Laboratory Five — Transient Response

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Pre-Lab

I

a

$\tau = RC = 1k\Omega \cdot 0.1 \times 10^{-6} = 1 \times 10^{-4}s$

b

$v_0 = 1V$
$v_R(t) = 1 - v_c(t)$
$v_c(t) = v_0(1 - e^{\frac{-t}{\tau}} = 1 - e^{\frac{0.001}{0.0001}} = 1V$

Element	$v_{PPK}(V)$
$v_{C,PPK}$	1
$v_{R,PPK}$	1

Table 1: Data for Pre-Lab 1b

c

We can assume the circuit reaches steady state because there are more than five time constants in that time period.

d

The capacitor must charge, so v_c increases with time. As this occurs, the voltage across the resistor must drop, as $v_0 = v_R + v_c$.

II

a

v_c charges when $v_0 = 1V$ and discharges when $v_0 = 0V$. Since $v_0 = v_R + v_c$, v_R is 1 when v_c is 0 and v_R is 0 when v_c is 1.

b

$v_c(t) = 1 - e^{\frac{0.001}{0.0001}} = 1V$
$v_0 = v_R + v_c$

Element	$v_{PPK}(V)$
$v_{C,PPK}$	1
$v_{R,PPK}$	2

Table 2: Data for Pre-Lab 2b

III

a

$v_c(t) = 1 - e^{\frac{-2.5 \times 10^{-4}}{0.0001}} = 0.918V$
The time constant has increased by a factor of 2.5, which means the circuit has not reached steady state.

b

$f_{max} = 1000Hz$
The circuit has not reached steady state because five time constants have not passed.

IV

a

$\omega_0 = 422.577$

b

Resistance ($k\Omega$)	**Damping Factor** α (s^{-1})	**Decay Time** $5/\alpha$ (s)	ω_d (rad/s)	f_d (kHz)
0.5	2500	$\frac{1}{500}$	422569	2.37×10^{-6}
1	50000	$\frac{1}{10000}$	419608	2.38×10^{-6}
8.45	422500	$\frac{1}{84500}$	8066	1.24×10^{-4}
25	1250000	$\frac{1}{250000}$	N/A	N/A

