Introduction to the Oscilloscope

Apparatus: GWINSTEK GOS620 20 MHz oscilloscope, BK Precision model 4017A signal generator, 1 MΩ resistor, a 1μF capacitor (200+ VDC), various connecting wires, battery, SPDT switch, circuit board.

Objectives: To introduce the digital 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 GOS620 20 MHz oscilloscope. In part two you will use the oscilloscope to study the charging and discharging behavior of a capacitor in an R-C circuit.

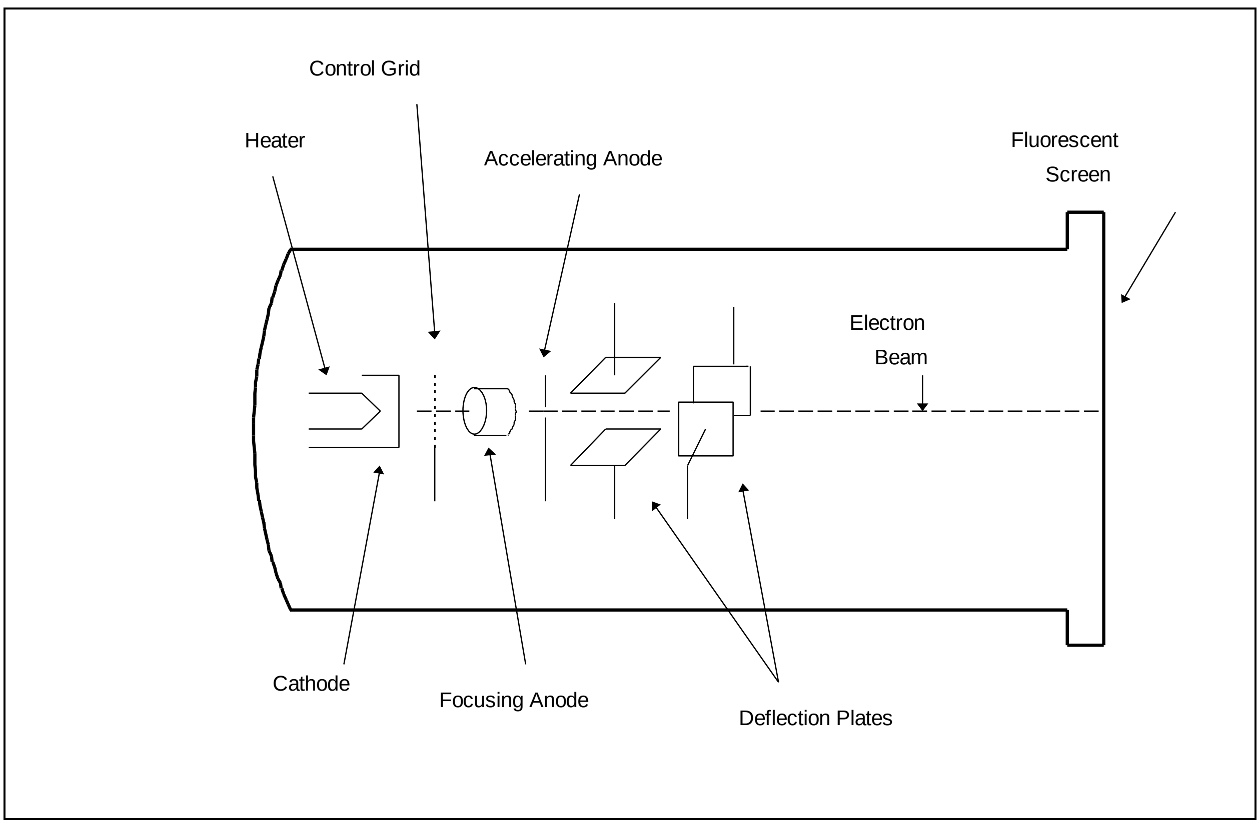

Figure 1. Elements of a Cathode Ray Tube.

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., 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 GOS620, the amplifier setting is controlled by the VOLTS/DIV knob on the front panel of the oscilloscope. 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 GOS620 the sweep generator is adjusted via the TIME/DIV knob in the front panel of the oscilloscope. The sweep of the electron beam across the screen is known as a *trace*.

