CMPE 110 Lab 1 Part 2: First-Order Passive RL Circuits

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***Abstract*—The purpose of this lab project is to learn about resistance, inductance, the time constant, and rise and fall times in RL circuits with a pulse generator.**

I. INTRODUCTION

This lab project is based on the implementation of 4 pairs of RL circuits in LTspice, where all pairs have the same time constant ($\tau = 1\ \mu s$) but different R and L values. Each pair of circuits is composed of almost identical RL series circuits, where the only difference is that the positions of the resistor and capacitor are swapped—see **Figure 3** and **Figure 5**.

We are asked to:

(a) Using the resistor values, R = 1KΩ, 10KΩ, 100KΩ and 1MΩ, **calculate** the inductor values for a time constant value of τ = 1ns in each case.

(b) Use each RL combination from part (a) in the circuits below and measure the rise time and the fall time at the output, vout. You need to connect a pulse generator that changes between 0 and 5V at the input of the circuit and observe the circuit response at the output terminal using the oscilloscope.

(c) Use each RL combination from part (a) in the circuits below and find the time constant. Use the mathematical expressions of vout for each circuit to extract the time constant, and then use the measured time and voltage values from your oscilloscope to determine the time constant.

Show the calculated and measured rise and fall times and time constants in an Excel table and explain the error between the measured and calculated values. In cases where you cannot take sensible measurements, show the results on your scope screen in the report and explain why measurements could not be made.

Figure 1. Instructions.

And to produce the following results:

Show the calculated and measured rise and fall times and time constants in an Excel table and explain the error between the measured and calculated values. In cases where you cannot take sensible measurements, show the results on your scope screen in the report and explain why measurements could not be made.

Figure 2. Expected results.

Before assembling the 4 pairs of RL circuits, the capacitance values that would make each pair of circuits' τ equal to 1 are calculated. For this, we use the RL circuits' equation:

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

And determined that:

R	L	$\frac{L}{R}$
$1K\Omega$	1nF	1 ns
$10K\Omega$	100pF	1 ns
$100K\Omega$	10pF	1 ns
$1M\Omega$	$1pF$	1 ns

Table 8. R and L values for the 4 pairs of circuits.

After setting up each circuit, measurements of the rise and fall times are made, and then used to obtain a new τ. For this we use the RC circuits' equations:

- $V_{out} = V_s\left(e^{-\frac{Rt}{L}}\right)$
- $V_{out} = V_s\left(1 - e^{-\frac{Rt}{L}}\right)$

Finally, the theoretical and measured values for the time constant and the rise and fall times are compared, for each individual circuit.

A. Parts List

- 0-5V pulse generator. See **Figure 4** and **Figure 6**.
- $1K\Omega$, $10K\Omega$, $100K\Omega$, and $1M\Omega$ resistors
- $1\mu H$, $10\mu H$, $100\mu H$,and $1mH$ inductors
- Grounding components
- LTspice software

II. DESCRIPTION OF THE CIRCUITS' SCHEMATICS

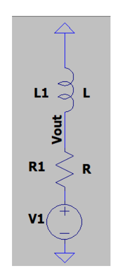

Figure 3. Configuration 1.

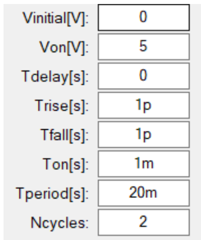

Figure 4. The pulse generator's settings for configuration 1 circuits.

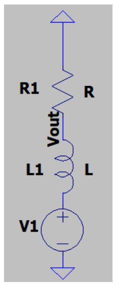

Figure 5. Configuration 2.

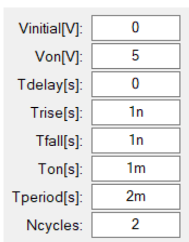

Figure 6. The pulse generator's settings for configuration 2 circuits.

III. Waveforms and Results

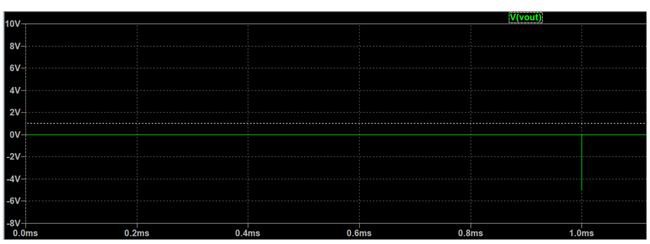

Figure 7. General waveform for configuration 1 circuits.

