Lab 7: Transient Response of a 2nd Order Circuit

Josh Ortiz & James Robinson
ECEN 214 - 502
TA: Yichi Zhang
Date Performed: 4/2/19
Date Report Due: 4/16/19

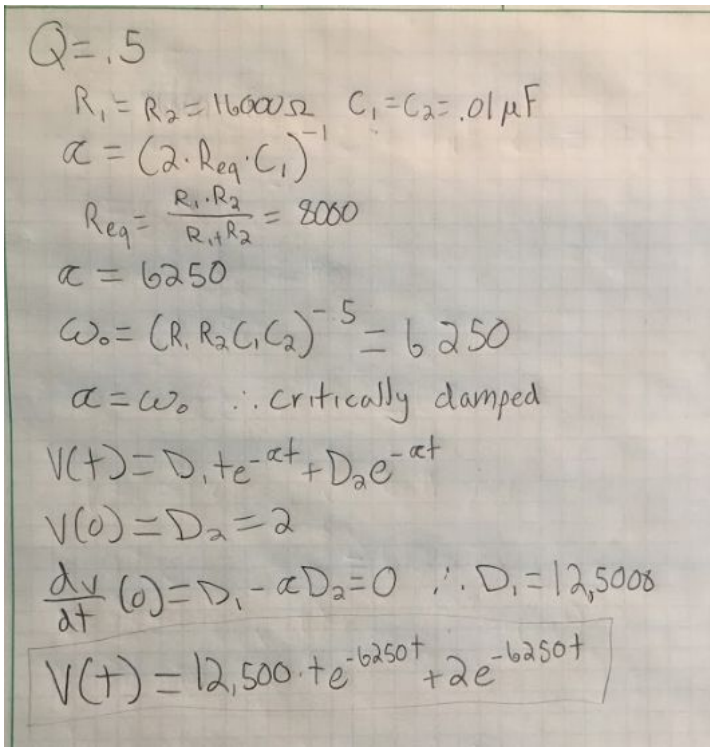
Procedure

1. Build the Sallen-Key circuit depicted in Figure 7.1.
2. Use a 100 Hz square wave with 2 Volts (peak to peak) as your input.
3. Produce the 5 cases that were discussed in the prelab with the correct component values
4. Save the waveforms.

Data and Results

Theoretical

Q = .5



Q = .25

$Q = .25$

$R_1 = 13000\,\Omega \quad R_2 = 5600\,\Omega \quad C_1 = .01\,\mu F \quad C_2 = .033\,\mu F$

$\alpha = (2R_{eq}C_1)^{-1}$

$R_{eq} = \frac{R_1 \cdot R_2}{R_1 + R_2} = 3913.9$

$\alpha = 12774.7$

$\omega_0 = (R_1 R_2 C_1 C_2)^{-.5} = 6451.7$

$|\alpha| > |\omega_0| \quad \therefore$ overdamped

$V(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t}$

$s_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$

$s_1 = -1748.9 \quad s_2 = -23800.5$

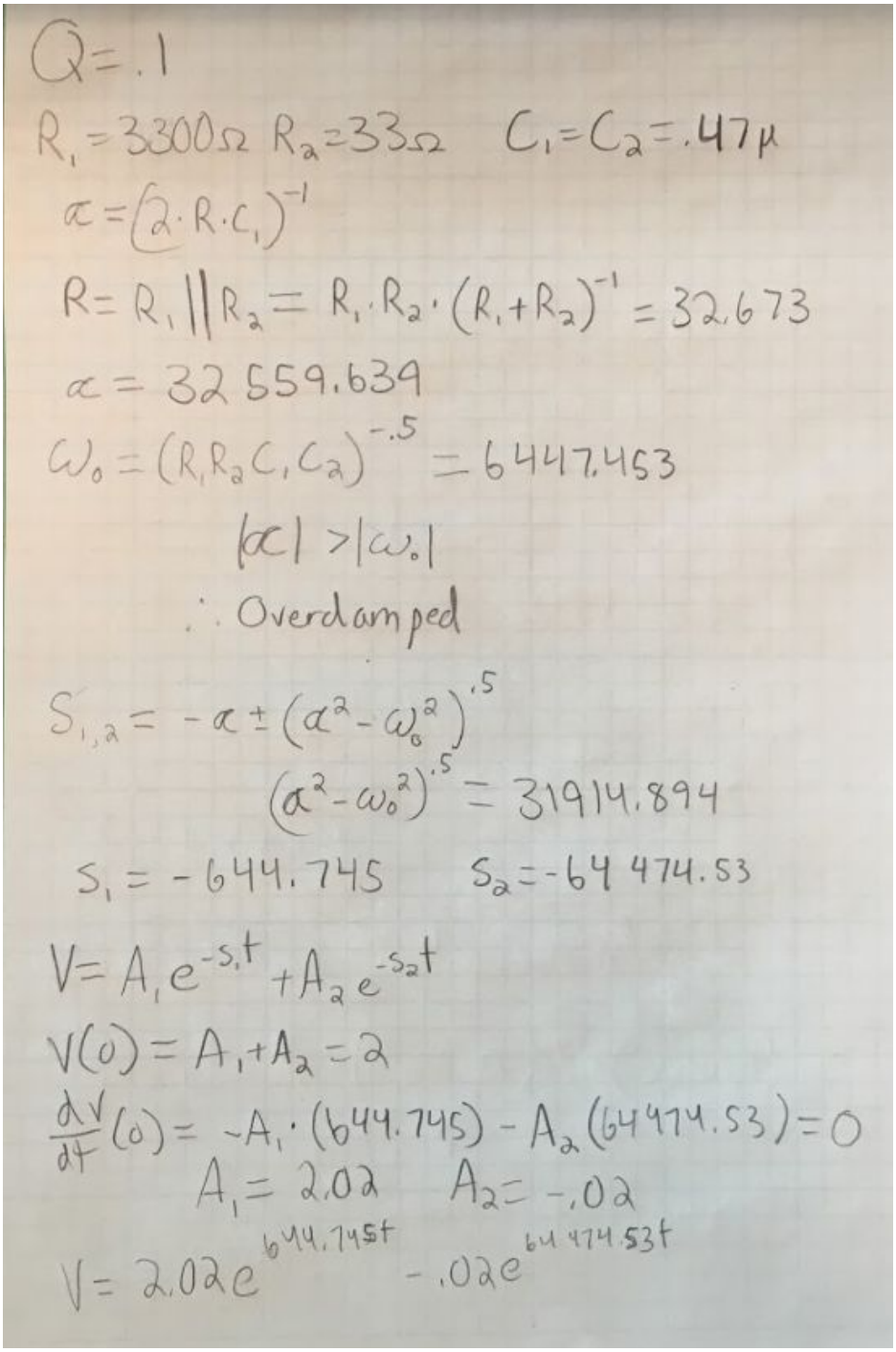
$V(0) = A_1 + A_2 = 2$

$\frac{dV}{dt}(0) = s_1 A_1 + s_2 A_2 = 0$

$A_1 = 2.16 \quad A_2 = -.16$

$V(t) = 2.16e^{-1748.9t} - .16e^{-23800.5t}$

Q = .1


Q = .1
$R_1 = 3300\Omega$ $R_2 = 33\Omega$ $C_1 = C_2 = .47\mu$
$\alpha = (2 \cdot R \cdot C_1)^{-1}$
$R = R_1 \| R_2 = R_1 \cdot R_2 \cdot (R_1 + R_2)^{-1} = 32.673$
$\alpha = 32559.639$
$\omega_0 = (R_1 R_2 C_1 C_2)^{-.5} = 6447.453$
$|\alpha| > |\omega_0|$
∴ Overdamped
$S_{1,2} = -\alpha \pm (\alpha^2 - \omega_0^2)^{.5}$
$(\alpha^2 - \omega_0^2)^{.5} = 31914.894$
$S_1 = -644.745$ $S_2 = -64474.53$
$V = A_1 e^{-S_1 t} + A_2 e^{-S_2 t}$
$V(0) = A_1 + A_2 = 2$
$\frac{dV}{dt}(0) = -A_1 \cdot (644.745) - A_2 (64474.53) = 0$
$A_1 = 2.02$ $A_2 = -.02$
$V = 2.02 e^{644.745t} - .02 e^{64474.53t}$

