Voltage divider forms using a load resistor and the output impedance of the function generator.

The voltage divider formula for this circuit is given as:

$$V_{out} = V \frac{R_{Load}}{R_{out} + R_{Load}} \tag{1.1}$$

Do some algebra to show that $1/V_{out}$ is related linearly to $1/R_{Load}$. If $1/V_{out}$ was graphed *vs.* $1/R_{Load}$, determine what would give the vertical intercept and what would give the slope. Keep in mind that graphing Y (dependent) vs. X (independent) means graph Y on the vertical axis and X on the horizontal. For your report: plot $1/V_{out}$ *vs.* $1/R_{Load}$ from your collected data. Explicitly show your algebra starting with the voltage divider formula to derive your final equation that you used to make your plot. Give the values for R_{out} and V as determined from your graph.

e) RMS amplitude.

A DMM in AC mode measures the Root Mean Square (RMS) amplitude of a time varying signal. This RMS amplitude is the DC voltage which would deliver the same average power as the time varying voltage. Use the DMM in AC mode to measure the RMS voltage of a 0 DC offset 2 V pp sine wave for the following frequencies: 10 Hz, 1 kHz, and 100 kHz. Then do the same for a square wave and a triangle wave. The theoretical values for RMS amplitudes are as follows:

sine wave: $A_{RMS} = A/\sqrt{2}$

triangle wave: $A_{RMS} = A/\sqrt{3}$

square wave: $A_{RMS} = A$.

For your report: Report your measured values for the 9 frequencies in a table. For each waveform, give a short comment on the sort of deviation from the theoretical values you observe at different frequencies.

f) Rise time.

Set the function generator to produce an ≈ 1 MHz square wave, and input it to the scope. After triggering on it, zoom in and measure the rise time or fall time of the square wave. This is defined as the time it takes to rise from 10% to 90% of the max value or vice versa. Hint: The "Measure" tools include risetime and falltime measurements. For your report: reproduce or sketch your observed waveform and report your measured rise (or fall) time.