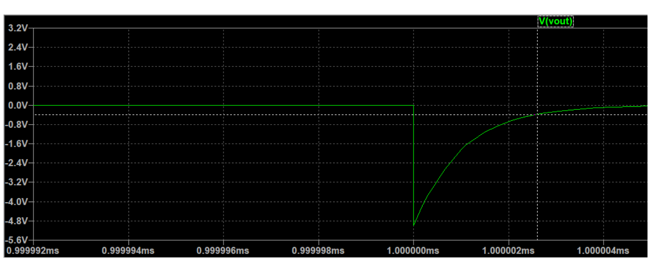

Figure 8. General rise zoom-in for configuration 1 circuits.

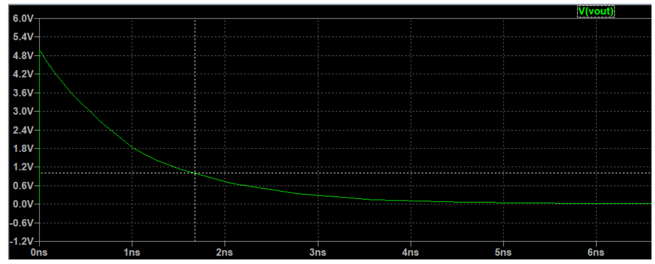

Figure 9. General fall zoom-in for configuration 1 circuits.

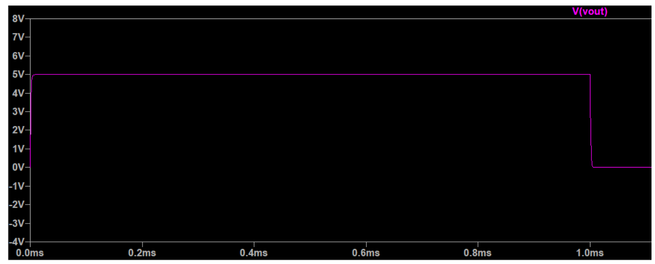

Figure 10. General waveform for configuration 2 circuits.

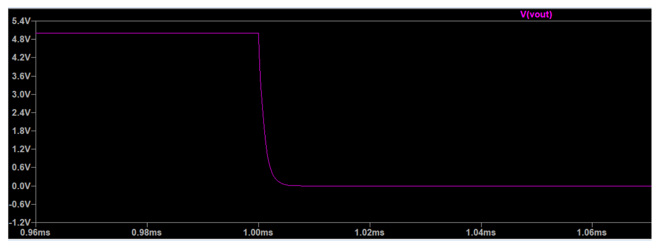

Figure 11. General rise zoom-in for configuration 2 circuits.

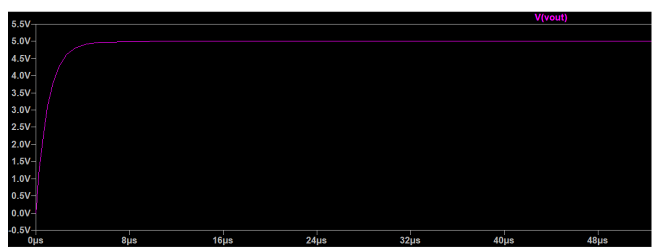

Figure 12. General fall zoom-in for configuration 2 circuits.

Rise time data				
R	**Configuration 1 circuits' times (ns)**		**Configuration 2 circuits' times ns)**	
$1K\Omega$	t1: 1000000.2	t2: 1000001.6	t1: 0.69361466	t2: 2.234643
$10K\Omega$	t1: 1000000.2	t2: 1000001.6	t1: 0.69361466	t2: 2.234643
$100K\Omega$	t1: 1000000.2	t2: 1000001.6	t1: 0.69361466	t2: 2.234643
$1M\Omega$	t1: 1000000.2	t2: 1000001.6	t1: 0.69361466	t2: 2.234643

Table 9. Rise time data table.

Fall time data				
R	**Configuration 1 circuits' times (ns)**		**Configuration 2 circuits' times (ns)**	
$1K\Omega$	t1: 0.23225447	t2: 1.6737202	t1: 1000.2292	t2: 1001.6316
$10K\Omega$	t1: 0.23225447	t2: 1.6737202	t1: 1000.2292	t2: 1001.6316
$100K\Omega$	t1: 0.23225447	t2: 1.6737202	t1: 1000.2292	t2: 1001.6316
$1M\Omega$	t1: 0.23225447	t2: 1.6737202	t1: 1000.2292	t2: 1001.6316

Table 10. Fall time data table.