Q = 1

$Q = 1$

$R_1 = 820\,\Omega \quad R_2 = 8205\,\Omega \quad C_1 = .4\mu F \quad C_2 = .1\mu F$

$\alpha = (2 \cdot R \cdot C_1)^{-1}$

$R = R_1 \cdot R_2 \cdot (R_1 + R_2)^{-1} = 672400 / 1640 = 410\,\Omega$

$\therefore \alpha = (2 \cdot 410 \cdot .4 \cdot 10^{-6})^{-1} = 3048.78$

$\omega_o = (R_1 \cdot R_2 \cdot C_1 \cdot C_2)^{-.5} = (672400 \cdot .04 \cdot 10^{-12})^{-.5}$

$= 6097.56$

$|\omega_d| > |\alpha|$: Underdamped

$\omega_d = \sqrt{\omega_o^2 - \alpha^2} = 5280.64$

$V(0) = A = 2V$

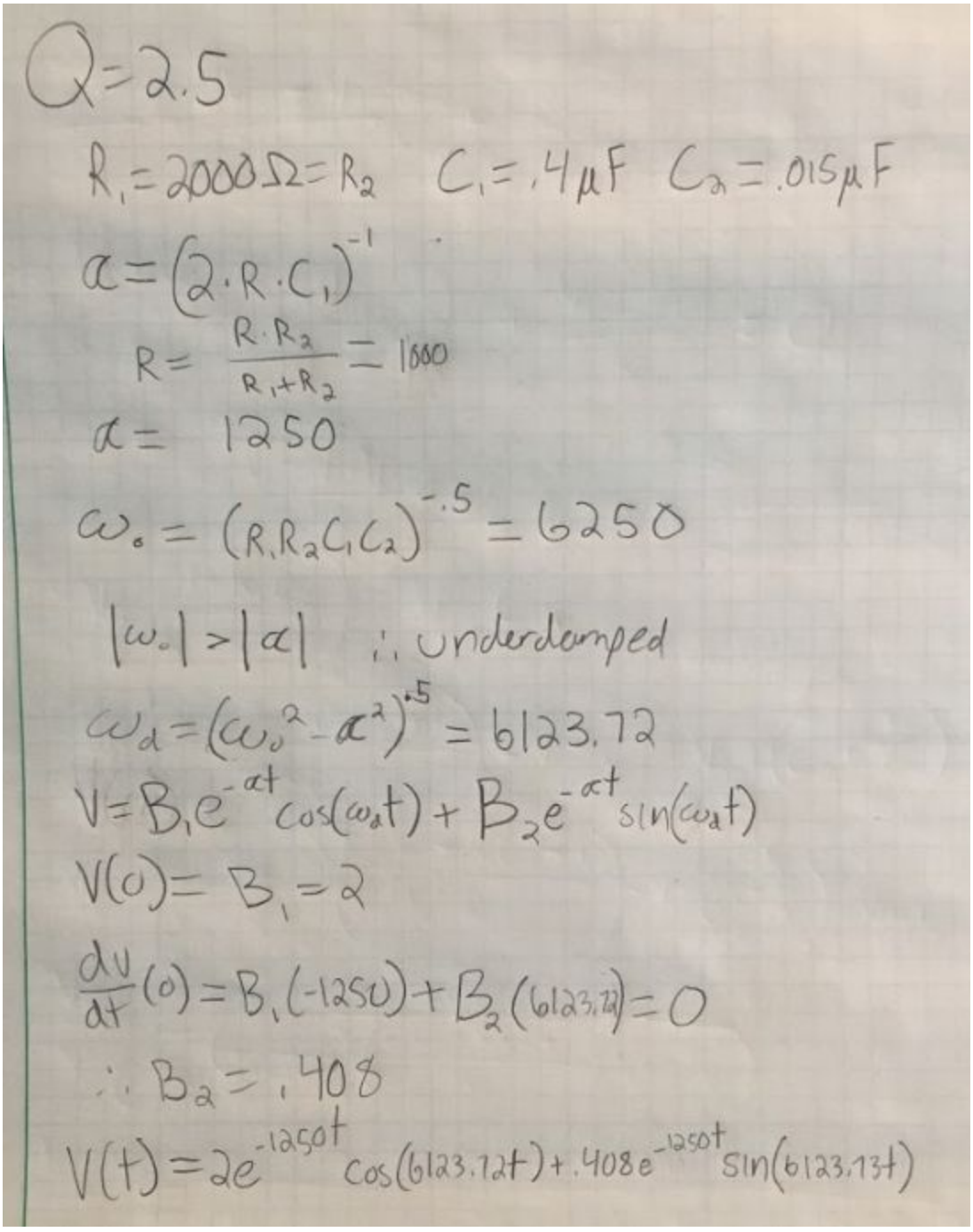
$V(t) = B_1 \cdot e^{-3048.78t} \cos(5280.64t) + B_2 e^{-3048.78t} \cdot \sin(5280.64t)$

$\frac{dV}{dt} = 0 = B_1 \cdot (-3048.78) + B_2 (5280.64)$

$\downarrow$

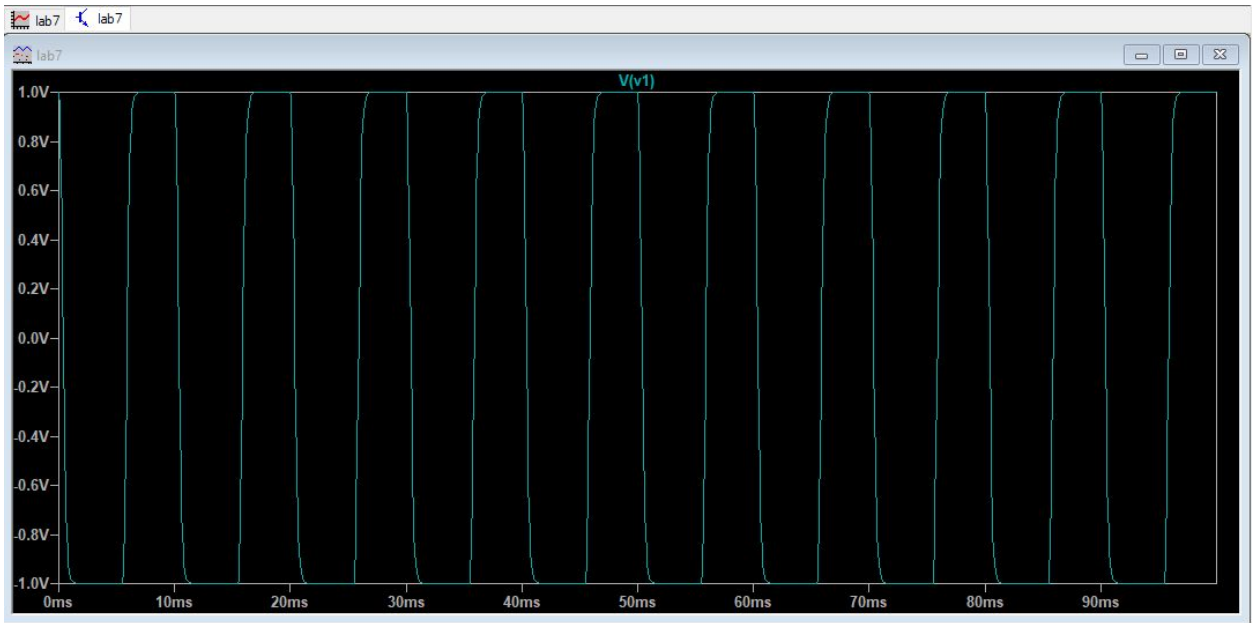
$V(t) = .00021 e^{-3048.78t} \cdot \sin(5280.64t) + 1.99864 e^{-3048.78t} \cdot \cos(5280.64t)$

