LAB #3 Position Control of a DC Motor System

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IN FULFILLMENT OF THE REQUIREMENTS FOR:
MTRE 4002L

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Contents

1. INTRODUCTION

The goal of this lab is to serve as an introduction to PID controllers. This was done my building several systems that included the different parts of the PID controller to build up to the final full PID controller. The systems built are the following, P, PI, PD, and finally the full PID controller. The difference this time is that we built used a physical DC motor system to visualize the controllers we built.

2. QUESTION 1 – P Controller

In question 1 we built a basic P controller. Various parameters were given to analyze of which the results are recorded in Table 1. From looking at the trend of the graphs, it can be seen that K_p impacts how fast the response has its rise time most aggressively. Please note that our last system was marginally stable, which never reached true steady state. I have included the error output of MATLAB in italics to indicate it does not represent its true characteristics, instead it would have never reached steady state.

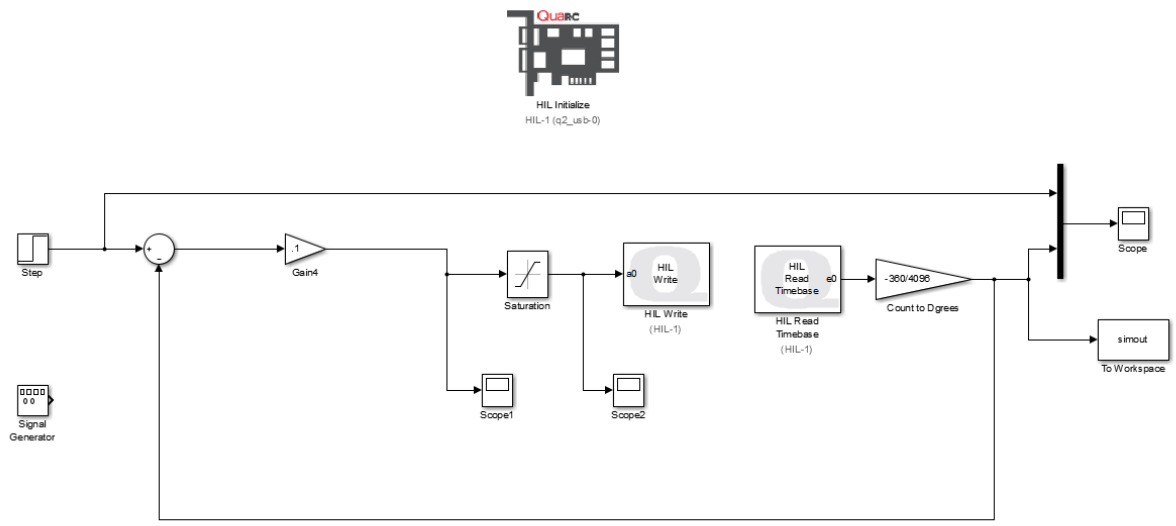
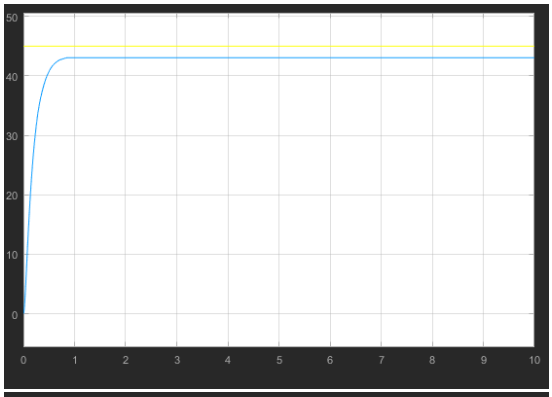
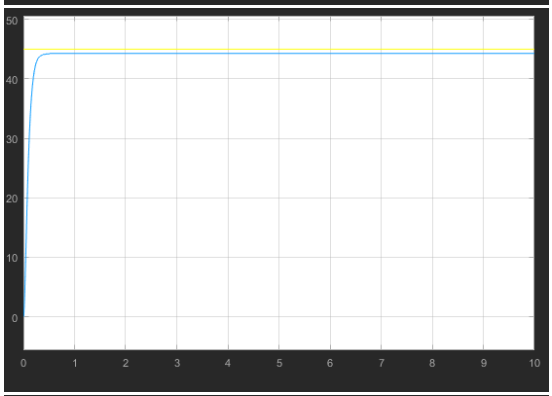


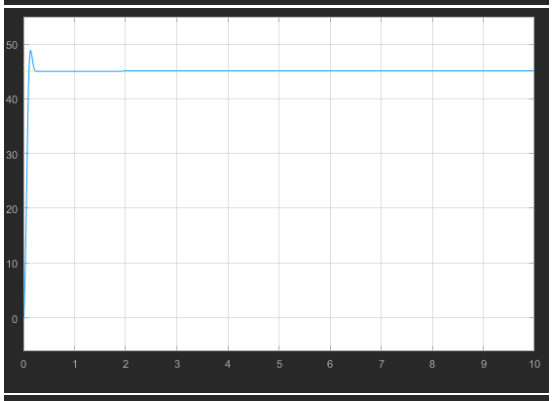
Figure 1



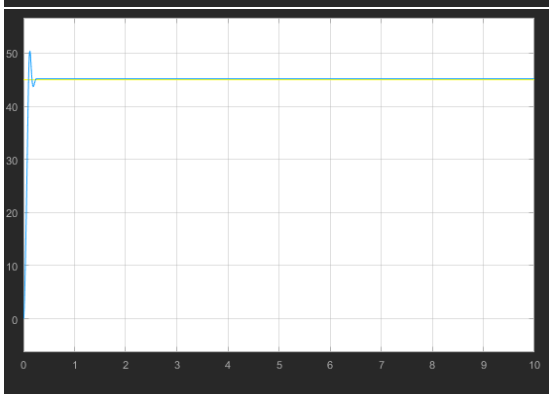
RiseTime:	0.3701
SettlingTime:	0.6643
SettlingMin:	38.9355
SettlingMax:	43.2422
Overshoot:	0
Undershoot:	0
Peak:	43.2422
PeakTime:	1.0520



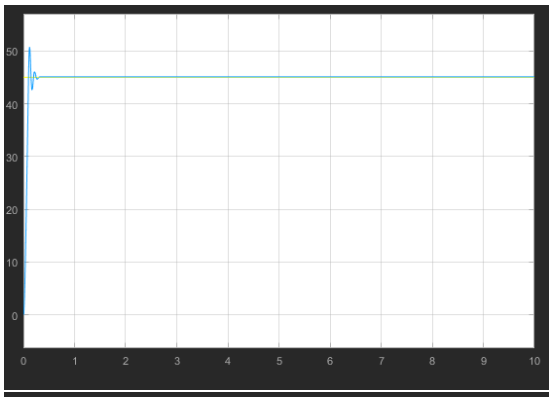
RiseTime:	0.1625
SettlingTime:	0.2818
SettlingMin:	39.9023
SettlingMax:	44.2969
Overshoot:	0
Undershoot:	0
Peak:	44.2969
PeakTime:	0.5120



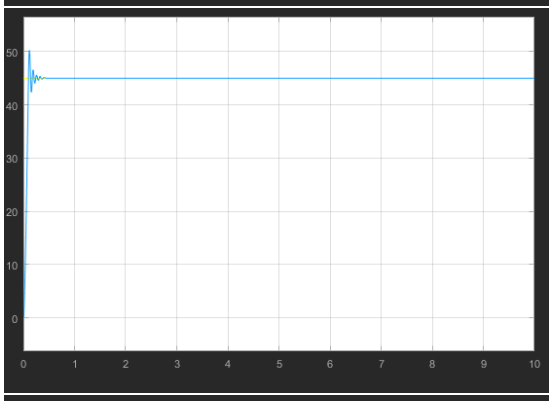
RiseTime:	0.0712
SettlingTime:	0.1955
SettlingMin:	40.9570
SettlingMax:	48.8672
Overshoot:	8.3821
Undershoot:	0
Peak:	48.8672
PeakTime:	0.1380



