Electric Circuits & Electronics Design Lab

EE 316-01

Lab 11&12: MOSFETs

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Lab Section 316-01

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Introduction:

The purpose of this lab is to look at the behavior of a MOSFET, specifically its saturation region, mode, and bandwidth. This report will have 5 main sections. First is the theoretical analysis which is done as the pre-lab and includes Multisim simulations. There is no handwritten theoretical part for this lab. Then we have the physical circuits which are constructed on breadboards in lab. Afterwards, we compare the results from those 3 sections and conclude with an analysis of the results.

Theoretical Analysis:

To start, we look at how a MOSFET is constructed, works, behaves depending on the state or mode it is in. The MOSFET is a three terminal unipolar semiconductor that is a voltage-controlled field effect transistor. The main gate is isolated from the current carrying channel and no current flows into the gate. They operate in two modes: depletion which requires the gate source voltage to switch off and enhancement which requires a gate source voltage to switch the device on. Figures 1 and 2 gives the characteristic curves for an n-channel MOSFET and p-channel MOSFET in depletion (a) and enhancement mode (b).

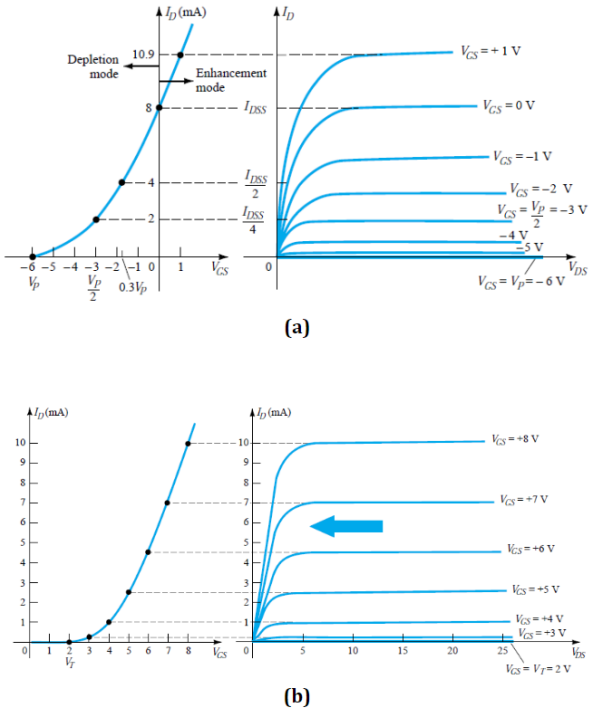


Figure 1. Characteristics of N-Channel MOSFET

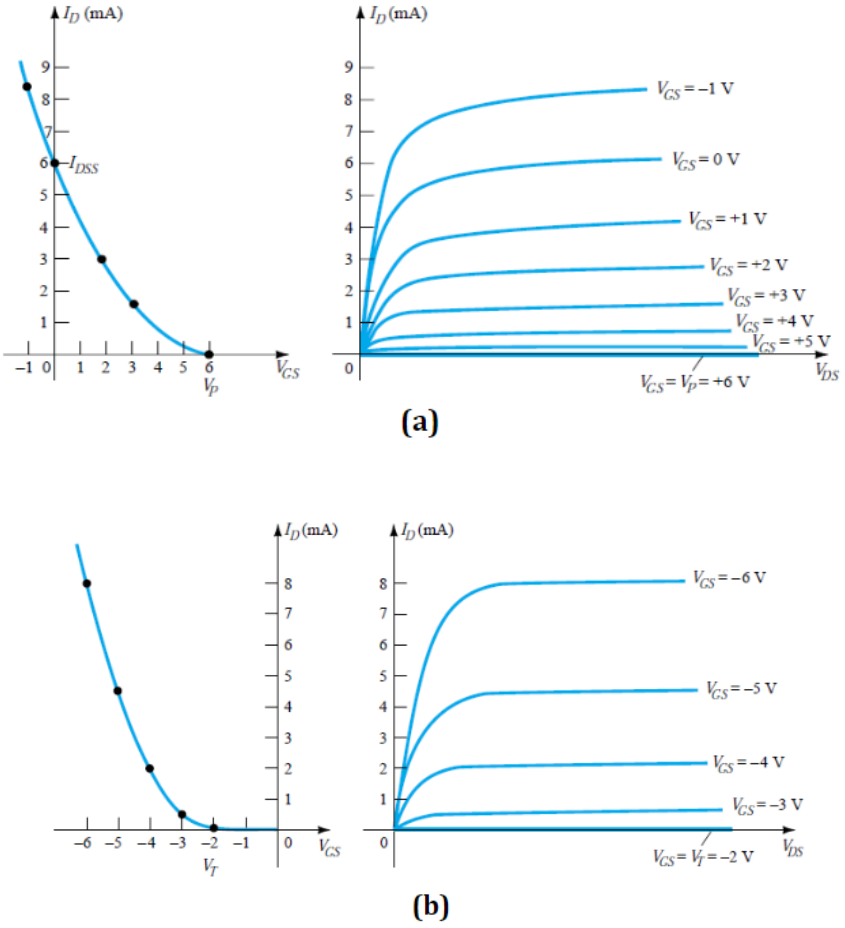


Figure 2. Characteristics of P-Channel MOSFET

Simulations:

For the next phase of the lab, we built the circuits shown in Figures 3 and 4 in Multisim. We used the 2N70000 MOSFET. For the circuit in Figure 3, we were taking note of the drain to source voltage and drain current when the MOSFET started to saturate. Using the plots, we created with the data obtained. we looked at the minimum drain to source voltage that put the MOSFET in saturation and whether it was n or p channel MOSFET in depletion or enhancement mode. For Figure 4, we were observing the MOSFET as an amplifier and what the bandwidth of the MOSFET was given a range of frequencies. We plotted the gain and frequency in order to determine the bandwidth.

Tables 1 – 3 is the data gathered from MultiSim and Figures 5 – 7 are plots generated from the data.

