PHYS 431 – Lab 1: Linear Components

Parts List

- Resistors: 5.1 kΩ, two each of 15 kΩ, 100 kΩ, 1 MΩ, 10 MΩ
- Capacitors: 0.01 µF

1.1 General Lab Comments

The laboratory will be the most important component of this course. All students should come away from this course feeling comfortable with basic practical electronics and associated techniques. Please obtain a hardcover lab notebook and use it. This will be the primary record of your lab work. Your lab report should include any pre-lab notes which are useful to you for carrying out the in-lab work. All data, observations, notes, calculations, etc. should be entered in the notebook.

After each lab, produce a brief report summarizing the work you did in the lab. Provide headings for your entries which correspond to the numbered sections of the lab instructions. Clearly indicate the location of required material within your report. Note any unusual or unexpected results. Your reports should be turned in to the instructor by noon on Monday for grading.

Note that there is nothing magical about the specific values for the components used in this lab. You may feel free to use any component value which is close, although you should always specify clearly in your notebook what you have used.

1.2 Goals of this Lab

The primary goal of this lab is to become familiar with lab instrumentation and methodology. The prototype board (or “breadboard”), digital volt meter (DVM), oscilloscope, resistors and capacitors, and cables will be used throughout the course. In particular, students unfamiliar with oscilloscope operation should use this lab as an opportunity to develop their skills. Read the online oscilloscope primer on the course web page (or Appendix O of Horowitz and Hill if you are really ambitious) prior to the lab and please seek help from your TA or instructor if you have trouble setting up the equipment or getting it to work properly. The important point is to learn how to use the tools. We will use oscilloscopes all term long, so investing a little time now will pay off later.

A secondary goal is to understand basic circuits involving resistors and capacitors which are elementary building blocks of electronics, specifically the voltage divider, and simple RC high-pass and low-pass filters. We will also take a first look at loading in DC circuits.

1.3 Voltage Divider

Construct the voltage divider circuit shown below in Fig. 1. For $V_{in}$, use the +0—15V variable DC power supply provided on the prototype boards, or use one of the bench power supplies. Layout your circuit on the board in an orderly manner, for example setting up one column which carries the +V and one for ground. Check your rails carefully with a DVM. Some of these are split in the middle. It is much better to use the small, portable breadboards than the ones built into the black box stations. Many of these are damaged, and with a portable board you can come back and finish your lab later if necessary.

1.3.1 Voltage and Current

Measure the voltage across and (separately) the current through the 15kΩ resistor for three different power supply voltages, e.g. 5V, 10V, and 15V. Use 2 DVMs, one measuring the voltage and the second measuring the current. Remember that to measure current, you have to break the circuit and insert the DVM in current mode. Check with the TA if you are not certain how to do this. Determine $R = V/I$ for each applied voltage. Make a table with your measurements of $V$ and $I$ for each value of $V_{in}$ and also determine $R = V/I$. Which resistance is being measured here?
1.3.2 Loading

Set the power supply at +10V. Place an additional 15kΩ resistor across $V_{\text{out}}$ to provide a load on the output of the voltage divider. Measure the voltage across the load. Is the voltage across the load larger or smaller than the voltage $V_{\text{out}}$ without the load?

1.3.3 Equivalent Circuit

Remove the load resistor. Understanding the loading of a circuit is a key skill to develop in this course, and using the Thévenin equivalent circuit is the most generally useful way to do this. We wish to directly determine the equivalent circuit of the voltage divider. Measure the open circuit voltage, $V_{\text{open}}$ (which is just $V_{\text{out}}$). Now measure the short circuit current, $I_{\text{short}}$ by shorting the output and measuring the current through this short. If you still have a DVM attached in series with the 15kΩ resistor, just put a wire across the resistor to short it out. If not, just place a DVM in current mode in parallel across the 15kΩ resistor. In current mode, a DVM has a very small resistance, and acts like a simple wire.