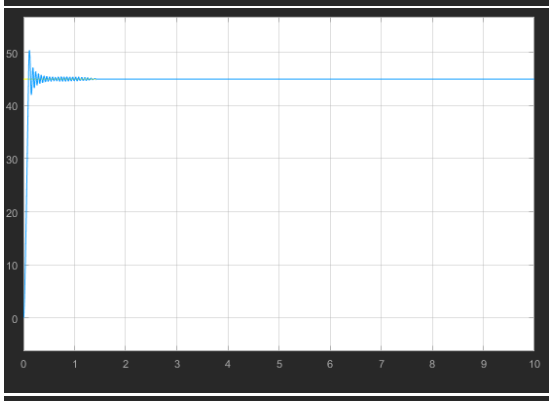
RiseTime:	0.0684
SettlingTime:	0.2134
SettlingMin:	40.9570
SettlingMax:	50.3613
Overshoot:	11.4786
Undershoot:	0
Peak:	50.3613
PeakTime:	0.1240



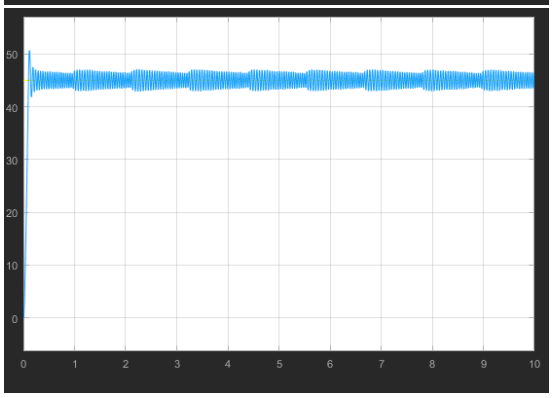
RiseTime: 0.0681
SettlingTime: 0.2215
SettlingMin: 40.7813
SettlingMax: 50.7129
Overshoot: 12.4756
Undershoot: 0
Peak: 50.7129
PeakTime: 0.1180



RiseTime: 0.0683
SettlingTime: 0.2255
SettlingMin: 41.2207
SettlingMax: 50.2734
Overshoot: 11.7188
Undershoot: 0
Peak: 50.2734
PeakTime: 0.1140



RiseTime: 0.0682
SettlingTime: 0.2975
SettlingMin: 41.0449
SettlingMax: 50.4492
Overshoot: 12.1094
Undershoot: 0
Peak: 50.4492
PeakTime: 0.1160



RiseTime: 0.0696
SettlingTime: 9.9926
SettlingMin: 41.8359
SettlingMax: 50.7129
Overshoot: 9.2803
Undershoot: 0
Peak: 50.7129
PeakTime: 0.1160

Table 1

Proportional Gain (k_p)	Rise Time (T_r)	Peak Time (T_p)	Setting Time (T_s)	Percent Overshoot (%OS)	Steady-state Error (e_{ss})	Is it a stable system? (Yes/No)	Type of the System (Under/Over/Critically damped System?)
0.05	0.3701	1.0520	0.6643	0	1.5	Yes	Over damped
0.1	0.1625	0.5120	0.2818	0	0.7	Yes	Critically damped
0.3	0.0712	0.1380	0.1955	8.3821	-0.2	Yes	Under damped
0.6	0.0684	0.1240	0.2134	11.4786	-0.1	Yes	Under damped
1	0.0681	0.1180	0.2215	12.4756	-0.1	Yes	Under damped
2	0.0683	0.1140	0.2255	11.7188	0	Yes	Under damped
3	0.0682	0.1160	0.2975	12.1094	0	Yes	Under damped
8	*0.0696*	*0.1160*	*9.9926*	*9.2803*	*1.2*	*No*	*Marginally stable*

3. QUESTION 2 – PI Controller

In question 2 we built a basic PI controller. Various parameters were given to analyze of which the results are recorded in Table 2. Please note that some responses in this set proved to go out of bounds of the graph which resulted in inaccurate results for some values. These values have been put in italics to mark their inaccuracy. These values are kept due to keeping consistently with what MATLAB outputs. It must be noted that when a response to go out of bounds of the plot it will never reach a steady state. It can be assumed that K_i is the parameter that effects the steady state error portion of the response as when that value is increased the response oscillates and may even go out of the bounds of the plot. These results are consistent with the simulations in Lab 2.

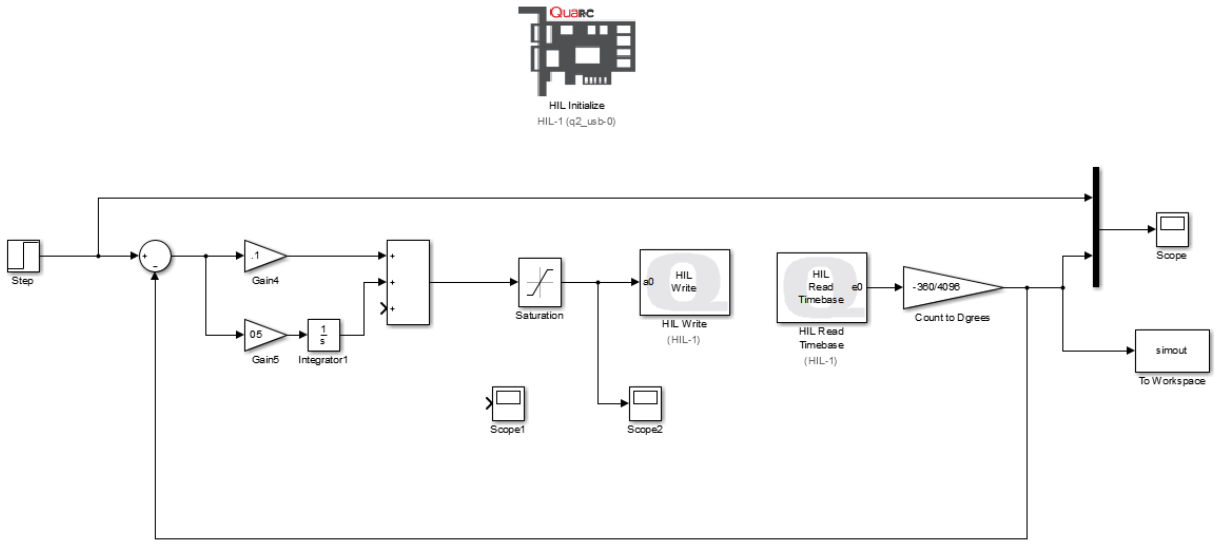
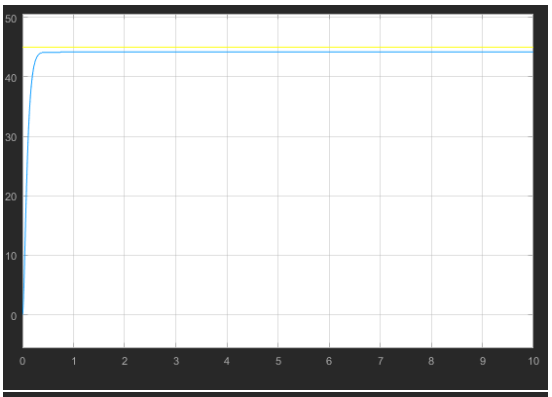
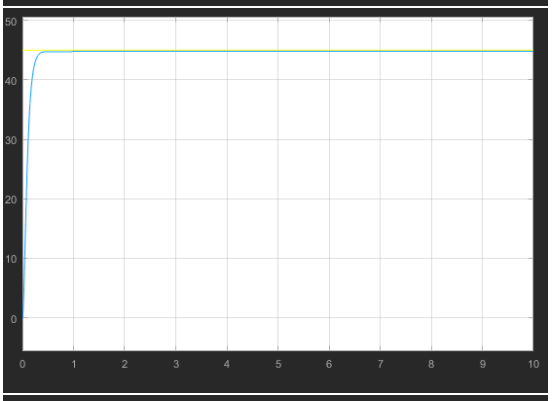


