Supercapacitor Lab

Acknowledgements: Developed by Jesus Casas, Faculty of Austin Community College, Austin, Texas.

Lab Summary: In this lab, a comparison is made between batteries, electrostatic capacitors, and supercapacitors as energy storage devices.

Lab Goal: The goal of this lab is to understand how the supercapacitor is a viable replacement for batteries in specific applications.

Learning Objectives

1. Calculate capacitor charge and discharge times using the RC time constant.
2. Construct a circuit to compare charge and discharge times for varying capacitor values.

Grading Criteria: This is left to the instructor's discretion.

Time Required: Approximately 1 hour

Lab Preparation

- Read the WRE Alternative Energy Sources Module Narrative.
- Read this document completely before you start on this experiment.
- Acquire required test equipment and appropriate test leads.
- Review RC circuits, RC time constant, and RC charge and discharge curves, and equations.
- Gather all circuit components.
- Print out the laboratory experiment procedure that follows.

Equipment and Materials

	Quantity
Volt Meter	1
Power Supply	1
Electrolytic Capacitor, 1000 µF, 10 volt rating or greater	1
Electrolytic Capacitor, 2200 µF, 10 volt rating or greater	1
Supercapacitor, .22 F, 5.5 volt	1
Supercapacitor, 1 F, 5.5 volt	1
74LS14 Digital Chip	1
Resistors, 220 Ω	2
LED	1

Introduction

Capacitors have been around for many, many years and are devices that store energy in the form of an electrostatic field. They are passive electronic components that store energy by physically separating positive and negative charges. In its simplest form, a capacitor is two electrodes facing each other separated by an insulator. The response of voltage and current on a capacitor is as follows: voltage across a capacitor cannot change instantaneously, while current through it can.

Capacitors have primarily been used in filters, for DC-blocking, and for providing quick surges of current when needed. Capacitance is a measure of energy storage ability and is typically expressed as

$$\text{Capacitance} = K * A/D$$

A is the area of the electrodes, D is their separation, and K is a function of the dielectric between the electrodes. The result of this formula is in farads (F). Typically, the farad is so large a unit that capacitors values are expressed in picofarads (pF = 10^{-12} F) or microfarads (uF = 10^{-6} F).

As the capacitance value increases, so does the energy storage capability, but so does the physical size. Until recently, a 1F capacitor typically was about the size of a tall glass. For years, researchers have been looking at the capacitor as a viable energy storage device to replace batteries in certain applications. Capacitors are very attractive energy devices for the following reasons:

- They charge and discharge at high efficiency
- They can be charged and discharged hundreds of thousand of cycles
- They are not as temperature-sensitive as batteries
- Their electrical behavior is easy to control

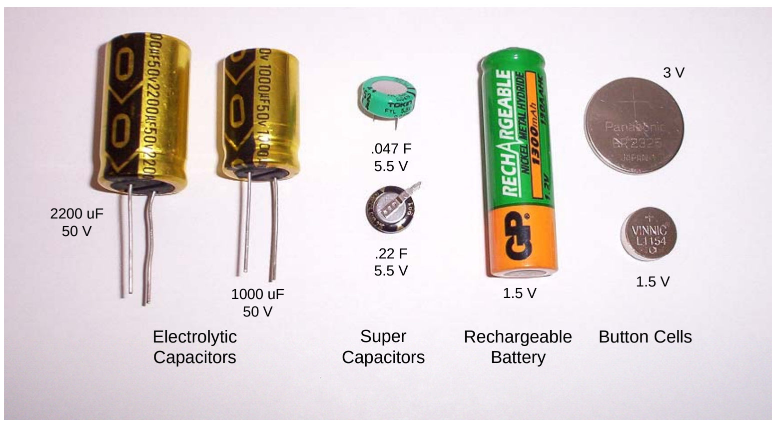
Recently, very high value capacitors have been developed and are known as “supercapacitors” and “ultracapacitors”. These are electric double layer capacitors (EDLCs). They are designed and constructed similar to electrolytic capacitors but have orders of magnitude more energy density. This type of supercapacitor uses high surface area carbon to accumulate charge as opposed to the relatively low surface area foils used in electrolytic capacitors. An electrochemical double layer is formed at the interface of the solid carbon electrode and liquid electrolyte. Another type of supercapacitor uses carbon aerogel as the active electrode material instead of activated carbon. Supercapacitors have virtually unlimited cycle life, low impedance which enhances load handling when put in parallel with a battery, and charge up in seconds without danger of overcharge.