Rise times calculations table (t2-t1)		
R	**Configuration 1 circuits' rise time (ns)**	**Configuration 2 circuits' rise time (ns)**
$1K\Omega$	1.4	1.54102834
$10K\Omega$	1.4	1.54102834
$100K\Omega$	1.4	1.54102834
$1M\Omega$	1.4	1.54102834

Table 11. Rise times calculations table

Fall times calculations table (t2-t1)		
R	**Configuration 1 circuits' fall time (ns)**	**Configuration 2 circuits' fall time (ns)**
$1K\Omega$	1.44146573	1.4024
$10K\Omega$	1.44146573	1.4024
$100K\Omega$	1.44146573	1.4024
$1M\Omega$	1.44146573	1.4024

Table 12. Fall times calculations table

Type	$V_{out}(V)$	$t_{exp}(ns)$	$\tau_{calc}(ns)$	$\%\ error$
Rise	-1	1.4	0.8699	13.01%
	-1	1.4	0.8699	13.01%
	-1	1.4	0.8699	13.01%
	-1	1.4	0.8699	13.01%
	4	1.54102834	0.9575	4.251%
	4	1.54102834	0.9575	4.251%
	4	1.54102834	0.9575	4.251%
	4	1.54102834	0.9575	4.251%
Fall	1	1.44146573	0.8956	10.44%
	1	1.44146573	0.8956	10.44%
	1	1.44146573	0.8956	10.44%
	1	1.44146573	0.8956	10.44%
	1	1.4024	0.8715	12.85%
	1	1.4024	0.8715	12.85%
	1	1.4024	0.8715	12.85%
	1	1.4024	0.8715	12.85%

Table 13. τ calculated using theoretical V_{out} and experimental t values.

Type	$V_{out}(V)$	$\tau_{calc}(\mu s)$	$t_{calc}(\mu s)$	$\%\ error$
Rise	-1	0.8699	1.40005004	0.05%
	-1	0.8699	1.40005004	0.05%
	-1	0.8699	1.40005004	0.05%
	-1	0.8699	1.40005004	0.05%
	4	0.9575	1.54103680	0.0008%
	4	0.9575	1.54103680	0.0008%
	4	0.9575	1.54103680	0.0008%
	4	0.9575	1.54103680	0.0008%
Fall	1	0.8956	1.44141259	0.0053%
	1	0.8956	1.44141259	0.0053%
	1	0.8956	1.44141259	0.0053%
	1	0.8956	1.44141259	0.0053%
	1	0.8715	1.40262514	0.0225%
	1	0.8715	1.40262514	0.0225%
	1	0.8715	1.40262514	0.0225%
	1	0.8715	1.40262514	0.0225%

Table 14. t calculated using theoretical V_{out} and calculated τ values.

IV. DISCUSSION

This lab project's recorded measurements fall along the lines of the theoretical values for our 8 circuits, as demonstrated through the relatively low percent error results, nevertheless there are still some discrepancies between the calculated and theoretical values for some quantities, particularly the time constant. Such errors could be explained through the accuracy of our equipment—selecting desired voltage levels was particularly challenging in our oscilloscope—but moreover, by the fact that an "adequate" measurement of one time constant is performed at 63 and 37% of the output voltage, rather than 80 and 20%. This claim is supported by the accuracy of our time measurements. Our time measurements reached certain time constants without much friction—see **Table 7**—but could not be used to obtain $\tau = 1$.

V. DESCRIPTION OF THE LEARNING EXPERIENCE

This lab project was a challenge that pushed me to learn in-depth details related to RL circuits. This was an incentive and an opportunity to not only use the existing knowledge I acquired from our lectures and our textbook, but also research, learn, and verify my current knowledge on RL circuits. To further and to supplement my education on RL circuits, I visited several higher education institution's websites, which provided me with additional resources on waveforms and how to approach them using different methods, to acquire the different possible variables of interest.

VI. CONCLUSION

In conclusion, this lab experiment was a fruitful RL circuits learning experience, where we tried to obtain a $\tau = 1$ from V_{out} at 80 and 20%, rather than 63 and 37%. We had to inquire and look for further educational resources to explain our relatively large percent error values—see **Table 6**—until we ultimately acknowledged a possible cause for these margins. Finally, while researching and trying to understand possible error sources, we became more familiar with RL circuits in the process.