Measurement Equipment and RC Circuits

Objective

The goal of this lab is to use several concepts from DC and AC circuit analysis and to become familiar with the test and measurement equipment in the lab. You will design RC lowpass and highpass filters to meet certain specifications. **Please bring your proto-type boards to lab. Please bring graphing/equation-solving calculators to lab.**

Background Information

A. The HP34401 DMM has 10-MΩ internal resistance when measuring DC voltages up to 10V, a 1-MΩ internal resistance when measuring AC voltages up to $10V_{RMS}$, and a 5-Ω internal resistance when measuring currents up to 100mA. The DMM is floating (not attached to ground). Thus, it doesn't matter how you attach the leads other than the sign.

B. The negative terminal of a function generator is attached to **earth ground**. Thus, it is extremely important that you attach it either to earth ground or to a floating ground. The function generator is designed with a 50-Ω source resistance and, upon power-up, **assumes** you will attach a 50-Ω external resistor. The TA's will show you how to change a setting (MENU, D SYSTEM, 1 OUT TERM, HIGH Z) to nullify that assumption. Note that you will have to change this setting **every time** you turn on the function generator.

C. Oscilloscopes have a 1-MΩ internal resistance and 30pF internal capacitance. If you use an oscilloscope, you add 1 MΩ || 30 pF from your circuit to earth ground. Note that the negative terminal of an oscilloscope is **earth ground**, similar to the function generator.

Name: ____

Note: you are encouraged to work on pre-lab questions prior to lab. However, the TA will give you a fresh piece of paper for you to work the pre-lab quiz, once you are in lab. Pre-lab quizzes are done individually, not as a group.

Pre-lab Questions Week 1 (5 points):

1. Design a voltage divider using an ideal voltage source and two resistors that has a gain of 0.7 V/V. Let the largest R be in the range of 600kΩ to 1.2MΩ.
2. Plot the signal: $v_s(t)$ = 25mV + 50mVsin(2π 250t)

Name: ____

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Pre-lab Questions Week 2 (5 points):

1. Design a voltage divider using an ideal voltage source and two resistors that has a gain of 0.425 V/V. Let the smallest *R* be in the range of 5 kΩ to 20kΩ.
2. What is the 3-dB corner frequency if you attach a 1nF capacitor across the output of the voltage divider in problem 1?

Exercise I. (21 points)

The objective of this exercise is to understand the limitations of the Digital Multimeter (DMM) for DC voltage and current measurements.

A. (3 points) Use a 5.0-Volt DC power supply and two unequal resistors in the 60Ω-120Ω range to build a voltage divider. Precisely measure the value of the resistors and the power supply voltage using the DMM before you put the circuit together. Draw the circuit and note the precise values below:

V_{CC} =

R_1 =

R_2 =

B. (2 points) Calculate the expected current through the voltage divider.

C. (3 points) Measure the current through the voltage divider. Modify the circuit in part A to show how measuring current with the DMM introduces a resistor, R_I, into your circuit.

D. (3 points) Using the measured value from part C, calculate R_I and compare to the expected value (given in the background information) using %error analysis.

E. (3 points) Use a 5.0-Volt DC power supply and 2 unequal resistors in the 600 kΩ – 1.2 MΩ range to build a voltage divider. Precisely measure the value of the resistors and the power supply before putting the circuit together. Draw the circuit and note the precise values below:

V_{CC} =

R_1 =

R_2 =

F. (2 points) Calculate the expected voltage drop across the larger resistor.

G. (2 points) Measure the DC voltage drop of part F using the DMM. Modify the circuit in part E to show how measuring voltage with the DMM introduces resistor, R_V, into your circuit.

