Introduction to the Oscilloscope

Key Terms: Capacitor, cathode, deflection plate, grid, time constant, anode, trace.

Apparatus: Oscilloscope, Signal generator, 1 MΩ resistor, a 1μF capacitor, various connecting wires, battery, SPDT switch, circuit board.

Objectives: To introduce the analog oscilloscope. To analyze the charging and discharging of a capacitor in an R-C circuit with an oscilloscope.

Discussion

This exercise consists of two parts, both designed to familiarize you with the use of the oscilloscope. During the first part of the exercise your lab instructor will acquaint you with the operation of the oscilloscope. In part two you will use the oscilloscope to study the charging and discharging behavior of a capacitor in a circuit containing a resistor and a capacitor. A capacitor is a circuit element used to store charge temporarily. It collects charge as current flows through it, and releases stored charge when there is no current.

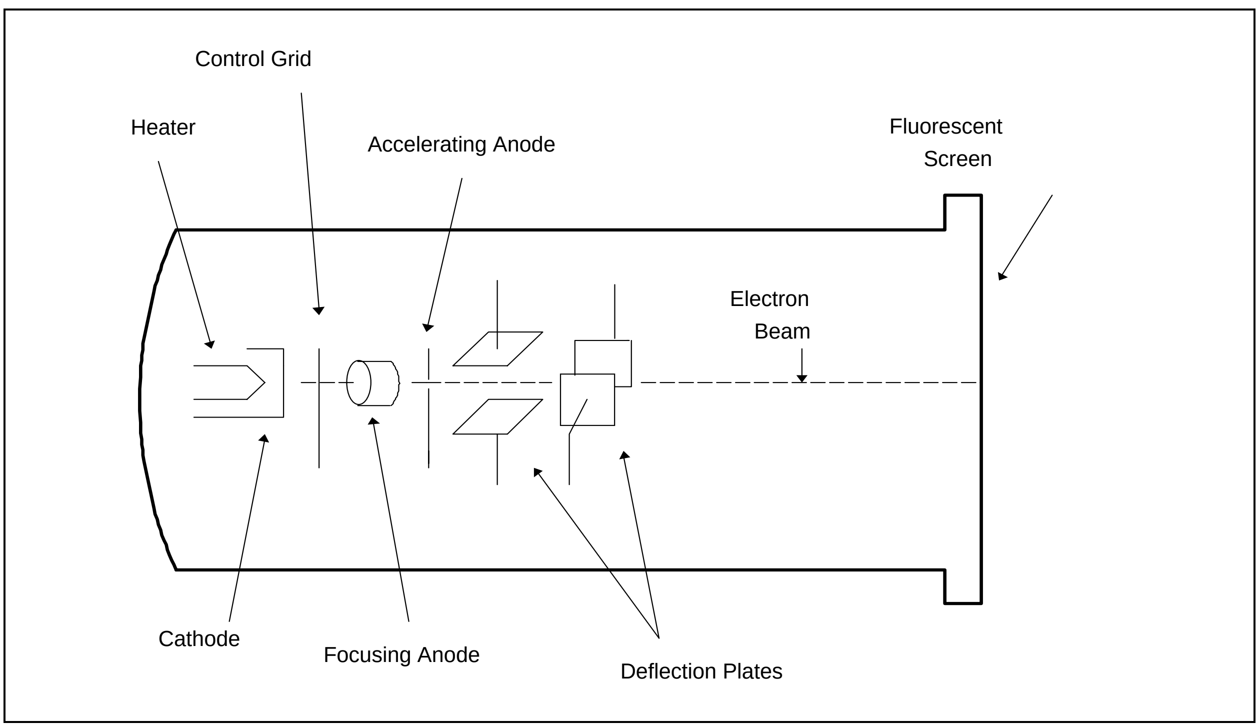

Figure 1. Basic Cathode Ray Tube Elements.

An oscilloscope is an instrument that measures voltage as a function of time. The major elements of an oscilloscope include a cathode ray tube for visual observation of the signal, a sweep generator, two amplifiers, and various power supplies.