From your measurements of $V_{\text{out}}$ and $I_{\text{short}}$, determine $V_{\text{Th}}$ and $R_{\text{Th}}$. Now use these values to build the Thévenin equivalent circuit of the voltage divider shown in Fig. 2. Place the 15kΩ load resistor across the output of this equivalent circuit and verify that the voltage across the load is the same as it was for the loaded voltage divider in section 1.3.2.

Note that the Thévenin equivalent resistance of the voltage divider should be equal to the two voltage divider resistors in parallel: $R_{\text{Th}} = R_1 \parallel R_2$. 

![Figure 1: First voltage divider](image1.png)

![Figure 2: Thévenin equivalent to voltage divider](image2.png)
1.4 Measurement Limitations

Set the power supply to +10V. Build a voltage divider using two 15kΩ resistors. Measure $V_{\text{out}}$. Repeat this measurement for dividers constructed of a pair of 100kΩ, 1MΩ, and 10MΩ resistors. In principle, each divider should give the same output voltage. However, the input resistance $R_{\text{DVM}}$ of the DVM begins to load the circuit when the output resistance $R_{\text{Th}}$ of the circuit to be measured becomes comparable. Using your voltage measurements and the Thévenin equivalent resistance for each voltage divider, estimate the input resistance of the DVM. Figure 3 shows how you should think of a non-ideal DVM in a circuit.

![Non-ideal DVM circuit](image3)

Figure 3: Non-ideal DVM circuit

1.5 Low-pass RC Filter

Construct the low-pass filter circuit shown below in Fig. 4. Connect a 10X probe to your oscilloscope; set the coupling to DC and the triggering to AUTO. Input a 500 Hz square wave to your circuit using a function generator. Using the probe, establish the input square wave on the scope. Now connect to and display the output signal. The rise and fall of the square pulses are no longer sharp, due to the charging of the capacitor. Use the scope to measure the rise (or fall) time, and hence calculate the RC time. Does it equal $R \times C$? (Remember that the time to rise to 63% of full value, or fall to 37% of full value, is the “RC time”.)

![Low-pass filter](image4)

Figure 4: Low-pass filter
1.5.1 Integrator

Drive the circuit above with a 100 kHz square wave. Sketch the input and output wave forms. Repeat with a 100 kHz triangle waveform and a 100kHz sine wave. Does the term “integrator” for this circuit seem apt?

1.5.2 Transfer Function

Using a sine wave input, we wish to determine the circuit’s response as a function of frequency. In this way, we will determine the so-called “transfer function” of the circuit. Vary the input frequency while measuring the amplitude of the output using the scope. Plot your data for amplitude versus frequency. The $f_{3\text{db}}$ point occurs where the ratio of output to input amplitude is $1/\sqrt{2}$. Determine this point. In theory, we expect $f_{3\text{db}} = [2\pi RC]^{-1}$. Compare this to your measurement. Note that capacitors can vary widely from their quoted values (errors of ±100 % are not uncommon) so you shouldn’t expect exact agreement here.

1.5.3 Phase Shift

At a frequency of about 10 times the $f_{3\text{db}}$ point, measure the phase shift of output relative to input. There are several ways to do this. Perhaps the most straightforward way is to use a second 10X probe to trigger the scope with the input signal. Display both input and output traces and note the shift in time.

1.6 High-pass RC filter

Rearrange the previous circuit to produce a high-pass filter (differentiator), as shown below in Fig. 5. Using an input sine wave as before, vary the input frequency to verify the high-pass property and to determine the $f_{3\text{db}}$ point.

1.6.1 Decoupling

As a special case of the high-pass property, verify that your circuit completely blocks any DC voltage in $V_{\text{in}}$. Add a DC offset to your input signal with the function generator while viewing the output on the scope. Capacitors used in this way are often called “decoupling” capacitors, as they allow DC voltages in different parts of circuits to be isolated, while the AC signals are passed through.

![Figure 5: High-pass filter](image)

$0.01 \mu F$

$15 \, k\Omega$

$V_{\text{in}}$

$V_{\text{out}}$