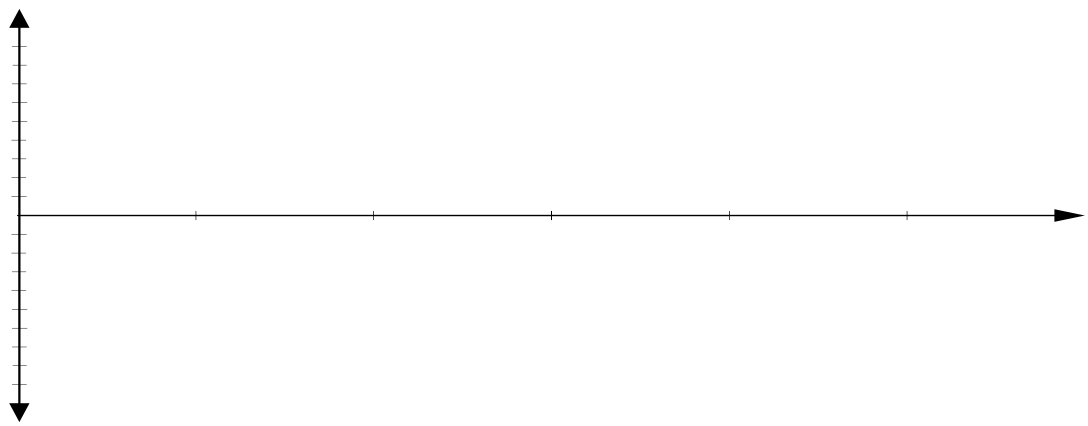
H. (3 points) Using the measured value from part G, calculate R_V and compare to the expected value using %error analysis.

Tip: *It is good laboratory technique to* ***measure the DC power supply voltage*** *and component values (R's and C's)* **before** *you use them in a circuit. Measure the DC power supply voltage* ***again*** *after the circuit is hooked up and turned on to make sure it hasn't changed.*

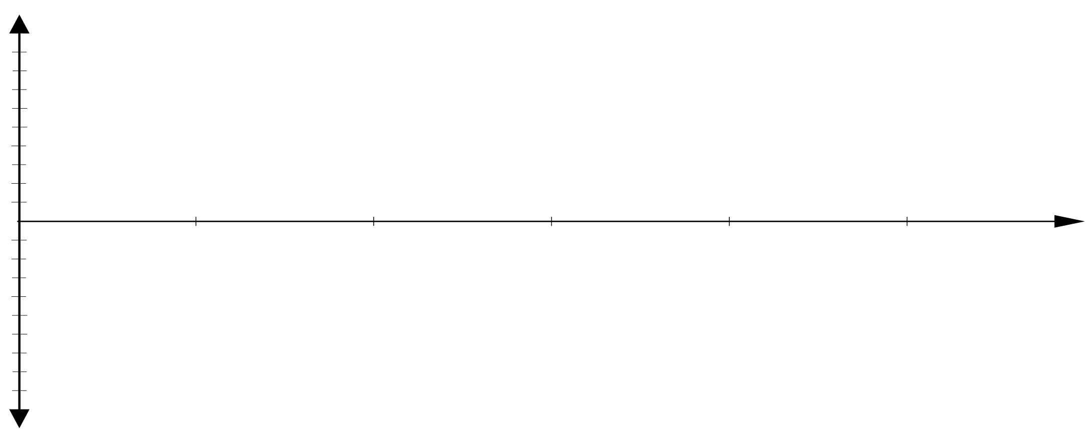
Exercise II. (19 points)

The objective of this exercise is to understand the limitations of the function generator and oscilloscope. In addition, we will see how the DMM complements the oscilloscope.

A. (3 points) Manually set the scope to DC coupling, 100μsec/div on the time axis, and 1V/div on the vertical axis. With the scope input grounded, put the trace exactly in the middle of the screen. Set the function generator to a sinusoid with a frequency of 2.25 kHz, an amplitude of 1.75 Vpp, and a DC bias (or offset) of 0.5 V. (**Be sure to change Output Termination to High-Z!!**) Attach the function generator to the scope, and plot what you see below. Use cursors to measure the period, peak-to-peak, and bias voltage. Indicate those on your plot.



B. (2 points) What happens when you change the coupling from DC to AC coupling? Plot what you see on the scope below. **Include peak-to-peak and period measurements on all plots.**



C. (2 points) Attach the function generator to the DMM, also. Measure the DC bias and the AC voltage. Note that the DMM measures RMS voltage. Compare these results to the measured values in part A using % error analysis.

DC voltage (Expect problems. Try reducing the sinewave amplitude to get a reading.)

AC voltage

D. (3 points) Measure the precise value of a 75-Ω resistor. Attach it across the output of the function generator. Use the DMM to measure the AC voltage across the resistor. What do you read? In addition, draw a circuit showing the function generator, the internal resistance of the function generator (R_S), the external resistor, and the DMM.

