20 Capacitors

OBJECTIVES:

After performing this experiment, you will be able to:

1. Compare total capacitance, charge, and voltage drop for capacitors connected in series and in parallel.
2. Test capacitors with an ohmmeter and a voltmeter as a basic charging test.

READING:

Floyd and Buchla, *Principles of Electric Circuits,* Sections 12–1 through 12–5

MATERIALS NEEDED:

Two LEDs
Resistors: Two 1.0 kΩ
Capacitors: One of each: 100 μF, 47 μF, 1.0 μF, 0.1 μF, 0.01 μF (35 WV or greater)
Application Problem: One additional 100 μF capacitor, one 100 kΩ resistor

SUMMARY OF THEORY:

A capacitor is formed whenever two conductors are separated by an insulating material. When a voltage exists between the conductors, there will be an electric charge between the conductors. The ability to store an electric charge is a fundamental property of capacitors and affects both dc and ac circuits. Capacitors are made with large flat conductors called *plates.* The plates are separated with an insulating material called a *dielectric.* The ability to store charge increases with larger plate size and closer separation.

When a voltage is connected across a capacitor, charge will flow in the external circuit until the voltage across the capacitor is equal to the applied voltage. The charge that flows is proportional to the size of the capacitor and the applied voltage. This is a fundamental concept for capacitors and is given by the equation:

$$Q = CV$$

where Q is the charge in coulombs, C is the capacitance in farads, and V is the applied voltage. An analogous situation is that of putting compressed air into a bottle. The quantity of air is directly proportional to the capacity of the bottle and the applied pressure.

Recall that current is defined as charge per time; that is,

$$I = \frac{Q}{t}$$

where I is the current in amperes, Q is the charge in coulombs, and t is the time in seconds. This equation can be rearranged as

$$Q = It$$

If we connect two capacitors in series with a voltage source, the same charging current flows through both capacitors. Since this current flows for the same amount of time, it can be seen that the total charge, Q_T, must be the same as the charge on each capacitor; that is,

$$Q_T = Q_1 = Q_2$$

Charging capacitors in series causes the same charge to be across each capacitor: however, the total capacitance *decreases*. In a series circuit, the total capacitance is given by the formula

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_i}$$

Now consider capacitors in parallel. In a parallel circuit, the total current is equal to the sum of the currents in each branch as stated by Kirchhoff's current law. If this current flows for the same amount of time, the total charge leaving the voltage source will equal the sum of the charges which flow in each branch. Mathematically,

$$Q_T = Q_1 + Q_2 + \cdots + Q_i$$

Capacitors connected in parallel will raise the total capacitance because more charge can be stored at a given voltage. The equation for the total capacitance of parallel capacitors is:

$$C_T = C_1 + C_2 + \cdots + C_i$$

There are two quick tests that can verify that a capacitor, larger than about 0.01 μF, can be charged. Although the two tests are not comprehensive, they are useful in troubleshooting a faulty capacitor. The first test uses only an ohmmeter as a visual indication of charging to a small voltage (the internal voltage in the ohmmeter). An analog ohmmeter is best for this test. This test is done as follows:

1. Remove one end of the capacitor from the circuit and discharge it by placing a short across its terminals.
2. Set the ohmmeter on a high resistance scale and place the negative lead from an ohmmeter on the negative terminal of the capacitor. You must connect the ohmmeter with the proper polarity. *Do not assume the common lead from the ohmmeter is the negative side!*
3. Touch the other lead of the ohmmeter onto the remaining terminal of the capacitor. The meter should indicate very low resistance and then gradually increase resistance. If you put the meter in a higher range, the ohmmeter charges the capacitor slower and the capacitance "kick" will be emphasized. For small capacitors (under 0.01 μF), this change may not be seen. Large electrolytic capacitors require more time to charge, so use a lower range on your ohmmeter. Capacitors should never remain near zero resistance, as this indicates a short. An immediate high-resistance reading indicates an open for larger capacitors.