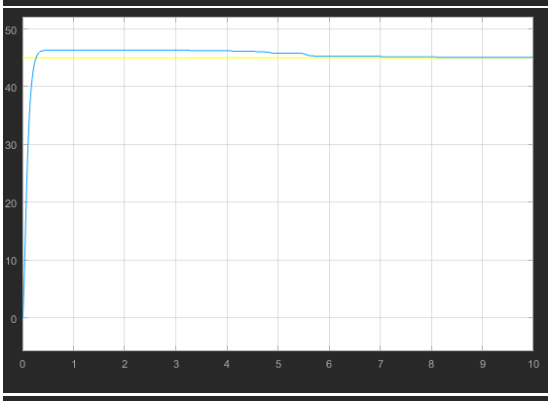
Figure 2



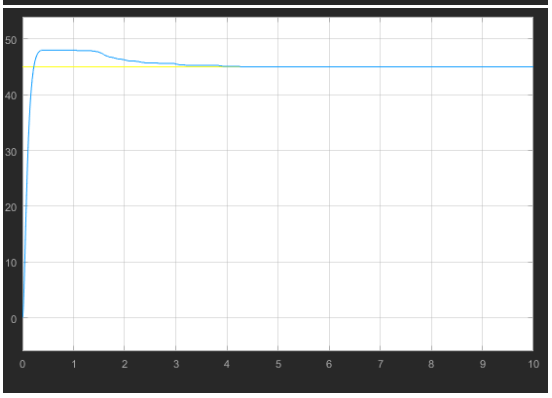
RiseTime: 0.1630
SettlingTime: 0.2799
SettlingMin: 39.8145
SettlingMax: 44.2090
Overshoot: 0
Undershoot: 0
Peak: 44.2090
PeakTime: 0.7440



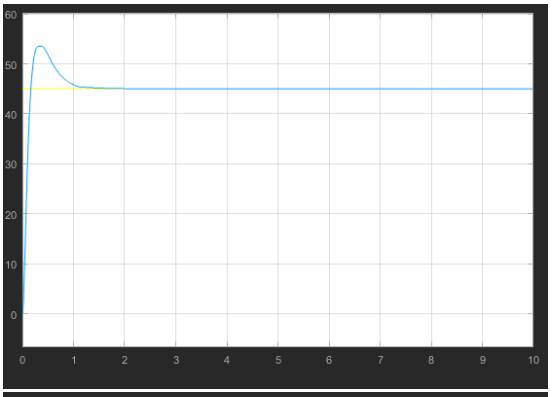
RiseTime: 0.1657
SettlingTime: 0.2896
SettlingMin: 40.4297
SettlingMax: 44.8242
Overshoot: 0
Undershoot: 0
Peak: 44.8242
PeakTime: 0.9660



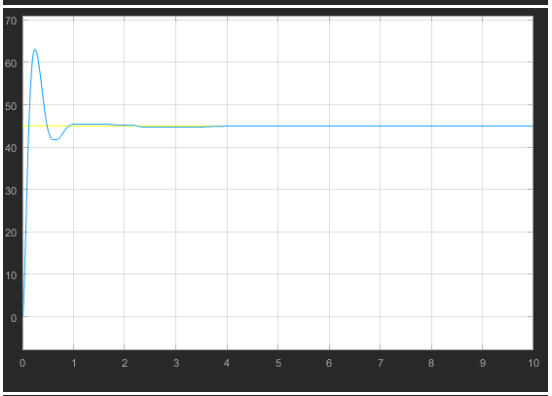
RiseTime: 0.0.1538
SettlingTime: 4.7535
SettlingMin: 40.6934
SettlingMax: 46.3184
Overshoot: 2.7290
Undershoot: 0
Peak: 46.3184
PeakTime: 0.4300



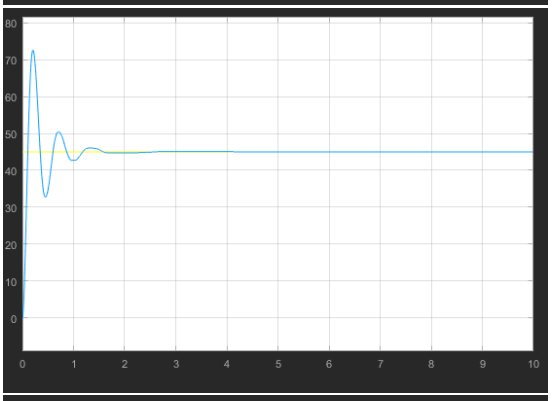
RiseTime: 0.1410
SettlingTime: 2.2815
SettlingMin: 40.6934
SettlingMax: 47.9883
Overshoot: 6.6406
Undershoot: 0
Peak: 47.9883
PeakTime: 0.3740



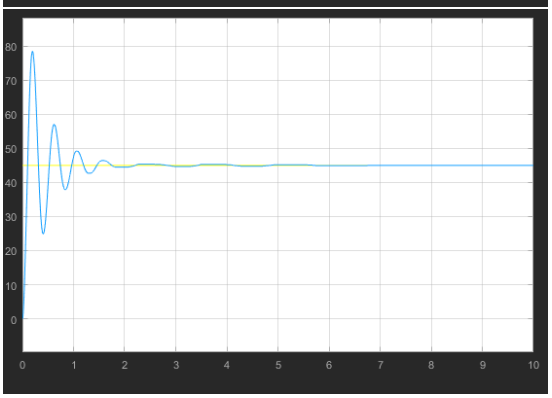
RiseTime: 0.1130
SettlingTime: 0.9715
SettlingMin: 40.5176
SettlingMax: 53.5254
Overshoot: 18.9453
Undershoot: 0
Peak: 53.5254
PeakTime: 0.3000



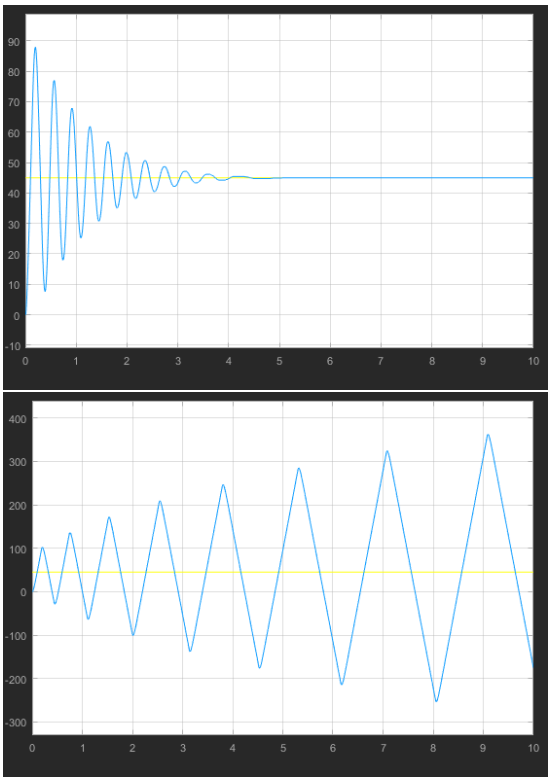
RiseTime: 0.0866
SettlingTime: 0.8355
SettlingMin: 40.9570
SettlingMax: 63.1055
Overshoot: 40.2344
Undershoot: 0
Peak: 63.1055
PeakTime: 0.2420



RiseTime: 0.0712
SettlingTime: 1.4355
SettlingMin: 32.7832
SettlingMax: 75.5977
Overshoot: 61.3281
Undershoot: 0
Peak: 72.5977
PeakTime: 0.2040



RiseTime: 0.0687
SettlingTime: 1.6715
SettlingMin: 24.8730
SettlingMax: 78.4863
Overshoot: 74.4141
Undershoot: 0
Peak: 78.4863
PeakTime: 0.1940



RiseTime: 0.0685
SettlingTime: 3.6635
SettlingMin: 7.6465
SettlingMax: 87.8906
Overshoot: 95.3125
Undershoot: 0
Peak: 87.8906
PeakTime: 0.1940

RiseTime: 4.0711
SettlingTime: 9.9824
SettlingMin: -253.3008
SettlingMax: 362.5488
Overshoot: 44.7514
Undershoot: 207.1823
Peak: 362.5488
PeakTime: 9.0940

