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4.1 Set the impedances Z1-Z5

From my pre-lab:
Z1 = 2.2k ohm
Z2 = 22k ohm
Z3 = 5k ohm
Z4 = 14.54k ohm + 0.215 nF
Z5 = 1k ohm

I tried using these parameters but I couldn’t finish the simulation. I kept getting “time step too small error”, so I’m going to use values that are already in the asc file for this lab.

From asc file:
Z1 = 2.2k ohm
Z2 = 22k ohm
Z3 = 4.7k ohm
Z4 = 33k ohm + 4.7 nF
Z5 = 1k ohm

4.2 Step responses

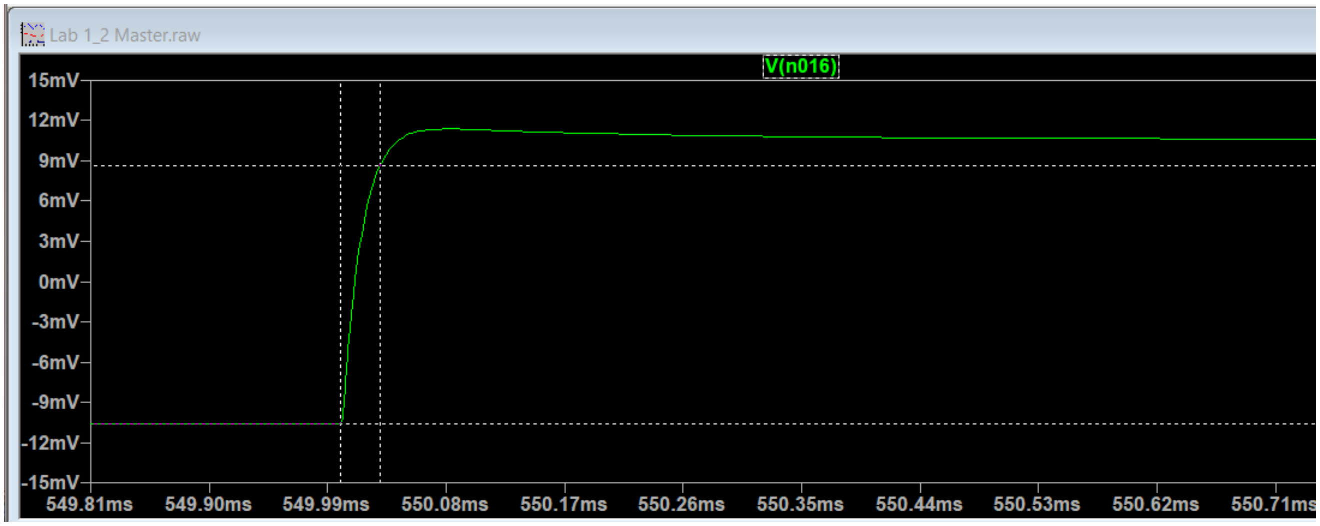

Figure 1: Vio = 0.1 Vpp

Figure 2: Vio = 0.2 Vpp

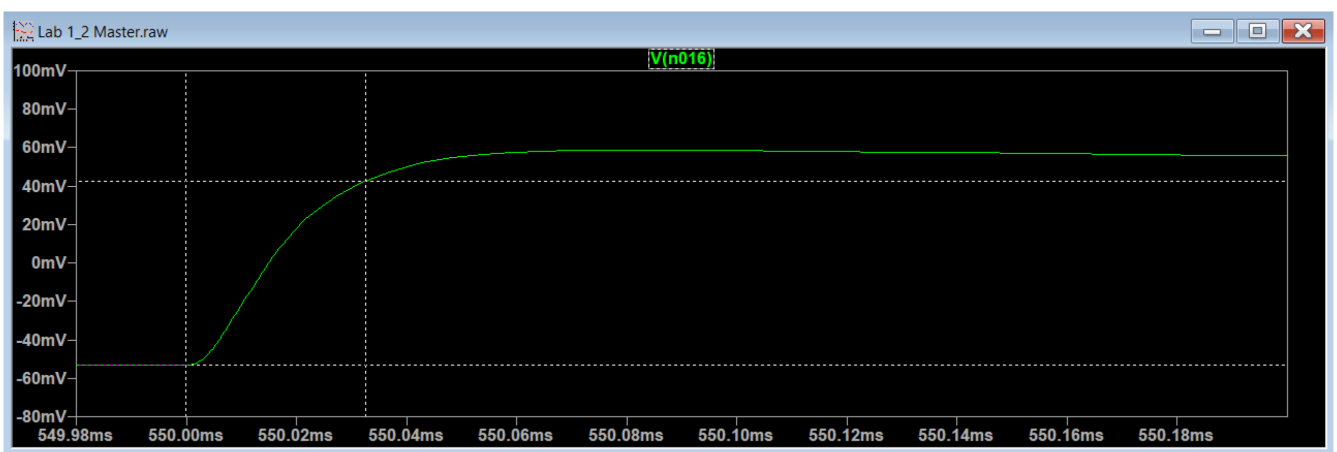

Figure 3: Vio = 0.5 Vpp

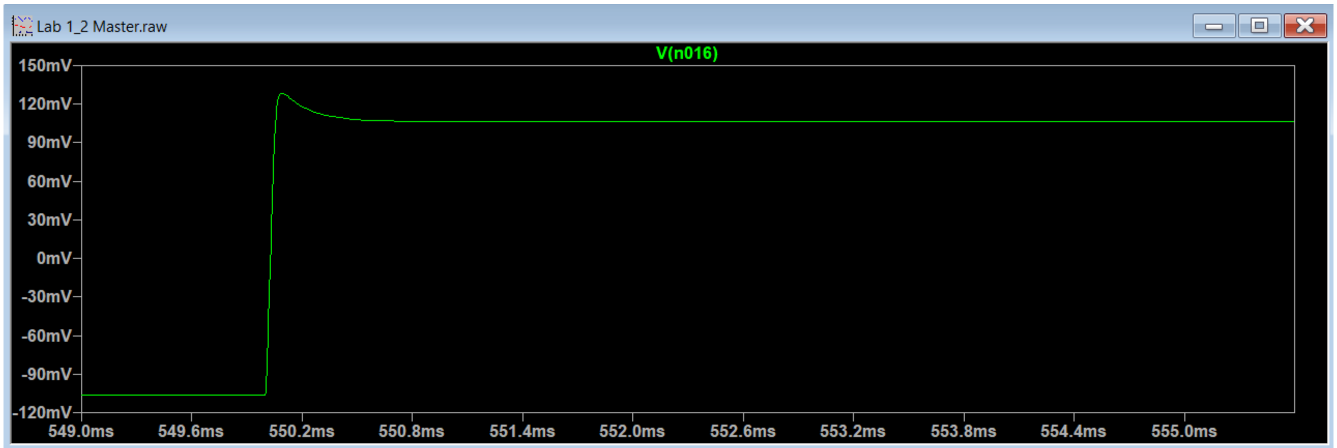

Figure 4: Vio = 1 Vpp

Vpp	SS (mV)	Overshoot (m'	Overshoot %	10.00%	90.00%	10% t (us)	90% t (us)	Rise time (us)
0.1	21.276787	21.98359	3.32%	2.1276787	19.1491083	3.333333	30.343902	27.010569
0.2	42.553184	44.164678	3.79%	4.2553184	38.2978656	3.5388557	29.784799	26.2459433
0.5	106.3831	111.94565	5.23%	10.63831	95.74479	5.4312553	32.713243	27.2819877
1	212.76579	234.74417	10.33%	21.276579	191.489211	7.9759863	47.221269	39.2452827

Table 1: % overshoot and rise time of 4 step responses

While my prelab prediction uses different impedance values than the lab's, I can still make some comparison, given that the prelab prediction is how the system is supposed to behave if the impedances are specified correctly. At Vir = 1 Vpp, steady state is 0.213V, which is very close to the targeted 0.2V. The rise time I got in my prediction is 69.02 us, which is also close to lab's rise time of 39.24 us. The main difference is there's overshoot in the lab, whereas there's no overshoot in the prelab; this makes sense since this is a second order system, and I've made some simplifications to the transfer function for the prelab.