A capacitor that passes the ohmmeter test may fail when working voltage is applied. A voltmeter can be used to check a capacitor with voltage applied. The voltmeter is connected in *series* with the capacitor and a dc voltage as indicated in Figure 20–1. When voltage is first applied, the capacitor charges through the voltmeter's large series resistance. As it charges, voltage will appear across it, and the

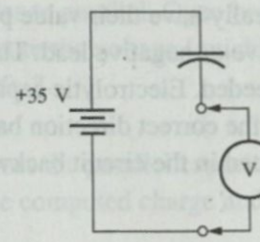


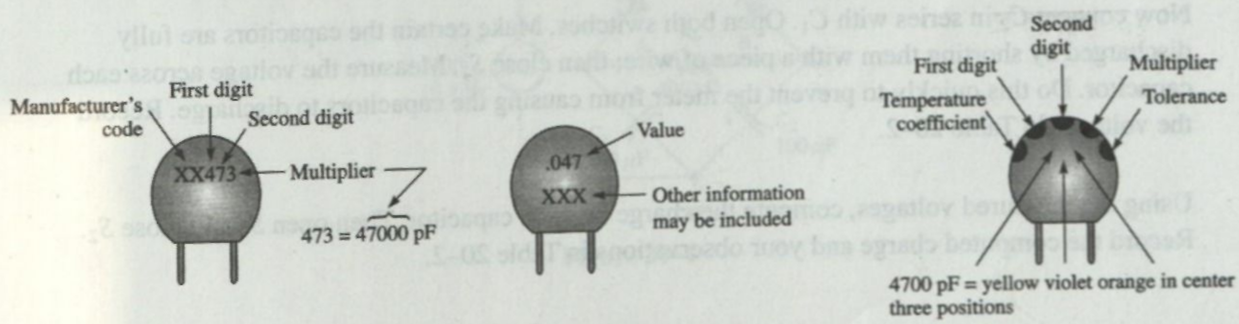
Figure 20–1

voltmeter indication will soon show a very small voltage. Large electrolytic capacitors may have leakage current that makes them appear bad, especially with a very high impedance voltmeter. In this case, use the test as a relative test, comparing the reading with a similar capacitor which you know is good.

The simple charging tests are satisfactory for determining if a gross failure has occurred. They do not indicate the value of the capacitor or if its value has changed. Value change is a common fault in capacitors, and there are other failures, such as high leakage current and dielectric absorption (the result of internal dipoles remaining in a polarized state even after the capacitor discharges). Some low cost DMMs include built-in capacitance meters. A more comprehensive test can be provided by an instrument such as a dynamic *component analyzer,* which measures the value as well as leakage current and dielectric absorption.

Capacitor Identification

There are many types of capacitors available with a wide variety of specifications for size, voltage rating, frequency range, temperature stability, leakage current, and so forth. For general-purpose applications, small capacitors are constructed with paper, ceramic, or other insulation material and are not polarized. Three common methods for showing the value of a small capacitor are shown in Figure 20–2. In Figure 20–2(a), a coded number is stamped on the capacitor that is read in pF. The first two digits represent the first 2 digits, the third number is a multiplier. For example, the number 473 is a 47000 pF capacitor. Capacitors under 100 pF will not include a multplier digit. Figure 20–2(b) shows the actual value stamped on the capacitor in μF. In the example shown, .047 μF is the same as 47000 pF. In Figure 20–2(c), a ceramic color-coded capacitor is shown that is read in pF. Generally, when 5 colors are shown, the first is a temperature coefficient (in ppm/°C with special meanings to each color). The second, third, and fourth colors are read as digit 1, digit 2, and a multiplier. The last color is the tolerance. Thus a 47000 pF capacitor will have a color representing the temperature coefficient followed by yellow, violet, and orange bands representing the value. Unlike resistors, the tolerance band is generally green for 5% and white for 10%.



