Lab 6: RC and RL Transients

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ECE 2205: Circuits and Systems

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Introduction

This lab explores the transient behavior of RC and RL circuits in response to a square-wave input. The objectives are to study and compare theoretical predictions and experimental observations of voltage and current transients across various capacitor and inductor circuits. Throughout the experiments, oscilloscope measurements are used to capture and quantify real-time transient responses. These results are then compared to calculated values to evaluate model accuracy and support hand calculations.

Background

Equation 1: time constant = R*C

Equation 2: Step response Cap $v(t) = V0(1 - e^{-\frac{t}{time\ const.}})$

Equation 3: time constant = L/R

Equation 4: Step response Ind $v(t) = L * \frac{d\frac{V0}{R}(1 - e^{-\frac{t}{time\ const.}})}{dt}$

Materials

1. Oscilloscope
2. Voltmeter
3. Voltage generator
4. Breadboard
5. Inductor
6. Various Resistors
7. Capacitors

Results/Discussion

Lab 6

Fig 1

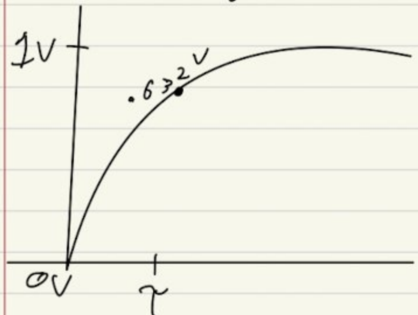
$\tau = 1K \cdot .1\mu F = 10^{-4} = .1ms$

Rising − $V_c(t) = 1(1e^{-0/.001}) = 1 \cdot 1 = 1V$

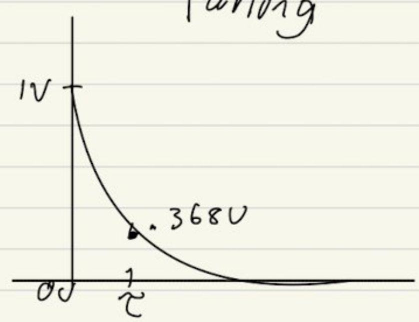
falling − $V_c(t) = 0 + e^{-.0001/.001} = 0V$

peak current $= \frac{1V}{1K\Omega} = 1mA$

rising



falling



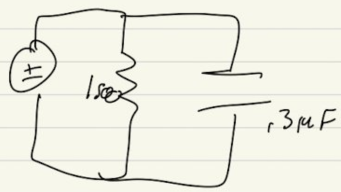
500mV/
-494.00mV
200mV/
891.350mV
500.0us/
0.0s
1
489mV
Auto
Meas
Freq(1):
499.99Hz
Pk-Pk(1):
1.19V
Ampl(1):
950mV
Autoscale Menu
Undo Autoscale
Fast Debug
Channels All
Acq Mode Normal

-494.00mV
891.350mV
50.00ns/
0.0s
1
489mV
Auto
Meas
Freq(1):
No edges
Pk-Pk(1):
1.12V
Ampl(1):
940mV
Undo Autoscale
Fast Debug
Channels All
Acq Mode Normal

Depicted above is the input vs output reading of figure 1 circuit and a square wave. Measured outputs on the oscilloscope matched with calculated values. The Voltage of .632 is significant because it represents the voltage at one time constant at the rising transient. Likewise, the Voltage of .368 represents the voltage at the time constant at the falling transient. Slight deviations in measured vs. calculated values could be due to natural resistance in probes and rounding of the machine or calculator.

Fig 2

$R_{eq} = \frac{1}{1/1K + 1/1K} + 1K = 1500\Omega$



$\tau = 1500 \cdot .3 \cdot 10^{-6} = 0.00045$

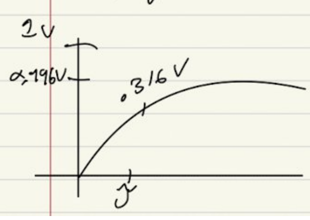
rising $\quad i_{peak} = \frac{15}{800} = 1mA$