R =

AC voltage

E. (3 points) Use your result from part D to determine R_S and compare to the expected value.

F. (3 points) Measure the precise value of a 750-kΩ resistor. Attach it to the positive terminal of the function generator. Use the DMM to measure the AC voltage from the other side of the resistor to the negative terminal of the function generator. What do you read? In addition, draw a circuit showing the function generator, the internal resistance of the function generator (R_S), the external resistor, the DMM, and the internal resistance of the DMM (R_V).

R =

AC voltage

G. (3 points) Use your result from part D to determine R_V and compare to the expected value.

Tip: *The scope gives a "picture" of the signal, whereas the DMM gives precise readings of the signal. It is good laboratory technique to look at the scope and DMM simultaneously. Plot what you see on the scope and write down values measured from the DMM.*

Design Exercise III (50 points).

The objective of this exercise is to design, simulate, and build an RC lowpass and an RC highpass filter.

A. (8 points) Design an RC lowpass filter with a DC gain of 0. 7V/V (+/- 3%) and a cutoff (corner) frequency of 2.2kHz (+/- 30%). Design the voltage divider first, then calculate the required value for *C*. When creating the required value for *C*, **only put capacitors in parallel, never in series**. Precisely measure all resistors and capacitors. Re-calculate the DC gain and cutoff frequency using the **measured** *R*'s and *C*'s. Show your completed design below along with equations.

B. (5 points) Following the procedure in Lab1, simulate your design using **measured values** with an AC analysis. Print your schematic. Plot the output magnitude (dB) and phase shift. Compare the low-frequency gain and cutoff frequency with theory using %error. In addition, measure the phase shift at the **calculated** cutoff frequency, which should be -45^{o}. Compare to theory using %error.

low-frequency gain

cutoff frequency

phase shift at **calculated** cutoff frequency

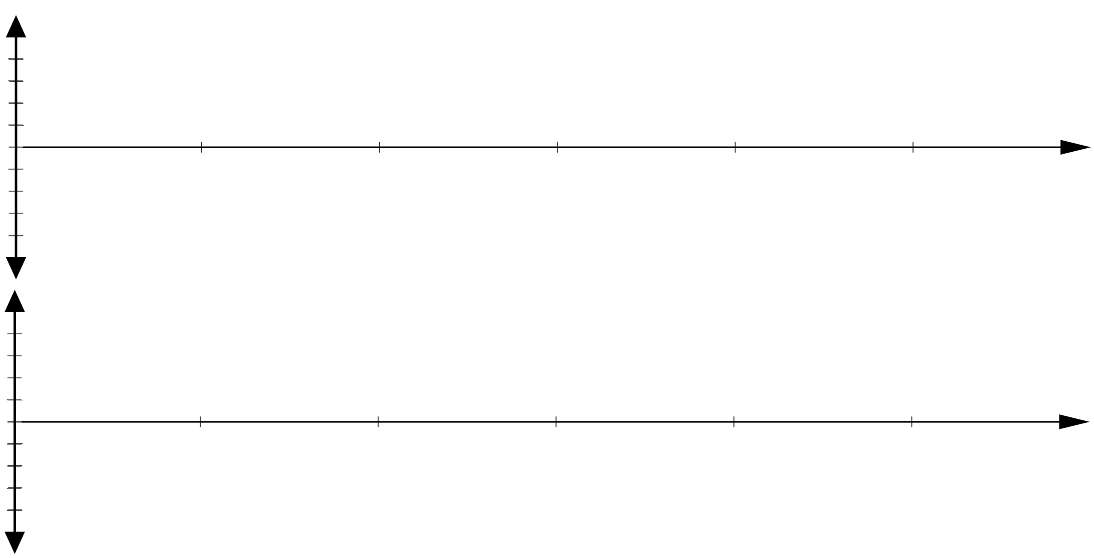
C. (4 points) Following the procedure in Lab1, simulate the circuit using a transient pulse waveform. Use a square wave pulse between -1V and 1V. Let the input frequency be $f_o/2$. Plot the input and output voltages. Compute the expected delay. Compare the delay with theory using %error.

expected delay

simulated delay

D. (6 points) Build the circuit on a breadboard. Use the function generator with 2.0-Vpp sinusoidal amplitude at a low frequency (< $f_o/10$) as the input. **Attach input and output nodes to the scope at the same time**. Also take precise measurements of the input and output AC voltages using the DMM. From the DMM measurements, calculate the actual low-frequency gain. Compare it to simulation results using % error analysis.

input and output waveforms (always measure period and peak-to-peak voltages)

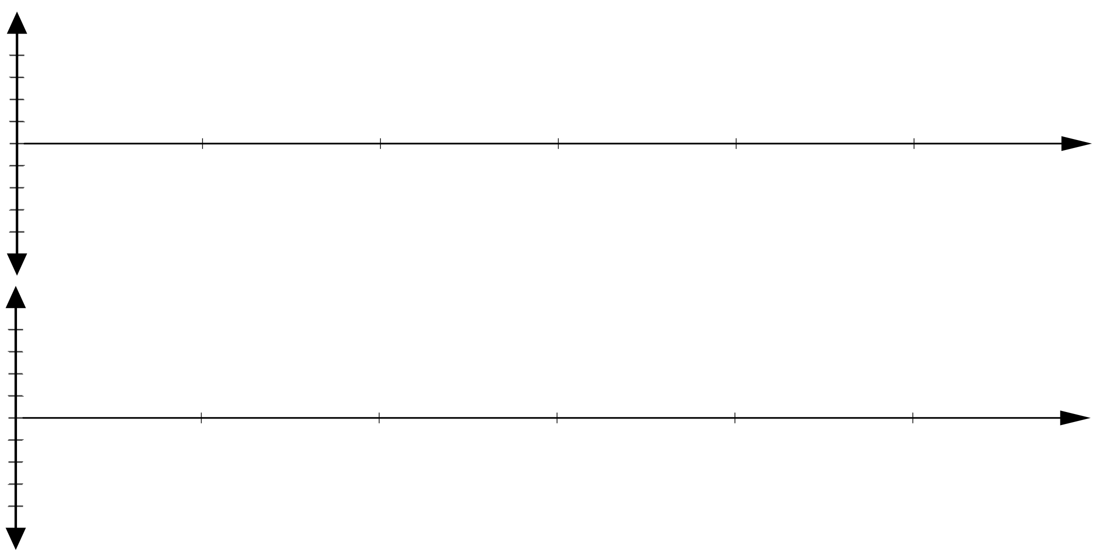


low-frequency gain measured with DMM

E. (4 points) Increase the input frequency until the gain is reduced by 3-dB, that is, the gain is lower than the maximum gain by a factor $1/\sqrt{2}$. That input frequency is the actual cutoff frequency. Compare it to the simulated cutoff frequency using % error analysis. Plot the input and output waveforms. Measure the phase difference between the input and output waveforms using the scope. Compare it to the simulated phase shift using %error analysis.