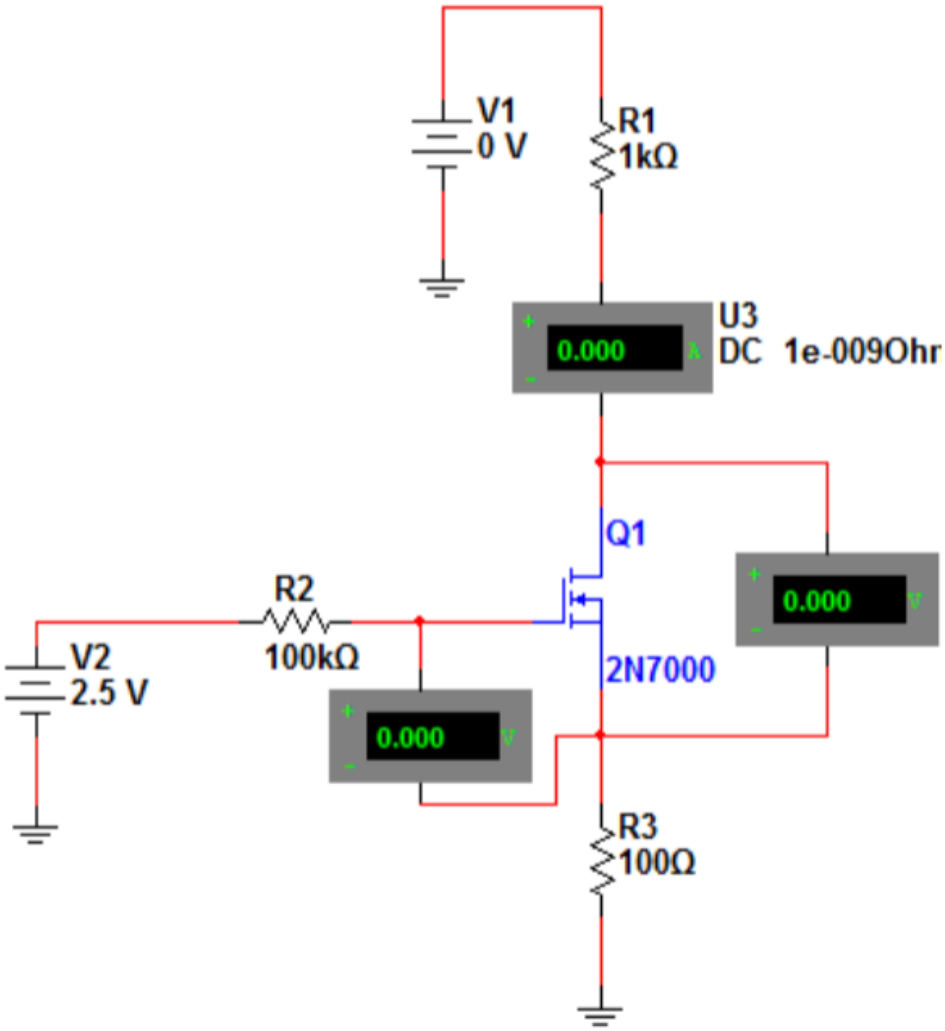


Figure 3: MOSFET circuit

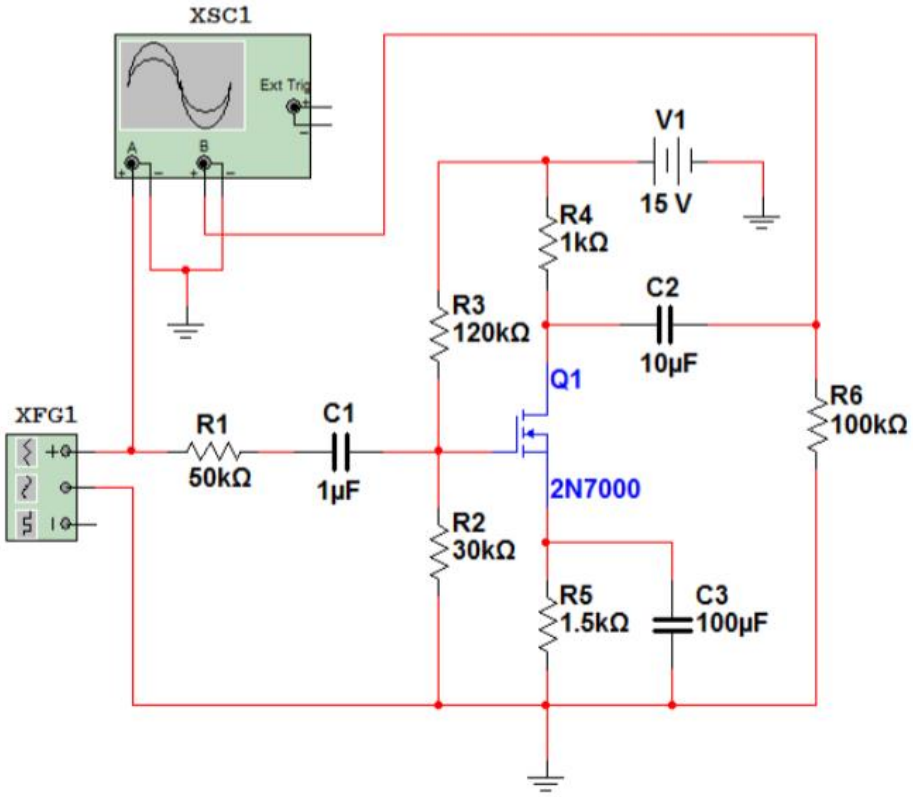


Figure 4. Signal Amplification with MOSFET

Table 1. Output Characteristics

V_2 = 2.5			
Vds	Vgs (mV)	Id (mA)	V1
0	2.475	0	0
0.008529	2.44	0.000356	0.4
0.019	2.405	0.00071	0.8
0.021	2.396	0.000799	1.1
0.028	2.379	0.000975	1.4
0.038	2.353	0.001238	1.7
0.051	2.327	0.001499	2.5
0.107	2.26	0.002176	3
0.215	2.225	0.002532	3.1
0.312	2.224	0.002534	3.2
0.412	2.224	0.002534	3.3
0.512	2.224	0.002534	3.4
V_2 = 3			
0	2.97	0	0