Table 3: Data for Pre-Lab 4b

c

$R = \frac{2L}{\sqrt{LC}} = 8451\Omega$

Lab Data

Series RC

Element	**Measured Value**
R_1	985.92Ω
C	$101.5nF$

Table 4: Measured values for circuit elements

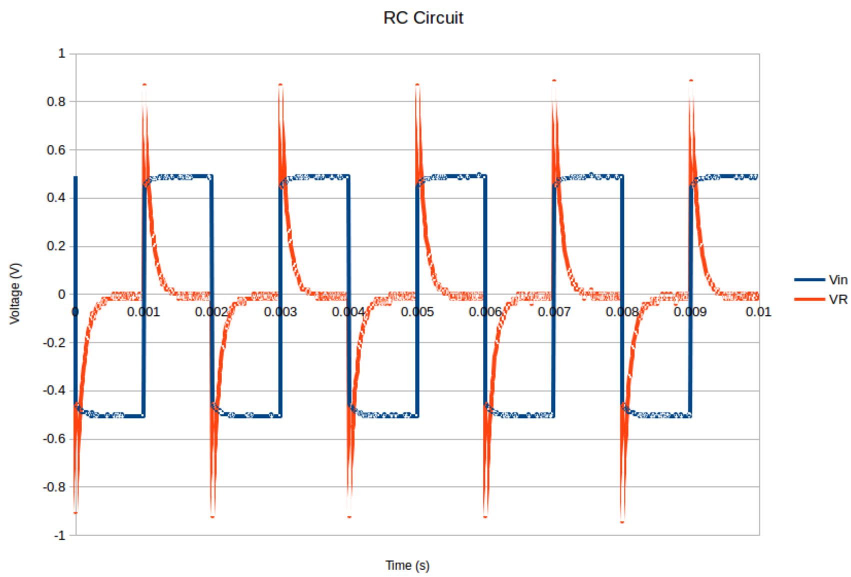

Figure 1: Plot of RC circuit measuring V_R

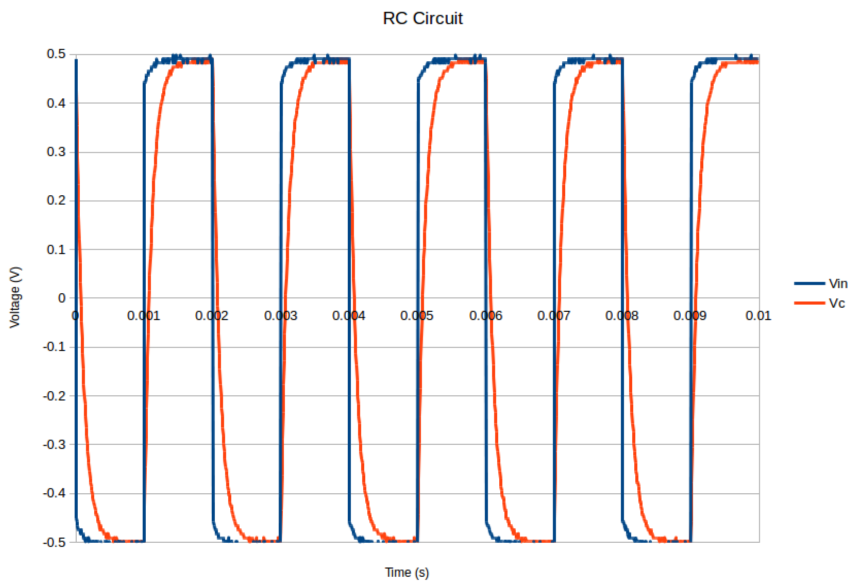

Figure 2: Plot of RC circuit measuring V_c