(a) Coded value

(b) Stamped value (in pF or μF)

(c) Color code

Figure 20–2

Larger electrolytic capacitors will generally have their value printed in uncoded form on the capacitor and a mark indicating either the positive or negative lead. They also have a maximum working voltage printed on them which must not be exceeded. Electrolytic capacitors are always polarized, and it is very important to place them into a circuit in the correct direction based on the polarity shown on the capacitor. They can overheat and explode if placed in the circuit backwards.

PROCEDURE:

1. Obtain five capacitors as listed in Table 20–1. Check each capacitor using the ohmmeter test described in the Summary of Theory. Record the results of the test on Table 20–1.

2. Test each capacitor using the voltmeter test. Because of slow charging, a large electrolytic capacitor may appear to fail this test. Check the voltage rating on the capacitor to be sure it is not exceeded. The working voltage is the maximum voltage that can safely be applied to the capacitor. Record your results in Table 20–1.

3. Connect the circuit shown in Figure 20–3. The switches can be made from jumper wires. Leave both switches open. The light-emitting diodes (LEDs) and the capacitor are both polarized components—they must be connected in the correct direction in order to work properly.

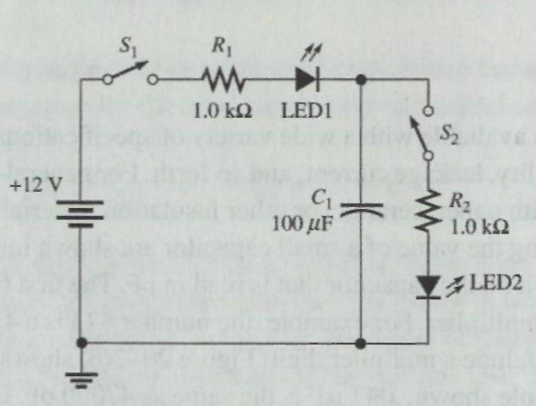


Figure 20–3

4. Close S_1 and observe the LEDs. Describe your observation in Table 20–2.

5. Open S_1 and then close S_2. Describe your observations in Table 20–2.

6. Now connect C_2 in series with C_1. Open both switches. Make certain the capacitors are fully discharged by shorting them with a piece of wire; then close S_1. Measure the voltage across each capacitor. Do this quickly to prevent the meter from causing the capacitors to discharge. Record the voltages in Table 20–2.

7. Using the measured voltages, compute the charge on each capacitor. Then open S_1 and close S_2. Record the computed charge and your observations in Table 20–2.

8. Change the capacitors from series to parallel. Open both switches. Ensure the capacitors are fully discharged. Then close S_1. Measure the voltage (quickly) across the parallel capacitors and enter the measured voltage in Table 20–2.

9. Using the measured voltage across the parallel capacitors, compute the charge on each one. Then open S_1 and close S_2. Record the computed charge and your observations in Table 20–2.

10. Replace the +12 V dc source with a signal generator. Set the signal generator to a square wave and set the amplitude to 12 V_{pp}. Set the frequency to 10 Hz. Close both switches. Notice the difference in the LED pulses. This demonstrates one of the principal applications of large capacitors—that of filtering. Record your observations.

FOR FURTHER INVESTIGATION:
Use the oscilloscope to measure the waveforms across the LEDs in step 10. Try speeding up the signal generator and observe the waveforms. Use the two-channel-difference measurement to see the waveform across the ungrounded LED (connect one channel to each side of the LED and select CH1 − CH2). Draw and label the waveforms on the plots provided in the report.