$\frac{1}{2}\left(1 - e^{.001(1/.00045)}\right) = \text{peak} - 0.446V$

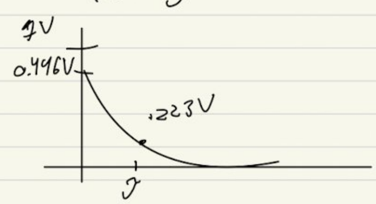
falling

$.04458\, e^{-.001/.00045} = 0.0389V$

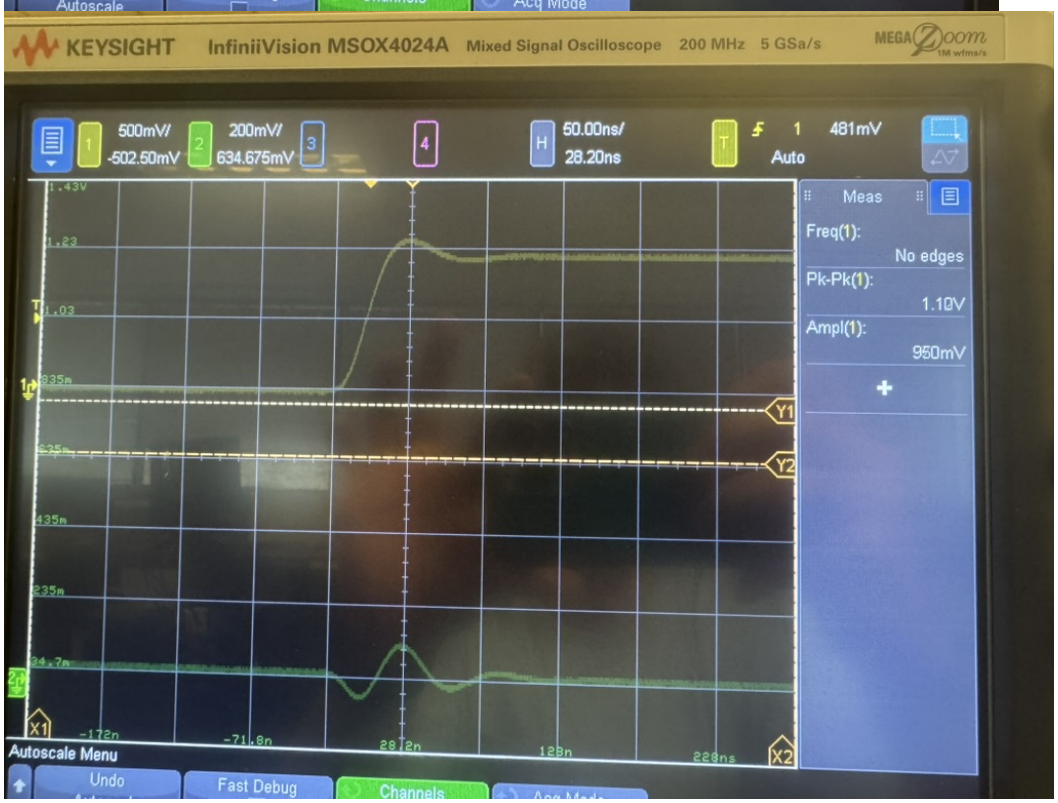
Rising



falling




500mV/
-502.50mV
200mV/
634.675mV
500.0us/
0.0s
1 481mV
Auto
Meas
Freq(1):
499.99Hz
Pk-Pk(1):
1.19V
Ampl(1):
970mV
Undo
Autoscale
Fast Debug
Channels
Acq Mode


KEYSIGHT
InfiniiVision MSOX4024A
Mixed Signal Oscilloscope
200 MHz
5 GSa/s
500mV/
-502.50mV
200mV/
634.675mV
50.00ns/
28.20ns
1 481mV
Auto
Meas
Freq(1):
No edges
Pk-Pk(1):
1.10V
Ampl(1):
950mV
Autoscale Menu
Undo
Fast Debug
Channels

