7.2.1: Passive RC Circuit Natural Response

Overview:

In this lab assignment, we will examine the natural response of a simple RC circuit. We will use both a manual switching operation and a square wave voltage source to create our circuit's natural response. We will see that the method used to create the response affects the circuit being measured.

Before beginning this lab, you should be able to:

- Determine the time constant of exponential functions
- Determine the natural response of passive RC circuits
- Correctly implement an electrolytic capacitor (Lab 6.3.2)
- Use the Analog Discovery waveform generator to apply a time-varying voltage input to an electrical circuit (Lab 6.2.1)
- Use the Analog Discovery oscilloscope to measure and display time-varying waveforms

After completing this lab, you should be able to:

- Use a manual switching operation to create the natural response of a first order circuit
- Use the trigger on the Analog Discovery oscilloscope to acquire a signal
- Be able to explain in your own words the difference between continuous and single-sequence data acquisition
- Use the Analog Discovery waveform generator to create the natural response of a first order circuit.
- Measure the initial condition and time constant of a first order circuit natural response

This lab exercise requires:

- Analog Discovery module
- Digilent Analog Parts Kit

Symbol Key:

DEMO — Demonstrate circuit operation to teaching assistant; teaching assistant should initial lab notebook and grade sheet, indicating that circuit operation is acceptable.

ANALYSIS — Analysis; include principle results of analysis in laboratory report.

SIM — Numerical simulation (using PSPICE or MATLAB as indicated); include results of MATLAB numerical analysis and/or simulation in laboratory report.

DATA — Record data in your lab notebook.

General Discussion:

The basic RC circuit being used in this assignment is shown in Figure 1. We will be interested primarily in the measured vs. expected behavior of the capacitor voltage, $v_c(t)$. Initially, the voltage applied to the RC circuit is 5V. We obtain the natural response of the RC circuit by changing the applied voltage to 0V instantaneously at time $t = 0$. The natural response of the capacitor voltage is $v_c(t)$, t>0.

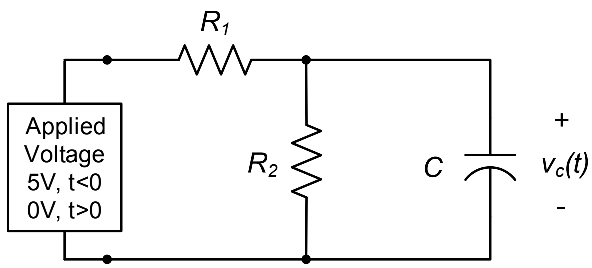
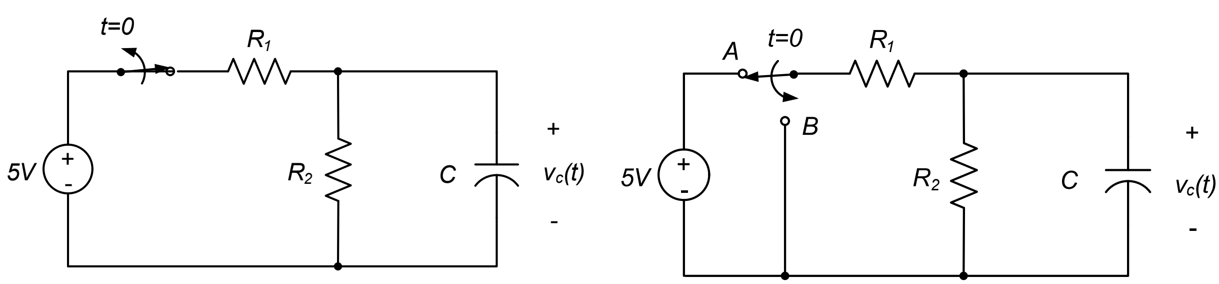


Figure 1. Basic RC circuit.

The way in which we reduce the applied voltage in Figure 1 from 5V to 0V can have an effect on the circuit's natural response. In this lab assignment, we will use two different approaches to the switching process involved in changing the applied voltage:

a. We will use a voltage source to apply the initial 5V, and physically open a switch to reduce the applied voltage to 0V. This will result in the circuit as shown in Figure 2(a). Notice that in Figure 2(a), the voltage source is replaced by an open circuit.

b. A voltage source will be used to apply the 5V source, as above. However, in order to reduce the applied voltage to 0V, we will simply turn off the voltage source. This approach will result in the circuit shown in Figure 2(b). Notice that in Figure 2(b), the voltage source is replaced by a short circuit.



Voltage change from switching *(b) Voltage change by turning "off" source.*

Figure 2. Models of physical approaches to reducing applied voltage.

