ECE 35 Lab 1   **Introduction to Analog Circuits**

This lab will illustrate some of the differences between analog and digital circuits. There are assignments for this first lab, A & B. In part A we design a circuit to produce an arbitrary voltage, rather than the digital *true* or *false* voltages. In part B we will observe that voltages do not change instantaneously, as one imagines in a digital circuit, and measure the rise and fall times.

Before starting this lab:
You must read the "Lab Syllabus" on the course website. You must have done the analysis for Part A in advance and be able to show the TA your results. You must have read the "Equipment Introduction" on the course website, because we will use all the instruments in that introduction in this project. You should also read "Lab Write-up Tips". You will need to have a few things for the lab to be used for the remainder of the quarter:

1. USB thumb/flash drive, to store and transfer your data.
2. ACMS printing account to print in the labs
   (http://acms.ucsd.edu/students/print/index.html).

Prelab:
Before each lab, you are required to read the corresponding lab assignment prior to arrival in the lab. Every student must individually complete the tasks and questions listed in the Prelab section on a piece of letter-sized paper and turn it in to your TA at the beginning of the lab. You will forfeit your prelab credits if you turn in late or to the wrong lab section. Prelab for this project is to complete the analysis in part A-1.

A. Design of a Voltage Reference Circuit:
The objective of this project is to design and test a voltage reference circuit which creates an open circuit voltage of 2.5 V ± 50 mV, from two 5 V supplies. The circuit is to be made with resistors and the constraint is that it should draw between 1 and 5 mA current from the supplies.
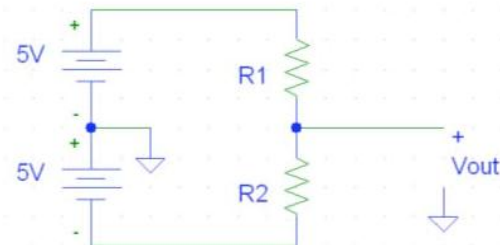
1. Analysis: The circuit diagram is shown to the right. Both batteries are 5V. Find the values of R1 and R2 that will give an output voltage of $V_{out} = 2.5V$, and a supply current of 1 mA. Then find the values that will give the correct output voltage with a supply current of 5 mA.

Hint: The current through R1 and R2 is the same. You can first figure out what the voltage drop across each resistor is by applying Ohm's Law for each resistor. Then find an equation that gives a R2/R1 relationship to get the desired voltage.   Then find the equivalent circuit with, R1 + R2, use the desired current to obtain your resistor values.

2. Components: In the lab it is hard to find resistors that have exactly your desired values because they are manufactured only in certain standard values (and with certain standard accuracies). However it is easy to obtain multiple resistors with nearly the same values. In prelab you calculated the upper and lower limits of your resistors that satisfy the specifications.   In this case we can use 4 resistors of the same (nominal) value.   One will form R1 and the other three in series will form R2.   Pick four resistors of nominal value somewhere between the limits you found in part 1. Measure them all with a multimeter. The resistances in the lab should be within 1% of the nominal value. Take the resistor closest to the average for R1 and use the series connection of the other three resistors to form R2. Now calculate V_{out} using these resistances. If the calculated value is 2.5 V ± 50 mV, go to the next step. If not, your resistors are not within 1% or you have made an error in your calculation. Get it right before you continue.

3. Construction: Build the circuit on your breadboard. Use the power supplies marked ± 20 V. First adjust them to be ± 5 V.   Then measure the current through your circuit.   Remember, current measurements need to be done in series with the circuit.   Connecting the leads in parallel with a resistor will cause a short; explain in your report why it would cause a short.   Is it what you expected when you take your measurement?   If the current is not zero but not correct, you have made a mistake somewhere. When you have the supply current right, measure the output voltage. Remember, the voltmeter measures the voltage difference of two points, and it is connected in parallel to the circuit. Connect the leads correctly and it will give you the V_{out}. Is it within spec? If so, show the TA your measurements and have your signature sheet signed off to move to the next step.