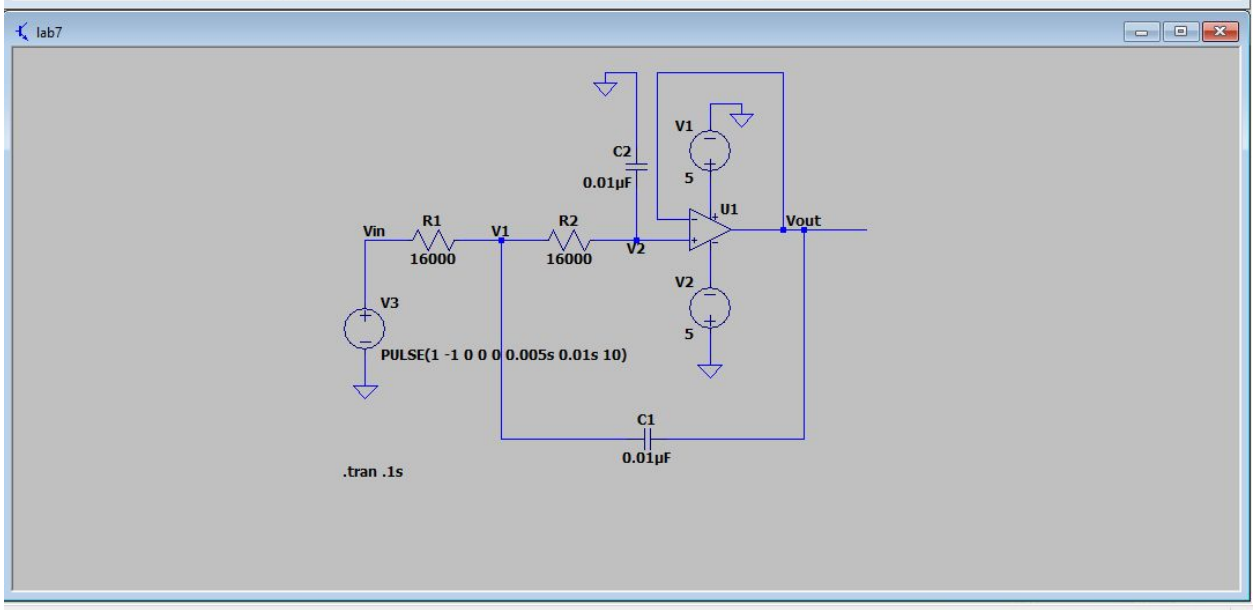
Q = 2.5


Q=2.5
$R_1 = 2000\Omega = R_2$ $C_1 = .4\mu F$ $C_2 = .015\mu F$
$\alpha = (2 \cdot R \cdot C_1)^{-1}$
$R = \frac{R \cdot R_2}{R_1 + R_2} = 1000$
$\alpha = 1250$
$\omega_0 = (R_1 R_2 C_1 C_2)^{-.5} = 6250$
$|\omega_0| > |\alpha|$ ∴ underdamped
$\omega_d = (\omega_0^2 - \alpha^2)^{.5} = 6123.72$
$V = B_1 e^{-\alpha t} \cos(\omega_d t) + B_2 e^{-\alpha t} \sin(\omega_d t)$
$V(0) = B_1 = 2$
$\frac{dV}{dt}(0) = B_1(-1250) + B_2(6123.72) = 0$
∴ $B_2 = .408$
$V(t) = 2e^{-1250t} \cos(6123.72t) + .408e^{-1250t} \sin(6123.73t)$