Procedure

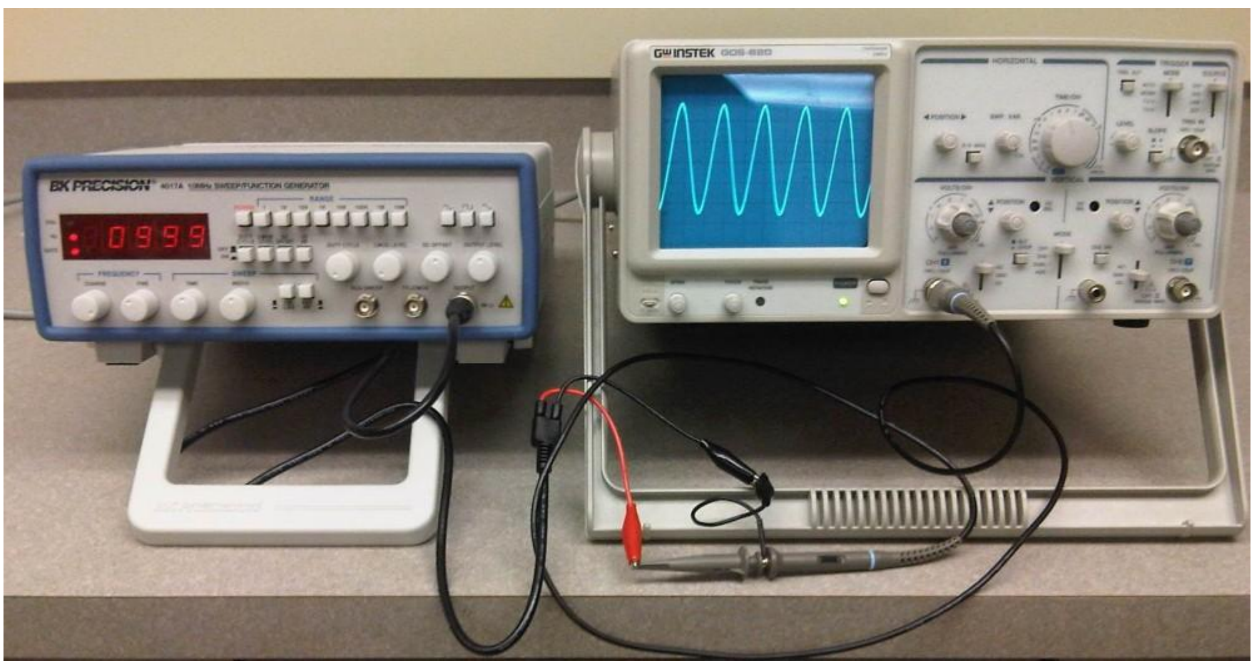

Figure 2. Function Generator and Oscilloscope.

Interpreting the Oscilloscope Display

Your instructor will help familiarize you with the operation of the GOS620 20 MHz oscilloscope by having you measure a variety of signals generated by the BK Precision model 4017A signal generator. You will use the signal generator to generate 60 Hz, 5 and 10 volt sine waves, 100 Hz, 5 and 10 volt sine waves and 1 kHz 5 and 10 volt sine waves. As you acquaint yourself with the oscilloscope, record in your lab notebook a description of each of the following controls: *graticule, vertical/horizontal position knobs, beam finder,* *volts/division (vertical sensitivity), time/division (sweep rate), calibration, probe adjust, trigger, level knob, slope switch, probe, channel selector, focus, brightness.*

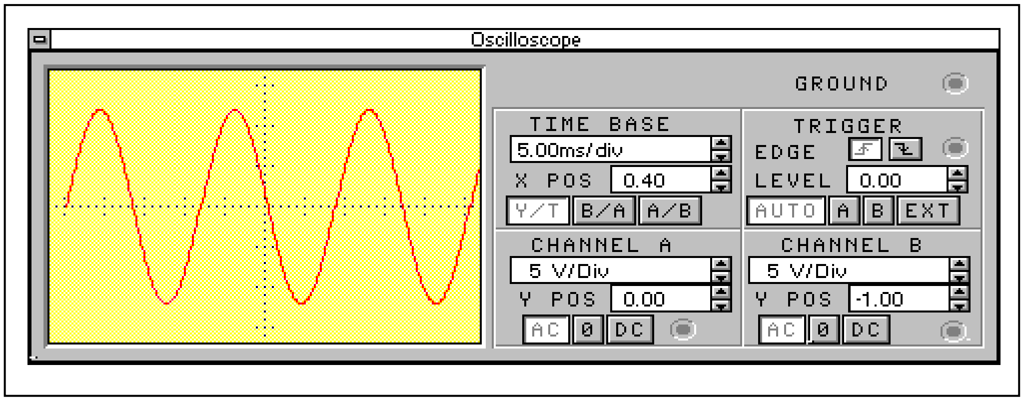

Figure 3. Oscilloscope Display.

Figure 3 shows a 62.5 Hz, 12 volt sine wave displayed on an oscilloscope. This particular oscilloscope has the vertical sensitivity set to a value of 5 volts/division and has the sweep set to a value of 5 milliseconds per division. Major divisions on the graticule are indicated by three dot patterns. By counting the number of divisions from the midpoint of the wave we may determine its amplitude (why the midpoint?) and from that the voltage of the signal. In this case there are about 2.4 divisions above or below the horizontal axis of the sine wave (its amplitude) and 2.4 divisions x 5 volts/division = 12 volts. Similarly, the wavelength for each wave is 3.2 divisions and 3.2 divisions x 0.005 seconds = 0.016 seconds (the period) and the inverse of this the frequency or 62.5 Hz. Set the function generator to generate the sine waves listed above and verify the signal parameters on the oscilloscope.