4. Effect of loading on voltage divider performance: Congratulations on your first circuit! However, notice that there is nothing connected to your circuit output (open circuit).   Even though you successfully measured a $V_{out} = 2.5V$ for an open circuit, in practice the output of a circuit can be affected by what is connected to this output (called loading effect). In this part of the lab you'll use a modified voltage divider circuit to investigate the effect of any resistor connected between the output and ground. The circuit is a simplified version of the one on page 1, with only a single 4V voltage source. R1 and R2 remain the same values. Without any load resistor in place (so-called open circuit situation), calculate and verify the V_{out} value on your breadboard. Add an R-Load resistor in parallel with and has a value much larger than R2, let's make it R-Load = 40 kΩ.   Now connect R-Load between V_{out} and ground. Using a multimeter, measure V_{out} and the current I_{out} through the resistor R-Load.   Does V_{out} deviate from its open-circuit value? Discuss the reason in your lab report.
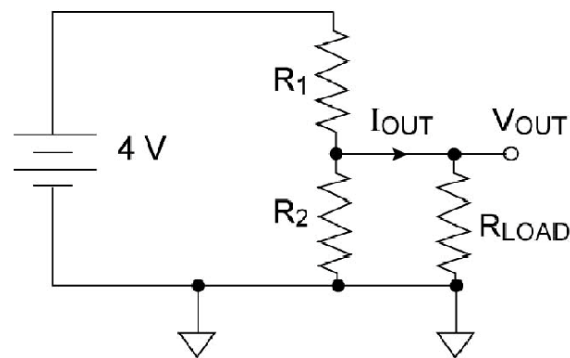
Now reduce R-Load to 30 kΩ, measure and record V_{out} and I_{out} again. Notice how much the deviation between V_{out} and its open circuit value change.   Keep decreasing R-Load to 20, 10 and then 5 kΩ. For each choice of R-Load, plot your collected sets of data points with the x-axis

being I_{out} and y-axis V_{out}. Fit a linear curve through these points. In your lab report discuss answers to these questions:

1. What is the y-axis intercept (V_{out}) of the curve at $I_{out} = 0A$?
2. Discuss the difference of V_{out} between no load (open circuit) and when the output is loaded with a resistor ($I_{out} > 0A$). This is called the loading effect.
3. What is the value of the slope? How does the slope relate to the R1 and R2 values in your circuit according to your calculations? (**Hint:** the equation of your line from the graph is V_{out} as a function of I_{out}. Start with voltage division of the circuit and Ohm's law for R_L. Eliminate R_L to derive an equation in the same form as the line).
4. Discuss the limitation on the range of R-Load one can connect to this circuit if we require V_{out} to deviate from its open circuit value by no more than 5%.

We will revisit the topic of circuit loading later this quarter when we introduce operational amplifiers, which are a very important type of circuit that actively compensate for these loading effect, thus effectively 'isolating' the output and making sure it's always the predicted value regardless of how much the load is.

B. Design of a Voltage divider for Digital Signals:
The objective of this project is to design a circuit that will match an old style 5 V digital system to a newer 2.5 V system. We will test it with a square wave. The square wave from the old system is 0 to +5 V, and the new system needs 0 to +2.5 V. We propose to do this with a voltage divider, as in part A above, except in a simpler fashion. All we require is two equal resistors (see the small circuit diagram in the left panel below). Make the voltage divider using two $R = 100$ kΩ resistors.
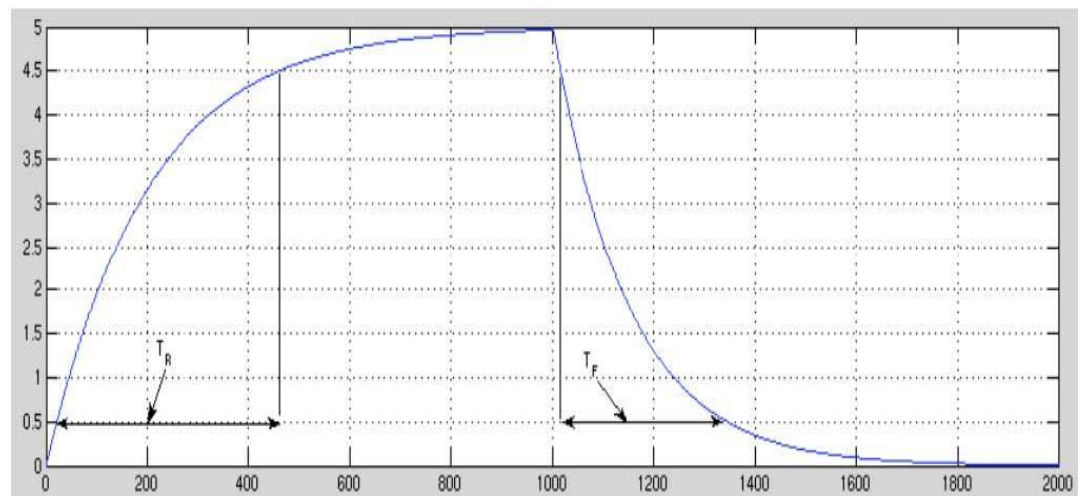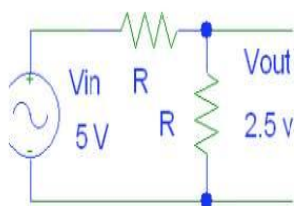