Table 2

Proportional Gain (k_p)	Integral Gain (k_i)	Rise Time (T_r)	Peak Time (T_p)	Setting Time (T_s)	Percent Overshoot (%OS)	Steady-state Error (e_{ss})	Is it a stable system? (Yes/No)	Type of the System (Under/Over/Critically damped System?)
0.1	0.001	0.1630	0.7440	0.2799	0	1.0	Yes	Over damped
0.1	0.01	0.1657	0.9660	0.2896	0	0.3	Yes	Critically damped
0.1	0.05	0.1538	0.4300	4.7535	2.7290	0.4	Yes	Under damped
0.1	0.1	*0.1410*	*0.3740*	*2.2815*	*6.6406*	*0.3*	*Yes*	Under damped
0.1	0.3	*0.1130*	*0.3000*	*0.9715*	*18.9453*	*0*	*Yes*	Under damped
0.1	0.8	*0.0866*	*0.2420*	*0.8355*	*40.2344*	*0.1*	*Yes*	Under damped
0.1	1.5	*0.0712*	*0.2040*	*1.4355*	*61.3281*	*0.2*	*Yes*	Under damped
0.1	2.0	*0.0687*	*0.1940*	*1.6715*	*74.4141*	*0*	*Yes*	Under damped
0.1	3.0	*0.0685*	*0.1940*	*3.6635*	*95.3125*	*0*	*Yes*	Under damped
0.1	10.0	*4.0711*	*9.0940*	*9.9824*	*44.7514*	*154*	*No*	*Unstable*

4. QUESTION 3 – PD Controller

In question 3 we built a basic PD controller. Various parameters were given to analyze of which the results are recorded in Table 3. K_d can be analyzed to affect the time to reach steady state. This effect can be clearly seen the further down in Table 3. As this parameter is increased the settling time becomes very large. These results proved to be consistent with the simulations in Lab 2.

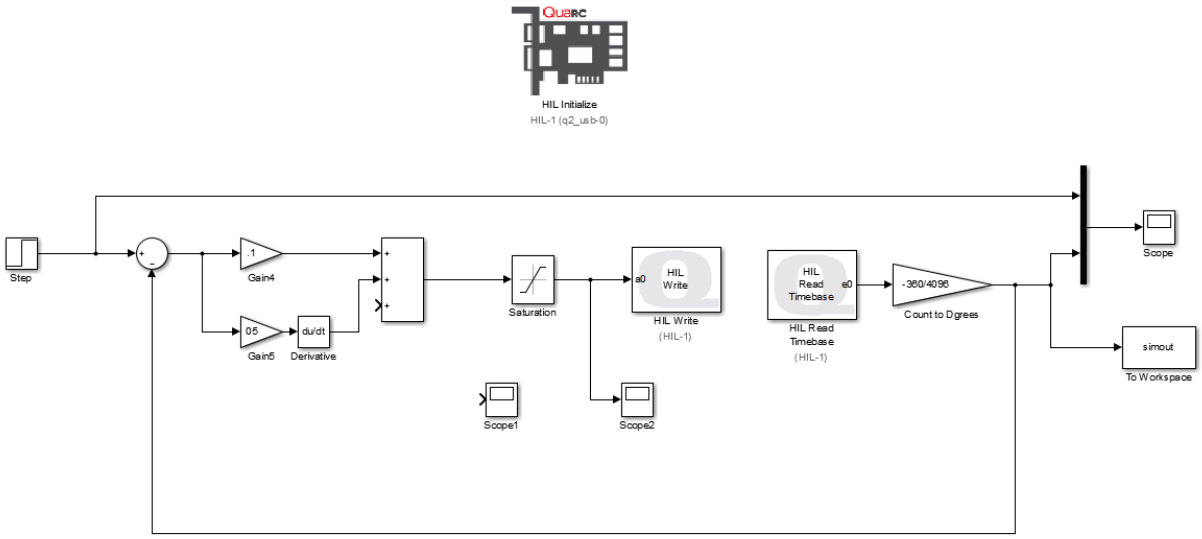
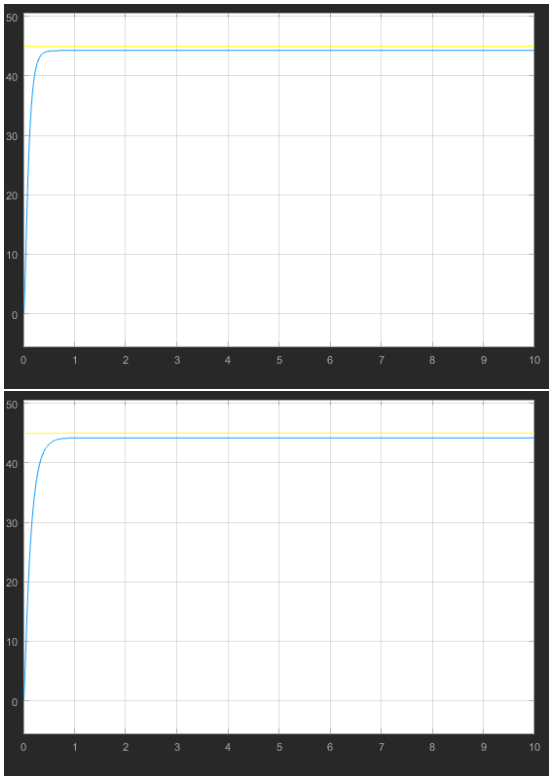
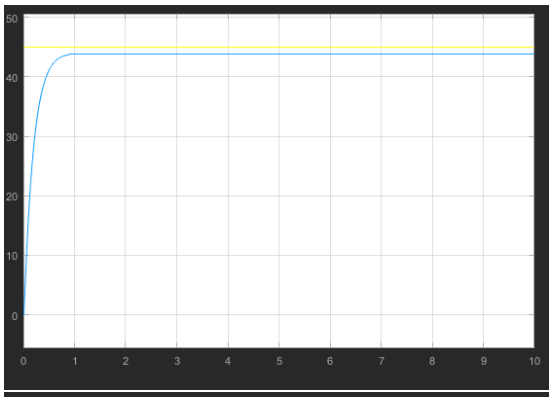


Figure 3

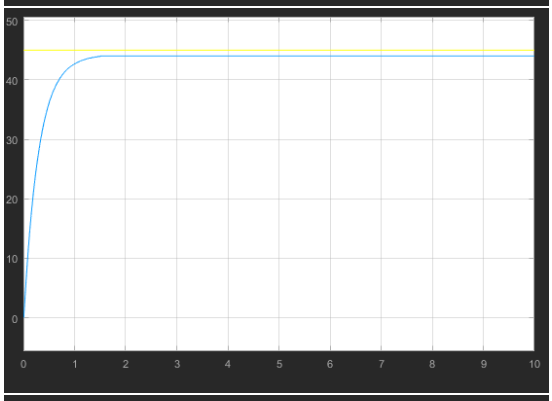


RiseTime: 0.1861
SettlingTime: 0.3358
SettlingMin: 39.9023
SettlingMax: 44.2969
Overshoot: 0
Undershoot: 0
Peak: 44.2969
PeakTime: 0.6760

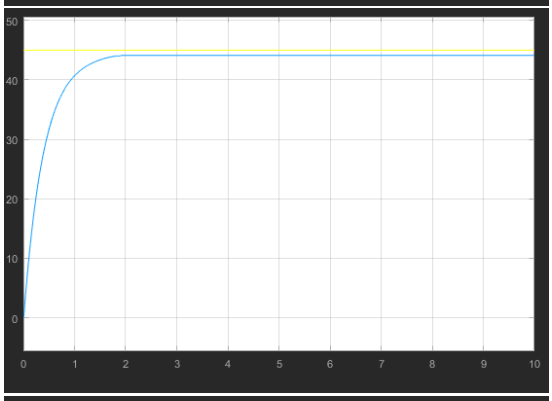
RiseTime: 0.2823
SettlingTime: 0.4979
SettlingMin: 39.7266
SettlingMax: 44.1211
Overshoot: 0
Undershoot: 0
Peak: 44.1211
PeakTime: 0.7160