4.3 Frequency responses

Since the impedances are different, I'll be using our targeted closed loop bandwidth of 5 kHz as w_h for this part, which means we'll be measuring from 50 Hz to 25000 Hz.

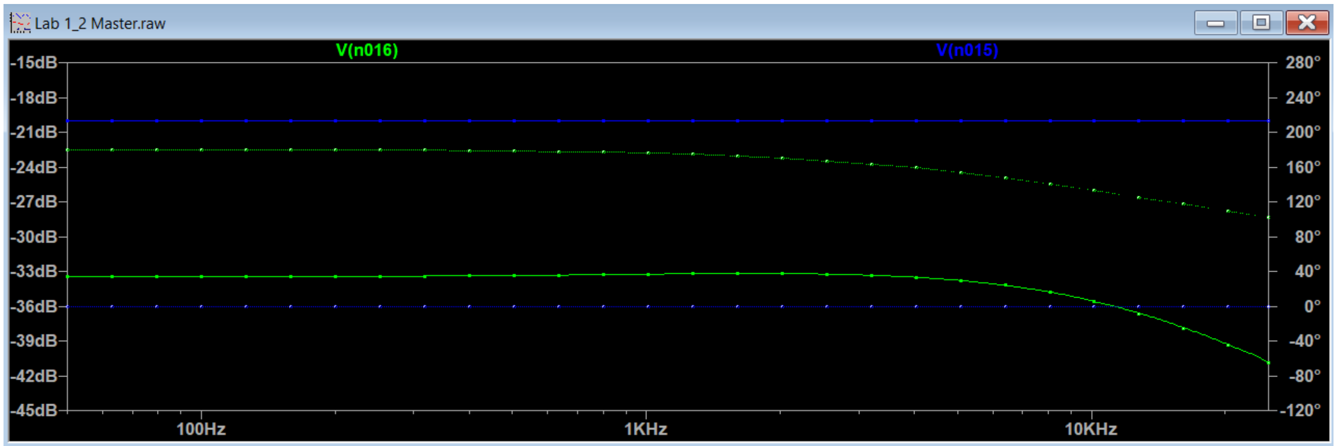

Figure 5: Magnitude and phases of voltages; Vir in blue, Vio in green

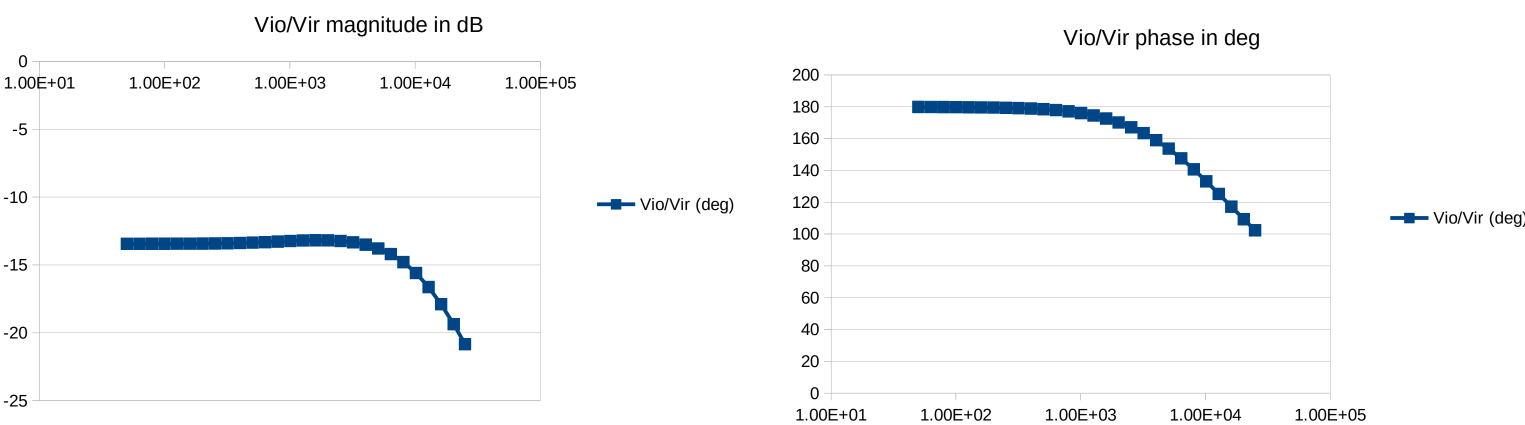

Figure 6: Bode plot of Vio/Vir

Looking at the magnitude plot, we can say that the DC gain is -13.3467504229261 dB (averaging first 19 data points), so we can say that -13.3467504229261-3 = -16.3467504229261 dB. Interpolating from the plot, the frequency that that happened at is 1.28E+04 rad/s. In my prelab, -3dB bandwidth is at 3.1912e+04 rad/s. While they're different, they're fairly close (same order of magnitude) considering different impedances.

The data points are in Appendix A.

4.4 Destabilize the current controller

Since it took quite a bit of decreasing-by-factor-of-two steps, I'll only be showing the notable ones.