The heart of an oscilloscope is the cathode ray tube (CRT). Figure 1 is a schematic of a CRT. The interior of the tube is highly evacuated (i.e., in a vacuum). The *cathode* at the left end of the tube is raised to a high temperature by a heater. This process liberates electrons from the surface of the cathode. The *accelerating anode* is maintained at a high potential with respect to the cathode. The resultant electric field causes the electrons liberated from the cathode to accelerate toward the accelerating anode. A hole in the center of the accelerating anode allows electrons traveling along the axis of the tube to pass through. Once the electrons have passed through the accelerating anode they travel with constant velocity to the right until striking the fluorescent screen. This collision causes the screen to fluoresce, thus creating a bright spot on the oscilloscope display.

The *focusing anode* is used to shape the electric field pattern within the region between the cathode and accelerating anode. This is accomplished by varying the potential of the focusing anode with respect to the accelerating anode. This regulation of the electric field focuses the electrons streaming from the cathode into a tight beam. The *control grid* is a mesh-like element that's potential relative to the cathode may be varied in order to control the density of the electron stream (i.e., the number of electrons reaching the anode). Since all of the electrons that pass through the anode eventually strike the fluorescent screen, the control grid ultimately controls the brightness of the display on the screen. Finally, two sets of *deflection plates* are used to create electric fields that can steer the electron beam toward any spot on the fluorescent screen.

The *horizontal deflection plates* control the vertical deflection of the electron beam. As the beam passes through the region between the plates it experiences a deflection that is proportional to the potential difference established between them. When a voltage signal is fed into an oscilloscope it passes through an amplifier and is applied to these plates. The setting on the amplifier determines the vertical deflection of the electron beam and hence its position on the display screen. The height of the beam on the screen is therefore proportional to the magnitude of the incoming voltage signal, multiplied by some constant factor supplied by the amplifier. On the oscilloscope, the amplifier setting is controlled by the VOLTS/DIV knob on the front panel. By knowing the vertical amplifier setting and determining the height of the signal on the display screen, one may measure the magnitude of any voltage signal being fed into the oscilloscope.

The horizontal steering imparted to the beam by the *vertical deflection plates* is also proportional to the potential difference between the two plates. This potential is controlled by a sweep generator within the oscilloscope. The sweep generator varies the voltage to the vertical plates in such a manner that the electron beam sweeps across the display screen from left to right at a uniform rate, then returns abruptly to the left side of the screen at the end of the sweep. This cycle is repeated continuously during the operation of the oscilloscope. The sweep rate, i.e., the rate at which the electron beam traces a path across the display screen, is adjustable. On the oscilloscope the sweep generator is adjusted via the SEC/DIV knob in the front panel. The sweep of the electron beam across the screen is known as a *trace*.

Procedure

Part 1: Your lab instructor will familiarize you with the operation of the oscilloscope by having you measure a variety of signals generated by the signal generator. As you acquaint yourself with the oscilloscope, record a description of each of the following features/controls:

graticule

vertical/horizontal position knobs

beam finder

vertical sensitivity

sweep rate

trigger

level knob

slope switch

probe

channel selector

After your instructor has approved this section, connect the probe supplied with the oscilloscope to the channel 1 vertical amplifier jack. The probe that you will be using is a 10x probe. Set the channel 1 vertical sensitivity to 1 VOLT/DIV (X10), the sweep rate (SEC/DIV) at .5 milliseconds, trigger source to LINE, trigger mode to NORM, and the slope switch to +. Be sure that the channel 1 vertical input switch is set to DC and turn the scope on.

Set the vertical position for channel 1 so that the trace sweeps the screen on one of the horizontal lines near the bottom of the display. *Note the position.*

Now connect the oscilloscope ground to the negative terminal of battery supplied with your setup. Touch the tip of the probe to the positive terminal of the battery. *What change occurs on the oscilloscope screen?*

Record the voltage level produced by the battery.

Disconnect the battery. Set the vertical sensitivity to .2 VOLT/DIV and change the sweep rate on the oscilloscope to 5 milliseconds. Now touch the tip of the probe with your fingertip. You should see a roughly sinusoidal trace on the screen. Sketch it below. *What phenomena do you think is responsible for this?*

Your lab instructor will show you how to connect the probe to the *probe adjust* output on the oscilloscope. Keep the vertical sensitivity at .2 VOLT/DIV and change the sweep rate back to .5 milliseconds. Compute the amplitude and frequency of the waveform on the display. *Sketch it below. What type of wave is this?*

Part 2: Your lab instructor will help you assemble the R-C circuit shown in Figure 2. Set the channel 1 vertical input switch on the oscilloscope to the GND position and adjust the vertical signal position until the trace sweeps across the center of the screen. Set the horizontal sweep so that a complete sweep takes 3 - 5 seconds. Return the vertical input switch to the DC position. Shift the SPDT switch to the *a* position and adjust the vertical amplifier so that the trace sweeps across the top of the screen. When the switch is in this position the capacitor is *charging*. Now flip the SPDT switch to the *b* position. In this configuration the capacitor is *discharging*. When the capacitor has completely discharged (indicated by a vertical stabilization of the trace on the screen), open the SPDT switch. No current flows through the circuit in this configuration.