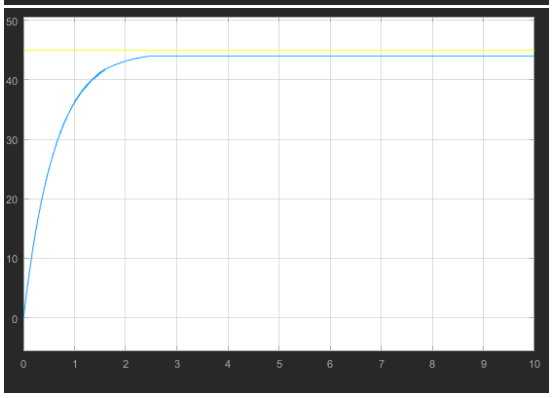
RiseTime: 0.3930
SettlingTime: 0.6680
SettlingMin: 39.5508
SettlingMax: 43.8574
Overshoot: 0
Undershoot: 0
Peak: 43.8574
PeakTime: 0.9200



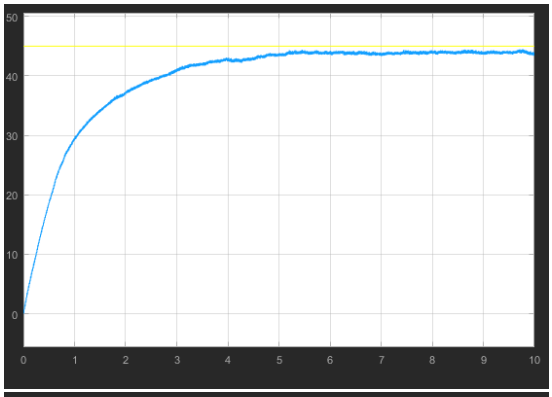
RiseTime: 0.6297
SettlingTime: 1.1000
SettlingMin: 39.6387
SettlingMax: 44.0332
Overshoot: 0
Undershoot: 0
Peak: 44.0332
PeakTime: 1.5060



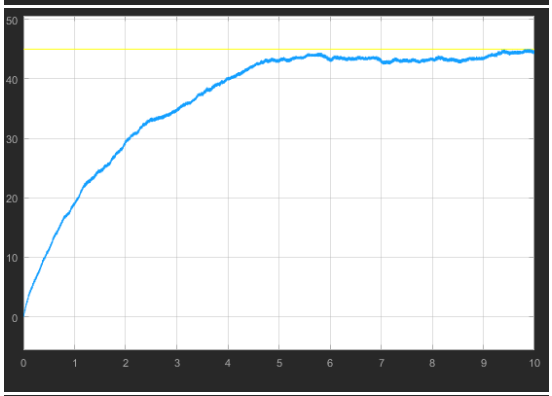
RiseTime: 0.8514
SettlingTime: 1.4439
SettlingMin: 39.7266
SettlingMax: 44.1211
Overshoot: 0
Undershoot: 0
Peak: 44.1211
PeakTime: 1.8880



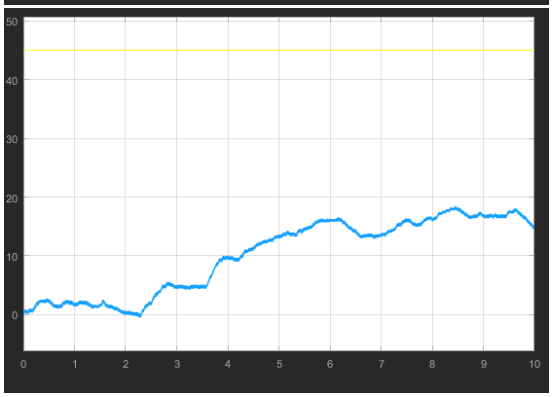
RiseTime: 1.2256
SettlingTime: 1.9860
SettlingMin: 39.5508
SettlingMax: 44.0332
Overshoot: 0
Undershoot: 0
Peak: 44.0332
PeakTime: 2.4500



RiseTime: 2.3562
SettlingTime: 9.7822
SettlingMin: 38.9355
SettlingMax: 44.4727
Overshoot: 2.0161
Undershoot: 0
Peak: 44.4727
PeakTime: 9.7160



RiseTime: 3.8732
SettlingTime: 9.2632
SettlingMin: 39.7266
SettlingMax: 45
Overshoot: 0.5894
Undershoot: 0
Peak: 45
PeakTime: 9.8160



RiseTime: 4.6705
SettlingTime: 9.9957
SettlingMin: 12.7441
SettlingMax: 18.4570
Overshoot: 27.2727
Undershoot: 3.6364
Peak: 18.4570
PeakTime: 8.4500

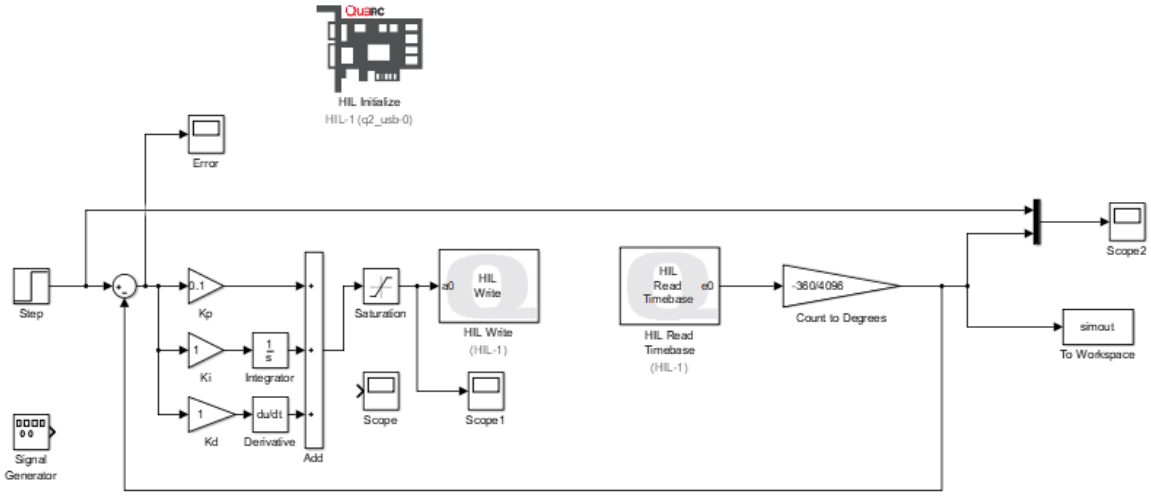
Table 3

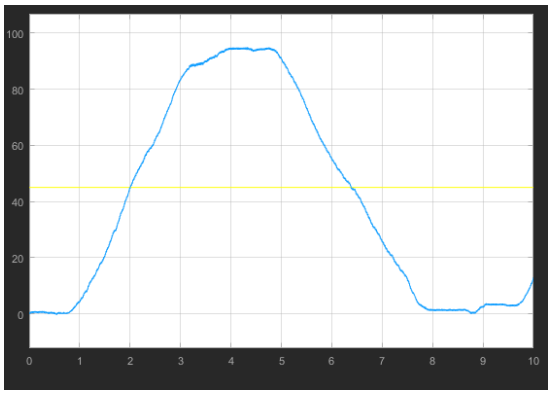
Proportional Gain (k_p)	Derivative Gain (k_d)	Rise Time (T_r)	Peak Time (T_p)	Setting Time (T_s)	Percent Overshoot (%OS)	Steady-state Error (e_{ss})	Is it a stable system? (Yes/No)	Type of the System (Under/Over/Critically damped System?)
0.1	0.001	0.1861	0.6760	0.3358	0	0.8	Yes	Critically damped
0.1	0.005	0.2823	0.7160	0.4979	0	0.8	Yes	Over damped
0.1	0.01	0.3930	0.9200	0.6680	0	1.1	Yes	Over damped
0.1	0.02	0.6297	1.5060	1.1000	0	1.0	Yes	Over damped
0.1	0.03	0.8514	1.8880	1.4439	0	1.1	Yes	Over damped
0.1	0.05	1.2256	2.4500	1.9860	0	1.0	Yes	Over damped
0.1	0.08	2.3562	9.760	9.7822	2.0161	1.4	Yes	Over damped
0.1	0.1	3.8732	9.8160	9.2632	0.5894	0.3	Yes	Over damped
0.1	1	4.6705	8.4500	9.9957	27.2727	30.5	No	Over damped

5. QUESTION 4 – PID Controller

In question 4 we built a basic PID controller. Various parameters were given to analyze of which the results are recorded in Table 4. Incorporating all three of these parameters we are given a highly tunable controller. Specifically in this portion we were tasked with tuning a PID controller to reach steady state as soon as possible without overshoot, in turn building a critically damped system. Our progress can we visualized below in the seven systems it took to reach this constraint given.