0.005374	2.926	0.00045	0.5
0.011	2.881	0.000899	1
0.018	2.837	0.001347	1.5
0.022	2.81	0.001616	1.8
0.028	2.775	0.001974	2.2
0.033	2.748	0.002243	2.5
0.04	2.713	0.0026	2.9
0.048	2.678	0.002956	3.3
0.057	2.642	0.003311	3.7
0.073	2.59	0.003842	4.3
0.089	2.546	0.004282	4.8
0.124	2.477	0.004978	5.6
0.19	2.402	0.005736	6.5
0.266	2.364	0.006121	7
0.294	2.358	0.006187	7.1
0.338	2.353	0.006238	7.2
0.432	2.352	0.006243	7.3
0.532	2.352	0.006243	7.4
$V_2 = 3.5$			
0	3.465	0	0
0.003699	3.421	0.000451	0.5
0.007609	3.376	0.000902	1
0.012	3.331	0.001353	1.5
0.016	3.287	0.001803	2
0.021	3.242	0.002254	2.5
0.026	3.198	0.002704	3
0.031	3.153	0.003153	3.5
0.037	3.109	0.003603	4
0.043	3.064	0.004051	4.5
0.05	3.02	0.0045	5
0.058	2.975	0.004947	5.5
0.066	2.931	0.005395	6
0.069	2.914	0.005573	6.2
0.075	2.887	0.005841	6.5
0.081	2.861	0.006108	6.8
0.085	2.843	0.006286	7
0.09	2.825	0.006464	7.2
0.097	2.799	0.00673	7.5
0.0104	2.773	0.006996	7.8
0.11	2.755	0.007173	8
0.115	2.738	0.007349	8.2
0.125	2.711	0.007614	8.5
0.135	2.685	0.007877	8.8
0.143	2.668	0.008052	9

0.151	2.651	0.008227	9.2
0.164	2.625	0.008487	9.5
0.179	2.599	0.008746	9.8
0.19	2.582	0.008918	10
0.203	2.566	0.009088	10.2
0.225	2.541	0.009341	10.5
0.252	2.516	0.009589	10.8
0.274	2.5	0.00975	11
0.337	2.47	0.01	11.4
0.361	2.463	0.01	11.5
0.5		0.01	
$V_2 = 4$			
0	3.96	0	0
0.002887	3.916	0.000452	0.5
0.005889	3.871	0.000904	1
0.009014	3.826	0.001355	1.5
0.012	3.781	0.001807	2
0.016	3.737	0.002258	2.5
0.019	3.692	0.00271	3
0.023	3.647	0.003161	3.5
0.027	3.603	0.003612	4
0.0031	3.558	0.004063	4.5
0.035	3.514	0.004513	5
0.04	3.469	0.004964	5.5
0.043	3.442	0.005234	5.8
0.045	3.424	0.005414	6
0.05	3.38	0.005864	6.5
0.055	3.335	0.006313	7
0.058	3.317	0.006493	7.2
0.061	3.291	0.006762	7.5
0.067	3.246	0.007211	8
0.07	3.229	0.007391	8.2
0.074	3.202	0.00766	8.5
0.082	3.158	0.008108	9
0.085	3.14	0.008287	9.2
0.089	3.113	0.008555	9.5
0.094	3.087	0.008823	9.8
0.098	3.069	0.009002	10
0.102	3.051	0.00918	10.2
0.107	3.025	0.009448	10.5
0.113	2.998	0.009715	10.8
0.118	2.981	0.009893	11
0.122	2.963	0.01	11.2
0.129	2.937	0.01	11.5

0.25		0.01	
0.4		0.01	
0.55		0.01	

Table 2. Mode Characteristics

Vgs	Id (mA)
1.98	0.003553
2.136	0.931
2.224	2.537
2.293	4.338
2.352	6.244
2.404	8.219
2.451	10
2.494	12
2.535	14
2.573	17
2.609	19
2.755	20
2.992	20