Set the function generator to give a 0 to +5 V square wave at a frequency of 10 kHz. The function generator will serve as our power source. To check the function generator settings we will use the O-scope and verify we have the desired signal. Get the O-scope probe and the function generator lead and connect them to their respective machines. The function generator leads are colored red and black. Connect the large center lead of the O-scope to the red lead of the function generator. The small black leads should be connected together. The O-scope

display will show you the signal you set on the function generator. If you set them correctly you should get a display similar to below.
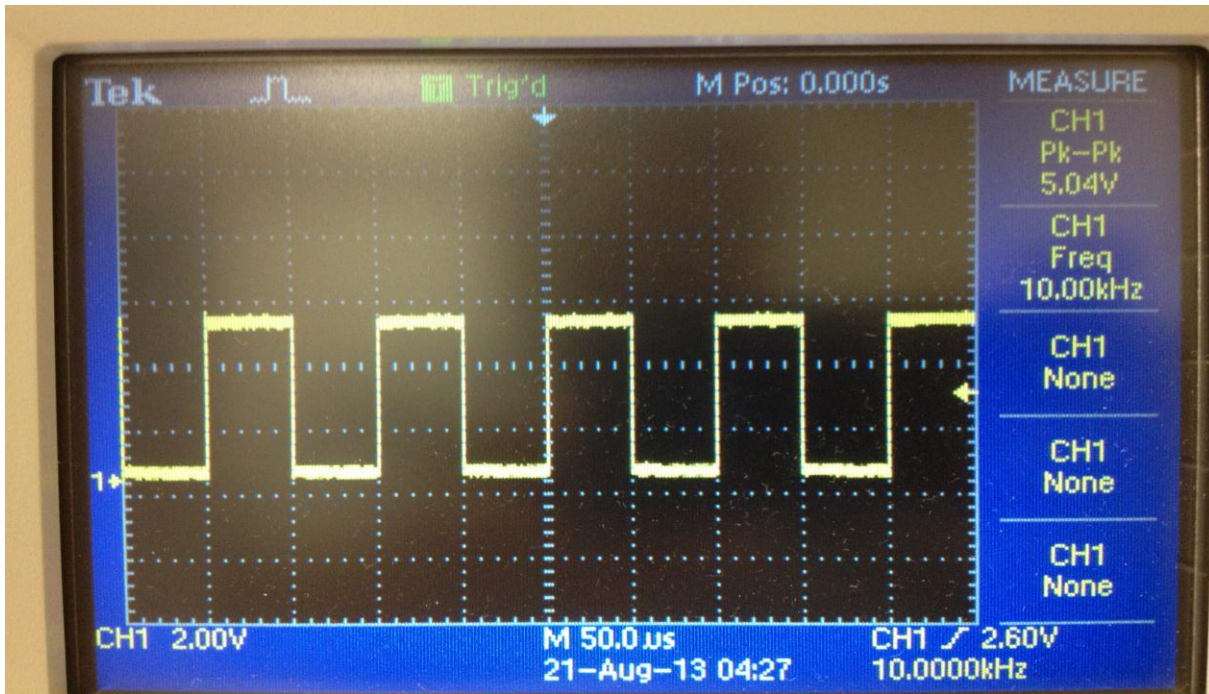
The small arrow with a "1" to the left indicates where zero volts is at. If your wave goes below this arrow then your DC offset on the function generator setting is wrong and should be adjusted before moving on. Also check the *channel 1 menu* to confirm that the *coupling* is DC, the *BW limit* is OFF; and *Probe* is 10X. Once the settings are verified, connect your function generator leads to each end of your circuit. Connect the O-scope lead to V_{out}, and the black lead to ground. To obtain a quick display press *Auto Set*. You should see another square wave. Verify the output has a pk-pk voltage of 2.5V on your O-scope display now.

