EXPERIMENT 8

Electrical Measurements: First-Order Transient Circuits

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The objectives of this experiment are to:

- Learn how to make measurements using an oscilloscope
- Learn how to experimentally determine the time constant of a first-order circuit
- Gain experience relating mathematical solutions to differential equations to real-world applications

I. Introduction

Previously, we have utilized a multimeter to measure voltage, current, and resistance in electrical circuits. The oscilloscope is another basic instrument used to measure electrical quantities in a system and is an indispensable tool for an electrical, computer, or wireless engineer. An oscilloscope receives an electrical signal and converts it to a waveform that is displayed on a screen.

A sample oscilloscope display is shown in Figure 1. The waveform in the display shows the variation in voltage with time and is plotted on a graphical grid called a graticule. The vertical or y-axis of the graticule typically represents voltage, while the horizontal or x-axis typically represents time.

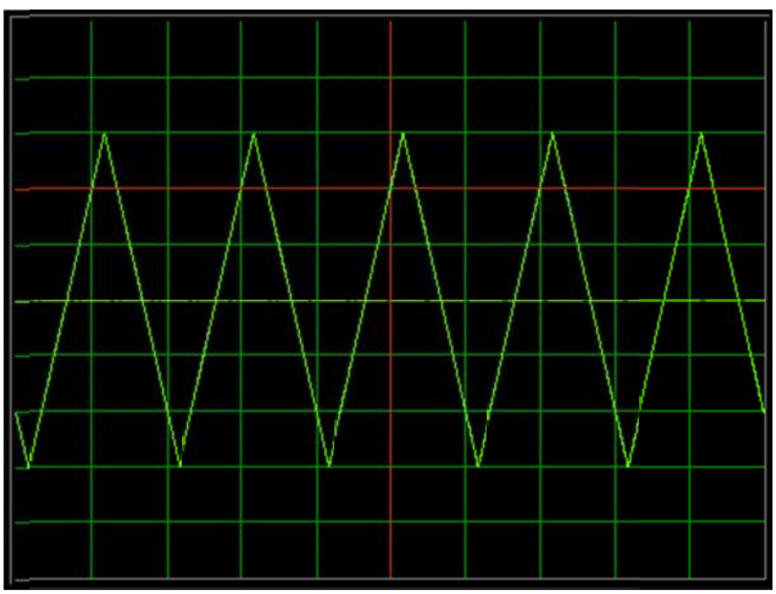

Figure 1: Sample Oscilloscope Display

The NI ELVIS board is connected to your computer which contains the NI Instrument Launcher software that gives you access to multiple measurement instruments. One of these instruments is an oscilloscope (“Scope”). Figure 2 is an overall view of the front panel. The pushbuttons to the right of the display are used to change various options in the menus. The different menu options are briefly described below.

- The Channel 0 and Channel 1 settings allow the user to adjust the following:
  - The dropdown menu, “Source”, indicates what ports on the NI ELVIS board to measure using the oscilloscope (for these labs, you will be using “AI0”, “AI1”, etc.)
  - Checking and unchecking the box “Enabled” enables the user to toggle between whether or not that Channel’s waveform is displayed.
  - When the Source is selected as "SCOPE CH #", one can adjust the “Coupling” between “DC”, “AC”, and “Ground”. The coupling feature is unavailable when using any of the AI’s as inputs.
  - The “Scale Volts/Div” knob allows the user to adjust the y-axis scale. Each horizontal line on the graticule represents one division.
  - The “Vertical Position (Div)” knob allows the user to adjust the position of the waveform vertically.

- The "Time/Div" knob allows the user to adjust the x-axis scale. Each vertical line on the graticule represents one division.

- The “Trigger” menu allows the user to control the triggering of the oscilloscope. Three types of triggering are available: immediate, digital, and edge. The oscilloscope display is triggered at the edge of the input signal if the edge triggering is selected. One is also allowed to pick at what level the trigger occurs and whether it will be on a falling or rising edge.

- The trigger settings will typically be used in conjunction with the “Acquisition Mode”. The user is allowed to choose between “Run Continuously” and “Run Once”.

- The “Autoscale” button automatically adjusts the oscilloscope controls (Volts/Div and Time/Div) to produce a usable display of the input signal. This usually only works well for periodic signals.

- The “Run” and “Stop” buttons allow the user to start and stop waveform acquisition.

- Toggling the “Cursors On” box allows access to the cursor menu and measurement cursors. The amplitude of a signal at particular time samples can be measured individually. One may also measure the difference in time between the two cursors. The cursors can be toggled between the two channels (CH0 and CH1), having either both measuring the same channel or one measuring on each.

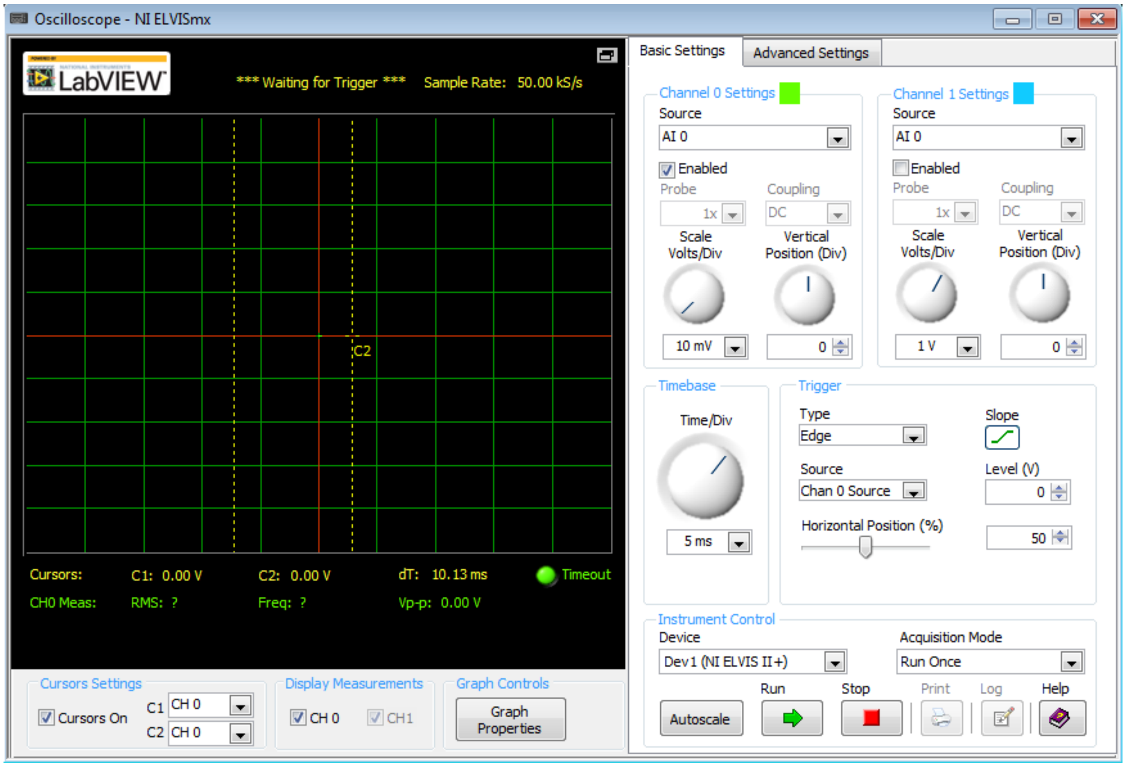

Figure 2: NI's Oscilloscope Front Panel

Another instrument in NI ELVIS's Instrument Launcher is the Function Generator (FGEN). Selecting "Function Generator" will cause its front panel to open and give you the ability to

- set the frequency of the output signal
- select the waveform including sine wave, square wave, and triangular wave
- select the waveform amplitude
- select the DC Offset of the waveform

II. Lab Exercises

1) On your computer, open the Function Generator under the NI ELVIS Instrument Launcher. Adjust yours to match the settings as shown in Figure 3. With these settings, the voltage on your prototyping board from FGEN to GROUND can be described as $v(t) = 2 + 5\cos(377t + 0^{\circ})$ V. Measure this function on the NI ELVIS Oscilloscope. To do this,
   - On the breadboard, connect FGEN to AI0+ and GROUND to AI0-.
   - On the oscilloscope front panel, set Channel 0 Source to "AI 0".
   - Turn on the NI ELVIS board and hit "Run" on both the function generator and oscilloscope.

- On the oscilloscope front panel, change the Trigger "Type" to "Edge". With periodic signals such as this one, the "Autoscale" button usually chooses adequate selections for the Volts/Div and Time/Div settings. Press "Autoscale".

Record the oscilloscope measurements for the frequency and peak-peak voltage. Click the box in the bottom left corner to turn "Cursors On", and set both cursors to measure on "CH 0". Use the two cursors to measure and record the minimum and maximum values of the waveform. Take a screenshot of the measured waveform with the cursors on and provide it in your lab report.

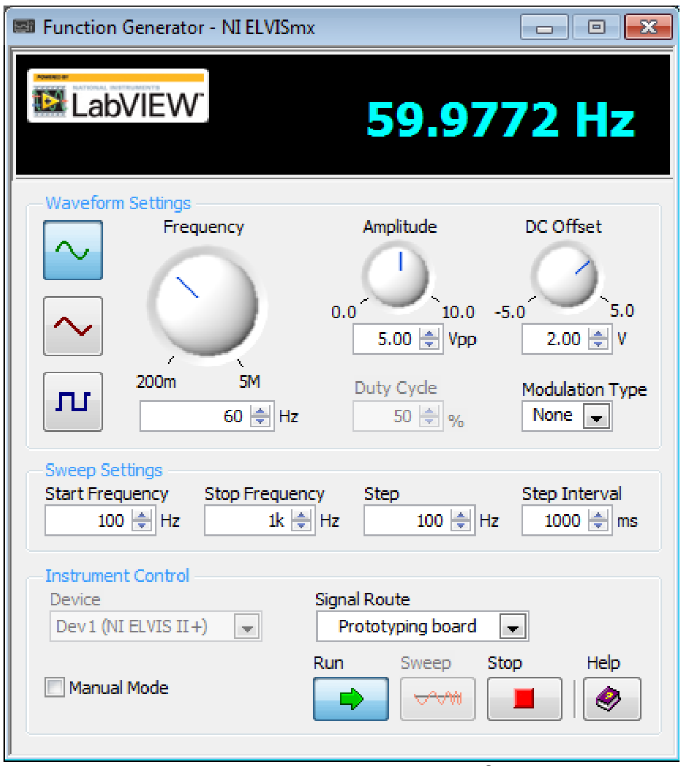

Figure 3: Function Generator Settings for Exercises 1-3

2) The trigger "Level" is selected in the box on the right side of the oscilloscope settings. Adjust the trigger level to 4.4V. Now change it to -0.3V. Now change it to 2V. Now change the slope from rising edge () to falling edge (). Describe what happens as the trigger level is varied. Now change the trigger level to 4.7V. After several seconds, the measured signal should disappear and nothing will be measured. Why? If you're still not sure what the trigger level does, try using the arrows to slowly increment the trigger level up and down.

3) Change the trigger level back to 2V. Now vary the Volts/Div knob for Channel 0. Press the "Autoscale" button again. Now vary the Time/Div knob under the "Timebase" label. Based on your observations, what do the Volts/Div and Time/Div knobs do? Press the Autoscale button again and "Stop" the oscilloscope and function generator.

NOTE: Disconnect and close the FGEN window - you will not need it for the remaining exercises.

4) Figure 4 shows a circuit with a charging capacitor. The capacitor's charging voltage transient solution will be of the form

$$v_C(t) = k_1 + k_2 e^{-t/\tau_1}\,\text{V}, \text{ for } t>0$$

<u>Solve</u> for k_1, k_2, k_1+k_2, and τ_1 in terms of Vs, R1, R2, and C.

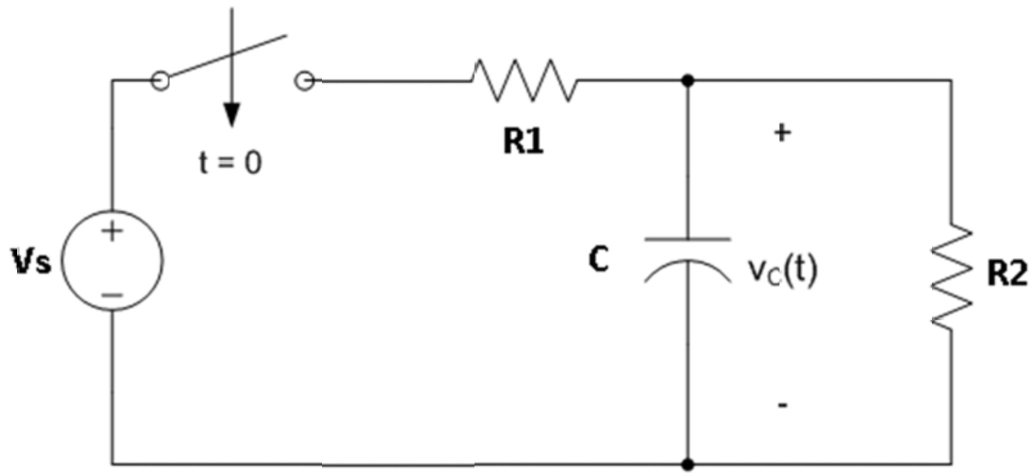

Figure 4: Charging

5) Figure 5 shows a circuit with a discharging capacitor. The capacitor's discharging voltage transient solution will be of the form

$$v_C(t) = k_3 + k_4 e^{-t/\tau_2}\text{ V, for } t>0$$

<u>Solve</u> for k_3, k_4, k_3+k_4, and τ_2 in terms of Vs, R1, R2, and C.

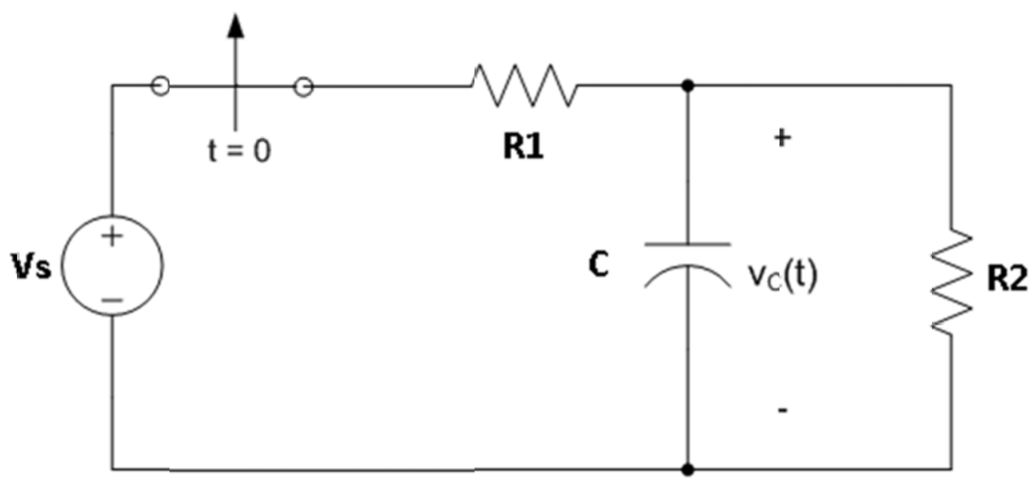

Figure 5: Discharging

For Exercises 6 & 7, wire up ELVIS's 15 V DC power supply (which is usually closer to 15.5 V) in series with the provided switch via the ELVIS's "BANANA" ports as shown in Figure 6.

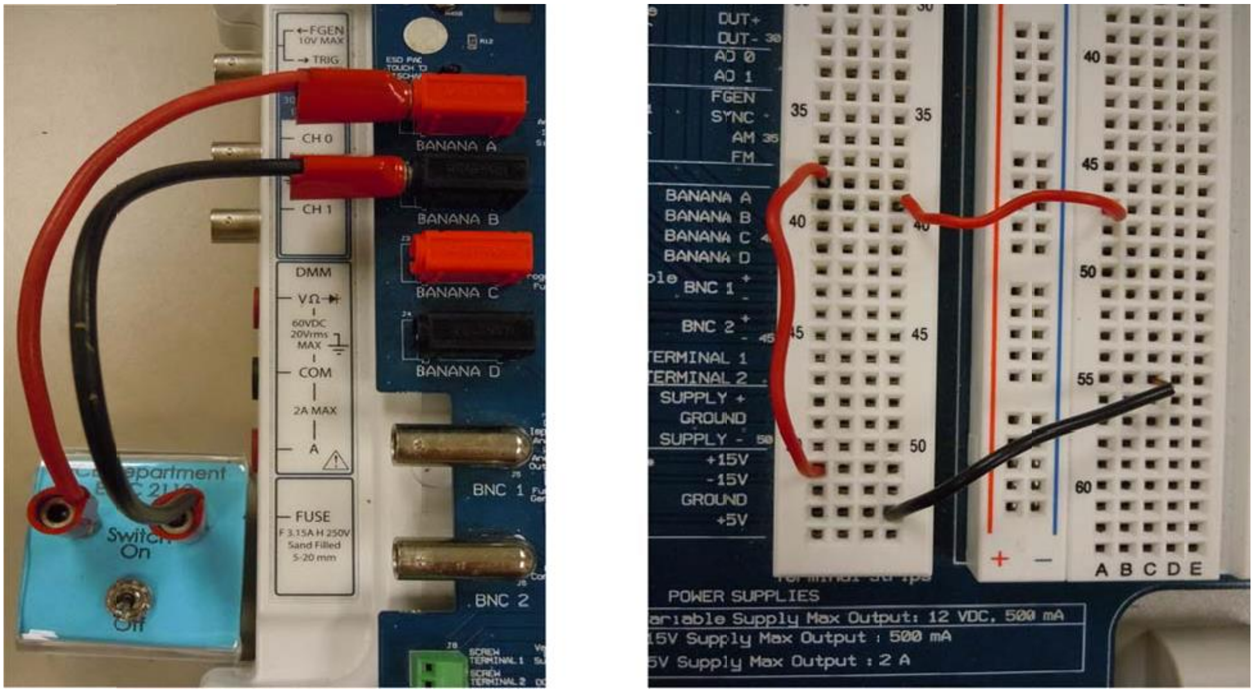

Figure 6: Wiring the Switch through ELVIS's BANANA Ports

6) Construct the capacitor charging circuit in Figure 4 on the ELVIS breadboard using

- Vs = 15.5 V (<u>measure</u> the exact value)
- R1 = R2 = 330Ω (<u>measure</u> the exact values before breadboarding)
- C = 10uF (these electrolytic capacitors are polarized; the lead on the stripped side is the negative)

Using the above values and your results from Exercise 4 (the charging transient), <u>calculate</u>

- the initial voltage across the capacitor, $v_C(0) = k_1 + k_2$
- the final voltage across the capacitor, $v_C(\infty) = k_1$
- the time constant, τ_1

Now use NI ELVIS's Oscilloscope to measure and capture $v_C(t)$'s charging transient. When you want to capture a signal on the oscilloscope that only occurs once, you must change the "Acquisition Mode" to "Run Once". Since this is the charging transient, the trigger will need to search for a rising slope. After a signal is detected at the set trigger "Level", one collection of measurements is displayed on the oscilloscope screen, centered on the trigger level. Use your calculated values to estimate good settings for the trigger "Level", the "Volts/Div", and the "Time/Div". Pick these values to make sure your plot

- displays the voltage's initial and final value, which happens around 5 to 6 τ_1 (i.e., don't have *too small* a Volts/Div or a Time/Div)
- displays the curve of the transient and is not just a straight vertical line (i.e., don't have *too large* Volts/Div or a Time/Div)

It may take you a few tries to get a "nice looking" plot (Figure 7 shows a decent example of "nice looking"). Once you do, use the oscilloscope's cursors to measure the following:

- the steady-state voltage across the capacitor , $v_C(\infty) = k_1$
- the time constant, τ_1 (i.e., the time from when the switch is closed to the time when $v_C(t) = 0.632 * v_C(\infty)$ ← You'll have to calculate that value.)

Include a screen shot of your oscilloscope with $v_C(t)$'s charging transient and the cursors measuring the time constant (C1 at $v_C(0)$ and C2 at $v_C(\tau)$, $dT=\tau_1$). Your plot should resemble the one shown in Figure 7, but make sure your screenshot includes the scope's entire front panel.

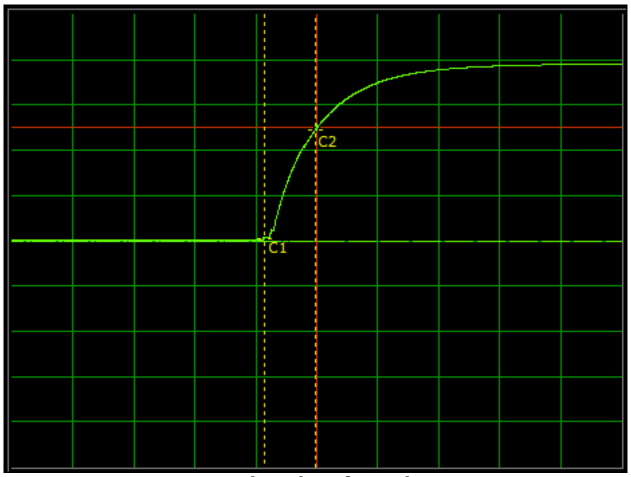

Figure 7: Example Plot for Charging Circuit

7) All the above calculations and measurements need to be repeated for the discharging circuit shown in Figure 5. Using your results from Exercise 5 (the discharging transient), calculate

- the initial voltage across the capacitor, $v_C(0) = k_3 + k_4$
- the final voltage across the capacitor, $v_C(\infty) = k_3$
- the time constant, τ_2

Now use NI ELVIS's oscilloscope to measure and capture $v_C(t)$'s discharging transient. When you want to capture a signal on the oscilloscope that only occurs once, you must change the "Acquisition Mode" to "Run Once". Since this is the discharging transient, the trigger will need to search for a falling slope . Use your calculated values to estimate good settings for the trigger "Level", the "Volts/Div", and the "Time/Div". Pick these values to make sure your plot

- displays the voltage's initial and final value (i.e., don't have *too small* a Volts/Div or a Time/Div)
- displays the curve of the transient and is not just a straight vertical line (i.e., don't have *too large* Volts/Div or a Time/Div)
- NOTE: These oscilloscope settings will most likely not be the same as the previous exercise.

Figure 8 gives you a decent example of a "nice looking" plot. Once yours looks similar, use the oscilloscope's cursors to measure the following:

- the initial voltage across the capacitor, $v_C(0) = k_3 + k_4$

- the time constant, τ_2 (i.e., the time from when the switch is opened to the time when $v_C(t) = 0.368 * v_C(0)$ ← You'll have to calculate that value.)

Include a screen shot of your oscilloscope with $v_C(t)$'s discharging transient and the cursors measuring the time constant (C1 at vC(0) and C2 at vC(τ), $dT=\tau_2$). Your plot should resemble the one shown in Figure 8, but make sure your screenshot includes the scope's entire front panel.

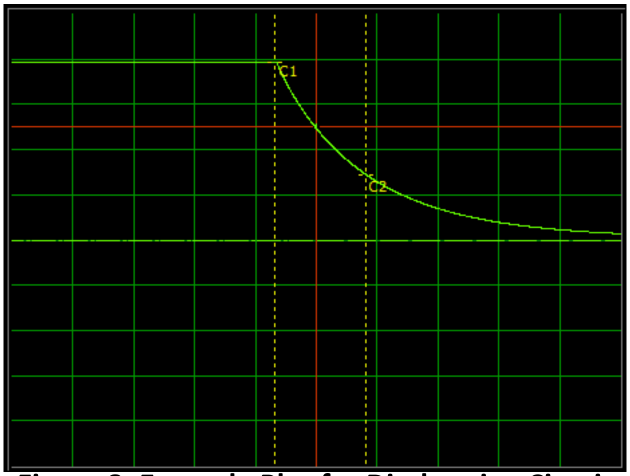

Figure 8: Example Plot for Discharging Circuit

8) Repeat Exercises 6 & 7 with

- Vs = 15.5V
- R1 = R2 = 1kΩ (measure the exact values before breadboarding)
- C = 10uF (should be the same as previous exercise)

9) Repeat Exercises 6 & 7 with

- Vs = 15.5V
- R1 = 1kΩ
- R2 = 330Ω
- C = 10uF (should be the same as previous exercises)

10) Once you have made all calculations, measurements, and screen shots, answer the following (you probably want to put a table together):

- Compare the final voltage, $v_C(\infty)$, across the charging capacitor for Exercises 6, 8 and 9. Why is one smaller, larger, or the same as the others? (i.e., What about the circuit "drives" what the final voltage will be?)
- Compare the charging time constant (τ1) for Exercise 6, 8, and 9. Why is one smaller, larger, or the same as the others? (i.e., What about the circuit "drives" what the charging time constant will be?)
- Compare the discharging time constant (τ2) for Exercise 7, 8, and 9. Why is one smaller, larger, or the same as the others? (i.e., What about the circuit "drives" what the discharging time constant will be?)