Nonzero DC Offset

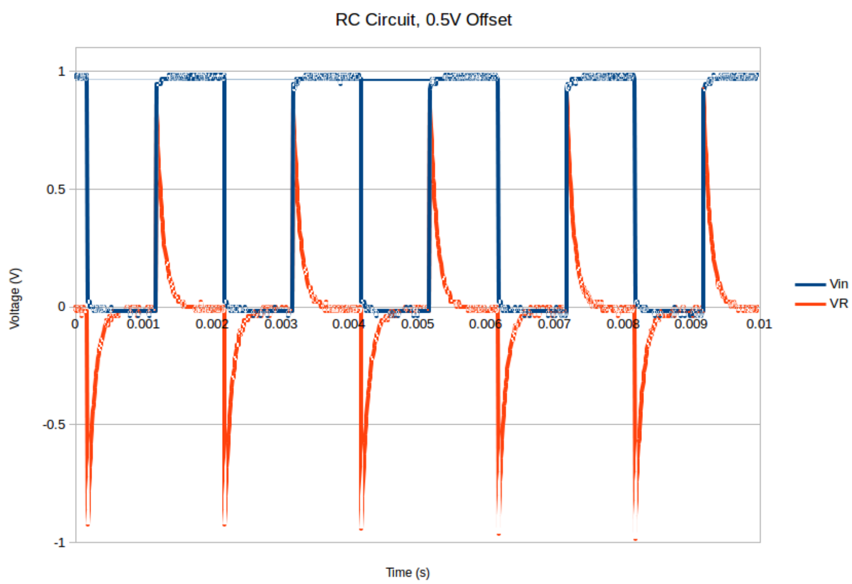

Figure 3: Plot of RC circuit, 0.5V offset measuring V_R

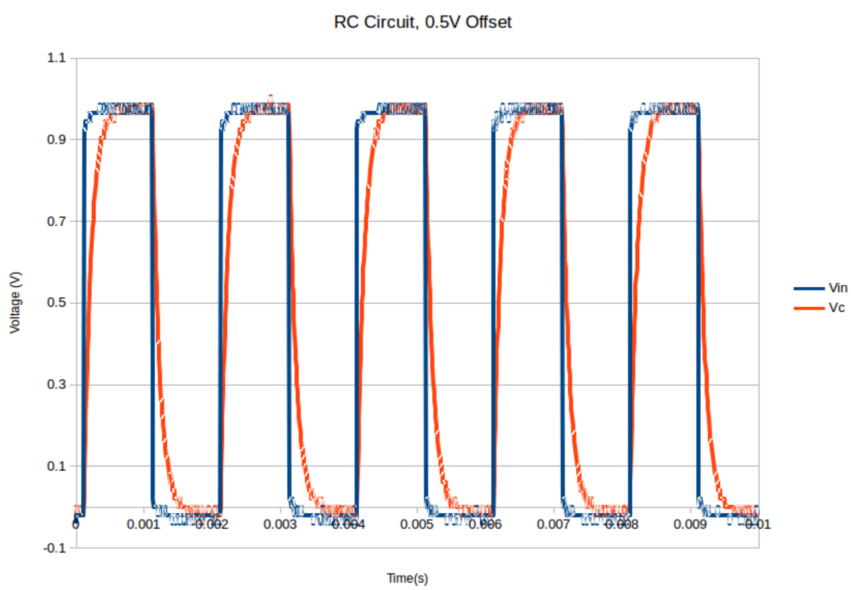

Figure 4: Plot of RC circuit, 0.5V offset measuring V_c

Frequency Response

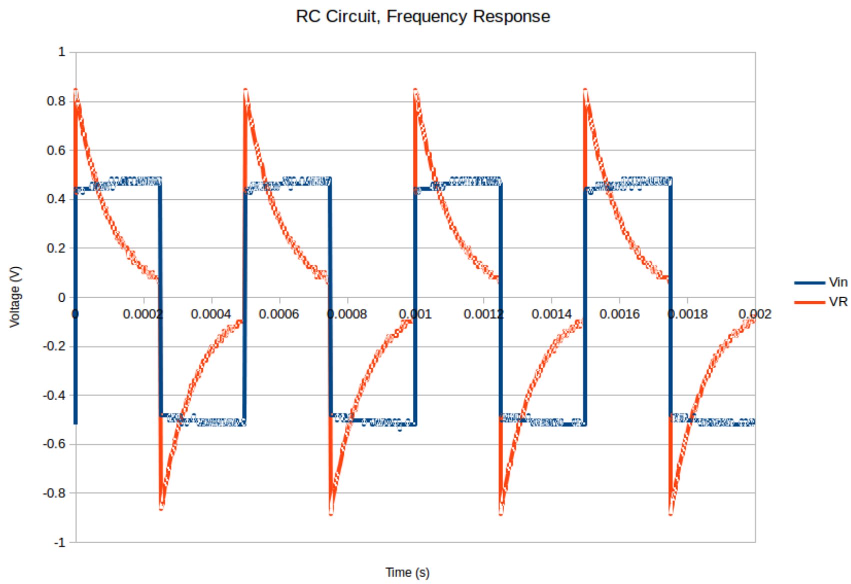

Figure 5: Plot of RC circuit, 2kHz measuring V_R

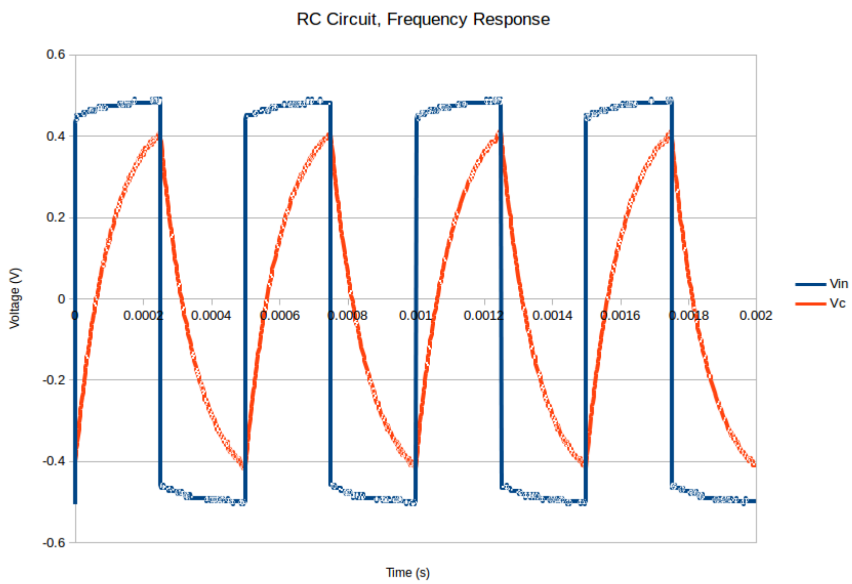

Figure 6: Plot of RC circuit, 2kHz measuring V_c

First Order OP Amp Circuit

Element	Measured Value
R_1	985.92Ω
R_2	981.50Ω
R_3	987.64Ω
C	$101.5nF$

Table 5: Measured values for circuit elements

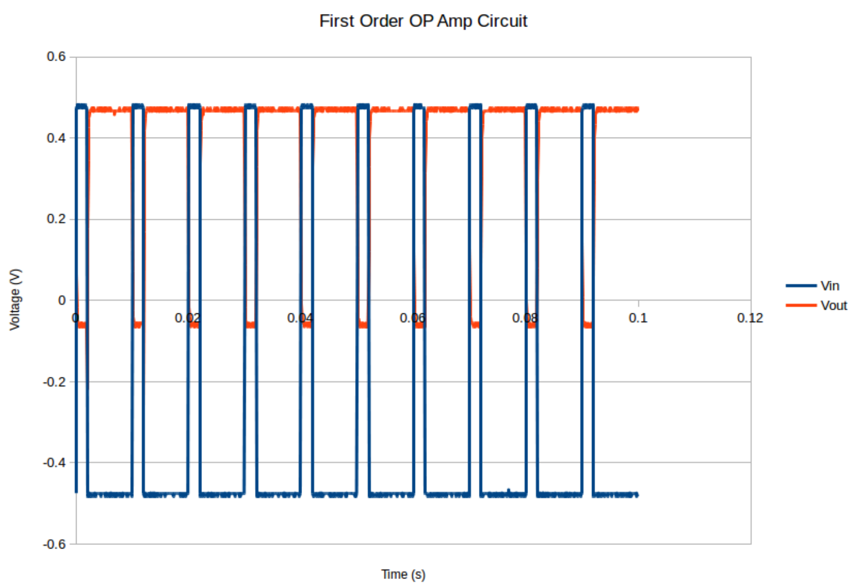

Figure 7: Plot of first order op amp circuit, 20% duty cycle, 100Hz

