Laboratory: The *RC* Time Constant

Objectives

- ✓ Investigate the time needed to discharge a capacitor in an *RC* circuit.
- ✓ Demonstrate an *RC* circuit decays with at an exponential rate.
- ✓ Measure the voltage across a resistor as a function of time in an *RC* circuit as a means to determine the *RC* time constant.

Equipment List

- (1) Oscilloscope (a.k.a. scope)
- (1) Function Generator (FG)
- (1) Resistance Decade Box
- (1) Capacitance Decade Box
- (2) BNC/Banana Jack Adaptors
- Electrical leads with banana jack plugs.

Background

An *RC* circuit is a series circuit with a capacitor and resistor in series with a power source, in this case, a Frequency Generator (FG) as shown in Figure 1. When a fully charged capacitor is discharged through a known resistor, with the power source turned off, the voltage drop across the circuit will decay with time. The decay of the electric potential follows the equation

$$V = V_0 e^{-t/\tau}$$

where τ represents the time constant of a *RC* circuit. The time constant is a function of the resistance and capacitance of the circuit

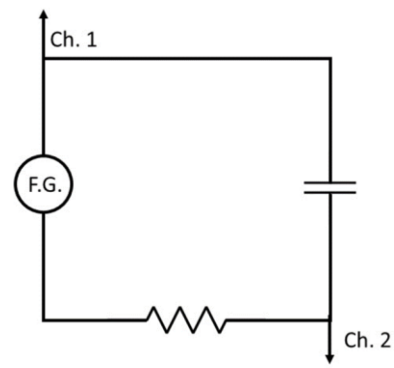

Figure 1 *RC* Circuit with Frequency Generator

$$\tau = RC$$

After time equal to one time constant $t = \tau$, the electric potential equation above becomes:

$$V = V_0 e^{-\tau/\tau} = V_0 e^{-1}$$

Since $e^{-1} \approx 0.37$, the potential across the capacitor has decreased to 37% of V_0. A typical graph of an RC circuit discharging showing electric potential with respect to time is shown in Figure 2.

In this laboratory we will be measuring the time it takes the voltage to decrease to 37% of its original value. This parameter is too fast to measure with a stopwatch, so we must leave the power supply on long enough to reach the steady-state-decay condition and use the decay graph as replicated on the oscilloscope (scope) screen to determine the time. The voltage will decay as shown in Figure 2. The exponential curve is dependent on the time constant $\tau = RC$.

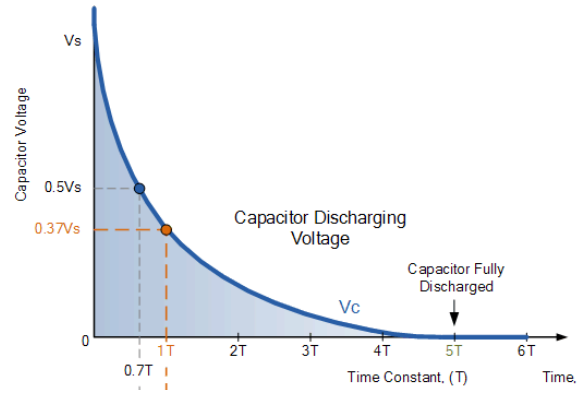

Figure 2 Potential Exponential Decay Curve

The objective of this laboratory is to be able to experimentally measure the value of the time constant for a given series *RC* circuit, then compare that to a calculated value of τ using the known Resistance and Capacitance values and using $\tau = RC$.

The oscilloscope has many capabilities as well as knobs and buttons. To facilitate this lab, an image from the user manual is shown in Figure 3. In the appendix, at the end of this lab, is a brief description of some of the controls, as described in the user manual.

