

## EE 462G Laboratory # 1

### Measuring Capacitance

By

Drs. A.V. Radun  
and K.D. Donohue (9/5/06)

Department of Electrical and Computer Engineering  
University of Kentucky  
Lexington, KY 40506

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
- Introduce automated lab measurement and data analysis

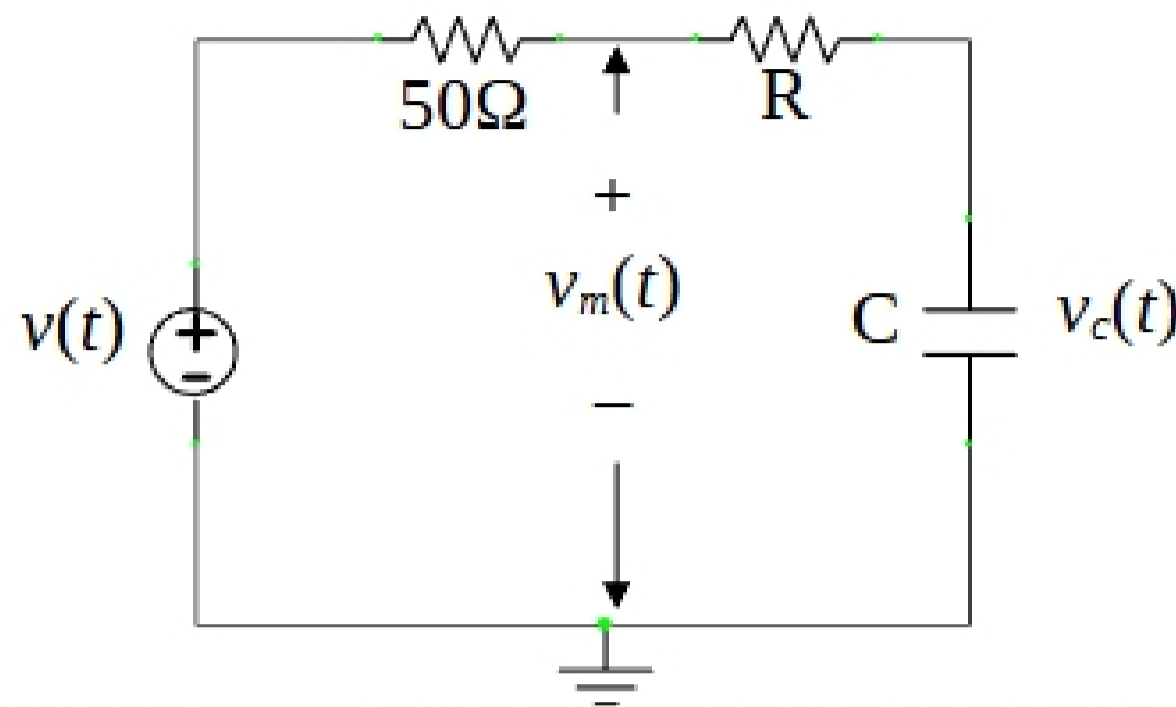
#### II. Background

A circuit design requires a capacitor. The value of an available capacitor cannot be determined from its markings, so the value must be measured; however a capacitance meter is not available. The only available resources are different valued resistors, a variable frequency signal generator, a digital multimeter (DMM), and an oscilloscope. Two 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. Assume the source ( $v(t)$ ) is a function generator, where the source voltage can only be measured after the  $50\ \Omega$  internal resistance. Find the step response (with amplitude  $A$ ) in terms of  $R$  and  $C$  for the both  $v_c(t)$  and voltage measured at the output of the function generator,  $v_m(t)$ , as shown in Fig. 1. (Hint: First find  $v_c(t)$  as in the previous problem (now total circuit resistance becomes  $(R+50)$  and the rest is the same). Then the loop current is  $Cdv_c/dt$  and  $v_m(t)$  is the drop over the circuit resistor +  $v_c$ ).



**Figure 1.** Test Circuit accounting for output impedance of function generator.

3. For the step response model derived in Problem 1, determine the value of  $C$  if  $R=500\Omega$ ,  $A = 2$  volts, and the step response is approximately 1.264 volts at  $t = 10$  ms (assume input step turns on at  $t=0$ ).
4. Describe an experimental procedure that uses ideas from the model of Problem 1 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, placement of oscilloscope probes, values read from the scope, and the formula used to estimate the capacitor value. It would be best to use a reading at a specific waveform amplitude to enhance accuracy of the reading and make final computation simpler.)

**Frequency Response Model:**

5. 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.
6. Repeat Problem 5 for the circuit of Fig. 1, and find transfer function from input  $v_m$  to output  $v_c$ . (Note: If you did the derivation correctly the  $50\Omega$  resistor does not affect this transfer function. Therefore, if the phase difference and magnitude scaling between  $v_m$  and  $v_c$  are measured directly, the  $50\Omega$  internal impedance will not have to be accounted for even when small resistors values are used.)
7. For the frequency response model derived in Problem 5, determine the value of  $C$ , given  $v(t)$  is a 4 volt peak-to-peak sinusoid at frequency  $f=1\text{kHz}$ ,  $R=150\Omega$ , and the amplitude of the sinusoidal voltage across the capacitor voltage  $v_c(t)$  is 3 volts peak-to-peak.
8. For the frequency response model derived in Problem 5, determine the value of  $C$ , given  $v(t)$  is a sinusoid at frequency  $f=4\text{kHz}$ ,  $R=8\text{k}\Omega$ , and the phase between  $v(t)$  and capacitor voltage  $v_c(t)$  is  $45^\circ$  ( $\pi/4$  radians).
9. Describe an experimental procedure that uses ideas from the frequency model along with a known resistor value, a periodic function generator, and a 2-channel oscilloscope to estimate a capacitor value.

### Automated Measurement and Data analysis method

10. Assume that data was automatically collected from a first-order low-pass filter (as shown in Fig. 2 at several frequency points list below in Table 1.

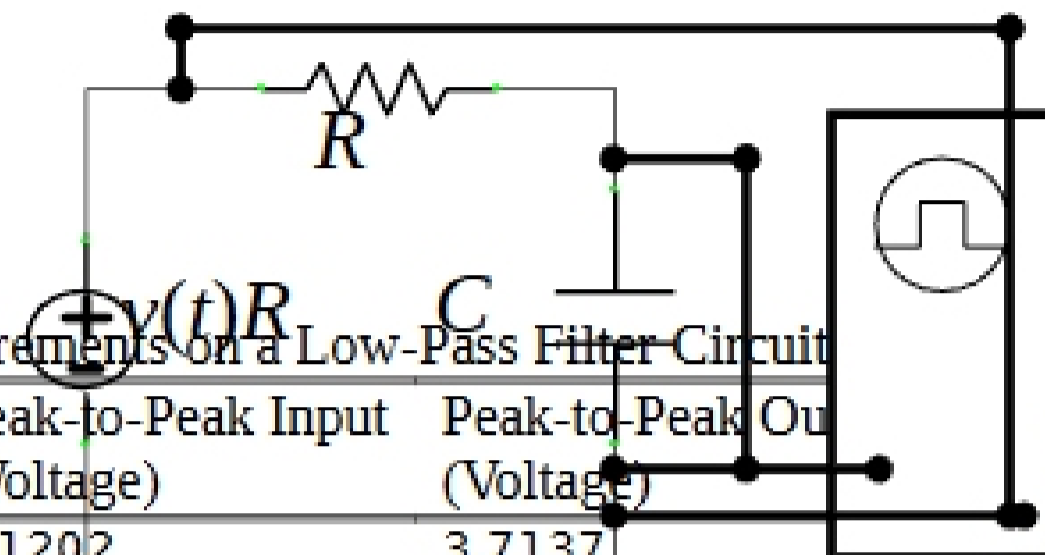


Table 1. Measurements on a Low-Pass Filter Circuit

Frequency (Hertz)	Peak-to-Peak Input (Voltage)	Peak-to-Peak Output (Voltage)	Phase of Input minus Output (Degrees)
120	4.1202	3.7137	-7.380
160	4.0984	3.6122	-27.6350
200	4.0939	3.4766	-32.5860
240	4.0939	3.3842	-37.1420
280	4.1080	3.1847	-38.8100
320	4.0994	3.0345	-41.8310
360	4.0994	2.8817	-45.8470
400	4.0833	2.7716	-47.4650
440	4.0875	2.5484	-52.3820

Figure 2. Circuit B measurement for frequency response model.

Write a Matlab script to find the 3 dB cut-off frequency (in Hertz) that results in the best-fit transfer function magnitude (best fit in a minimum mean squared error sense). Hand in the code and indicate the resulting cutoff frequency. Modify the script to find the cut-off frequency that results in the best-fit transfer function phase. Hand in the code and indicate the resulting cutoff frequency. Note the code must be commented correctly with sufficient detail so that someone can understand how your program works without having to figure out details from the code from the syntax. Comments should focus on the purpose of each code line or block relative to the function of the code.

### IV. Laboratory Exercise

1. To use the **step response model** in the capacitor measurement, build the Circuit A shown in Fig. 3. Use a 0 to 5V square wave input (function generator and voltage offset setting so wave starts at 0 volts), and use the oscilloscope to measure the voltage waveform across the capacitor. Enter on your data sheet the critical time and amplitude points for 4 different values of  $R$  (measure the resistance values with the DMM). Use the waveform save feature on the scope to record **JUST ONE** of the capacitor voltage waveforms from the 4 trials that you used to obtain the time and amplitude point measurement. Proper use of the horizontal and vertical cursors would be helpful in making this measurement. The waveform should be presented as a figure in the **results section and just sketched in data sheet**. Compute the mean and 95% confidence limits over the capacitor values determined from each trial, and