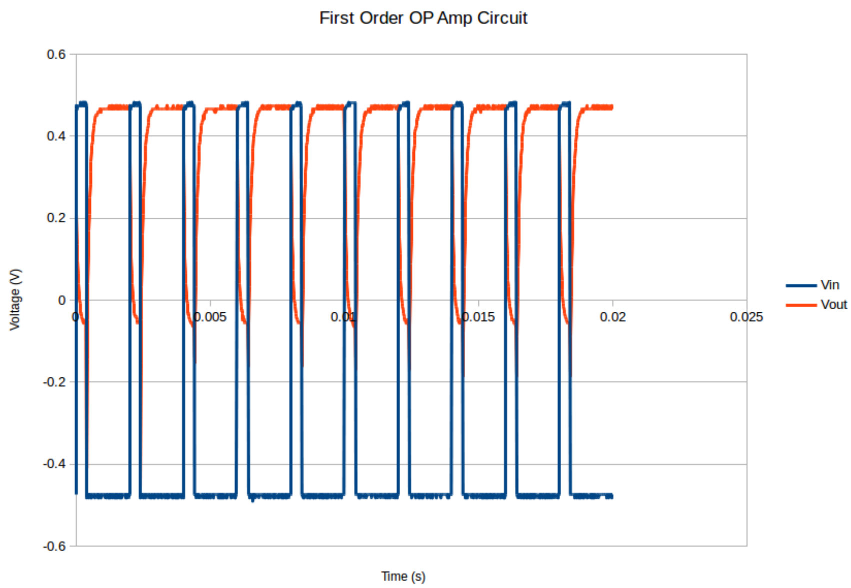

Figure 8: Plot of first order op amp circuit, 20% duty cycle, 500Hz

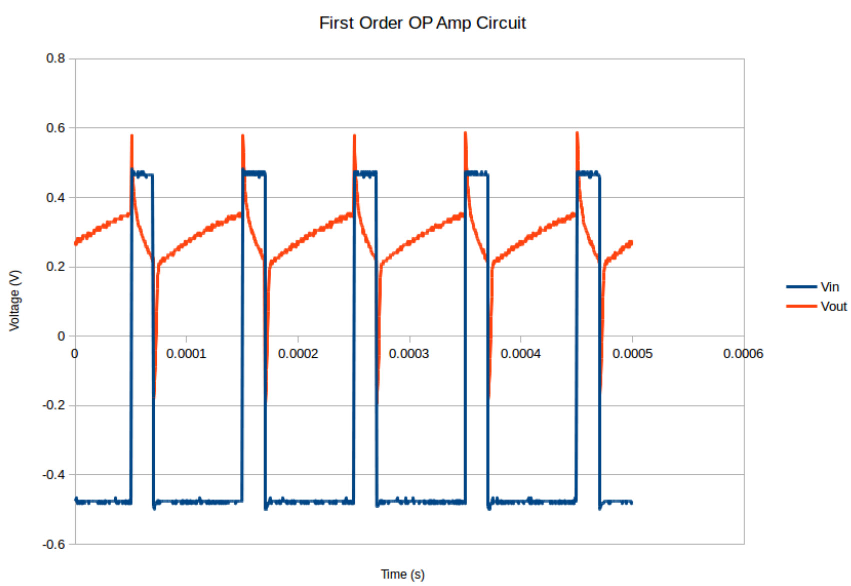

Figure 9: Plot of first order op amp circuit, 20% duty cycle, 10kHz

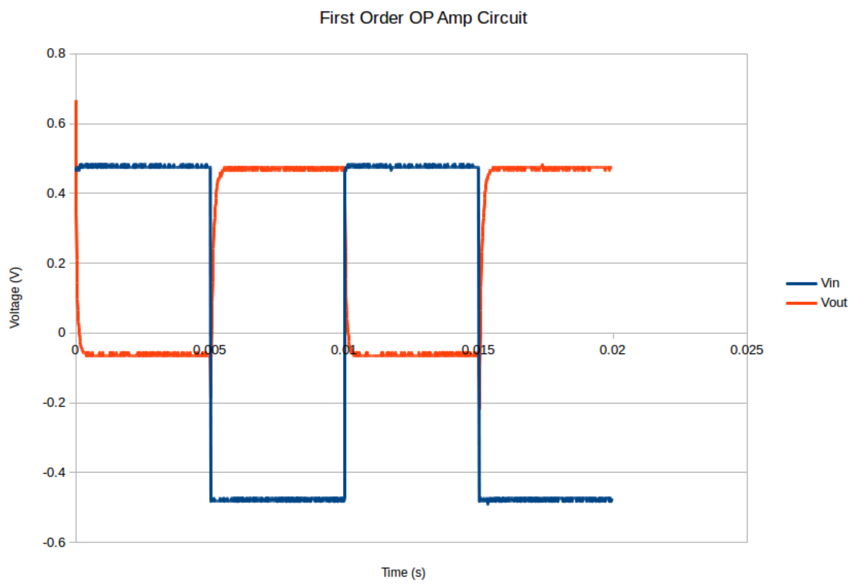

Figure 10: Plot of first order op amp circuit, 50% duty cycle, 100Hz

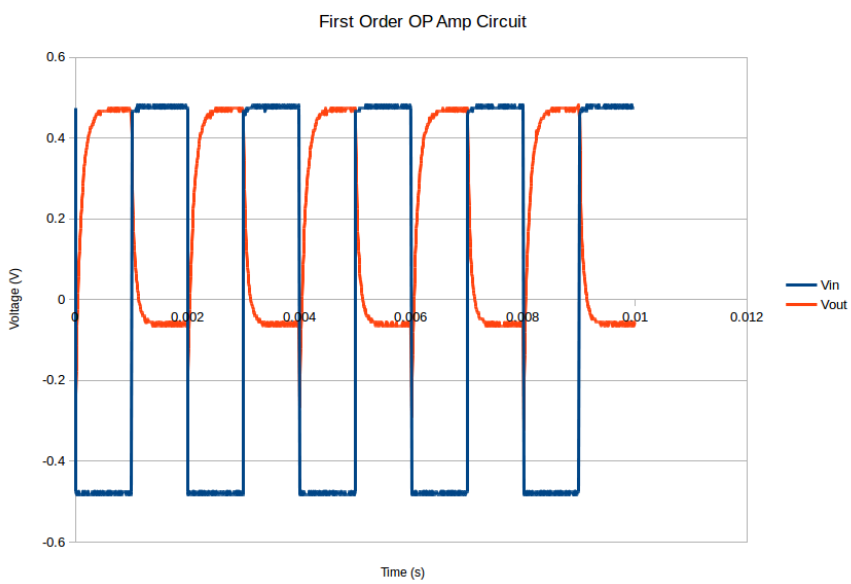