APPLICATION PROBLEM:
A voltage multiplier is a circuit that uses diodes and capacitors to increase the peak value of a sine wave. Voltage multipliers can produce high voltages without requiring a high-voltage transformer. The circuit illustrated in Figure 20–4 is a full-wave voltage doubler. The circuit is drawn as a bridge with diodes in two arms and capacitors in two arms. The diodes allow current to flow in only one direction, charging the capacitors to near the peak voltage of the sine wave. Generally, voltage doublers are used with 60 Hz power line frequencies and with ordinary diodes, but in order to clarify the operation of this circuit, you can use the LEDs that were used in this experiment. (Note that the output voltage will be reduced.) Connect the circuit, setting the function generator to 20 V_{pp} sine wave at a frequency of 1 Hz. (If you cannot obtain a 20 V_{pp} signal, use the largest signal you can obtain from your generator.) Observe the operation of the circuit; then try speeding up the generator. Look at the waveform across the load resistor with your oscilloscope using the two-channel-difference method. What is the dc voltage across the load resistor? What happens to the output as the generator is speeded up? Try a smaller load resistor. Can you explain your observations?

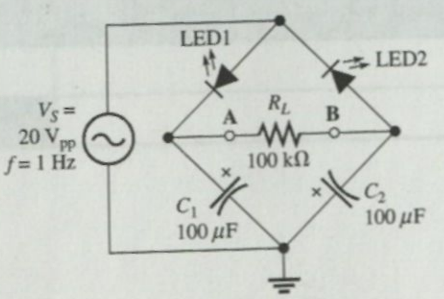


Figure 20–4

Report for Experiment 20

Name ____________
Date ____________
Class ____________

ABSTRACT:

DATA:

Table 20–1

Capacitor	Listed Value	Ohmmeter Test Pass/Fail	Voltmeter Test Pass/Fail
C_1	100 μF		
C_2	47 μF		
C_3	1.0 μF		
C_4	0.1 μF		
C_5	0.01 μF		

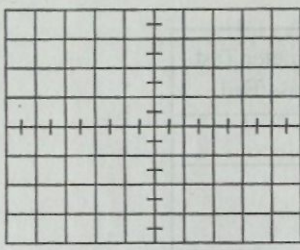
Table 20–2

Step	V_1	V_2	Q_1	Q_2	Observations
4					
5					
6					
7					
8					
9					
10					

RESULTS AND CONCLUSION:

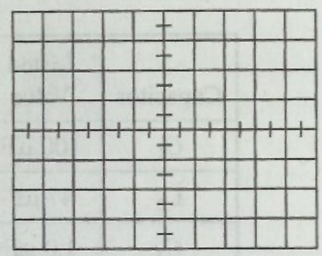
FURTHER INVESTIGATION RESULTS:

Ungrounded LED:



Plot 20–1

Grounded LED waveform:



Plot 20–2

APPLICATION PROBLEM RESULTS:

EVALUATION AND REVIEW QUESTIONS:

1. Why did the LEDs flash for a shorter time in step 6 than in steps 4 and 5?

2. What would happen if you added more series capacitance in step 7?

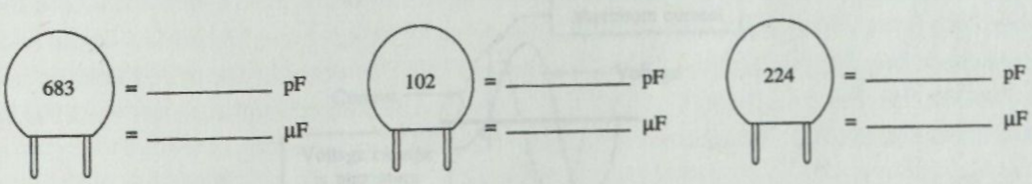
3. (a) What is the total capacitance when a 1.0 μF capacitor is connected in parallel with a 2.0 μF capacitor?

   (b) If the capacitors are connected in series, what is the total capacitance?

   (c) In the preceding series connection, which capacitor has the greater voltage across it?

4. A 3 μF capacitor is charged to 100 V. If it is then connected in *parallel* with a 10 μF capacitor, what voltage will be across the capacitors? (Hint: total charge is conserved.)

5. Determine the value in pF and μF for each small capacitor with the coded numbers as shown:



6. Write the coded number that should appear on each capacitor for the values shown: