Name: ______________________________ Lab Section: _________ Date: ______________

Introduction

This exercise will investigate some of the characteristics of circuits containing inductive and/or capacitive elements along with resistive elements. Specifically, the transient response of inductive and capacitive elements within DC circuits as well as their steady-state DC characteristics will be observed.

Prelab Investigation – Transient Response of R-L and R-C Circuits

Note **–** You will analyze the transient response of R-L and R-C series circuits, specifically in terms of response of the circuits to a step function, which is equivalent to having the circuits supplied by a DC voltage source that is initially "off" and then switched "on" at some arbitrary time.

Note **–** See **Appendix A** for a detailed analysis of the R-C circuit transient solution.

Note **–** Use the following values for the circuits shown in Figures 9.1 and 9.3:

$$V_{DC} = 10\,volts, \quad R = 510\Omega, \quad L = 68mH, \quad C = 0.082\mu F.$$

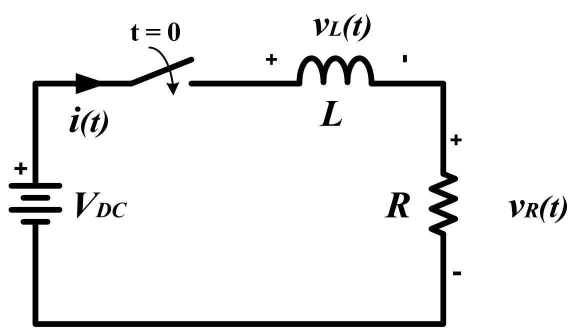


Figure 9.1 – Transient Response of an R-L Circuit

Part 1: PSpice R-L Circuit Transient Response

1. Given the circuit in shown in Figure 9.1, **perform a transient analysis** of the circuit in order to determine expressions for the resistor voltage, the inductor voltage, and the current, all as functions of time for $\mathbf{t \geq 0}$.

2. Neatly write out the resultant expressions in the spaces provided below:

   $v_R(t)$ = ____

   $v_L(t)$ = ____

   $i(t)$ = ____

3. Based on the expression for the resistor voltage, determine the resistor voltage at times **0.1**ms, **0.2**ms, **0.3**ms, **0.4**ms, and **0.5**ms after the source "turns-on". Record the results in Table 9.0A.

Part 2: P-Spice Simulation of Pulsed R-L Circuit

4. Using the **r**, **L**, **VPULSE**, and **GND_EARTH** components, enter into P-Spice the R-L circuit shown in Figure 9.2 and configure the **VPULSE** source as shown below:

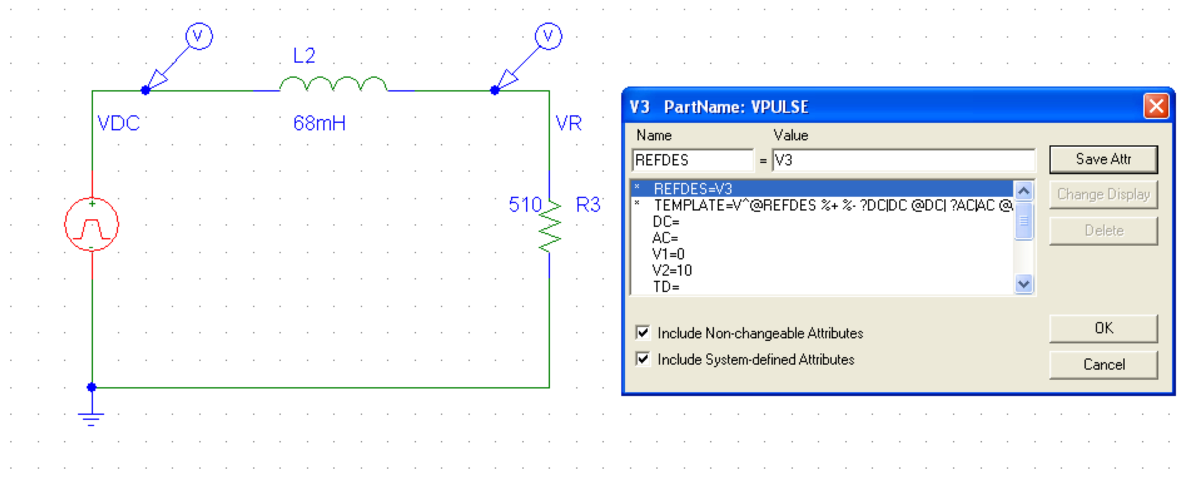
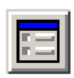
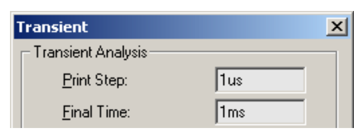


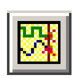
Figure 9.2 – R-L P-Spice Circuit

5. As shown in the figure, label the wire attached to the positive terminal of the source "***VDC***" and the wire connected to the top of the resistor "***VR***", and add voltage probes to the two wires.

6. Choose **Analysis→Setup**… or click .

7. Enable a "Transient" analysis, set the **Print Step** to **1us** and the **Final Time** to **1ms** (as shown to the right), and check the box to "**Skip initial transient solution**".



8. Choose **Analysis→Simulate**… or click  .

9. Add a trace to display the inductor voltage ***V(VDC) – V(VR)*** on the same plot with the resistor voltage. Capture the plot and save it on a USB memory stick.

10. Based on the plot, determine the resistor voltage at times **0.1**ms, **0.2**ms, **0.3**ms, **0.4**ms, and **0.5**ms after the source "turns-on". Record the results in Table 9.0A.

11. Create a second plot of the current flowing in the circuit for times ranging from $t = 0 \rightarrow 1.0$ msec. Capture that plot and also save it on a USB memory stick.

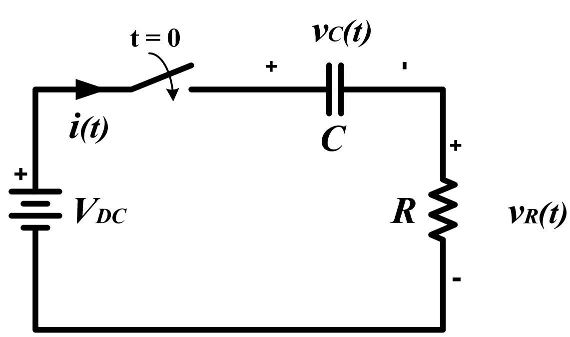


Figure 9.3 – Transient Response of an R-C Circuit

Part 3: PSpice R-C Circuit Transient Response

12. Given the circuit in shown in Figure 9.3, **perform a transient analysis** of the circuit in order to determine expressions for the resistor voltage, the capacitor voltage, and the current, all as functions of time for **t ≥ 0**.

13. Neatly write out the resultant expressions in the spaces provided below:

$v_R(t)$ = ____

$v_C(t)$ = ____

$i(t)$ = ____

14. Based on the resistor voltage expression, determine the resistor voltage at times **0.04**ms, **0.08**ms, **0.12**ms, **0.16**ms, and **0.20**ms after the source "turns-on". Record the results in Table 9.0B.

15. Discuss your results, as represented by the data shown on your plots. Be sure to include a discussion of a "time constant" as it relates to this section of the experiment.

Part 4: P-Spice Simulation of Pulsed R-C Circuit

16. Replace the inductor in the P-Spice circuit with an 82nF capacitor, reconfigure the Transient Analysis for a **Print Step** of **0.2us** and a **Final Time** of **0.2ms**, and perform the same simulation in order to obtain a plot of both the resistor voltage and the capacitor voltage as a function of time ranging from $t = 0 \rightarrow 0.2$ msec. Capture the plot and save it on a USB memory stick.

17. Based on the plot, determine the resistor voltage at times **0.04**ms, **0.08**ms, **0.12**ms, **0.16**ms, and **0.20**ms after the source "turns-on". Record the results in Table 9.0B.

18. Create a second plot of the current flowing in the circuit for times ranging from $t = 0 \rightarrow 0.2$ msec. Capture that plot and also save it on a USB memory stick

Laboratory Procedure

Part 5: Laboratory Measurements

19. Measure the values of all of the circuit components using the LCR meter at the front of the lab. Record the results in Table 9.1. Note any important observations about the measured values below in the space below the table. (Specifically pay close attention to the Inductor's value)

20. Build an R-L series circuits, similar to that shown in Figure 9.1, but replace the DC source and switch combination with a function generator.

21. Adjust the function generator produce a **10**Vpp, **1000**Hz square wave with a **+5**Vdc offset and set the output to HighZ by pressing **Utility → Output Setup → High Z → Done**. This will simulate a DC source that is turning on and off.

22. Use the oscilloscope to measure the voltage produced by the function generator and the voltage across the resistor in the R-L circuit by connecting CH1 to across the function generator and CH2 to the top of the resistor.

23. Press **Cursor → Horizontal** to enable the horizontal cursor and use the cursor to measure the resistor voltage at times **0.1**ms, **0.2**ms, **0.3**ms, **0.4**ms, and **0.5**ms after the source "turns-on". Record the results in Table 9.2 and save the images on a USB Flash Drive.

24. Replace the inductor in the R-L circuit with a capacitor and adjust frequency to **2000**Hz. Repeat the previous measurements at times **0.04**ms, **0.08**ms, **0.12**ms, **0.16**ms, and **0.20**ms after the source "turns-on". Record the results from the R-C circuit in Table 9.3 and save the images on a USB Flash Drive.

Report Guide

You are required to submit a lab report for this experiment. This single document should contain all of the required components of your report including, but not limited to, sample equations, data tables, plots, and discussions. Your report should show all of the work that you performed to complete the required procedural section of this experiment.

The following notes may be helpful in the completion of your report:

1) Use the equations in the appendix to calculate the expected voltages using the measured values in Table 9.1 at the times shown in Tables 9.2 and 9.3. Compare the calculated values to the PSpice prelab values. Also compare the calculated values to the measured values in the laboratory. Table the comparisons.

2) The report should be written sequentially, with the work, results and analysis shown for each part of the experiment in the order specified within the procedure. In other words, you should present your work, results table, plots, and discussion for the "R-L Circuit Response" section first, followed by that for the "R-C Circuit Response" section, etc.

3) The "detailed analysis" required for each section should be written in paragraph form. You may import figures to help make your point, especially when referring to the "real world" discussions for the AC Circuits.

4) This report is to be written individually, with no collaboration allowed between students. If you utilize any "outside" sources to assist in your analysis/discussion of the various results, you must provide a reference to the original location of the material and you must clearly show what material within your report came from the outside sources.

Data

Table 9.0A: R-L Series Resistor Voltages from PSpice Simulation and Hand Calculations

	t=0.1ms	t=0.2ms	t=0.3ms	t=0.4ms	t=0.5ms
$v_R(t)$ (PSpice)					
$v_R(t)$ (Hand Calc)					

Table 9.0B: R-C Series Resistor Voltages from PSpice Simulation and Hand Calculations

	t=0.04ms	t=0.08ms	t=0.12ms	t=0.16ms	t=0.20ms
$v_R(t)$ (PSpice)					
$v_R(t)$ (Hand Calc)					

Table 9.1: Measured Circuit Components Values

	R=510Ω	L=68mH	C=0.082μF
Measured Value			

Table 9.1 notes:

Table 9.2: Measured Resistor Voltages from R-L Series Circuit

	t=0.1ms	t=0.2ms	t=0.3ms	t=0.4ms	t=0.5ms
$v_R(t)$					

Table 9.3: Measured Resistor Voltages from R-C Series Circuit

	t=0.04ms	t=0.08ms	t=0.12ms	t=0.16ms	t=0.20ms
$v_R(t)$					

Approved by: ______________________________ **Date:** ______________

Appendix A

R-C Circuit Response

Figure A.1 shows a simple R-C charging circuit. In this circuit, a DC source is used to supply a resistor and a capacitor that are connected in series with each other. A switch is placed in the circuit to allow the circuit to be "turned-on" at an arbitrary time $t = 0$. For this discussion, it is assumed that the capacitor is initially uncharged, thus having a voltage $v_C(t \le 0) = 0$ before the switch closes.

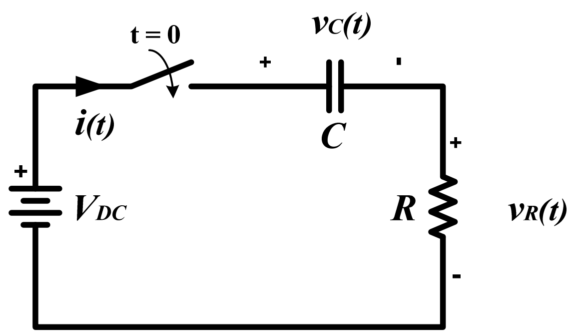


Figure A.1 – Simple R-C Transient Circuit

When the switch closes, as shown in Figure A.2, a KVL equation may be written for the circuit as:

$$V_{DC} - v_C(t) - v_R(t) = 0\,.$$

The equation may be rewritten to solve for the resistor voltage as:

$$v_R(t) = V_{DC} - v_C(t)\,.$$

The resistor current may then be determined by applying Ohm's Law:

$$i(t) = \frac{v_R(t)}{R} = \frac{V_{DC} - v_C(t)}{R}\,.$$

When the switch is closed at $t = 0$, the capacitor's voltage will be $v_C(0) = 0$ if the capacitor is initially uncharged, resulting in an initial current i_0 of:

$$i_0 = i(0) = \frac{V_{DC} - 0}{R} = \frac{V_{DC}}{R}\,.$$

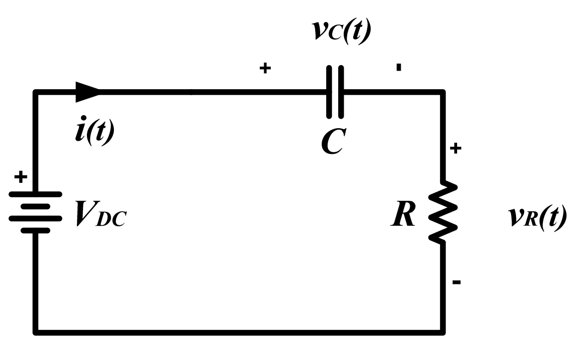


Figure A.2 – R-C Transient Circuit After the Switch Closes

Yet, as current begins to flow in the circuit, the capacitor will begin to store a charge, resulting in an increase of the capacitor's voltage. The increasing capacitor voltage directly results in a decreasing the current, due to the relationship:

$$i(t) = \frac{V_{DC} - v_C(t)}{R}.$$

Thus, as the current decreases, the rate at which the capacitor charges will also decrease.

This process will continue until the capacitor stores enough charge such that the capacitor's voltage is equal to that of the DC source. When this finally occurs, the current stop flowing since:

$$i(t) = \frac{V_{DC} - v_C(t)}{R} = \frac{V_{DC} - V_{DC}}{R} = \frac{0}{R} = 0.$$

At this point, the circuit has reached its steady-state condition.