Figure 11: Plot of first order op amp circuit, 50% duty cycle, 500Hz

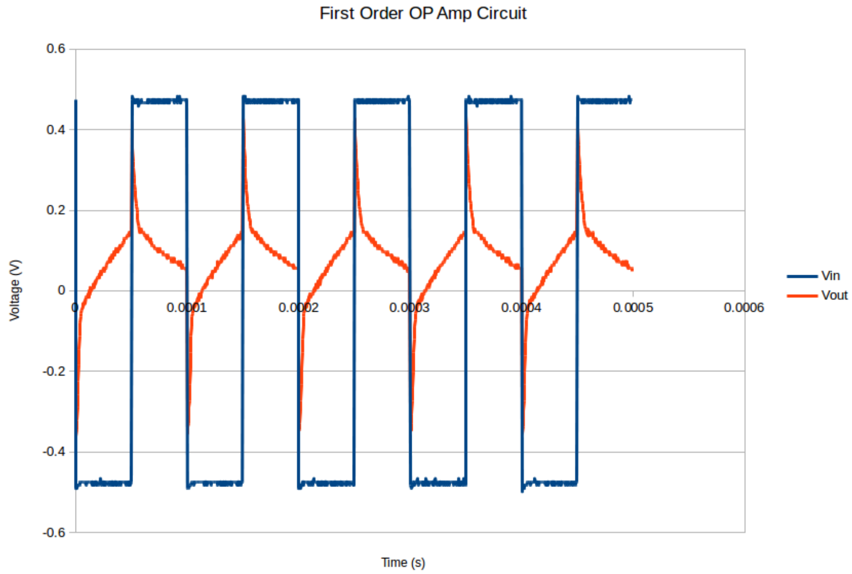

Figure 12: Plot of first order op amp circuit, 50% duty cycle, 10kHz

Series RLC Circuit — Underdamped Response, $R = 1k\Omega$

Element	**Measured Value**
Combined Resistance	990.57Ω
C	$575pF$
T_1	$17\mu s$
L	$10.30mH$
L_R	23.94Ω