Sometimes digital signals do not switch instantaneously between high and low like an ideal square wave does. Instead signals take some time to rise up or fall down. It is important to observe and understand the *rise* and *fall* times τ_R and τ_F. These are usually measured as the time for the output to change between 10% and 90% of the final voltage. We will measure t_R and t_F at the output of the voltage divider with the oscilloscope using the graph on top as a guide. To get a graph like above, you will have to zoom in. Adjust the two knobs labeled "scale" on the O-scope, one scales vertically and the other scales horizontally. You may have to re-adjust the position of the wave with the knobs labeled "position." Zoom in enough so you can see either the rise or fall of the wave separately and clearly on the scope display. To measure t_R or t_F of the output square wave we will use the "cursor" option of the O-scope. Press the button labeled "cursor" and change the type to "Time." Make sure the source is "CH1." Two Cursors will appear, they will give you a time and voltage reading. Move one to 10% V_{out} and 90% V_{out}. Below the source menu you will see "**Δ t**," it is calculating the time difference where you placed the cursors. The figure below is an example of how to measure with the cursor.
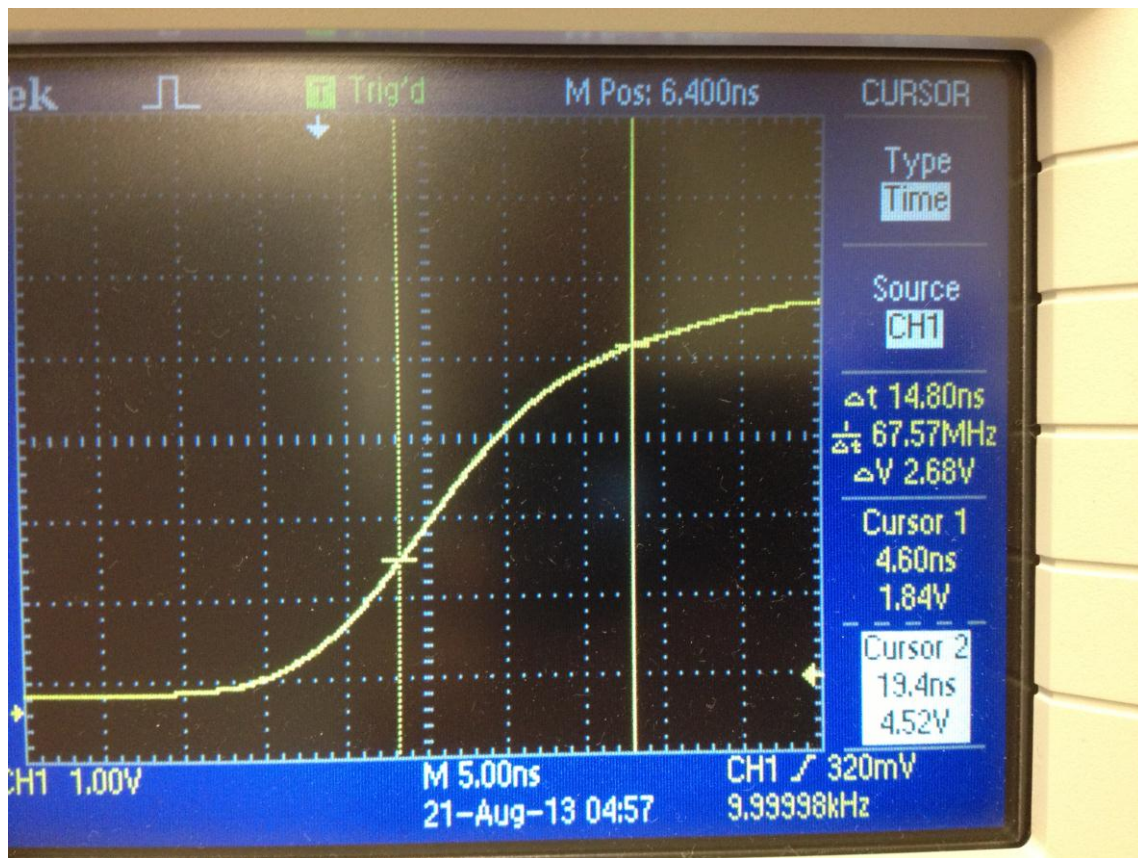
Use your USB thumb drive to save the scope trace showing these values, for both rise and fall. Include all scope traces in your lab report. Show the TA your traces and have them sign your signature sheet.

Discuss in your lab report:

- How is a voltage meter and a current meter modeled when making measurements
- The definition of a short circuit and how it effects a circuit if it was introduced into a circuit by mistake
- The definition of an open circuit and why is this important to have open circuit conditions when making voltage measurements
- Qualitatively explain the finite rise and fall times that you measured and the reasons for the delay.