Pre-lab:

ANALYSIS Estimate the initial capacitor voltage, $v_c(t<0)$, and the time constant for the circuits of Figures 2(a) and 2(b). Your solutions may be functions of R_1, R_2, and C.

Lab Procedures:

DATA

a. Construct the circuit shown in Figure 1, using R_1=1kΩ, R_2=2.2kΩ, and C = 22µF. (As always, measure the actual resistance value; measure the capacitance value if you have the appropriated instrument – some DMMs have a capacitance meter – otherwise, assume that the nominal capacitance value is correct.)

DATA

i. Use the Analog Discovery oscilloscope to measure the capacitor voltage $v_C(t)$ and use V+ on the Analog Discovery to apply a 5V source to the circuit. While acquiring data with the oscilloscope, quickly disconnect the power supply from your circuit. Record an image of the oscilloscope window, showing the response $v_C(t)$ of the capacitor voltage after the power is disconnected. <u>The data acquisition process can be difficult unless you use the oscilloscope's trigger to acquire a single sequence of the data. Brief instructions for doing this are in Appendix A of this lab assignment, more detailed instructions are provided in the on-line tutorials on Digilent's website</u>.

DEMO

ii. Demonstrate operation of your circuit to a teaching assistant and have them initial your lab notebook and the lab checklist.

ANALYSIS

iii. Estimate the time constant of the circuit from your measured data. Compare this result with your expectations based on your pre-lab analysis and the measured values of R_1, R_2, and C. Calculate a percent difference between the expected and measured time constants. Comment briefly on your results.

b. Still using the circuit shown in Figure 1, (with R_1=1kΩ, R_2=2.2kΩ, and C = 22µF as in part a), use a square wave with an amplitude of 2.5V and an offset of 2.5V to create a square wave that oscillates between 0V and 5V. We will be using this square wave to implement a transition between 5V and 0V; use a very low frequency, 1Hz or so[1].

DATA

i. Record an image of the oscilloscope window, showing the response $v_C(t)$ of the capacitor voltage after the applied voltage goes to zero. Again, it is suggested that you use a trigger to assist in the data acquisition. The trigger settings from part (a) should also be appropriate for this section, but you may want to acquire the data differently. This is presented in Appendix B of this assignment.

DEMO

ii. Demonstrate operation of your circuit to a teaching assistant and have them initial your lab notebook and the lab checklist.

ANALYSIS

iii. Estimate the time constant of the circuit from your measured data. Compare this result with your expectations based on your pre-lab analysis and the measured values of R_1, R_2, and C. Calculate a percent difference between the expected and measured time constants. Comment briefly on your results.

[1] Since we really just want to turn "off" the voltage once after charging the capacitor, we want our square wave to be "on" and "off" for long times relative the time required for the circuit to respond. Typically, a "long" time is considered to be at least five times the time constant of the circuit. You can use this fact, along with your calculated time constant based on the pre-lab, to choose a square wave frequency yourself if you want.

Appendix A – Triggering and Single Acquisition

The *trigger* essentially defines where on the horizontal axis "zero" time occurs. The trigger point is commonly set by a particular feature on the waveform being measured. The basic trigger controls on the oscilloscope toolbar are shown in Figure A1. These controls allow you to choose the trigger mode, the source, the condition, and the trigger level. Additional trigger controls are available by clicking on the **View** option on the oscilloscope menu bar and selecting the **Advanced Trigger** option.

Figure A1: Basic trigger controls.

Options for the primary trigger controls consist of the following:

- *Trigger mode:* basic options are **Normal**, **Auto**, or **None**. For this lab, we will use **Normal.**
- *Source:* Choose the channel which controls the trigger. A wave form feature on this channel will determine zero time.
- *Cond* and *Level:* These options specify the waveform feature used to set the trigger. *Cond* specifies a condition on the trigger – this is either **Rising** or **Falling**. If Rising is chosen, the trigger will set when the signal is increasing; Falling results in the trigger being set when the signal is decreasing. *Level* sets a voltage level for the trigger. In Figure A2, example settings for this lab are shown. In this example, the trigger is set to activate when the signal first reaches 1V and is decreasing[2] (**Falling**). Figure 2 shows that zero time on the horizontal axis corresponds to this condition on the wave form.