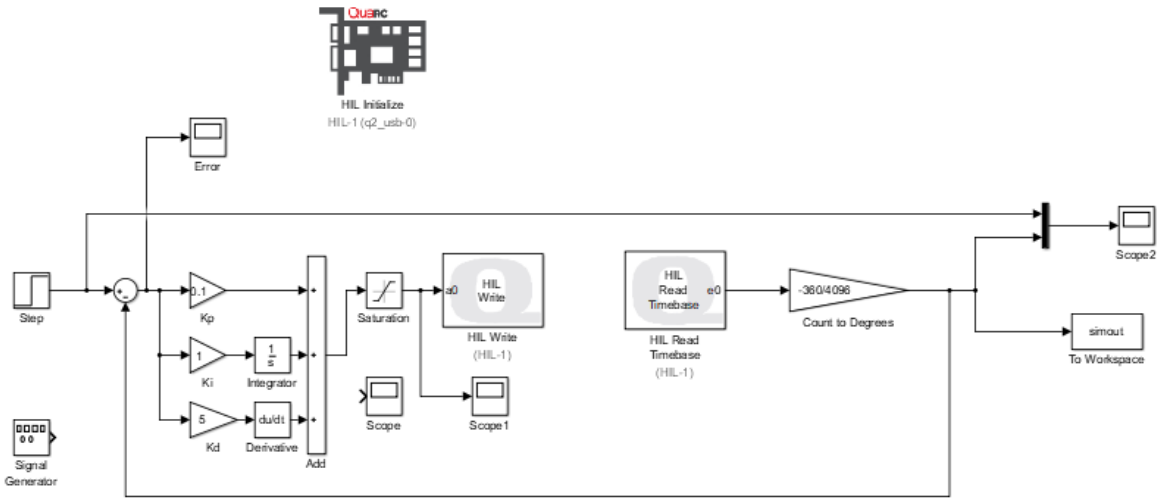
System 1

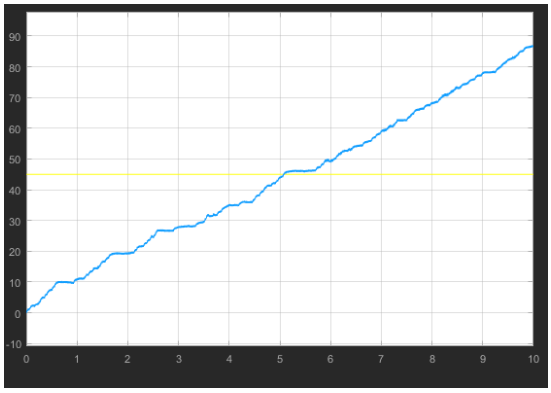




RiseTime:	0.3776
SettlingTime:	9.9802
SettlingMin:	-0.0879
SettlingMax:	94.9219
Overshoot:	634.6939
Undershoot:	2.7211
Peak:	94.9219
PeakTime:	4.3320

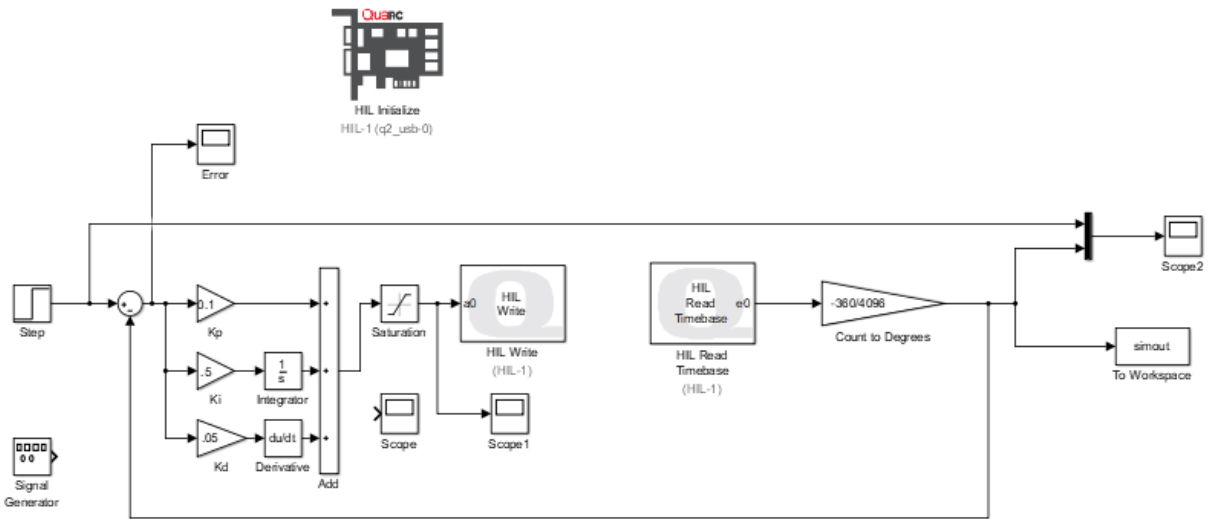
System 2

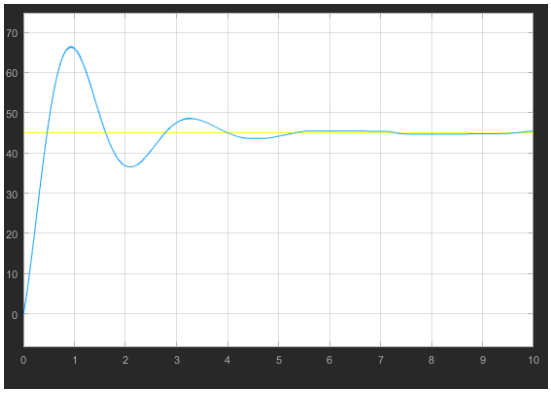




RiseTime:	8.4517
SettlingTime:	9.8048
SettlingMin:	77.6953
SettlingMax:	87.0117
Overshoot:	0.3040
Undershoot:	0
Peak:	87.0117
PeakTime:	9.9720