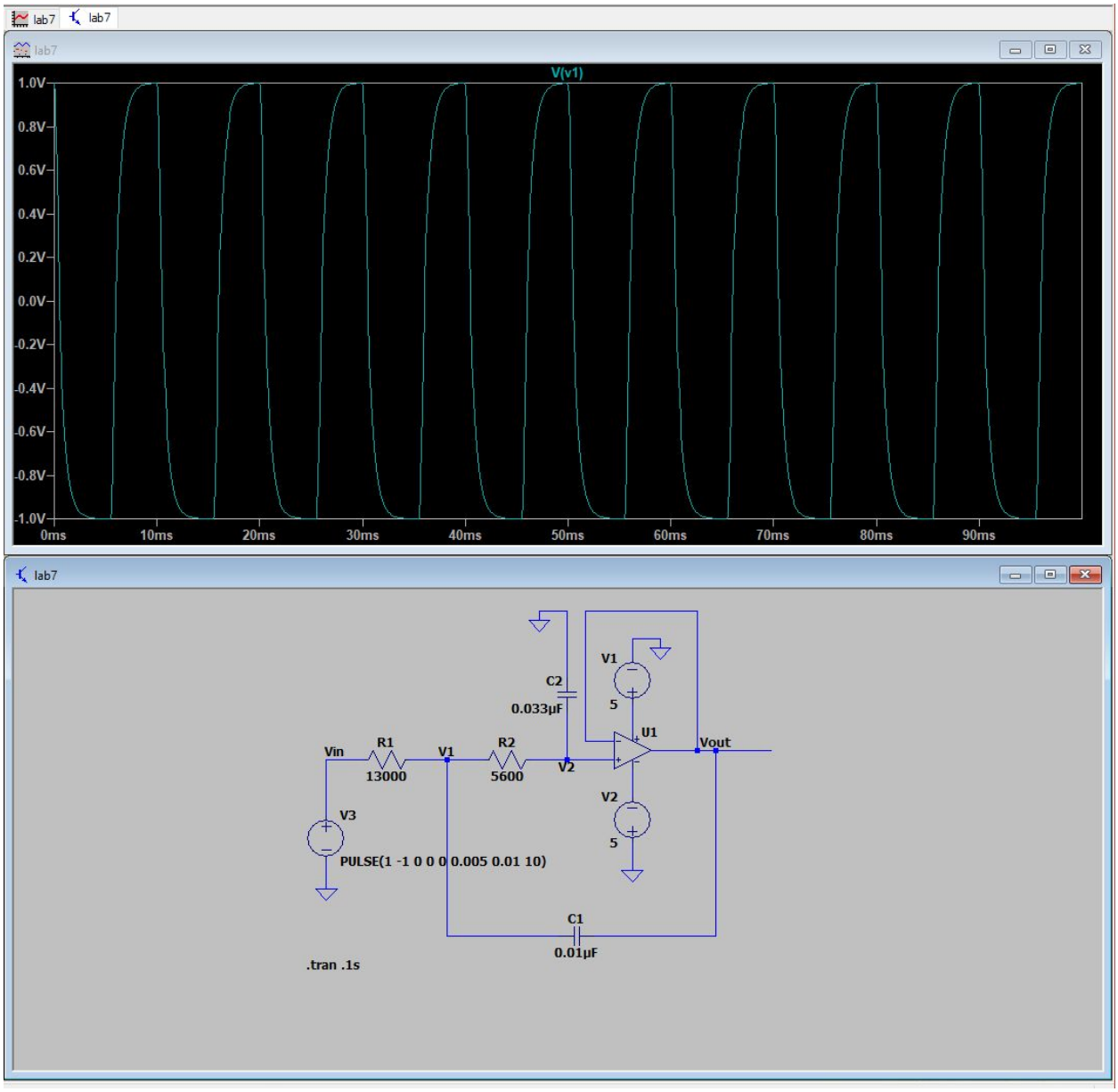
Simulations

Q = .5

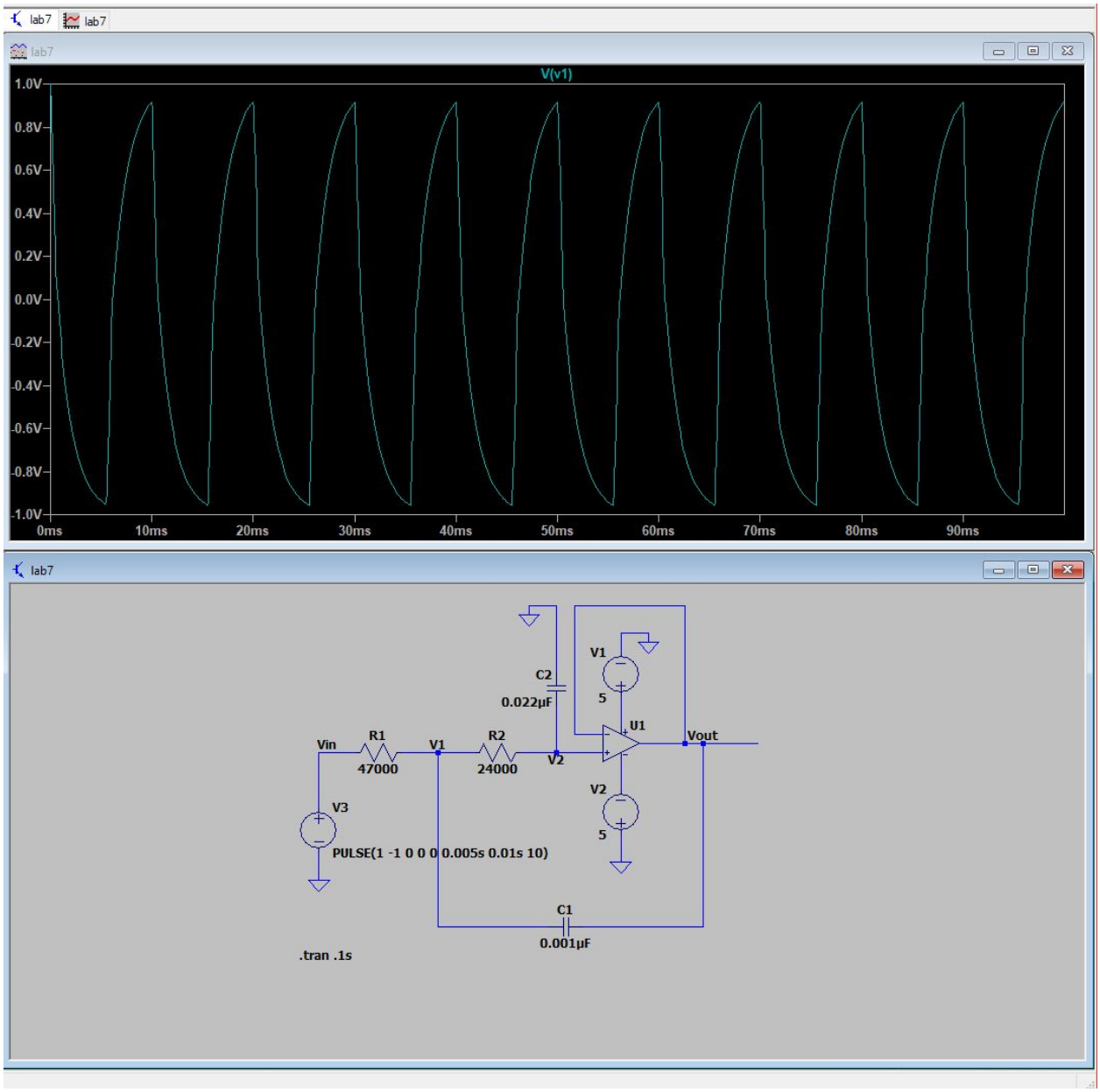




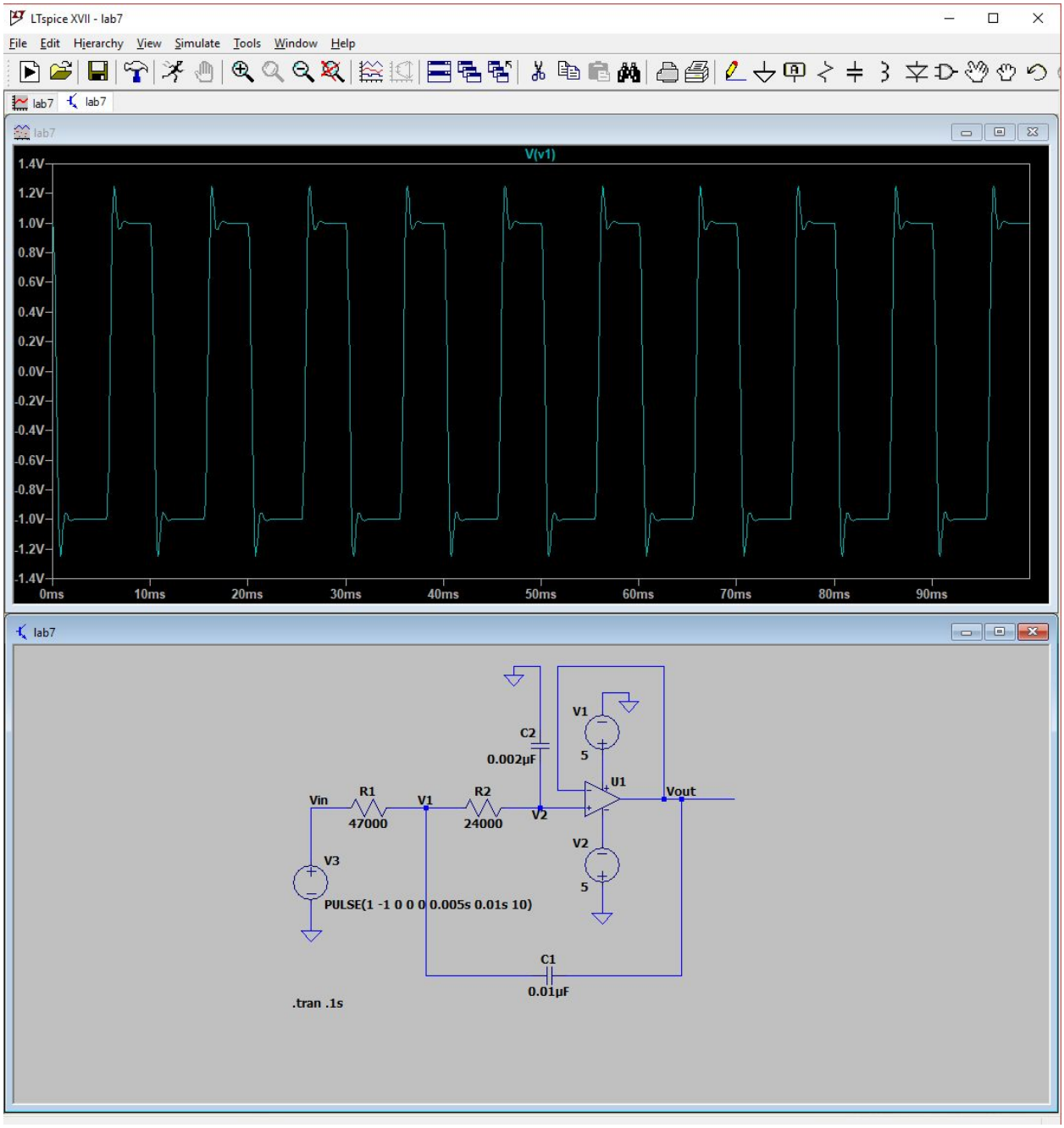
Q = .25


lab7
lab7
lab7
V(v1)
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
-0.8V
-1.0V
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
lab7
C2
0.033µF
V1
5
U1
Vin
R1
13000
V1
R2
5600
V2
Vout
V2
5
V3
PULSE(1 -1 0 0 0 0.005 0.01 10)
C1
0.01µF
.tran .1s

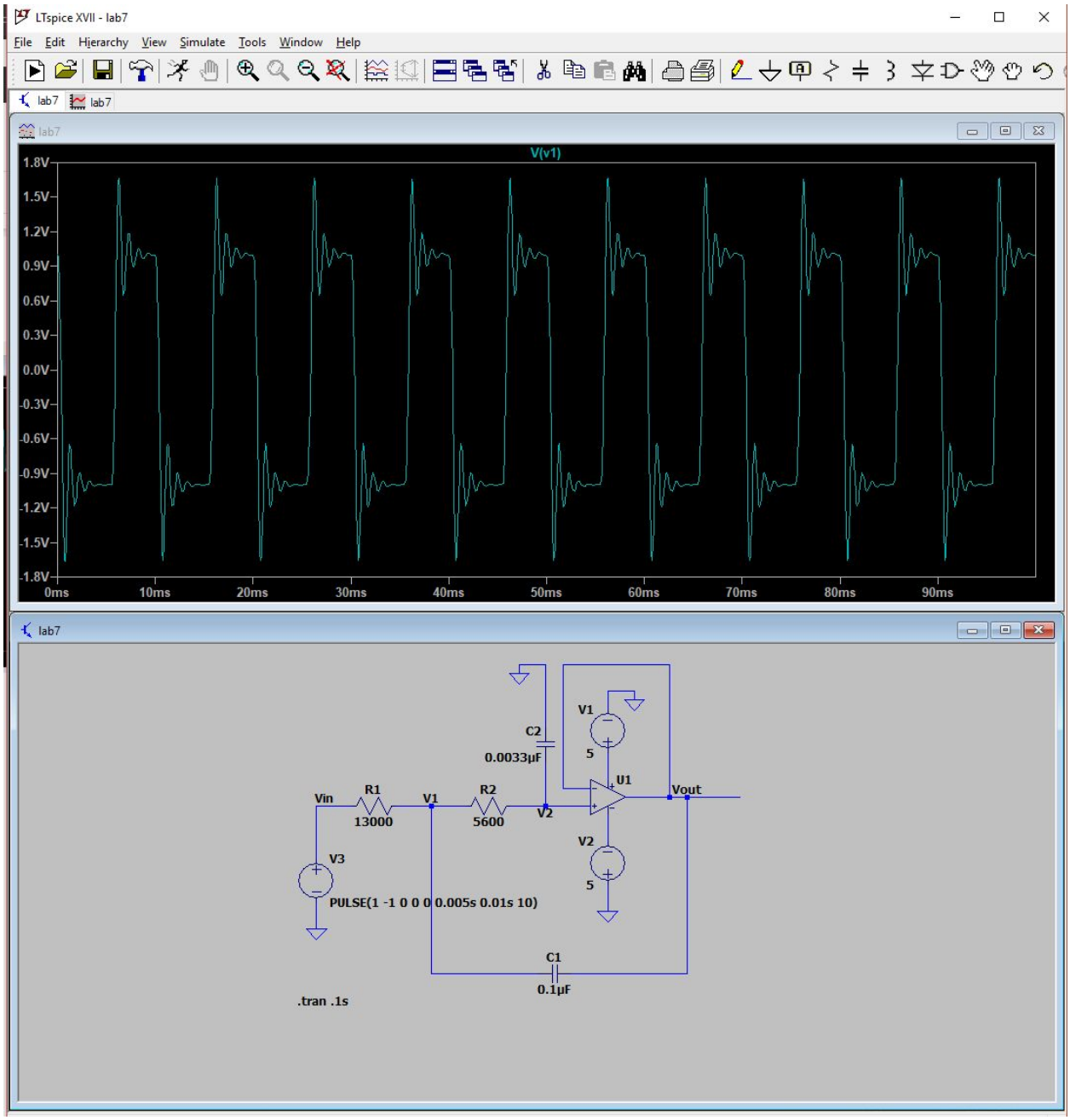
Q = .1


lab7
lab7
V(v1)
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
-0.8V
-1.0V
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
lab7
C2
0.022µF
V1
5
U1
Vin
R1
47000
V1
R2
24000
V2
Vout
V2
5
V3
PULSE(1 -1 0 0 0 0.005s 0.01s 10)
C1
0.001µF
.tran .1s

Q = 1

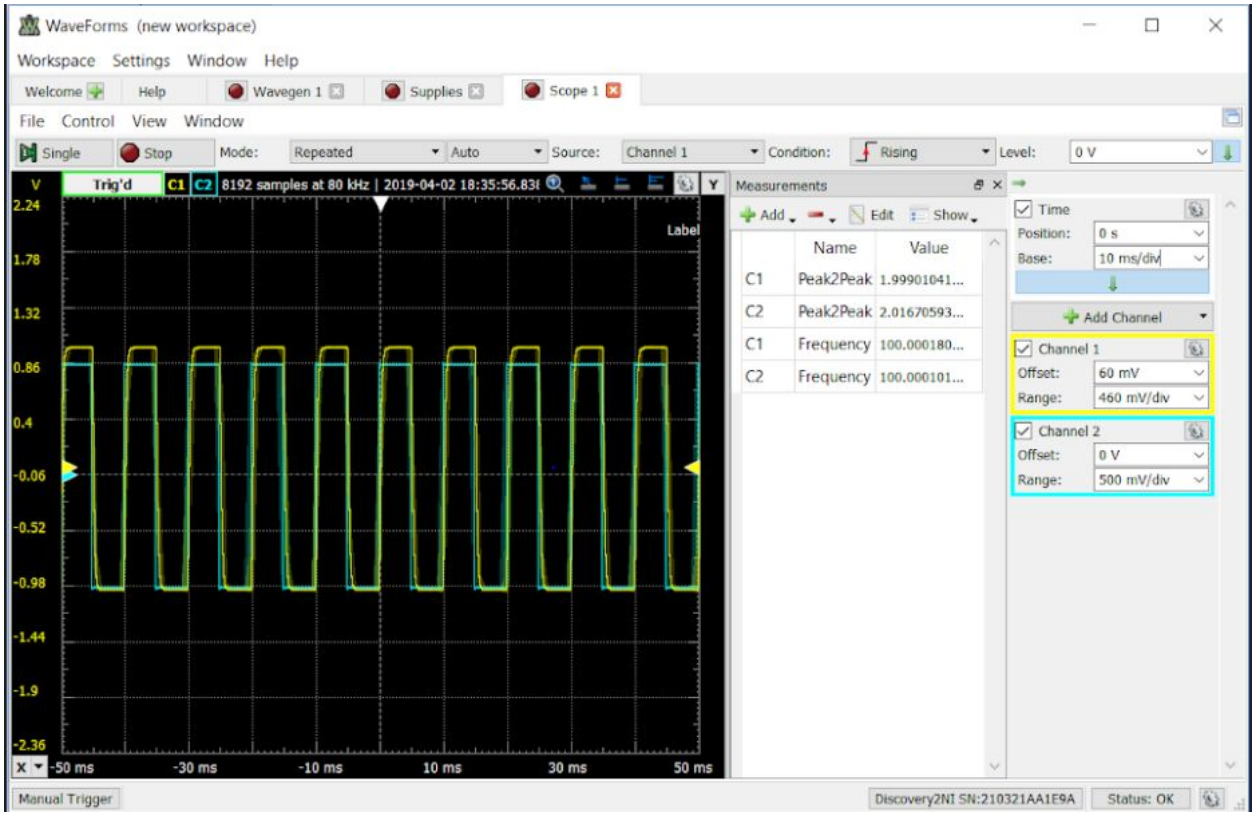

LTspice XVII - lab7
File Edit Hierarchy View Simulate Tools Window Help
lab7
lab7
V(v1)
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
-0.8V
-1.0V
-1.2V
-1.4V
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
lab7
V1
5
C2
0.002µF
U1
Vin
R1
47000
V1
R2
24000
V2
Vout
V2
5
V3
PULSE(1 -1 0 0 0 0.005s 0.01s 10)
C1
0.01µF
.tran .1s

Q = 2.5

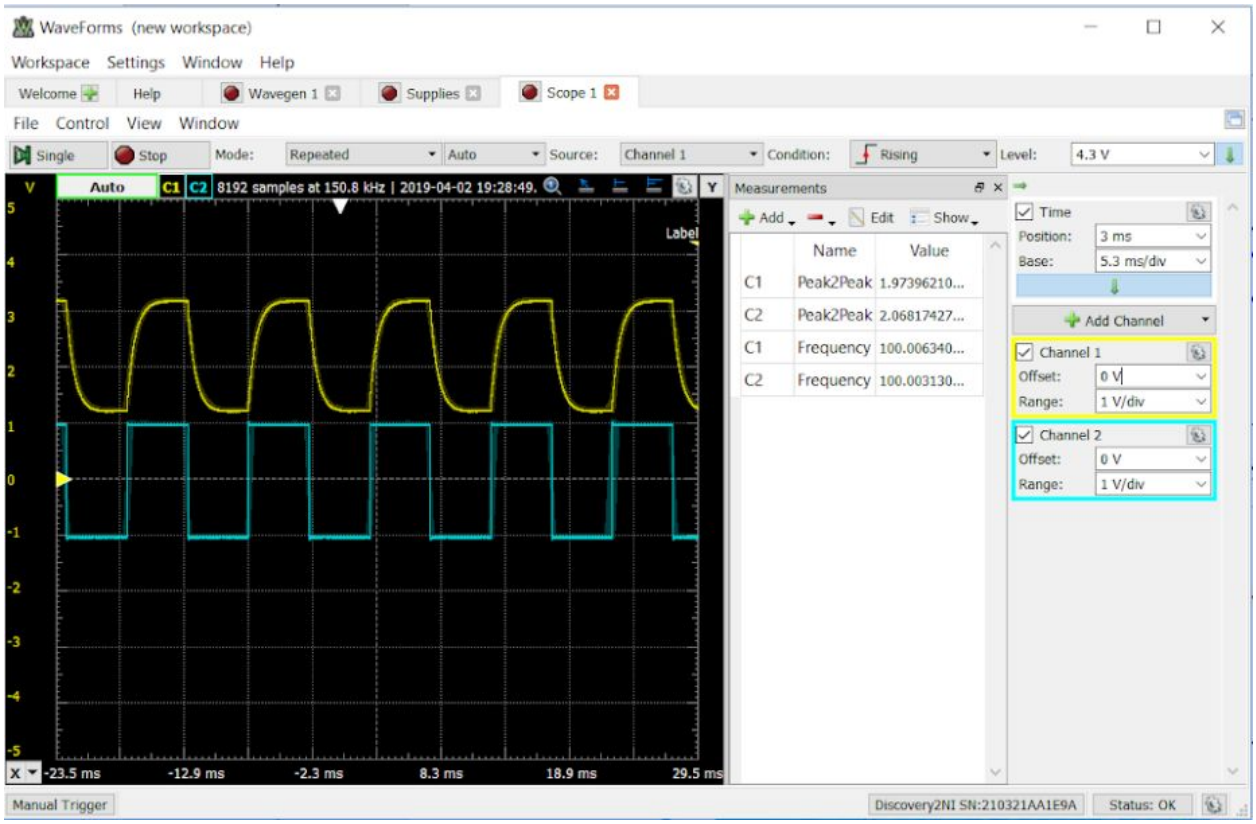

LTspice XVII - lab7
File Edit Hierarchy View Simulate Tools Window Help
lab7
lab7
V(v1)
1.8V
1.5V
1.2V
0.9V
0.6V
0.3V
0.0V
-0.3V
-0.6V
-0.9V
-1.2V
-1.5V
-1.8V
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
lab7
V1
5
C2
0.0033µF
U1
Vout
Vin
R1
13000
V1
R2
5600
V2
V2
5
V3
PULSE(1 -1 0 0 0 0.005s 0.01s 10)
C1
0.1µF
.tran .1s