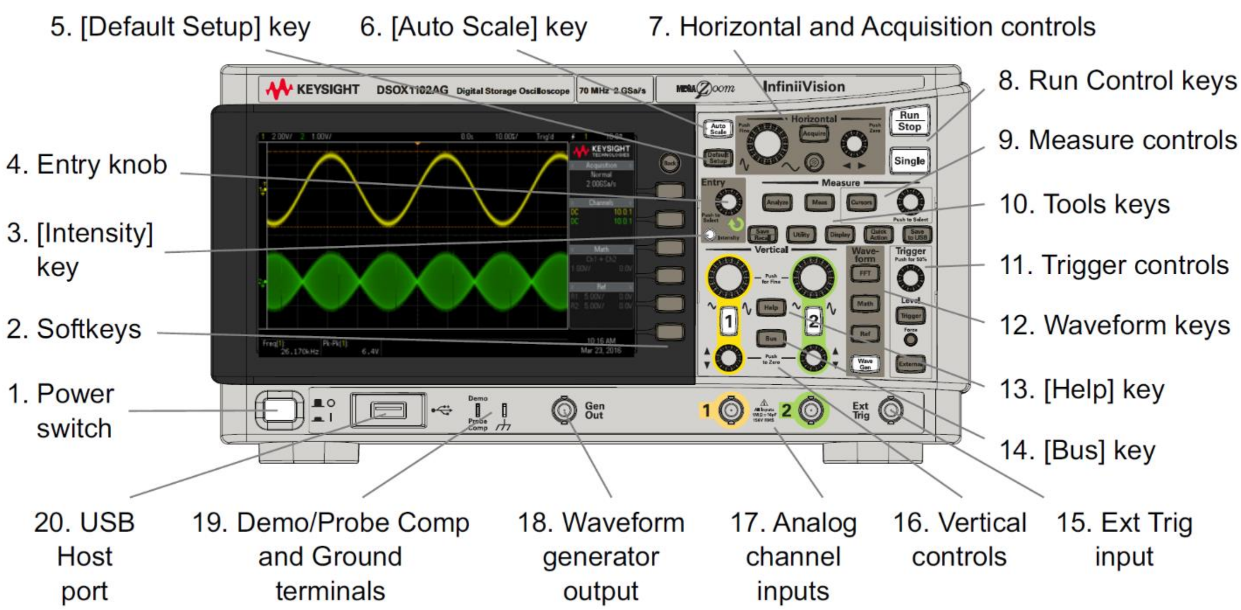

Figure 3 Keysight Oscilloscope

Setup Procedure

Work in groups of three or four people. Proper units must be on ALL quantities for credit!

CAUTION: To avoid damage to the equipment, disconnect all powered devices from power and their verify switches are in the OFF position until your instructor verifies your circuit.

1. Create an *RC* series circuit (Figure 1) by installing the electrical connectors from the positive port (red) of each device to the negative port (black) of the next device, moving clockwise around the schematic. Ignore the references to Ch. 1 and Ch. 2 at this time.

2. Configure the resistance and capacitance boxes to the first configuration of settings indicated in the Excel template.
3. Attach the BNC/Banana Jack adaptors to the analog channels of the scope (#17 in Figure 3).
4. From channel 1 of the scope, install (2) electrical leads into the red and black ports. Install the other ends into the top of the plugs on the FG.
5. Connect an electrical lead into the red plug of channel 2. Connect the other end into the electrical connector the joins the resistance box to the capacitance box.
6. STOP! Have your instructor verify your setup before proceeding.
7. Plug in the scope and FG to the 120-VAC power supply.
8. Turn on the FG and set it the Square Wave.
9. Turn on the scope. Enable channels [1] and [2]. The buttons are in the **Vertical** group of the scope (#16 in Figure 3).
10. In the **Run Control keys** group, the **[Run/Stop]** key should be green, indicating it is acquiring data. If it is red, press the **[Run/Stop]** key.
11. Press the [Auto Scale] key (#6 in Figure 3). Your screen on the scope should resemble Figure 4. If it does not, consult your instructor.
12. In the **Measure controls** group (#9 in Figure 3), use the cursor knob to position cursor X1 at the peak voltage of the discharge curve (near the center of the screen).
13. Adjust the voltage amplitude of the FG until X1 voltage is approximately 100 V. This will be the yellow measurement at the bottom of the screen. NOTE: the scope scales the voltage by a factor of 10:1. The FG is only capable of generating a ±7.5 V signal (i.e., 15 V potential difference).