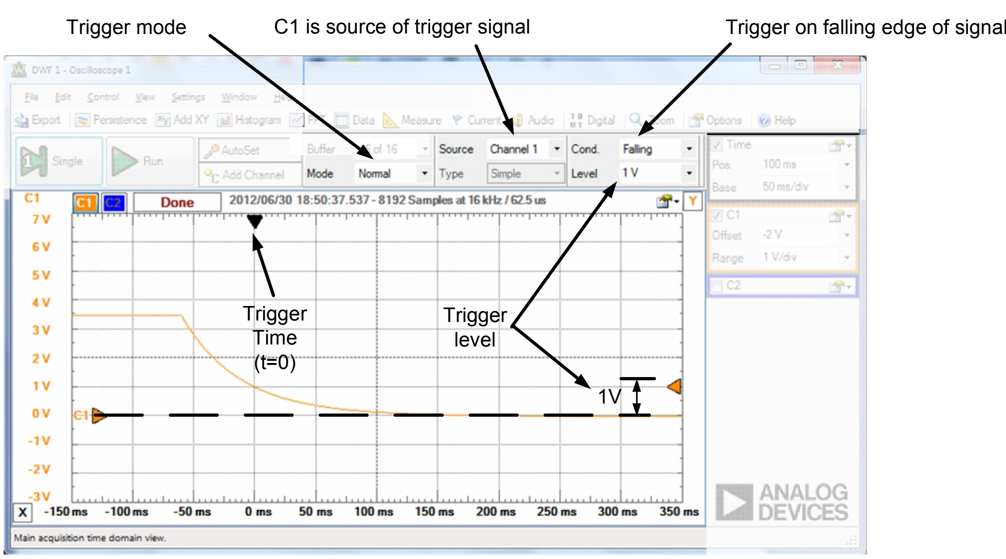
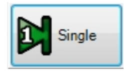


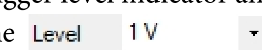
Figure 2. Example trigger settings and resulting waveform.

[2] Since the natural response will decrease, it would be useless to try to trigger on a rising condition. This will only cause the scope to trigger when – and if – we turn the power back on.

After you have set up the trigger, you can acquire the data. For part (a) of the lab procedures, we will generate a single natural response – once this response is generated, we want to display it in the oscilloscope window and freeze it there. <u>We do not want to continue to display data after the response has decayed to zero</u>. To generate a single screen of data and then stop acquiring additional data, click on the 

button on the scope instrument.

It will be worth your time, at this stage, to spend some time playing around with the trigger controls. Especially try changing the trigger point and the trigger level, as discussed below:

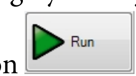
- Notice that the trigger point is denoted in the plot window by the black inverted triangle at the top of the plot window, ▼. The position of the trigger can be set by the *Pos* value in the time axis setting box, or by clicking on the trigger indicator (▼) with your left mouse button and dragging the trigger point to the desired position. Try it and observe its effect on the display.
- If the trigger source is one of the oscilloscope channels, the trigger level is shown on the plot window by the trigger level indicator – this is a triangular symbol of the same color as the trigger source channel on the right side of the plot window. For example, if the trigger source is channel 1, the indicator will be . The trigger level can be adjusted by clicking with your left mouse button on the trigger level indicator and dragging the indicator to the desired location or by changing the trigger level in the 

box.

Appendix B – Continuous Acquisition

In part (b) of these procedures, we are using the waveform generator to apply voltage to the circuit. The waveform generator continuously applies the selected waveform to your circuit, so the input to the circuit is a series of on/off steps which lasts as long as the waveform generator is running. In this case, we can use single-sequence acquisition as we did in part (a) and display the result of one arbitrary sample of turning power to the circuit off. However, it is more typical to use continuous acquisition of the waveform.

At small time scales on the oscilloscope, the oscilloscope is essentially taking a series of "frames" of data and successively displaying them in the main scope window[3]. If the waveform is repetitive, triggering allows us to assign a "zero time" to a particular feature on the signal. That feature gets placed on the same point on the plot window every time the oscilloscope screen updates; if the signal repeats itself based on this feature, the oscilloscope will display the same section of the signal every time the screen updates, making the signal appear to be unchanging.

To continuously acquire data for part (b) of this lab, set your trigger point to be as you desire. (The same settings as you used in part (a) should work, though you may feel like modifying them.) Apply power to your circuit using the waveform generator and then click on 

. The data should be displayed in the window. The waveform displayed should appear to be unchanging, but it is actually being updated at rapid intervals – the successive waveforms simply lie directly on top of one another.

[3] At time scales larger than about 100ms/div, the data scrolls from left to right across the window – things are happening slowly enough so that it makes sense to watch the signal evolve. If we try this approach at small time scales, the data scrolls by too quickly to be useful.

