EE 2101 - EXPERIMENT 8
MEASUREMENT OF CAPACITORS

INTRODUCTION

Actual capacitors have some inductance and resistance associated with the leads, the capacitor plates (stacked, rolled foil, etc.), any clamps, tabs, and clips used, and the dielectric material. The distributive nature of capacitance, inductance, and resistance means that the capacitor has a complex impedance which may be capacitive over one range of frequencies, and inductive over another. One model of the capacitor is

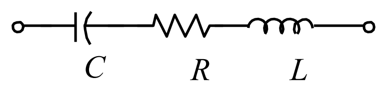


Figure 1: Capacitor model.

The values of *C*, *R,* and *L* depend on the type of capacitor and its physical construction. At some frequency the capacitor is series resonant.

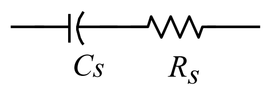
Inductance: Most of the inductance associated with a capacitor can be attributed to the wire leads. Straight leads have approximately 20 *nH* per inch of length, depending on wire size. The inductance is somewhat higher when the leads are formed into a loop of about half a turn and the ends soldered into a circuit.

Capacitance: The capacitance depends on the number, size, and spacing of the capacitor plates, and on the dielectric constant of the material between the plates. The dielectric constant depends on frequency, so capacitance is frequency dependent. Except for electrolytic capacitors, there should be no deterioration with age, except when excessive voltage is applied. Excessive voltage may cause deterioration and breakdown of the dielectric material.

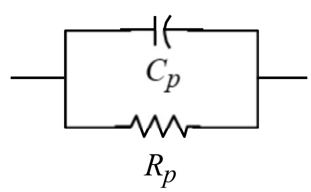
Resistance: The resistance of the leads and the capacitor plates, as well as the resistance of the dielectric between the plates, are included in the series resistance *R*. Additional loss occurs because the dielectric absorbs energy to increase molecular motion. This dielectric absorption is frequency dependent and can be represented as an imaginary component of dielectric constant.

Dielectric Absorption: Because the dielectric itself absorbs energy, a capacitor with a solid or liquid dielectric takes longer to charge and discharge than an ideal capacitor having the same capacitance. When such a capacitor is short-circuited, it fails to discharge instantaneously and a second discharge may be obtained a few seconds later. The capacitance is a function of the duration of applied DC voltage and, when used in an AC circuit, the capacitance decreases as frequency increases. The effect can be pronounced with some dielectrics.

For the purpose of this experiment, we will assume the inductive component L is negligible. At a single frequency, the capacitor can be modeled either as a series RC circuit or as a parallel RC circuit, as shown in Figure 2.



Series RC model



Parallel RC model
Figure 2: Capacitor models.

An LCR meter (depending on the specific meter used) will base its measurements on the series model or on the parallel model, or it will allow the use to choose the model. Make sure you know which model your meter is using when making your measurements.

You can convert back and forth between the two models with the following equations:

$$R_s = \frac{1}{1 + \left(\omega R_p C_p\right)^2} R_p \quad C_s = \frac{1 + \left(\omega R_p C_p\right)^2}{\left(\omega R_p C_p\right)^2} C_p$$

$$R_p = \frac{1 + (\omega R_s C_s)^2}{(\omega R_s C_s)^2} R_s \quad C_p = \frac{1}{1 + (\omega R_s C_s)^2} C_s$$

where $\omega = 2\pi f$ and f is the frequency of interest (the frequency the LCR meter uses in its measurement).

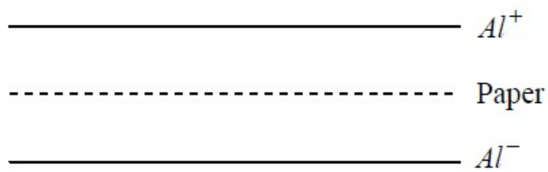
Capacitor Construction

To construct your capacitor, you will have available aluminum foil in the form of 2" wide strips which you can cut to whatever length you need and wax paper 2 1/2" wide by 0.002" thick. Construct the capacitor in the form of a compact cylindrical roll.