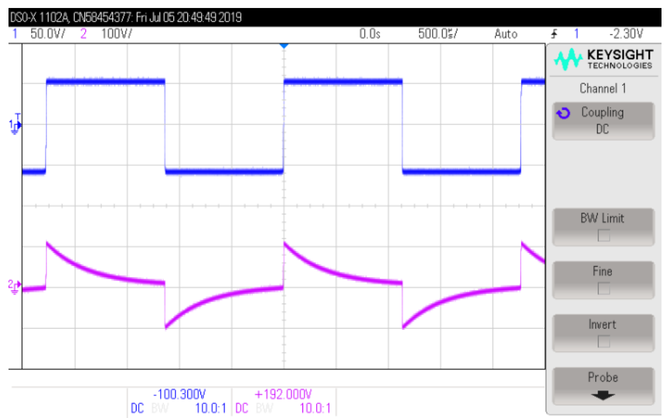

Figure 4 Example of Square Wave and Decay

14. Disable channel [1] to facilitate screen viewing. Press the [Auto Scale] key (#6 in Figure 3). Your screen on the scope should resemble Figure 5.
15. In the **Run Control keys** group, press the **[Single]** key (#8 in Figure 3). This will prevent the scope from continuously updating the display with new decay curves.
16. Calculate the time-delay constant τ for this RC circuit ($\tau = RC$).
17. In the **Measure controls** group (#9 in Figure 3), use the cursor knob to position cursor X2 to a time equal to the time associated with X1 plus the time-delay constant τ.

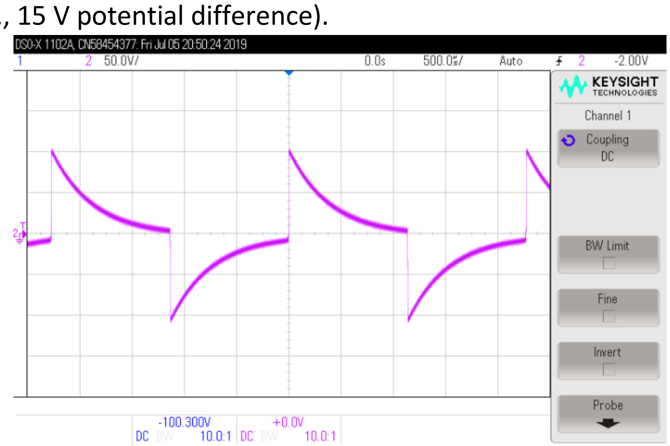

Figure 5 Example of Potential Decay Curve

18. STOP! Have your instructor verify your setup!

19. In the **Measure controls** group (#9 in Figure 3), use the cursor knob to configure the cursor setting to move X1-X2 together as a window.

Experimental Procedure (Group – 50%)

1. Move the cursor window so X1-Y1 is at the peak voltage (start of the decay). Record X1, X2, Y1, and Y2 in the data table.
2. Move the cursor window so X1 is at 100 μs. Record X1, X2, Y1, and Y2 in the second row of the data table.
3. Repeat step 2 until the entire table is complete.
4. Generate a scatterplot in Excel. Plot V_1 on the x-axis and V_2 on the y-axis. Add a best-fit linear trendline. Display the best-fit equation, allowing the constant. Size and place the plot over the area indicated on the worksheet.
5. Record the slope in the indicated field above the plot. Calculate the %-error with respect to e^{-1}.
6. In the 2nd data table, calculate the natural log of each of the initial electric potentials ($\ln V_1$).
7. Generate a scatterplot in Excel. Plot t_1 on the x-axis and $\ln V_1$ on the y-axis. Add a best-fit linear trendline. Display the best-fit equation, allowing the constant. Size and place the plot over the area indicated on the worksheet.
8. Record the slope in the indicated field above the plot. Calculate the %-error with respect to theoretical time constant τ.
9. In the 3rd data table, calculate the instantaneous current I that is flowing at each recorded time t (Hint: remember Ohm's law!).
10. Generate a scatterplot in Excel. Plot t_1 on the x-axis and current I on the y-axis. Size and place the plot over the area indicated on the worksheet.
11. Repeat this entire procedure for each of the (3) remaining *RC* combinations.

Appendix

[Auto Scale] key — When you press the [AutoScale] key, the oscilloscope will quickly determine which channels have activity, and it will turn these channels on and scale them to display the input signals.

Cursors knob — Push this knob select cursors from a popup menu. Then, after the popup menu closes (either by timeout or by pushing the knob again), rotate the knob to adjust the selected cursor position.

[Single] key — To capture and display a single acquisition (whether the oscilloscope is running or stopped), press [Single]. The [Single] key is yellow until the oscilloscope triggers.