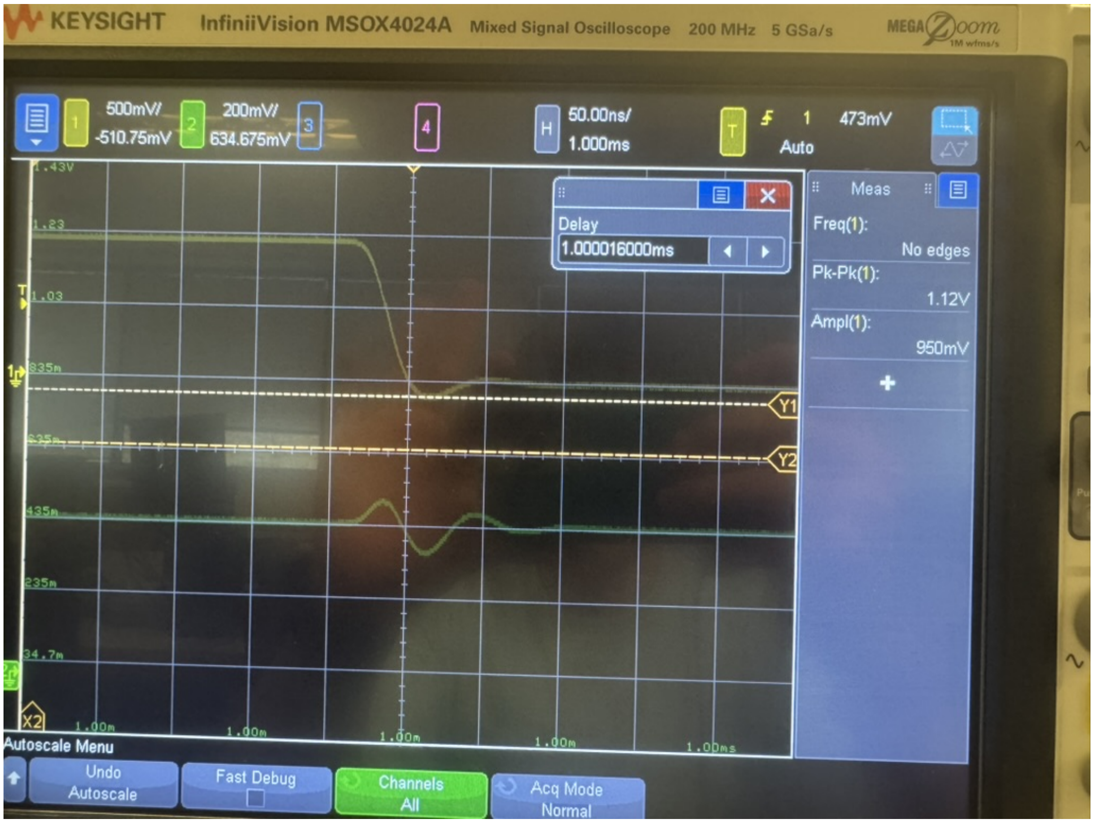


Figure 2 was a similar RC circuit, except it was in parallel with multiple resistors. After finding Req and Ceq, the circuit was fairly easy to calculate. With the resistor value being larger than in fig. 1, the voltage on the cap was yielded smaller than that of the cap in fig.1. With this, the time constant was different than in fig 1. The voltage at the rising transient for the time constant was 3.16V, while the falling transient was .164V. Compared to fig 1, the peak voltage was about half the magnitude. This also correlated with the time transients of this circuit being about half the first circuit as well, proving the exponential equation of RC circuits. Slight deviations in measured vs. calculated values could be due to natural resistance in probes and rounding of the machine or calculator.

Fig 3

$\tau = \frac{L}{R} = \frac{.033}{1K} = 33\mu s$ $\tau_L = \frac{.033}{1060\Omega} = \boxed{31.13\mu s}$