Individual EDLCs have capacitance values that range from around 1 farad to upward of thousands of farads. NessCap, a Korean manufacturer of supercapacitors, offers units up to 5000 farads. Supercapacitors can be used as replacements for batteries or in conjunction with batteries as either back-up or main power. What makes supercapacitors attractive as battery replacements is that they can be recharged hundreds of thousands of times, unlike conventional batteries, which last for only a few hundred recharge cycles. This eliminates frequent battery replacement and disposal.

As an example of back-up power, devices such as PDA's, mobile phones, and alarm clocks use supercapacitors to maintain data/time integrity for a short period of time if the main power fails. If the device is battery operated, it allows the user a window, usually a few hours to a few days, in which to replace or recharge the main batteries without experiencing a loss in data or correct time.

Examples where supercapacitors can be found as the main power source are in quick charge motor drives, such as are found in toys and electric toothbrushes. They can also be used for fail-safe positioning which provides the power for open or close positioning in case of power failures. Supercapacitors can also be found in vehicle starter applications where environmental conditions are too cold for batteries.

One of the best features of supercapacitors is their size in comparison to electrolytic capacitors and batteries as shown in the figure below.



The following table is a general comparison of different parameters of capacitors, supercapacitors, and batteries.

	Electrostatic Capacitor	**Supercapacitor**	**Battery**
Charge Time	10^-6 thru 10^-3 sec	1 thru 30 sec	.3 thru 3 hrs
Discharge Time	10^-6 thru 10^-3 sec	1 thru 30 sec	1 thru 5 hrs
Energy Density (Wh/Kg)	Less than .1	Between 1 and 10	Between 20 and 100
Power Density (W/Kg)	Greater than 10,000	Between 1000 and 2000	Between 50 and 200
Cycle Life	Greater than 500,000	Greater than 100,000	Between 500 and 2000
Charge/Discharge Efficiency	Around 1.0	Between 0.90 and 0.95	Between 0.7 and 0.85

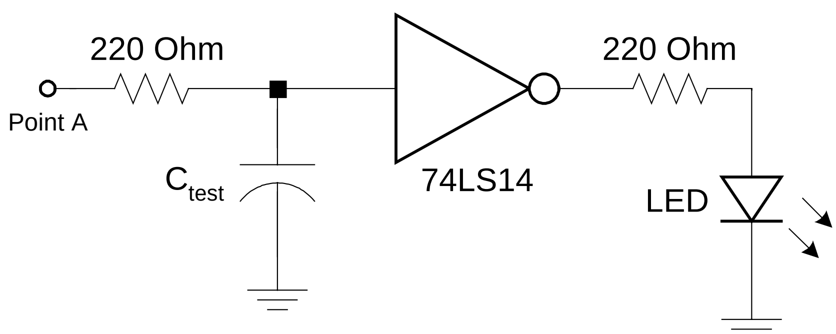
Note: Cycle life is the number of charges and discharges a device is able to provide.

As can be determined from the table above, the supercapacitor surpasses the battery in all parameters except in energy density. Supercapacitors at this point cannot compete with batteries at providing a steady power output over an extended period of time. Capacitor voltage does drop faster than that of a battery during discharge so a DC-to-DC converter may be needed to maintain voltage and to make more of the energy stored in the capacitor usable. Even though the energy density of the supercapacitor is less than that of a battery, supercapacitors provide power for short periods of time and can also provide large amounts of power in an instant.

Lab Procedure

Note: Photos showing the layout are at the end of this procedure.

1. Assemble the circuit shown below using a supply voltage of +5 volts. The circuit makes use of one of the inverters found in the 74LS14 digital chip. Each inverter contains a Schmitt trigger followed by a Darlington level shifter and a phase splitter driving a TTL totem pole output. These inverters are capable of transforming slow changing input signals into sharply defined, jitter-free output signals. The LED will be used to indicate the status of the input signal. Note that the capacitor under test is charged and discharged through a 220 Ω resistor.



2. Using the charging time equation, fill in the following table for the given capacitor values. Use 4.5 volts for the capacitor voltage and 5 volts for the source voltage.

$$\text{Charging time} = -RC * \text{Ln}\left(1 - \frac{V_{capacitor}}{V_{source}}\right)$$

Capacitor Value	Charging Time (sec)
1000 uF	
2200 uF	
.22 F	
1 F	

3. Using the discharge time equation, fill in the following table for the given capacitor values. Use .8 volts for the capacitor voltage and 4.5 volts for the source voltage.

$$\text{Discharging time} = -RC * \ln\left(\frac{V_{capacitor}}{V_{source}}\right)$$

Capacitor Value	Discharging Time (sec)
1000 uF	
2200 uF	
.22 F	
1 F	

4. Analyzing the results of both Steps 2 and 3, which capacitor has the slowest charge rate? Which one has the slowest discharge rate?

5. Using the circuit in Step 1, test each of the capacitors in the following manner.

   a. First, ensure the test capacitor is discharged and remember that electrolytic and supercapacitors have polarity, so they must be connected correctly.

   b. Next, insert the capacitor and then connect Point A to +5 volts allowing the capacitor to charge up to 4.5 volts. See the photo at the end of this procedure to see the correct charge position.

   c. When 4.5 volts have been reached, immediately disconnect Point A from +5 volts.

   d. Monitor the voltage across the capacitor while it is charging and also keep track of the charging time.

   e. Record the charge time in the table below.

6. At this point, the test capacitor should still have 4.5 volts across it.

   a. Connect Point A to ground, allowing the capacitor to discharge down to .8 volts. The LED will light when the voltage across the capacitor drops to .8 volts. See the photo at the end of this procedure to see the correct discharge position.

   b. Monitor the voltage across the capacitor while it is discharging

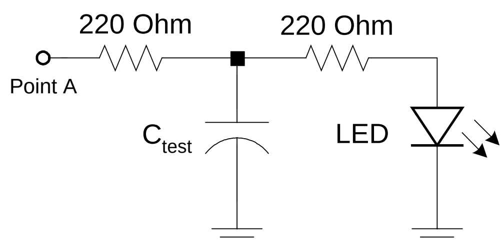
   c. Keep track of the discharging time.

   d. Record the discharge time in the table below.

Capacitance Value	Charging Time (sec)	Discharging Time (sec)
1000 uF		
2200 uF		
.22 F		
1 F		

7. How do the experimental charging and discharging times compare to the theoretical ones from Step 3? Which capacitor has the slowest discharge rate? Which capacitor provides the greatest amount of energy storage?

8. Assemble the circuit shown below.



9. Using the circuit in Step 8, test each of the capacitors in the following manner:
   a. Insert the capacitor and then connect Point A to +5 volts,
   b. Allow the capacitor to charge to + 5 volts or as close to +5 volts as possible. Monitor the capacitor voltage using a voltmeter.
   c. Disconnect Point A from +5 volts
   d. Record the duration of time that the LED stays on in the table provided.

Capacitance Value	Time LED Stays On(sec)
1000 uF	
2200 uF	
.22 F	
1 F	

10. Which of the capacitors keeps the LED on the longest?

Proto-board Layout