EE 462G Laboratory # 1

Measuring Capacitance

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Laboratory #1: Pre-lab and data sheet due for Laboratory 1 at the end of the class period.

I. Instructional Objectives

- Introduce lab instrumentation with linear circuit elements
- Introduce lab report format
- Develop and analyze measurement procedures based on 2 theoretical models

II. Background

A circuit design requires a capacitor. The value of an available capacitor cannot be determined from its markings. Thus, the value must be measured; however a capacitance meter is not available. The only available resources are different value resistors, a variable frequency signal generator, a digital multimeter, and an oscilloscope. Three possible ways of measuring the capacitor's value are described in the following paragraphs. For this experiment, the student needs to select resistors and frequencies that are ***convenient*** or ***feasible*** for the required measurements and instrumentation. Be sure to use the digital multimeter (DMM) to measure and record the actual resistance values used in each measurement procedure.

III. Pre-Laboratory Exercise

Step Response Model:

1. For a series voltage source ($v(t)$) , resistor (R), and capacitor (C), derive the complete solution for the capacitor voltage when the source is a step with amplitude A and the capacitor voltage is 0 right before the step function turns on.
2. For the step response model derived in Problem 1, determine the value of C if R=1kΩ, A = 5 volts, and the step response is $5(1-\exp(-1)) \approx 3.16$ volts at t = 10 ms (assume input step turns on at t=0).
3. Describe an experimental procedure that uses ideas from the above model along with a known resistor value, a periodic function generator, and an oscilloscope to estimate a capacitor value. (Hint: It is critical to describe the circuit you construct, where you attach the oscilloscope, how you select the period of your square wave, what values you read off the scope, and the formula to you to estimate the capacitor value. Hint: Recommend specific readings to make on the waveform to enhance accuracy of the reading and make final computation simpler.)

Frequency Response Model:

4. For a series voltage source ($v(t)$) , resistor (R), and capacitor (C), derive the transfer function with input $v(t)$ and output the capacitor voltage. Write explicit equations for the magnitude and phase of the transfer function.
5. For the frequency response model derived in Problem 4, determine the value of C the circuit is being excited by a 10 volt peak-to-peak sinusoidal source of frequency f=5kHz. If R=200□ and the amplitude of the sinusoidal voltage over the capacitor is $5/\sqrt{2} \approx 3.54$ volts.
6. For the frequency response model, determine the value of C the circuit is being excited by a 10 volt peak-to-peak sinusoidal source of frequency f=10kHz. If R=10k□ and the phase difference between the input sinusoidal voltage and the capacitor sinusoidal voltage is 45□ (□/4 radians).
7. Describe an experimental procedure that uses ideas from the above model along with a known resistor value, a periodic function generator, and a 2-channel oscilloscope to estimate a capacitor value.

IV. Laboratory Exercise

1. To use the **step response model** in the capacitor measurement, build the Circuit A shown in Fig. 1. Use a 0 to 5V square wave input (function generator), and use the oscilloscope to measure the voltage across the capacitor. Enter on your data sheet the critical time and amplitude points for 3 different values of R (measure the resistance values with the DMM). Use the waveform save feature on the scope to record one of the capacitor voltage waveforms that you did your measurement on for presentation in the **results section and data sheet**. Adjust the square wave so the voltage swings from 0 to 10V and repeat your measurements (time and voltage amplitude points) for the 3 different R values. Compute the C values for each of the time-amplitude points recorded for presentation in the **results section**. Also compute the mean and standard deviation of all your capacitor estimates. From these values compute the 95% confidence interval for your capacitor estimate (use the t-statistic) and present your final estimate (mean of all your measurement with plus/minus 95% confidence intervals). In the **procedure section**, address/include the following:

a. Describe the quantities you want to measure and/or the relationship you want to find. Identify independent and dependent variables, if applicable.
b. Describe the set up (equipment and supplies used and configured). Include a description of probe placement, and grounding issues associated with your circuit if appropriate. (Where are the grounds for the oscilloscope and signal generator this circuit, and why should they be there?) Add proper ground symbols to your circuit and measurement equipment.
c. Describe formulae used on the measured data to estimate final results, if applicable.
d. For this experiment you must select a square wave frequency. So, describe the critical issues in selecting a square wave frequency for the experimental measurement and indicate how you determined the specific square wave frequencies used in your measurements.

2. To use the **frequency response model** for the capacitor measurement, build Circuit B shown in Fig. 2. Use a 10V peak-to-peak sine wave input (function generator). Input and output waveforms must be displayed simultaneously on the oscilloscope. Adjust the frequency so the capacitor and the source voltages are 45 degrees out of phase (and/or output 3 dB down from input). Use the waveform save feature on the scope to record one of the capacitor and source voltage waveforms that meet the required conditions for presentation in the **results section and data sheet**. Record the critical frequency values for presentation in the **results section and data sheet** for 3 different values of *R*. Adjust the peak-to-peak sine wave input to 4 volts and repeat your measurements (critical frequency values) for the 3 different *R* values. Compute the values of *C* in for presentation in the **results section** from the recorded information. Also compute the mean and standard deviation of all your capacitor estimates. From these values compute the 95% confidence interval for your capacitor estimate (use the *t*-statistic) and present your final estimate (mean of all your measurement with plus/minus 95% confidence intervals). In the **procedure section**, address/include the following:

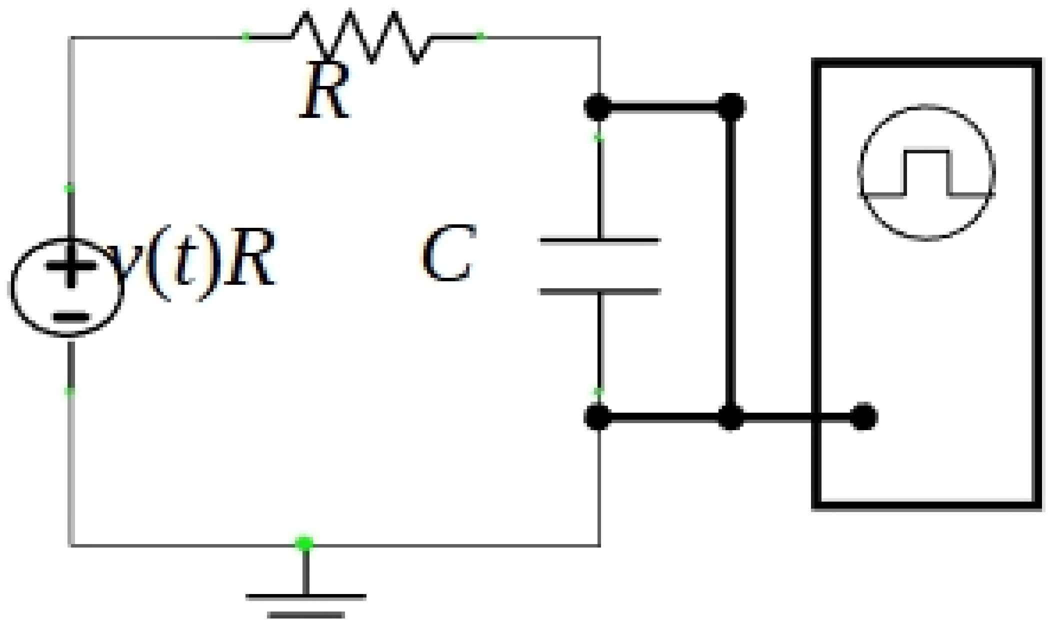

Figure 1. Circuit A

a. Describe the quantities you want to measure and/or the relationship you want to find. Identify independent and dependent variables, if applicable.
b. Describe the set up (equipment and supplies used and configured). Include a description of probe placement, and grounding issues associated with your circuit if appropriate. (Where are the grounds for the oscilloscope and signal generator this circuit, and why should they be there?) Add proper ground symbols to your circuit and measurement equipment.
c. Describe formulae used on the measured data to estimate final results, if applicable. In this case, indicate the general relationship between capacitance reactance (X_c) and *R* when the source and the capacitor voltages are 45 degrees out of phase or the capacitor voltage is 3 dB down from the input.
d. Briefly describe your process for determining the frequencies that generated the 45 degree phase shift and/or 3dB down capacitor voltage. (What did you vary? What did you look for to indicate this condition?).

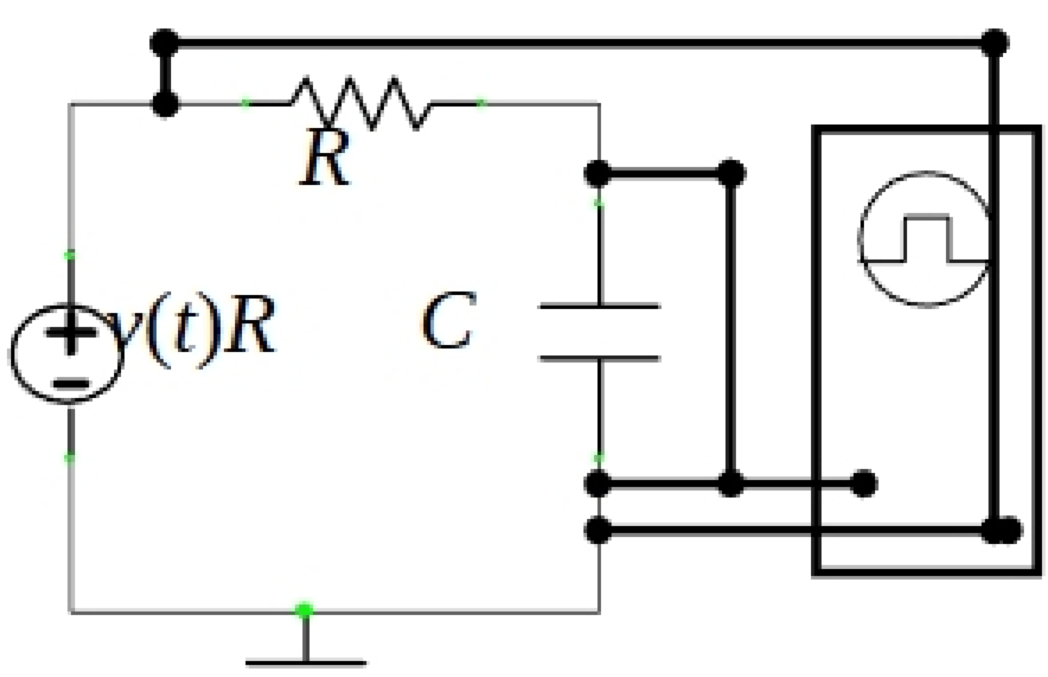

Figure 2. Circuit B