Table 3. Output and Gain

F(HZ)	V_{OUT}	Gain(db)
30	0.02135	-13.4120424
45	0.06591	-3.62097377
60	0.126	2.007410902
100	0.192	5.666024574
200	0.286	9.127320663
500	0.368	11.31695637
1k	0.372	11.4108588
10k	0.37	11.36403448
100k	0.372	11.4108588
500k	0.372	11.4108588
1M	0.371	11.38747819
1.5M	0.363	11.1981325
2M	0.352	10.93085327
3M	0.338	10.57833401
4M	0.305	9.685996787
5M	0.271	8.659385817
7M	0.145	3.227360045
10M	0.102	0.172003435
11M	0.07789	-2.17036592

12M	0.0534	-5.44917486
15M	0.04295	-7.34073664
16M	0.02952	-10.5976729

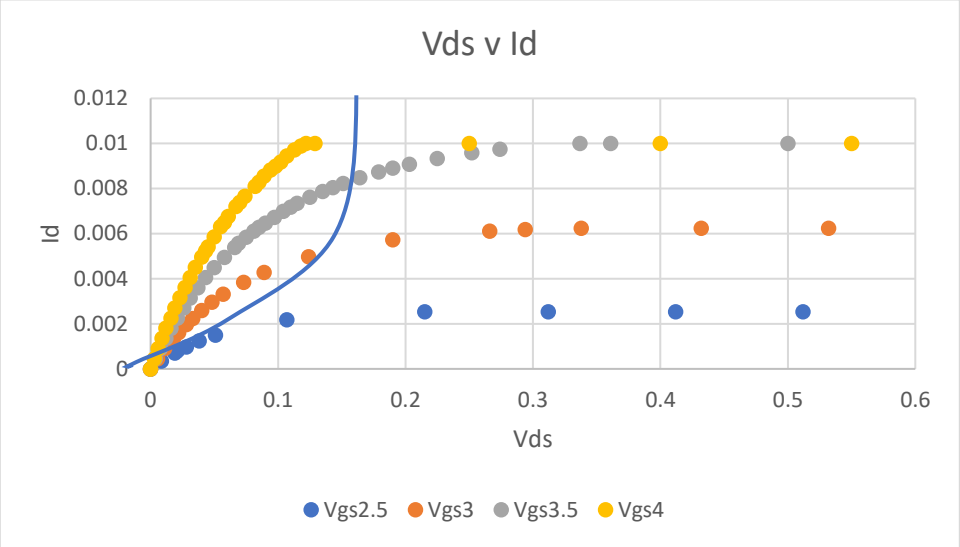


Figure 5. Characteristics of MOSFET

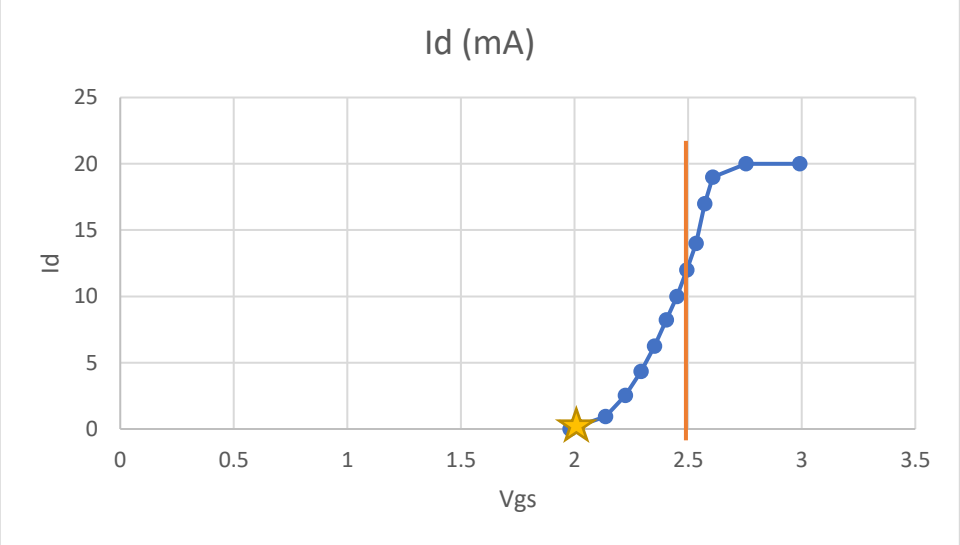


Figure 6. Transfer Characteristics

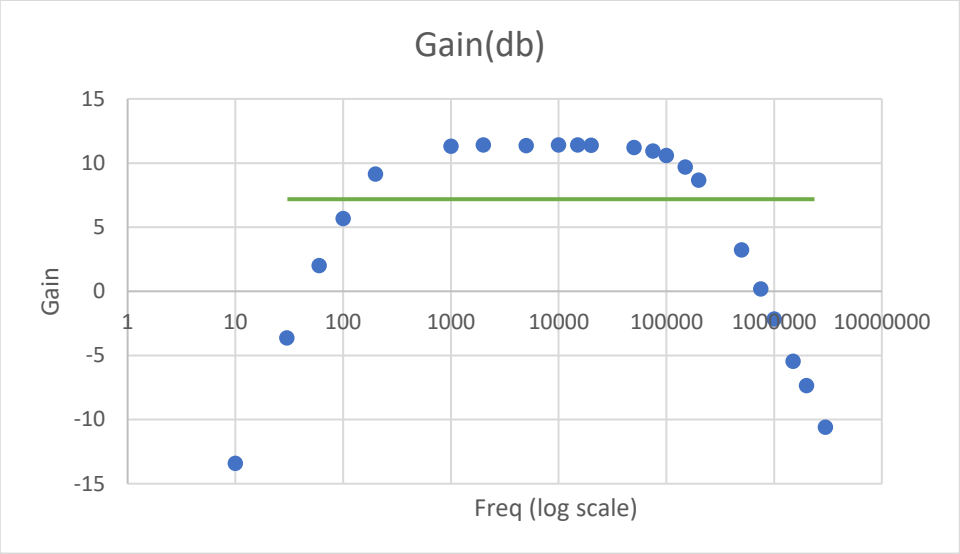


Figure 7. Gain vs Frequency

Experimental:

For the last portion of the lab, we did the same things as prior but on a physical board to further validate the output results we obtained. For the first part, we looked at the drain source voltage versus the drain current characteristics of the MOSFET. Excel was used for any calculations and plots. Table 4 and 5 gives the values collected and Figures 8 and 9 are the characteristic plots. A few extra values were added at the end so that the points would all extend to around the same ending V_{DS} value. The star marks the threshold voltage. Extra values were also added to the mode characteristics table to make the line connect from 0 to the threshold voltage.