Table 6: Measured values for circuit elements

Parameter	**Calculated Value**
$f_{d,1}$	$58823.5294Hz$

Table 7: Calculated $f_{d,1}$

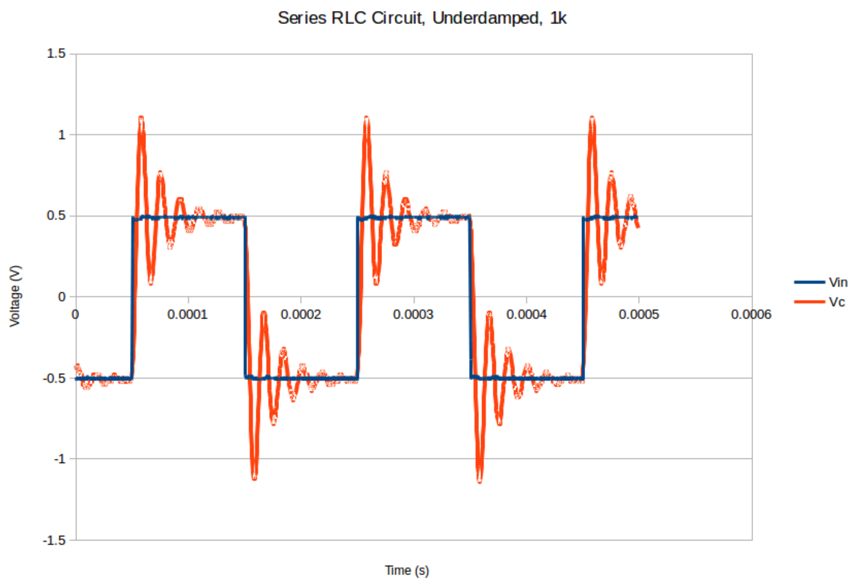

Figure 13: Plot of Series RLC Circuit — Underdamped Response, $R = 1k\Omega$

Series RLC Circuit — Underdamped Response, Minimum Response

Element	Measured Value
Combined Resistance	1.186Ω
C	$575pF$
T_1	$17\mu s$
L	$10.30mH$
L_R	23.94Ω

Table 8: Measured values for circuit elements

Parameter	Calculated Value
$f_{d,1}$	$58823.5294Hz$

Table 9: Calculated $f_{d,1}$

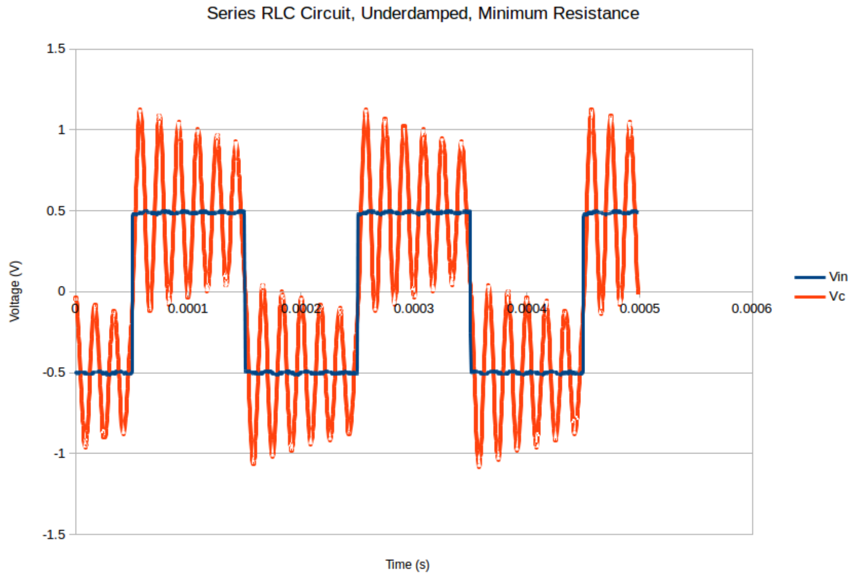

Figure 14: Plot of Series RLC Circuit — Underdamped Response, Minimum Response

Series RLC Circuit — Critically Damped Response

Element	**Measured Value**
Combined Resistance	$4.6208k\Omega$
C	$575pF$
L	$10.30mH$
L_R	23.94Ω

Table 10: Measured values for circuit elements

Figure 15: Plot of Series RLC Circuit — Critically Damped Response

Series RLC Circuit — Overdamped Response

Element	**Measured Value**
Combined Resistance	$0.12726M\Omega$
C	$575pF$
L	$10.30mH$
L_R	23.94Ω