cutoff frequency

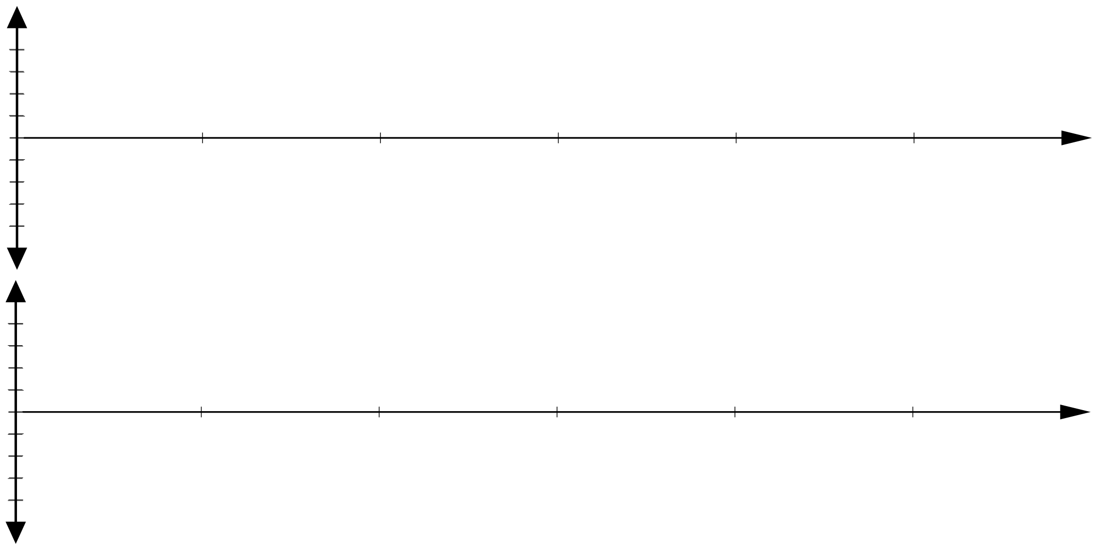
input and output waveforms



phase difference at the cutoff frequency

F. (4 points) Use the function generator with 2.0-Vpp amplitude square wave at a frequency equal to $f_o/2$ as the input. Plot the input and output waveforms. Measure the delay between the input and output waveforms rising using the scope. Compare it to the simulated delay using %error analysis.

input and output waveforms



delay

G. (4 points) Using the same components as in your lowpass filter, design an RC highpass filter with a gain that is less than unity. Draw the circuit below. What is the high-frequency gain of your design? What is the cutoff frequency?

H. (5 points) Simulate your design with an AC analysis. Print your schematic. Plot the output magnitude (dB) and phase shift. Compare the high-frequency gain and cutoff frequency with theory using %error. In addition, measure the phase shift at the **calculated** cutoff frequency, which should be 45°. Compare to theory using %error.

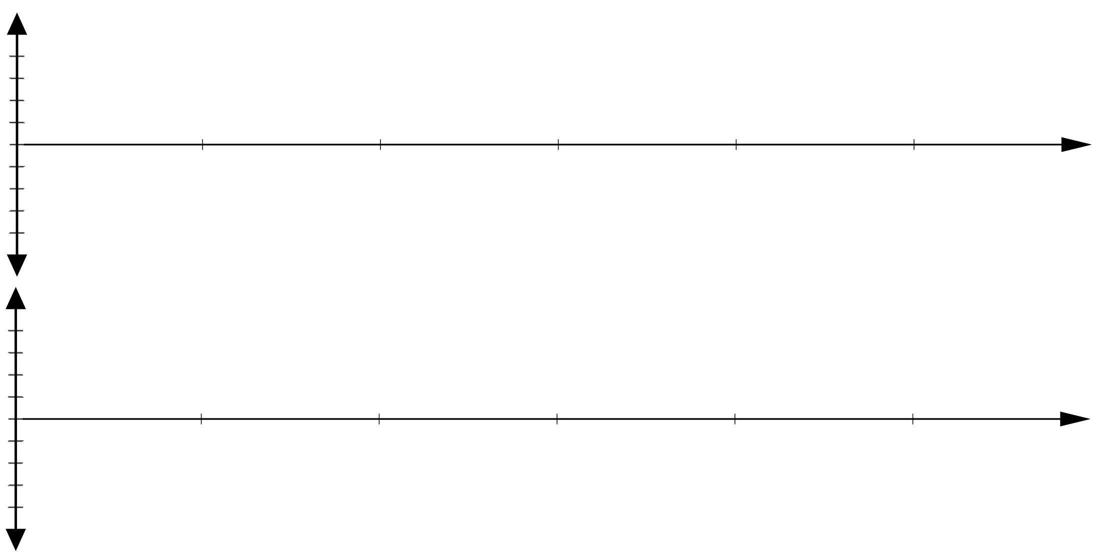
high-frequency gain

cutoff frequency

phase shift at **calculated** cutoff frequency

I. (6 points) Build the circuit on your breadboard. Use the function generator with 2.0-Vpp amplitude at a high frequency (greater than $10f_o$) as the input. Attach input and output nodes to the scope at the same time. Plot both waveforms. Also take precise measurements of the input and output AC voltages using the DMM. From the DMM measurements, calculate the actual high-frequency gain. Compare it to simulation results using % error analysis.

input and output waveforms (measure period and peak-to-peak voltages)

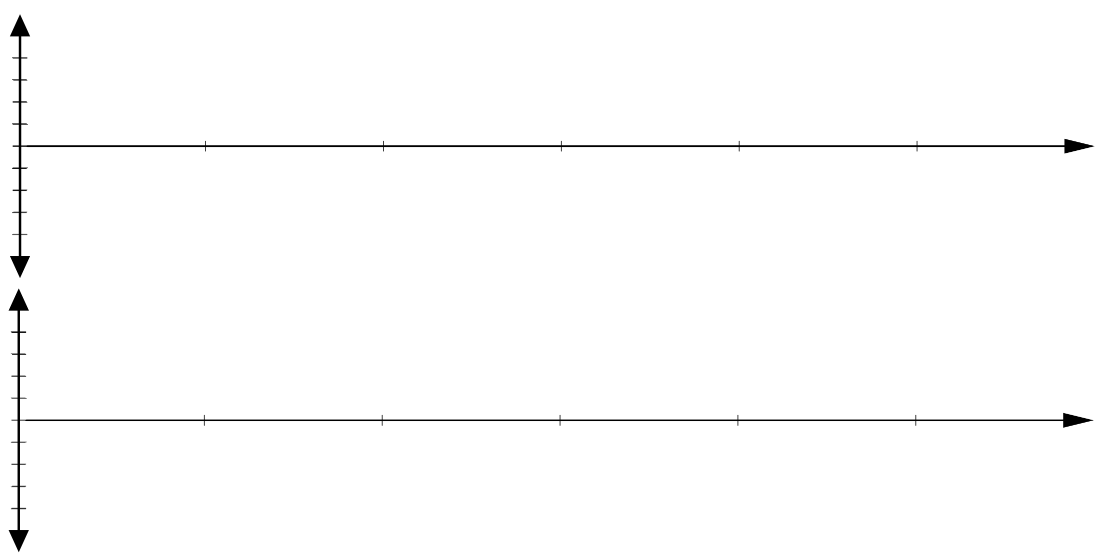


high-frequency gain measured with DMM

J. (4 points) Decrease the input frequency until the gain is reduced by 3-dB. That input frequency is the actual cutoff frequency. Compare it to the simulated cutoff frequency using % error analysis. Measure the phase difference between the input and output waveforms using the scope. Compare it to the simulated phase shift using %error analysis. Finally, plot input and output waveforms.

cutoff frequency

input and output waveforms



phase difference at the cutoff frequency

Exercise IV. Summary and Discussion. (10 points)

The objective of this exercise is to summarize and discuss this 2-week lab. Write 1-1.5 pages, using 1.5 line spacing, 12-point type (like this document). At the top of the page, place names of all team members and the title of the lab. Indicate which teammate is typing up the summary (typist) and who is the recorder (handwritten part of the lab). In the summary, include:

- An introductory paragraph that describes the main objectives of the laboratory, listing the major exercises you did.
- A table summarizing your simulation and measurement results, including all % error calculations. Omit measurements of component values or supply values in the table. A sample table for this lab is given below. Write one paragraph that discusses the table.
- Two paragraphs discussing several things that you learned, such as a new measurement technique or a new troubleshooting technique. Of particular interest are things that you struggled with, e.g., a bad component or wire that needed to be changed, etc.

What to Include in the Lab Report:

- First, the summary and discussion. Indicate the typist and the recorder.
- A neat, hand-written version of the lab, all in the recorder's handwriting.
- All simulation results.

Table 1 - Sample Summary of Major Results (Incomplete)

	Expected Value	Measured Value	% error
Ri, DMM, DC current	5.0 Ohms	5.58 Ohms	+11.6 %
Rv, DMM, DC voltage	10 MOhms	9.80 MOhms	-2.0%
Rs, function generator	50 Ohms	50.6 Ohms	+1.2 %
Rv, DMM, AC voltage	1.0 MOhms	0.780 MOhms	-22.0 %
Lowpass Gain (Simulation)	0.650 V/V	0.652 V/V	+0.3 %
Lowpass fo (Simulation)	3.20 kHz	3.19 kHz	-0.3%
Lowpass phase @ fo (Simulation)	-45 deg	-45 deg	0 %
Lowpass Gain (Measured)	0.652 V/V	0.661 V/V	+1.4%