DC Measurements

Turn the oscilloscope off then connect the probe supplied with the oscilloscope to the channel 1 vertical amplifier jack. The probe that you will be using may be switched to 10x but it should not be necessary for you to do so unless your battery is very weak. Set the channel 1 vertical sensitivity to a <u>calibrated value</u> of 1 VOLT/DIV, the sweep rate (TIME/DIV) at 0.5 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 in your lab notebook. 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 in your notebook. Disconnect the battery. Switch the probe back to 1X if you had to adjust the sensitivity.

Measuring Extraneous Signals

Set the vertical sensitivity to .2 VOLT/DIV and change the sweep rate on the oscilloscope to 5 milliseconds. Touch the tip of the probe with your fingertip. You should see a roughly sinusoidal trace on the screen. Sketch this signal in your notebook and compute its frequency. You should come up with a figure around 60 Hz. What phenomena do you think is responsible for this? Hint: by touching the probe to your fingertip you are using your body like an antenna. What nearby signals might it be picking up?

Your lab instructor will show you how to connect the probe to the *probe adjust* output on the oscilloscope. Keep the vertical sensitivity at 0.5 VOLT/DIV and change the sweep rate back to 0.5 milliseconds. Compute the amplitude and frequency of the waveform on the display. What type of wave is this? Sketch it in your lab notebook.

Charging Characteristics of a Capacitor

Assemble the R-C circuit shown in Figure 4. Use the resistor and capacitor supplied by your lab instructor. The capacitors are directional and your lab instructor will show you how to install them on the board. After your instructor has checked and approved your circuit 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. Connect the high-potential lead of the power supply to the circuit 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*. When the capacitor has completely charged the potential across it is at a maximum value (as indicated by a trace near the top of the screen) but no current flows in the circuit (why?). Now disconnect the high potential lead. In this configuration the capacitor is *discharging*. When the capacitor has completely discharged (indicated by a vertical stabilization of the trace on the screen near its center) the potential across the capacitor goes to zero and no current flows through the circuit.

Wait until the beam is just beginning a new sweep and connect the high-potential lead. Observe the pattern formed by the beam as it sweeps across the screen. Discharge the capacitor by disconnecting the high potential lead and try this procedure again, several times if necessary, until you are able to sketch the pattern of the trace in your notebook. Be sure to include a sketch of the graticule and its divisions in your sketch. You will need this to make some estimates concerning the characteristics of this circuit.

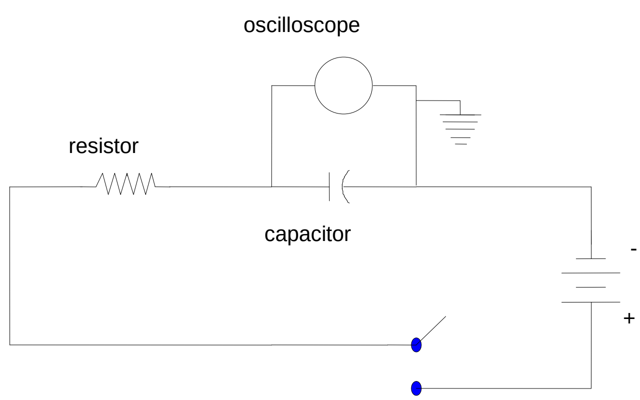

Figure 4. Circuit used for studying the charging characteristics of a capacitor.

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 $\tau = t$, $V(t) = V_0(1 - 1/e) = 0.632V_0$. This means that in a time of one time constant (1τ) the voltage across the capacitor has increased to more than 63% of its final value.

Compute the time constant of your circuit by finding the product RC. Now have a look at the sketch of the oscilloscope trace in your lab notebook. How does the curve you have sketched compare the theoretical curve? Does the computed time constant appear to correlate to the curve in your lab notebook? About how many time constants does it take for the capacitor to fully charge?

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 $\tau = t$, $V(t) = V_0/e = 0.368\,V_0$ or 37% of the original voltage. Repeat the above procedure while discharging the capacitor. Sketch this curve in your lab notebook. How does this curve compare with what theory predicts?

Exercises

1. What, physically, does an oscilloscope measure?

2. Explain the basic operation of a Cathode Ray Tube.

3. Show that the RC time constant, τ, has units of time.

4. What does the calibration setting on the vertical and horizontal sensitivity controls do?

5. What, physically, do you think explains the charging and discharging curves of a capacitor? Specifically, why does it take longer to add additional charge on the plates of the capacitor (as shown by the slow growth of voltage) as time grows?

6. For an R-C circuit,

Given:

$$I(t) = \frac{V}{R} e^{-\frac{t}{RC}}$$

Show:

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