Table 11: Measured values for circuit elements

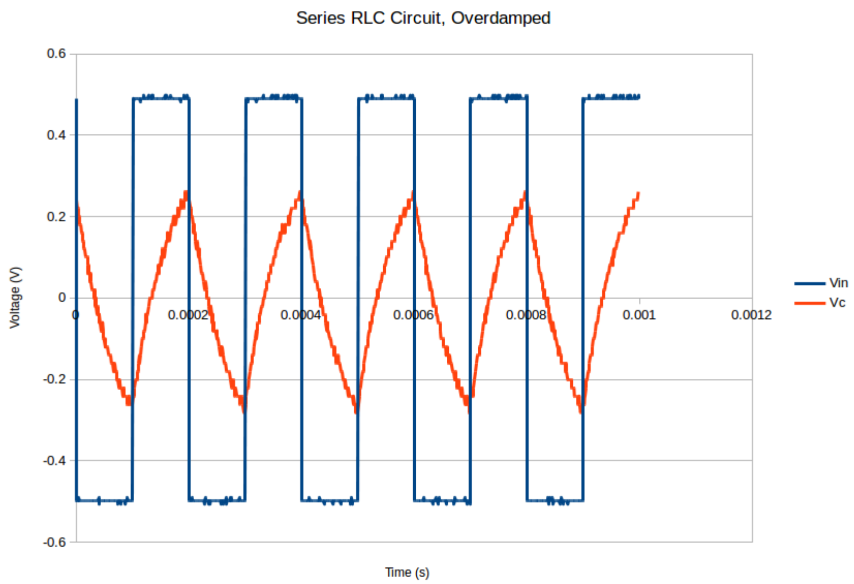

Figure 16: Plot of Series RLC Circuit — Overdamped Response

Post-Lab

Series RC Circuit

Zero DC Offset

$V_{C,PPK,Calculated} = 0.99995V$
$V_{C,PPK,Measured} = 0.99698V$
$PercentageError = \frac{|measured-calculated|}{calculated} = \frac{|0.99698-0.99995|}{0.99995} = 0.297\%$
These values are very close.

Nonzero DC Offset

$V_{C,PPK,Measured,ZeroOffset} = 0.99698V$
$V_{C,PPK,Measured,NonZeroOffset} = 1.04523V$
$V_{C,PPK,Measured,ZeroOffset} = 1.82915V$
$V_{R,PPK,Measured,NonZeroOffset} = 1.90955V$
The waveforms shapes are the same, except the values are shifted by 0.5V.

Frequency Response

$V_{C,PPK,Calculated} = 0.91777$
$V_{C,PPK,Measured} = 0.82814$
$PercentageError = \frac{|measured-calculated|}{calculated} = \frac{|0.82814-0.91777|}{0.91777} = 9.766\%$
These values are similar, but differ due to experimental errors.

First Order Op Amp Circuit

$\tau = RC = (R_1 + R_2 + R_3)C = (985.92 + 981.50 + 987.64)(101.5 \times 10^{-9} = 2.999 \times 10^{-4}$

100Hz

Steady state is reached.

$T = 5ms$
$\frac{5\times10^{-3}}{2.999\times10^{-4}} = 16.67\tau$
The measurements of v_{out} agree with my expectations.

500Hz

Steady state is reached.
$T = 2ms$
$\frac{2\times10^{-3}}{2.999\times10^{-4}} = 6.67\tau$
The measurements of v_{out} agree with my expectations. The larger frequency results in a smaller period, which is reflected in the waveform.

10kHz

Steady state is not reached.
$T = 50\mu s$
$\frac{50\times10^{-6}}{2.999\times10^{-4}} = 0.17\tau$
Due to the high frequency, it was difficult to predict the waveform. However, it was known that the circuit would not reach steady state, which was found to be the case.

Series RLC Circuit

R = 1kΩ

$f_{calculated,ideal} = 50000Hz$
$f_{calculated,real} = 49705.8252Hz$
$f_{measured} = 58823.5294Hz$
$PercentageError_{ideal} = \frac{|measured-calculated|}{calculated} = \frac{|58823.5294-50000|}{50000} = 17.65\%$
$PercentageError_{real} = \frac{|measured-calculated|}{calculated} = \frac{|58823.5294-49705.8252|}{49705.8252} = 18.34\%$
$T_{calculated,ideal} = 20\mu s$
$T_{calculated,real} = 20.1184\mu s$
$T_{measured} = 17\mu s$
$PercentageError_{ideal} = \frac{|measured-calculated|}{calculated} = \frac{|17-20|}{20} = 15\%$
$PercentageError_{real} = \frac{|measured-calculated|}{calculated} = \frac{|17-20.1184|}{20.1184} = 15.50\%$
The difference between ω_d and ω_0 is that ω_0 is the resonant frequency of the circuit, while ω_d is the imaginary part of the natural frequency of an underdamped circuit.

Critically Damped Response

The experimental data created a waveform that was close to being critically damped, but was not. This is due to the human error in determining when the circuit reaches critical damping, as well as the real values of the circuit elements which are difficult to model.

Maximally Damped Response

The circuit does reach a new DC steady state during each half period of the square wave.