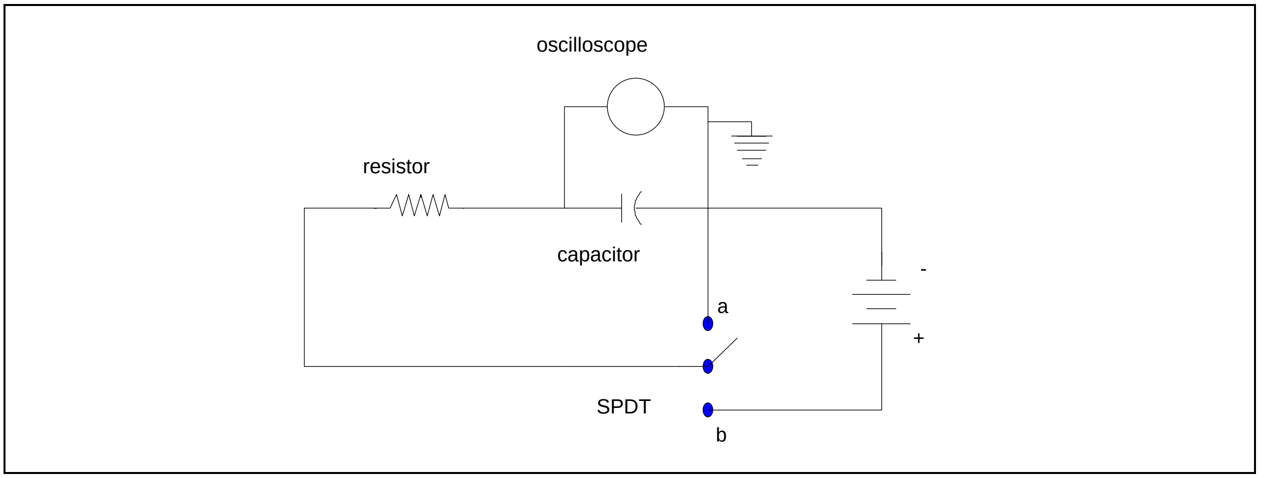

Figure 2. Circuit Diagram for Studying the Charging and Discharging of a Capacitor.

Wait until the beam is just beginning a new sweep and quickly flip the SPDT switch to the *a* position. Observe the pattern formed by the beam as it sweeps across the screen. Discharge the capacitor and try this procedure again, several times if necessary, and sketch the charge and discharge of the capacitor below.

It can be shown that the potential as a function of time across a capacitor being charged in an R-C circuit is given by:

$$V(t) = V_A [1 - e^{-\frac{t}{RC}}]$$

Where V is the voltage at time t, V_A is the applied voltage (*and* the voltage at time $t = \infty$), R is the resistance of the resistor in ohms, C is the capacitance of the capacitor in farads, and t is the time in seconds measured from the instant in which V was equal to 0. The product RC in the exponent of this expression is a quantity known as the *time constant* for the circuit, usually denoted by the symbol τ. Notice that when $\tau = t$, $V(t) = V_0(1 - e^{-1}) = 0.632V_0$. This means that in a time of one time constant (1τ) the voltage across the capacitor has increased to approximately 63% of its final value.

Calculate the time constant for your circuit. $R \times C =$

Does the trace on the screen appear to be approximately 63% of the final voltage after one time constant?

The decreasing potential across a discharging capacitor in an R-C circuit as a function of time is given by:

$$V(t) = V_0 \, e^{-\frac{t}{RC}}$$

Where V_0 is the voltage at time $t = 0$, and t is the time in seconds measured from the instant in which V was equal to V_0. Notice that when $\tau = t$, $V(t) = V_0 e^{-1} = 0.368\, V_0$ or approximately 37% of the original voltage.

Does the trace on the screen appear to be approximately 37% of the final voltage after one time constant?

Questions for Thought

1. What, physically, does an oscilloscope measure?