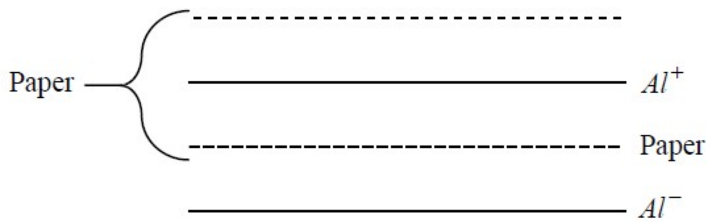
A reasonable approach is to design a parallel plate capacitor using the foil and paper then roll it up. We know the formula for a parallel plate capacitor is

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

where ε_o is the permittivity of free space, ε_r is the relative dielectric ($\varepsilon_r \simeq 2.0$ for wax paper), A is the area of the plates ($A = wl$ for a tape of width w and length l) and d is the plate separation. Given a desired value of C, it is a simple matter to compute the length of foil required for the plates. However, suppose we calculate this and construct it as follows



Clearly, when we roll it up we will short-circuit the plates. This can be overcome by putting in another strip of paper.



But when we roll it up we will have capacitance as shown in Figure 3.

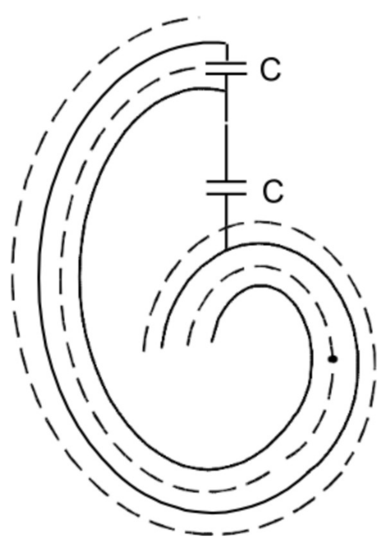


Figure 3: Rolled up aluminum foil and wax paper capacitor.

Careful examination of the drawing will show that the two capacitances are in parallel, so that the total capacitance is $2C$. Thus, to build a capacitor of value C we use the parallel plate formula to compute the foil length required for a capacitor of value $C/2$. Then we build the capacitor as described above. Your instructor will tell you what value of capacitance you are to construct so that you can do the calculations before coming to lab. The value will be between $0.005\mu F$ and $0.02\mu F$.

OBJECTIVE

To design and construct a capacitor of a specified value and measure its actual capacitance. Calculate the foil length needed to construct a capacitor of the value specified by the instructor. Its value should be between $0.005\mu F$ and $0.02\mu F$.

PROCEDURE

In lab you are to do the following things:

1. Construct the capacitor as described. Cut the wax paper about a half inch larger on each side than the aluminum and tape the inside end to keep everything in place. Use metal paper clips and tape to hold leads to the aluminum foil.

2. Measure this capacitor using the LCR meter and compare with the design value. Measure the dissipation factor and calculate the parallel resistance in the equivalent circuit. The dissipation factor is defined as

$$D = \frac{1}{2\pi f C_p R_p}.$$

3. Using a resistor, whose size can be chosen for convenience, construct a series circuit with your capacitor and a square wave generator and measure the time constant using the oscilloscope. Measure the resistance on the bridge so that you have an accurate value and compute the capacitance from the time constant measurement. For a 10 to 90% Rise Time measurement, the rise time is 2.2 times the time constant, or $t_r = 2.2\tau$, where $\tau = RC$. Compare with the design value and the measurement in (2).

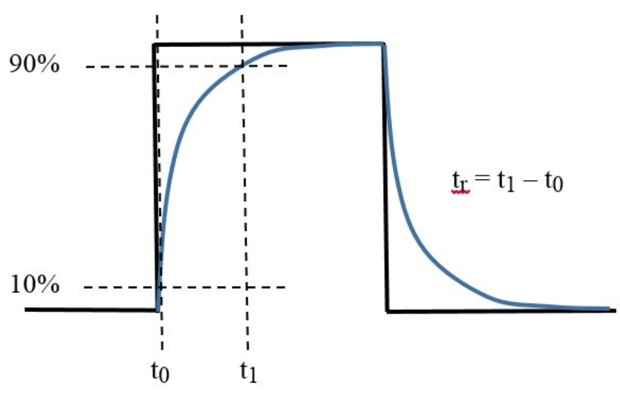


Figure 4: Rise Time Measurement.

4. Measure *C* and *D* for several capacitors of various types and sizes. Seek to draw comparisons concerning tolerance, loss, and temperature dependence. (you may raise the temperature to > 90^{o}F by grasping capacitors in your hands.