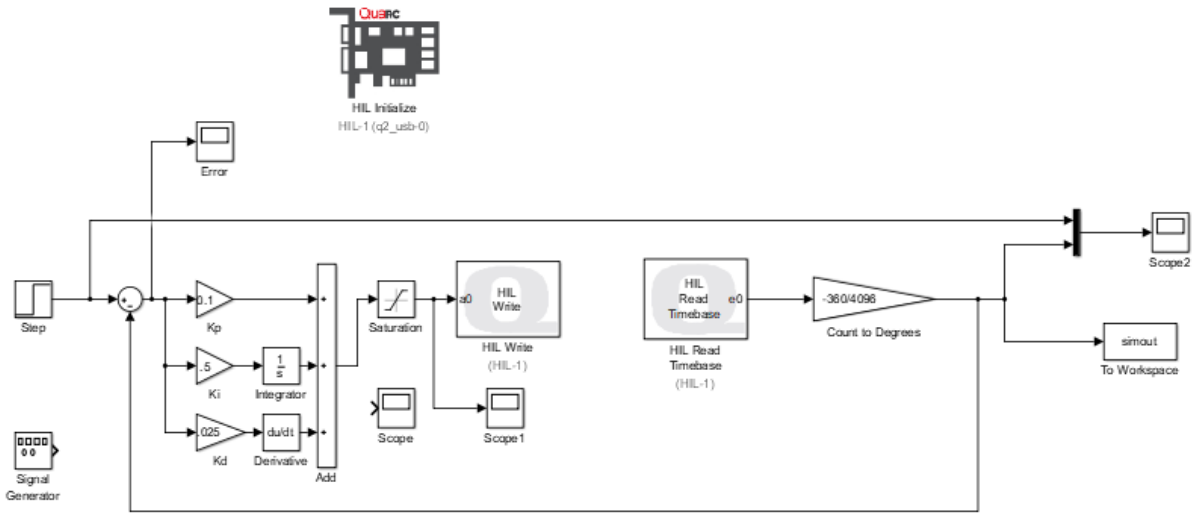
System 3

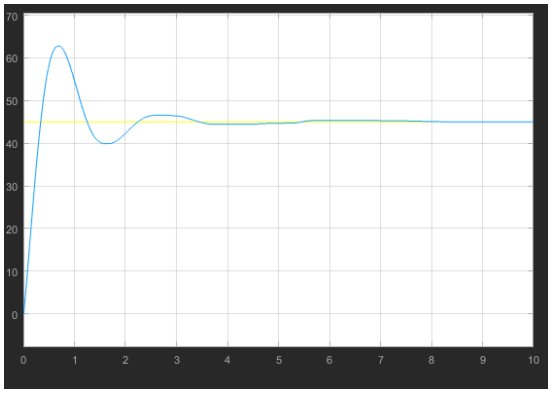




RiseTime:	0.3596
SettlingTime:	5.1034
SettlingMin:	36.5625
SettlingMax:	66.5332
Overshoot:	46.7054
Undershoot:	0
Peak:	66.5332
PeakTime:	0.9220

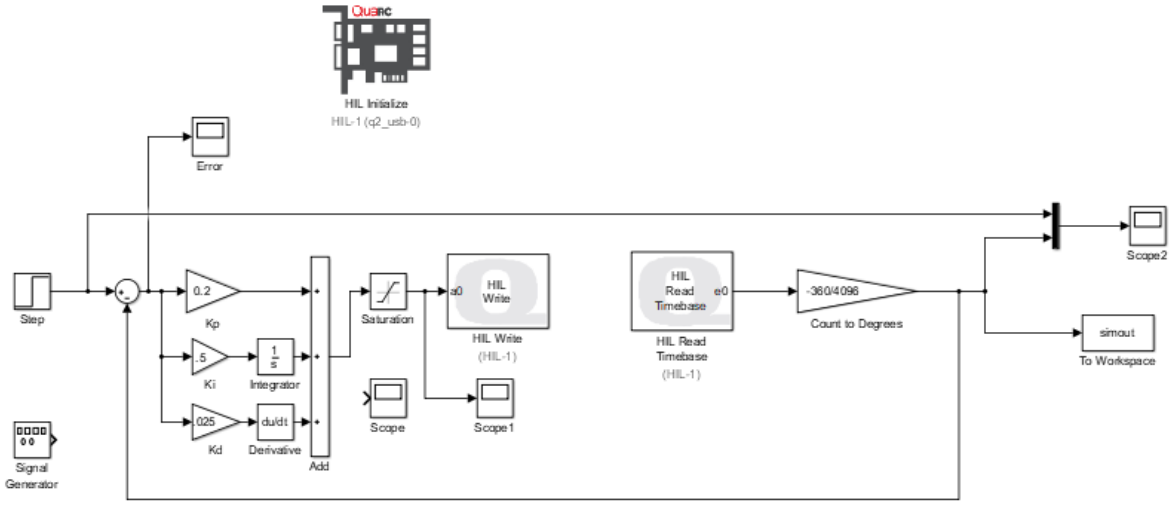
System 4

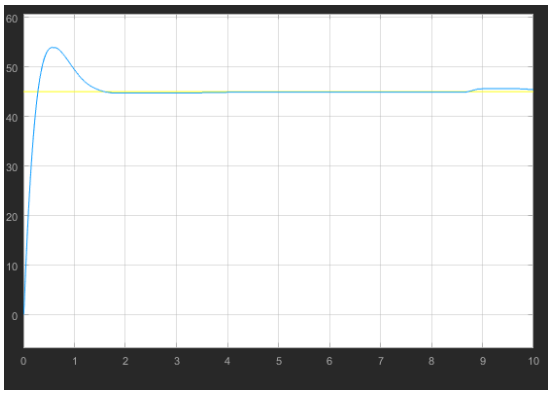




RiseTime:	0.2590
SettlingTime:	3.1955
SettlingMin:	39.9023
SettlingMax:	62.7539
Overshoot:	39.4531
Undershoot:	0
Peak:	62.7539
PeakTime:	0.6620

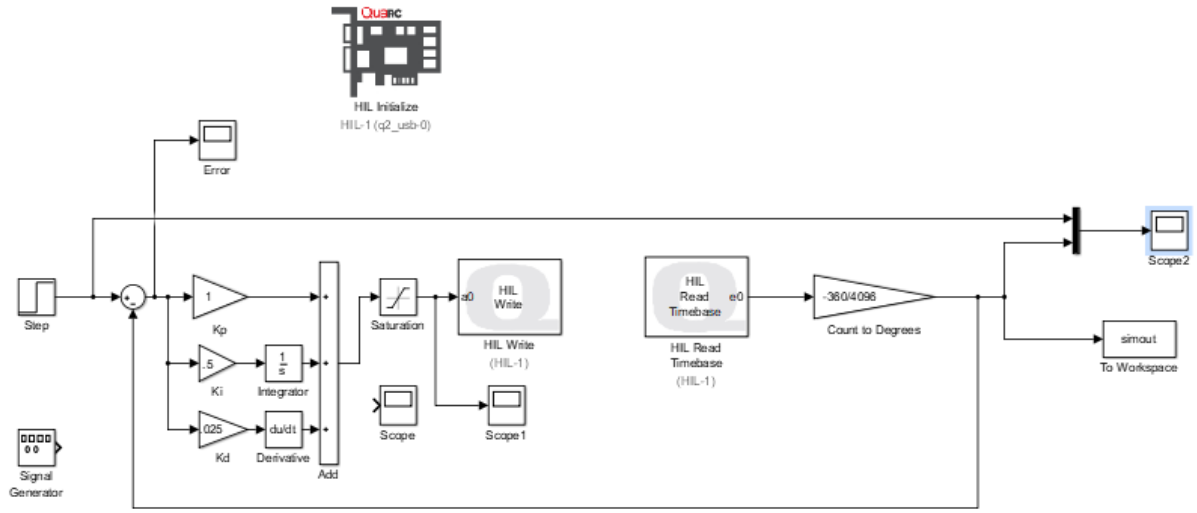
System 5

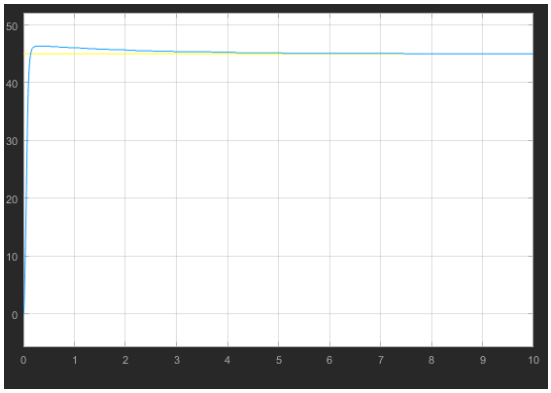




RiseTime:	0.2127
SettlingTime:	1.2853
SettlingMin:	41.0449
SettlingMax:	53.9648
Overshoot:	18.7621
Undershoot:	0
Peak:	53.9648
PeakTime:	0.5600