Measured

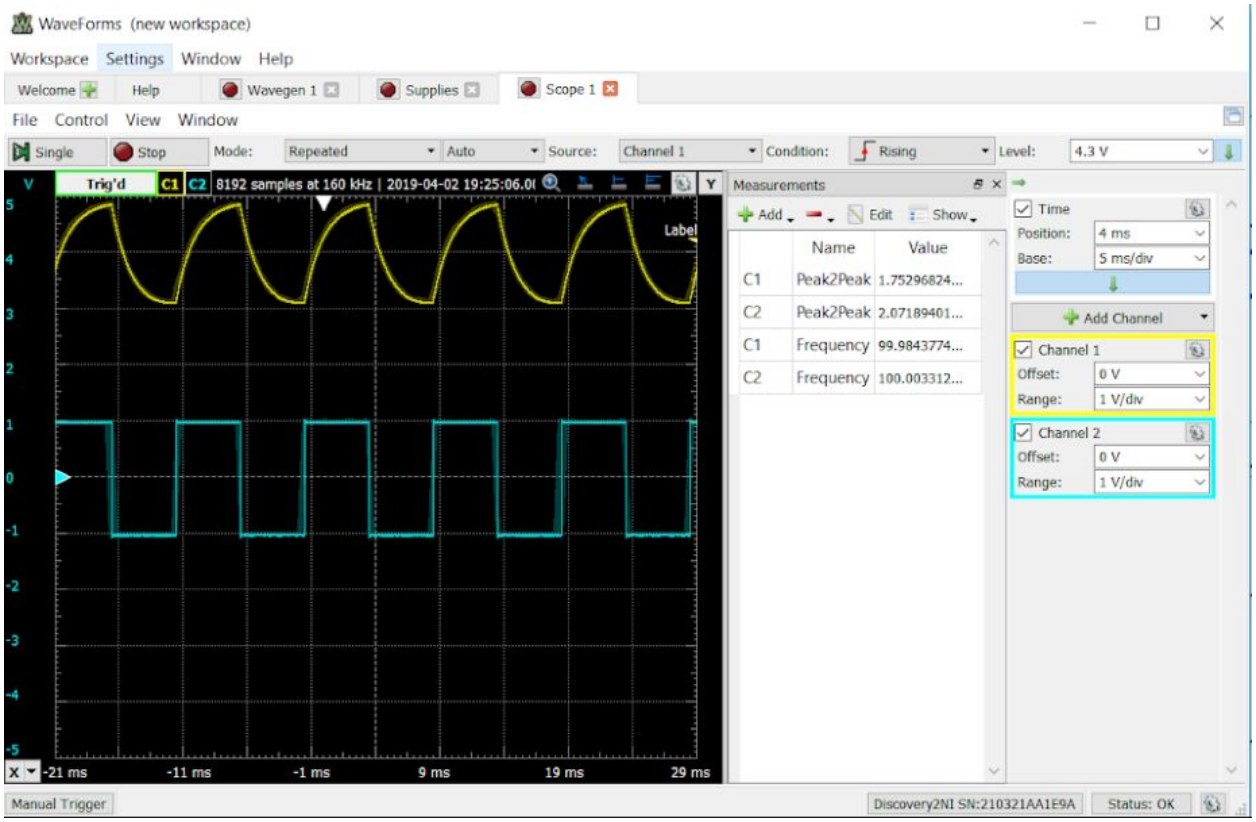
Q = .5


WaveForms (new workspace)
Workspace Settings Window Help
Welcome Help Wavegen 1 Supplies Scope 1
File Control View Window
Single Stop Mode: Repeated Auto Source: Channel 1 Condition: Rising Level: 0 V
Trig'd C1 C2 8192 samples at 80 kHz | 2019-04-02 18:35:56.83
Label
2.24
1.78
1.32
0.86
0.4
-0.06
-0.52
-0.98
-1.44
-1.9
-2.36
-50 ms -30 ms -10 ms 10 ms 30 ms 50 ms
Measurements
Add Edit Show
Name Value
C1 Peak2Peak 1.99901041...
C2 Peak2Peak 2.01670593...
C1 Frequency 100.000180...
C2 Frequency 100.000101...
Time
Position: 0 s
Base: 10 ms/div
Add Channel
Channel 1
Offset: 60 mV
Range: 460 mV/div
Channel 2
Offset: 0 V
Range: 500 mV/div
Manual Trigger
Discovery2NI SN:210321AA1E9A
Status: OK

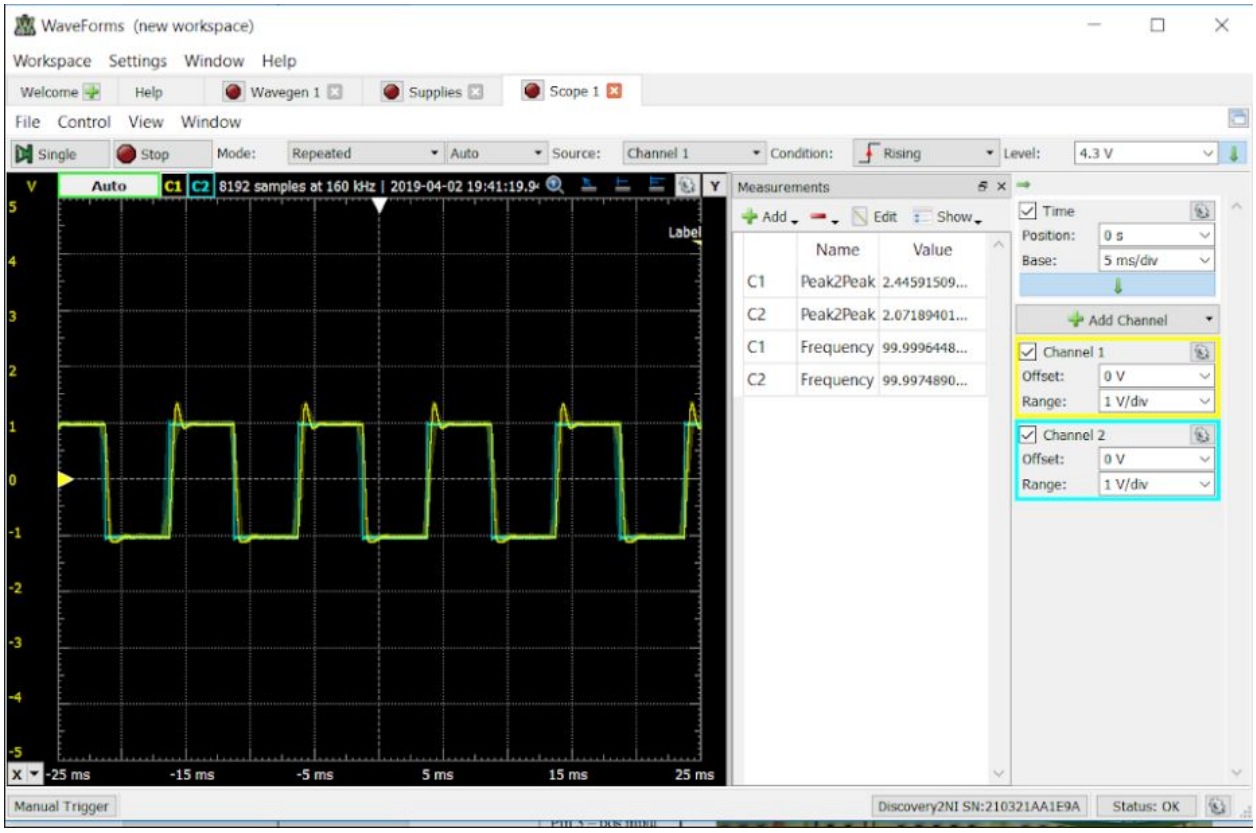
Q = .25


WaveForms (new workspace)
Workspace Settings Window Help
Welcome Help Wavegen 1 Supplies Scope 1
File Control View Window
Single Stop Mode: Repeated Auto Source: Channel 1 Condition: Rising Level: 4.3 V
Auto C1 C2 8192 samples at 150.8 kHz | 2019-04-02 19:28:49.
Label
-23.5 ms -12.9 ms -2.3 ms 8.3 ms 18.9 ms 29.5 ms
Measurements
Add Edit Show
Name Value
C1 Peak2Peak 1.97396210...
C2 Peak2Peak 2.06817427...
C1 Frequency 100.006340...
C2 Frequency 100.003130...
Time
Position: 3 ms
Base: 5.3 ms/div
Add Channel
Channel 1
Offset: 0 V
Range: 1 V/div
Channel 2
Offset: 0 V
Range: 1 V/div
Manual Trigger
Discovery2NI SN:210321AA1E9A
Status: OK