Rising

$V_L = 1(1-e^{-\tau(\tau)}) = .6321V$

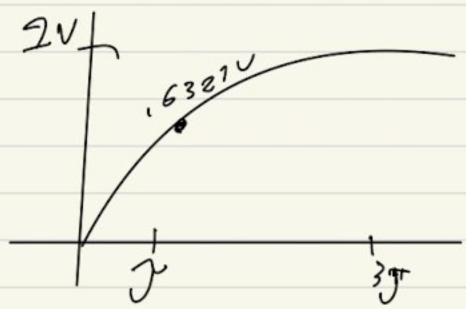
max $1(1-e^{-3\tau/\tau}) = 0.95V$

falling

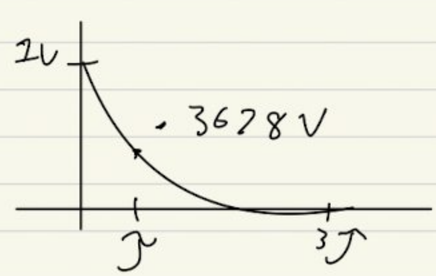
$1 \cdot e^{-\tau/\tau} = .3678V$

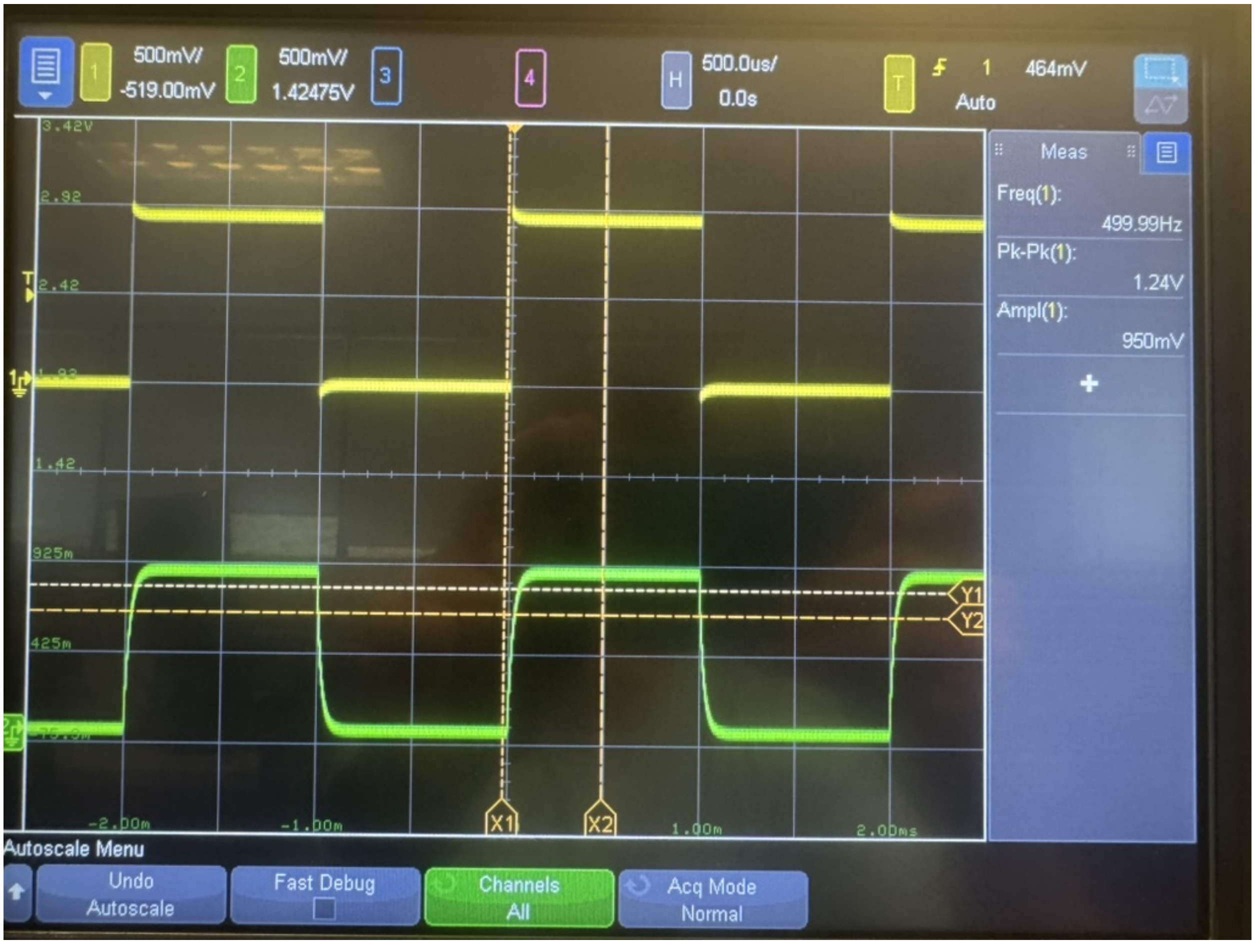
max $1 \cdot e^{-3\tau/\tau} = .05V$

rising

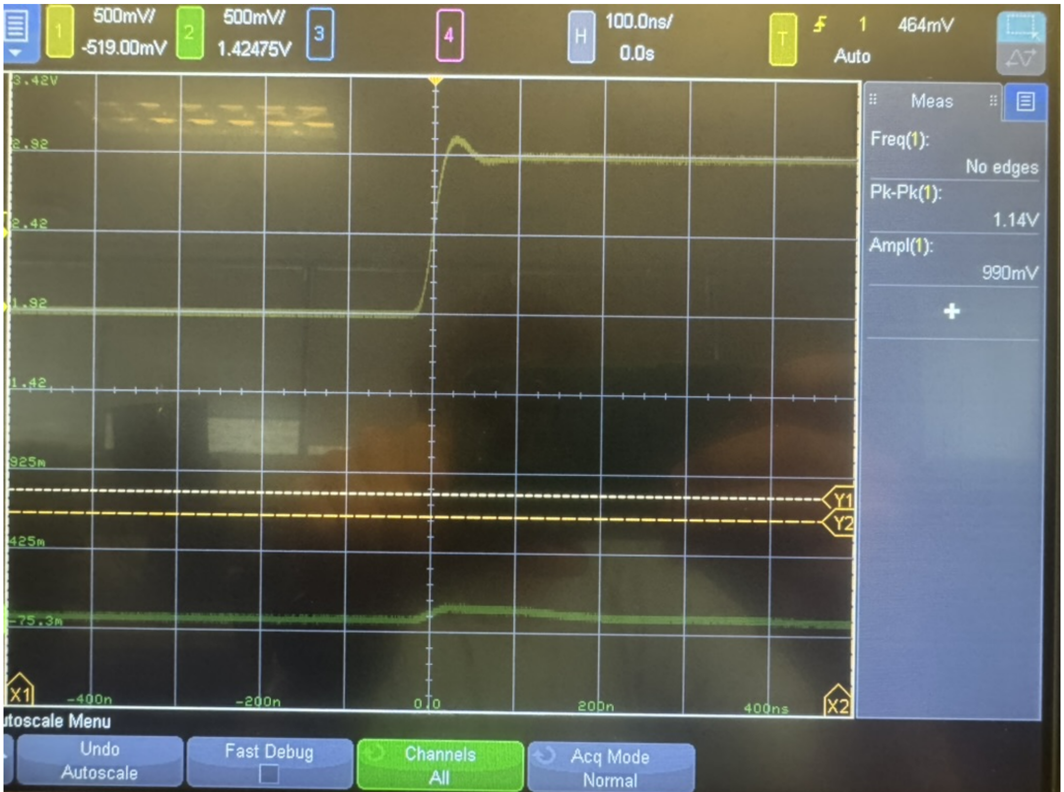


falling





500mV/
-519.00mV
500mV/
1.42475V
500.0us/
0.0s
464mV
Auto
Meas
Freq(1):
499.99Hz
Pk-Pk(1):
1.24V
Ampl(1):
950mV
Autoscale Menu
Undo Autoscale
Fast Debug
Channels All
Acq Mode Normal


500mV/
-519.00mV
500mV/
1.42475V
100.0ns/
0.0s
464mV
Auto
Meas
Freq(1):
No edges
Pk-Pk(1):
1.14V
Ampl(1):
990mV
-400n
-200n
200n
400ns
Autoscale Menu
Undo Autoscale
Fast Debug
Channels All
Acq Mode Normal