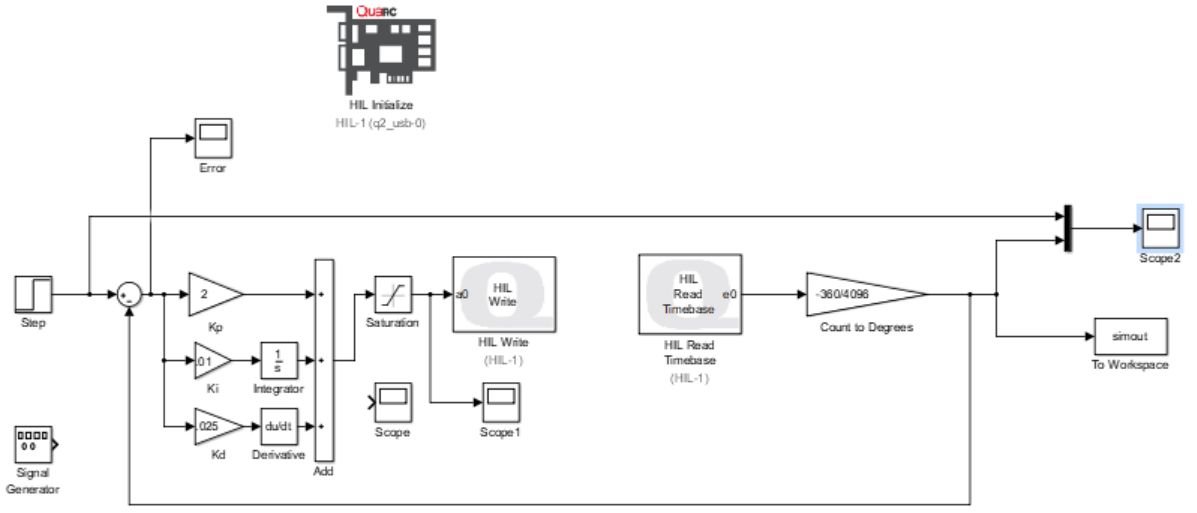
System 6

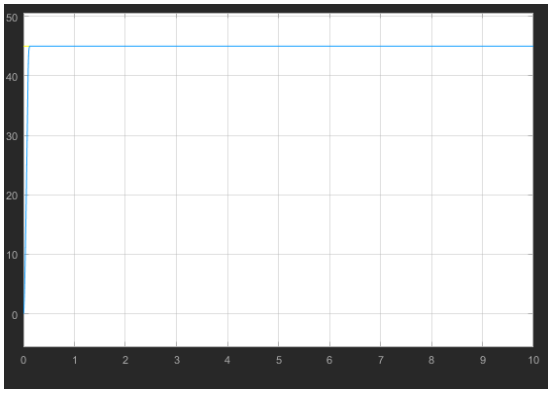




RiseTime: 0.0786
SettlingTime: 1.2535
SettlingMin: 40.5176
SettlingMax: 46.3184
Overshoot: 2.9297
Undershoot: 0
Peak: 46.3184
PeakTime: 0.2300

System 7





RiseTime:	0.0688
SettlingTime:	0.1054
SettlingMin:	41.2207
SettlingMax:	45
Overshoot:	0
Undershoot:	0
Peak:	45
PeakTime:	0.1240

Table 4

Proportional Gain (k_p)	Integral Gain (k_i)	Derivitive Gain (k_d)	Rise Time (T_r)	Peak Time (T_p)	Setting Time (T_s)	Percent Overshoot (%OS)	Steady-state Error (e_{ss})	Is it a stable system? (Yes/No)	Type of the System (Under/Over/Critically damped System?)
0.1	1	1	0.3776	4.3320	9.9802	634.6939	32.1	No	Under damped
0.1	1	5	8.4517	9.9720	9.8045	0.340	-41.7	No	Under damped
0.1	0.5	0.05	0.3596	0.9220	5.1034	46.7054	-0.4	Yes	Under damped
0.1	0.5	0.025	0.2590	0.6620	3.1955	39.4531	0	Yes	Under damped
0.2	0.5	0.025	0.2127	0.5600	1.2853	18.7621	-0.4	Yes	Under damped
1	0.5	0.025	0.0786	0.2300	1.2535	2.9297	0	Yes	Under damped
2	0.01	0.025	0.0688	0.1240	0.1054	0	0	Yes	Critically damped

6. SQUARE WAVE

In this portion we were tasked with switching our step input for a square wave, which simulates what PWM might look like. We see that with these PID parameters the square wave output has considerable overshoot which is undesirable. An error plot has been provided to clearly see its performance.

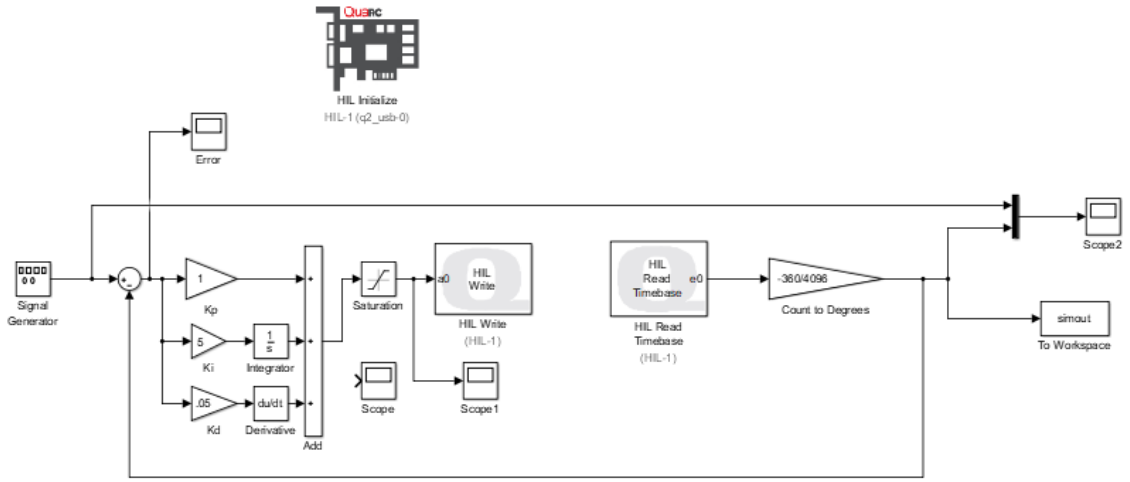
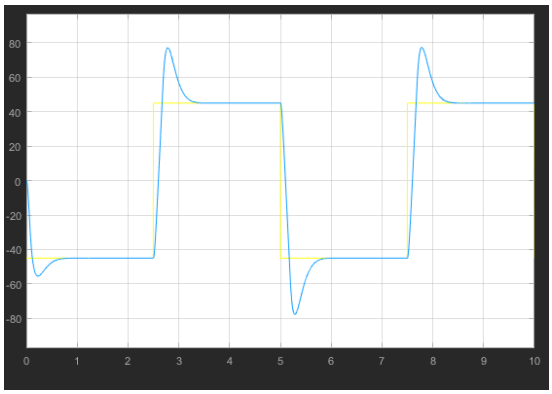
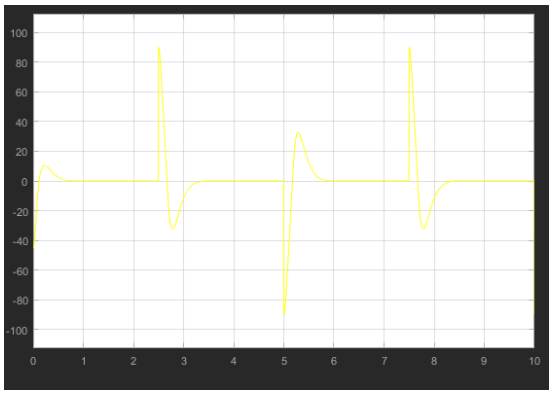


Figure 4





RiseTime: 0.0589
SettlingTime: 8.1910
SettlingMin: -77.8711
SettlingMax: 77.4316
Overshoot: 72.0703
Undershoot: 173.0469
Peak: 77.8711
PeakTime: 5.2880

Error plot

Proportional Gain (k_p)	Integral Gain (k_i)	Derivitive Gain (k_d)	Rise Time (T_r)	Peak Time (T_p)	Setting Time (T_s)	Percent Overshoot (%OS)	Steady-state Error (e_{ss})	Is it a stable system? (Yes/No)	Type of the System (Under/Over/Critically damped System?)
1	5	0.05	0.0589	5.2880	8.1910	72.0703	N/A	Yes	Under damped

7. CONCLUSION

In conclusion, this lab was a very helpful exercise in visualizing what each component does in a PID controller. Understanding each component on their own was enlightening and will certainly aid in designing controllers. Additionally, this has shown to show the power of MATLAB in analyzing PID controllers. Using a physical system this time really helping is visualizing the power of PID tuning, and some the of the concerns that come along with it. Change one parameter too much and one might have a wildly unstable system. This was a very good lab to bring what have been learned in class into the real world.