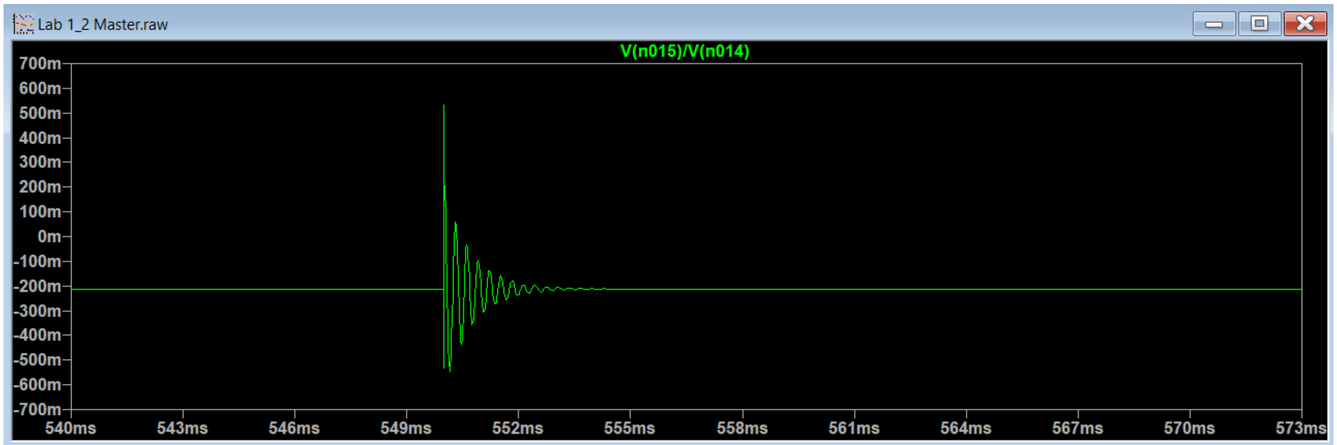

Figure 7: Vio/Vir where R3 = 4.7kohm, C4 = 4.7nF, R5 = 1kohm

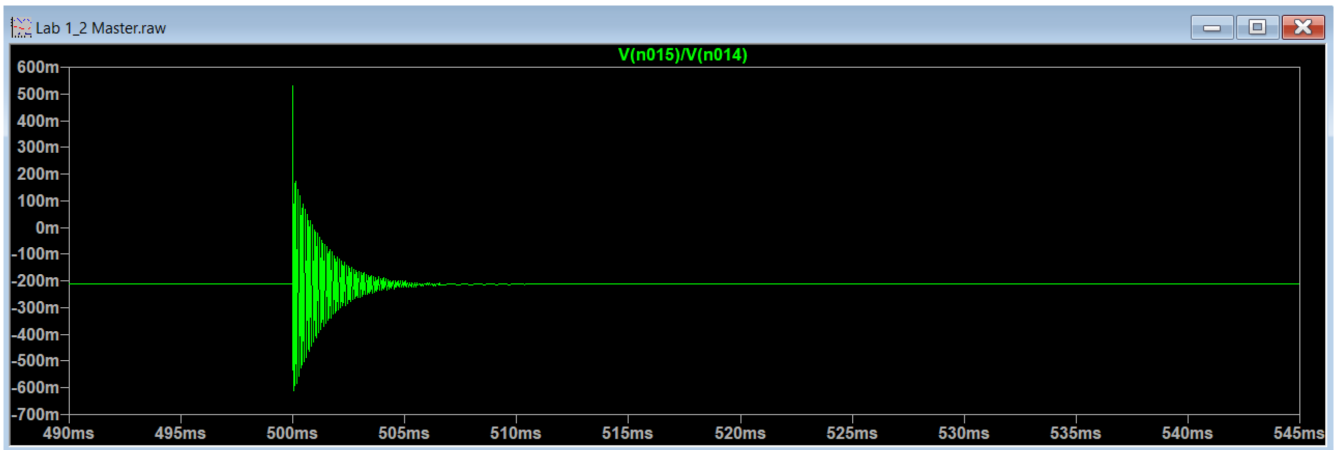

Figure 8: Vio/Vir where R3 = 4.7kohm, C4 = 0.5875nF, R5 = 1kohm

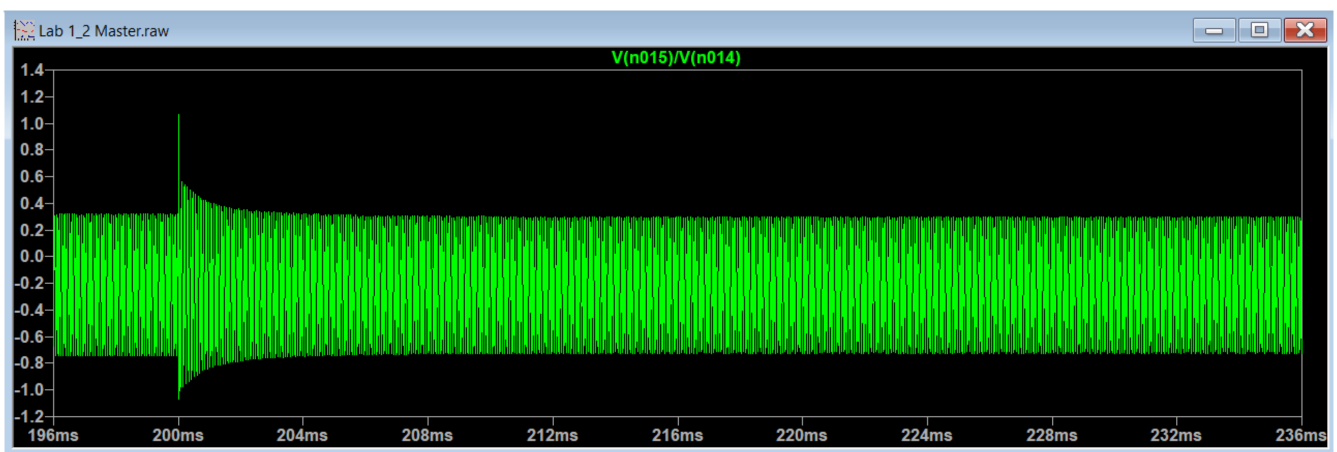

Figure 9: Vio/Vir where R3 = 4.7kohm, C4 = 0.29375nF, R5 = 1kohm

Given a step response of a second order system with transfer function in this form:

$$H(s) = \left[\frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \right]$$

We can say that the settling time of the system has the equation of:

$$T_s = -\frac{\ln\left[0.02\sqrt{1-\zeta^2}\right]}{\zeta\omega_n} \approx 4\tau = \frac{4}{\zeta\omega_n}$$

Where it is inversely proportional to damping ratio and natural frequency. Since C4 is a coefficient in our Vio/Vir transfer function, we correlate it to damping ratio and natural frequency. Therefore, when C4 decreases, damping ratio and natural frequency decreases, which increase settling time. At some point, Vir switches before settling time is reached, and Vir is unable to reach steady state, causing system to be unstable.