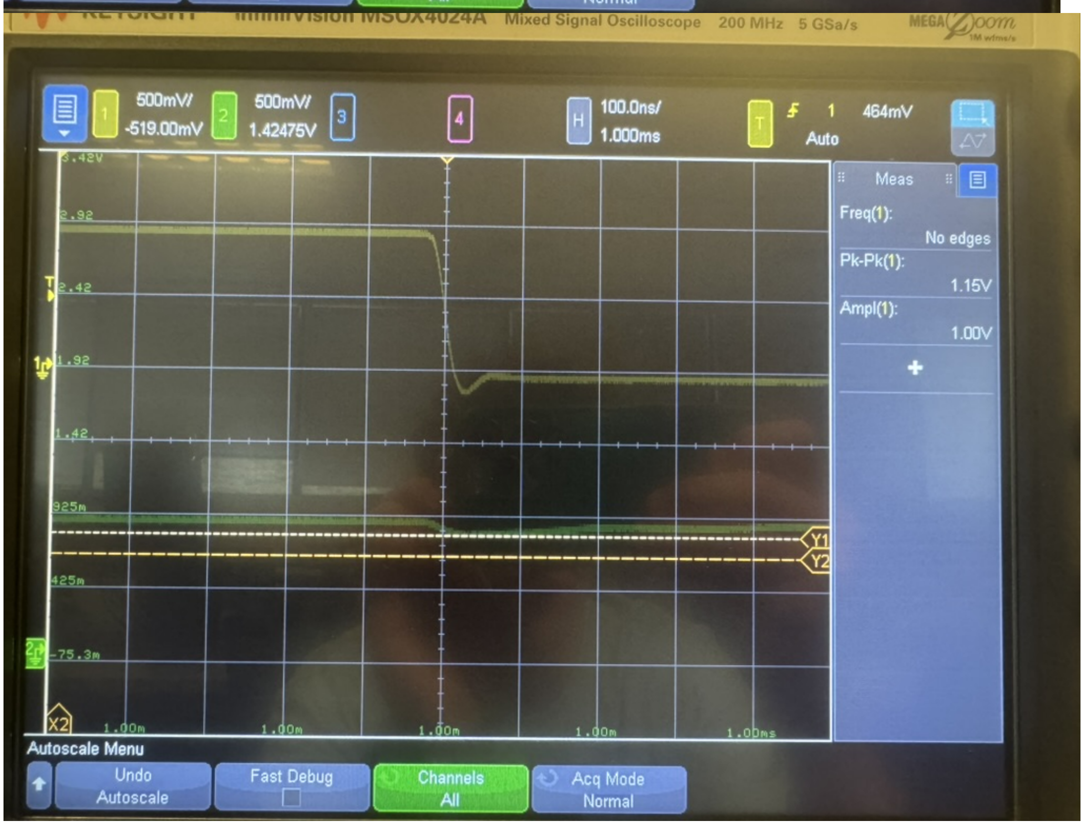

InfiniiVision MSOX4024A Mixed Signal Oscilloscope 200 MHz 5 GSa/s
500mV/
-519.00mV
500mV/
1.42475V
100.0ns/
1.000ms
464mV
Auto
Meas
Freq(1):
No edges
Pk-Pk(1):
1.15V
Ampl(1):
1.00V
Autoscale Menu
Undo Autoscale
Fast Debug
Channels All
Acq Mode Normal

Figure 3 showed the transient behavior of a RL circuit. The inductor current was expected to exponentially rise from 0 to 1 mA when the voltage stepped from 0 to 1 V, and decay from 1 mA back to 0 when the voltage returned to 0 V. This is consistent with the nature of inductors resisting changes in current, producing a smooth exponential curve rather than an immediate jump. The natural parasitic resistance of the inductor acted like another resistor in the circuit, limiting voltage and therefore affecting the graph and time constant lowering them both than if only the resistance of the 1 resistor in the circuit was accounted for. Taking this into effect in calculations led to a number much closer to that of the graphed output on the oscilloscope.

Summary

In the RC circuit experiments, both a simple series configuration and a parallel configuration were analyzed. For each setup, theoretical values for the capacitor voltage's initial and final states, time constants, and peak transient currents were calculated and compared with oscilloscope measurements. Results confirmed the expected exponential nature of the voltage transitions and showed good agreement with theoretical predictions. While numbers were slightly off, theoretical calculations will never match real world examples due to natural resistance of the components and noise. In the RL circuit, the effects of the inductor's parasitic resistance lowered the time constant compared to the time constant calculated without the inductor resistance. This also led to a lower voltage being output on the oscilloscope than the theoretical voltage calculated.