The exact nature of this process may be determined mathematically by means of a first-order differential equation. The first step in this process is to set the capacitor and the resistor currents equal to each other, $i_C(t) = i_R(t)$, since the elements are connected in series. Once set equal, the two currents can then be expressed in terms of the voltage across the individual elements, as follows:

$$C \cdot \frac{dv_C(t)}{dt} = \frac{v_R(t)}{R}$$

The resistor voltage can be rewritten in terms of the source and the capacitor voltages to reduce the number of unknown in the equality to one, resulting in:

$$C \cdot \frac{dv_C(t)}{dt} = \frac{V_{DC} - v_C(t)}{R}.$$

This equality can then be rearranged by bringing both terms to one side of the equation and then dividing all terms by C, resulting in the following single-order differential equation:

$$\frac{dv_C(t)}{dt} + \left(\frac{1}{RC}\right) \cdot v_C(t) - \frac{V_{DC}}{RC} = 0.$$

The general solution to the differential equation for capacitor voltage $v_C(t)$ is:

$$\boxed{v_C(t) = V_{DC} \cdot \left[1 - e^{\frac{-t}{RC}}\right]}$$

From this result, the current flowing in the circuit may be derived as follows:

$$\boxed{i(t)} = C \cdot \frac{dv_C(t)}{dt} = C \cdot \frac{d}{dt}\left(V_{DC} \cdot \left[1 - e^{\frac{-t}{RC}}\right]\right) = C \cdot \frac{d}{dt}\left(V_{DC} - V_{DC} \cdot e^{\frac{-t}{RC}}\right)$$

$$= C \cdot \frac{d}{dt} V_{DC} - C \cdot \frac{d}{dt} V_{DC} \cdot e^{\frac{-t}{RC}} = 0 - C \cdot \frac{V_{DC} \cdot e^{\frac{-t}{RC}}}{RC} = \boxed{\frac{V_{DC}}{R} \cdot e^{\frac{-t}{RC}}}.$$

Finally, the resistor voltage may be attained by applying Ohm's Law:

$$\boxed{v_R(t)} = i(t) \cdot R = \boxed{V_{DC} \cdot e^{\frac{-t}{RC}}}.$$

These expressions may be simplified by defining a new term τ, referred to as the "time constant" for the circuit, such that:

$$\tau = RC .$$

Thus, for the R-C transient circuit shown in Figure A.1, the following set of equations can be applied to predict the current or any of the voltages in the circuit after the switch closes at time $t = 0$:

$$i(t) = \frac{V_{DC}}{R} \cdot e^{\frac{-t}{\tau}}$$

$$v_C(t) = V_{DC} \cdot \left[1 - e^{\frac{-t}{\tau}}\right]$$

$$v_R(t) = V_{DC} \cdot e^{\frac{-t}{\tau}}$$

R-L Circuit Response

Similar to the analysis of the R-C circuit, the response of the R-L circuit shown in Figure A.3 can be derived with the following results:

$$i(t) = \frac{V_{DC}}{R} \cdot \left[1 - e^{\frac{-t}{\tau}}\right]$$

$$v_L(t) = V_{DC} \cdot e^{\frac{-t}{\tau}}$$

$$v_R(t) = V_{DC} \cdot \left[1 - e^{\frac{-t}{\tau}}\right]$$

where:

$$\tau = \frac{L}{R}.$$

for the R-L circuit.

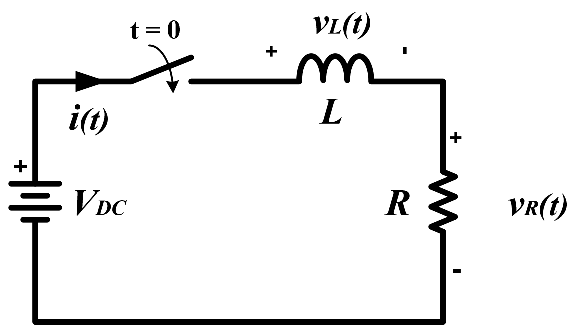


Figure A.3 – Simple R-L Transient Circuit