Appendix A: Part 4.3 data points

Freq.	Vir (dB)	Vir (deg)	Vio (dB)	Vio (deg)	Vio/Vir (deg)	Vio/Vir (deg)
5.00E+01	-2.00E+01	0.00E+00	-3.34E+01	1.80E+02	-13.44092259	179.8759025
6.30E+01	-2.00E+01	0.00E+00	-3.34E+01	1.80E+02	-13.4403134	179.843388
7.94E+01	-2.00E+01	0.00E+00	-3.34E+01	1.80E+02	-13.43934992	179.8021652
1.00E+02	-2.00E+01	0.00E+00	-3.34E+01	1.80E+02	-13.43782939	179.7497171
1.26E+02	-2.00E+01	0.00E+00	-3.34E+01	1.80E+02	-13.43543791	179.6826275
1.59E+02	-2.00E+01	0.00E+00	-3.34E+01	1.80E+02	-13.43169668	179.5961187
2.00E+02	-2.00E+01	0.00E+00	-3.34E+01	1.79E+02	-13.42589288	179.4832763
2.52E+02	-2.00E+01	0.00E+00	-3.34E+01	1.79E+02	-13.41700636	179.3337532
3.17E+02	-2.00E+01	0.00E+00	-3.34E+01	1.79E+02	-13.40367123	179.1316814
4.00E+02	-2.00E+01	0.00E+00	-3.34E+01	1.79E+02	-13.38426346	178.8525906
5.04E+02	-2.00E+01	0.00E+00	-3.34E+01	1.78E+02	-13.35727329	178.4595942
6.35E+02	-2.00E+01	0.00E+00	-3.33E+01	1.78E+02	-13.32213044	177.9002711
8.00E+02	-2.00E+01	0.00E+00	-3.33E+01	1.77E+02	-13.28043679	177.1071406
1.01E+03	-2.00E+01	0.00E+00	-3.32E+01	1.76E+02	-13.23705051	176.0042597
1.27E+03	-2.00E+01	0.00E+00	-3.32E+01	1.75E+02	-13.20011751	174.5177233
1.60E+03	-2.00E+01	0.00E+00	-3.32E+01	1.73E+02	-13.17982437	172.5818117
2.02E+03	-2.00E+01	0.00E+00	-3.32E+01	1.70E+02	-13.18707701	170.1344492
2.54E+03	-2.00E+01	0.00E+00	-3.32E+01	1.67E+02	-13.23367708	167.1063154
3.20E+03	-2.00E+01	0.00E+00	-3.33E+01	1.63E+02	-13.33428722	163.4147591
4.03E+03	-2.00E+01	0.00E+00	-3.35E+01	1.59E+02	-13.50916024	158.9705462
5.08E+03	-2.00E+01	0.00E+00	-3.38E+01	1.54E+02	-13.78621368	153.6994494
6.40E+03	-2.00E+01	0.00E+00	-3.42E+01	1.48E+02	-14.20094585	147.5762036
8.06E+03	-2.00E+01	0.00E+00	-3.48E+01	1.41E+02	-14.79262069	140.6616661
1.02E+04	-2.00E+01	0.00E+00	-3.56E+01	1.33E+02	-15.59607685	133.1233818
1.28E+04	-2.00E+01	0.00E+00	-3.66E+01	1.25E+02	-16.6314267	125.2153412
1.61E+04	-2.00E+01	0.00E+00	-3.79E+01	1.17E+02	-17.8971417	117.2108067
2.03E+04	-2.00E+01	0.00E+00	-3.94E+01	1.09E+02	-19.37133009	109.3170322
2.50E+04	-2.00E+01	0.00E+00	-4.08E+01	1.02E+02	-20.84422592	102.3983411