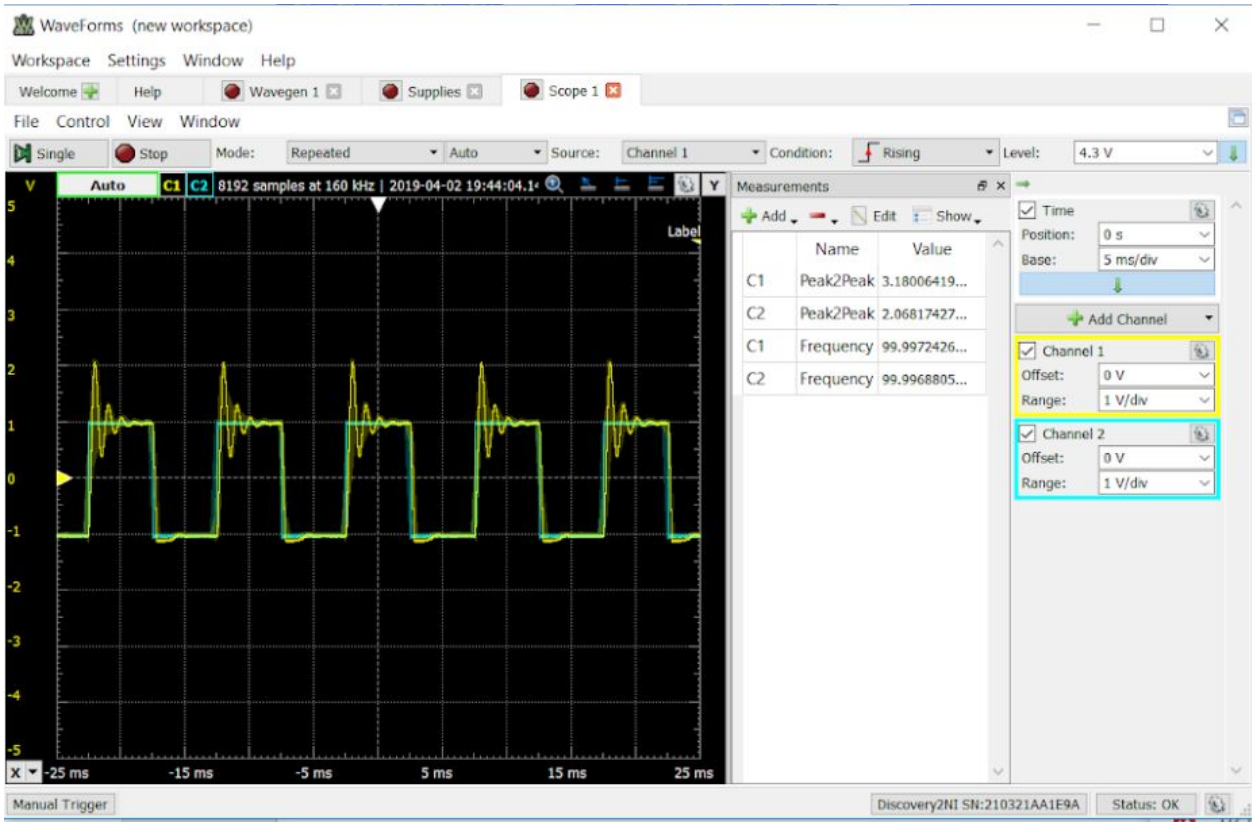
Q = .1


WaveForms (new workspace)
Workspace Settings Window Help
Welcome Help Wavegen 1 Supplies Scope 1
File Control View Window
Single Stop Mode: Repeated Auto Source: Channel 1 Condition: Rising Level: 4.3 V
Trig'd C1 C2 8192 samples at 160 kHz | 2019-04-02 19:25:06.0
Label
5 4 3 2 1 0 -1 -2 -3 -4 -5
-21 ms -11 ms -1 ms 9 ms 19 ms 29 ms
Measurements
Add Edit Show
Name Value
C1 Peak2Peak 1.75296824...
C2 Peak2Peak 2.07189401...
C1 Frequency 99.9843774...
C2 Frequency 100.003312...
Time
Position: 4 ms
Base: 5 ms/div
Add Channel
Channel 1
Offset: 0 V
Range: 1 V/div
Channel 2
Offset: 0 V
Range: 1 V/div
Manual Trigger
Discovery2NI SN:210321AA1E9A
Status: OK

Q = 1


WaveForms (new workspace)
Workspace Settings Window Help
Welcome Help Wavegen 1 Supplies Scope 1
File Control View Window
Single Stop Mode: Repeated Auto Source: Channel 1 Condition: Rising Level: 4.3 V
Auto C1 C2 8192 samples at 160 kHz | 2019-04-02 19:41:19.9
Label
5 4 3 2 1 0 -1 -2 -3 -4 -5
-25 ms -15 ms -5 ms 5 ms 15 ms 25 ms
Measurements
Add Edit Show
Name Value
C1 Peak2Peak 2.44591509...
C2 Peak2Peak 2.07189401...
C1 Frequency 99.9996448...
C2 Frequency 99.9974890...
Time
Position: 0 s
Base: 5 ms/div
Add Channel
Channel 1
Offset: 0 V
Range: 1 V/div
Channel 2
Offset: 0 V
Range: 1 V/div
Manual Trigger
Discovery2NI SN:210321AA1E9A
Status: OK

Q = 2.5


WaveForms (new workspace)
Workspace Settings Window Help
Welcome Help Wavegen 1 Supplies Scope 1
File Control View Window
Single Stop Mode: Repeated Auto Source: Channel 1 Condition: Rising Level: 4.3 V
Auto C1 C2 8192 samples at 160 kHz | 2019-04-02 19:44:04.1
Label
-25 ms -15 ms -5 ms 5 ms 15 ms 25 ms
Measurements
Add Edit Show
Name Value
C1 Peak2Peak 3.18006419...
C2 Peak2Peak 2.06817427...
C1 Frequency 99.9972426...
C2 Frequency 99.9968805...
Time
Position: 0 s
Base: 5 ms/div
Add Channel
Channel 1
Offset: 0 V
Range: 1 V/div
Channel 2
Offset: 0 V
Range: 1 V/div
Manual Trigger
Discovery2NI SN:210321AA1E9A
Status: OK

Discussion

The results of our theoretical, simulated and measured circuits all matched up. The lab proceeded exactly as it was intended to. Therefore there would be no changes that we would need to make in order for our results to come out better.

Conclusion

This lab was very complicated and forced us to use all of the things we had learned thus far in ECEN 214. As discussed in the overview, there were several different components that were required to function together. The calculations were cumbersome at times, but that was the toughest part of the experiment, once we understood all the concepts in the lab, implementing the circuits and taking the measurements were very straightforward.