For the amplification circuit, Table 6 contains the output voltage and gain observed for each frequency. Figure 10 is the plot of gain versus frequency. The lowest frequency that could be done in lab with results was 20 Hz and the highest frequency was 3M Hz, so the table for this portion looks a little different than the one for the previous section. The bandwidth is shown by the green line.

Table 4. Output Characteristics

V_2 = 2.5			
Vds	Vgs (mV)	Id (mA)	V1

0	2.49	0	0
0.00386	2.46	0.000438	0.5
0.009057	2.40	0.000955	1
0.01127	2.39	0.001077	1.2
0.0156	2.37	0.001243	1.4
0.01938	2.35	0.001496	1.6
0.02428	2.33	0.001642	1.8
0.03294	2.31	0.001891	2.1
0.04287		0.002076	2.3
0.05952		0.002285	2.5
0.08109		0.002449	2.7
0.10443		0.002554	2.9
0.128		0.00262	3
0.204		0.002718	3.2
0.348		0.002775	3.4
0.5		0.002776	
$V_2 = 3$			
0	2.96	0	0
0.00158	2.91	0.000453	0.5
0.00259		0.000718	0.8
0.004174		0.001095	1.2
0.005133	2.83	0.001306	1.4
0.006971		0.001676	1.8
0.008371		0.001927	2.1
0.010719		0.002303	2.5
0.013359		0.002663	2.9
0.015752		0.00295	3.2
0.018294		0.003205	3.5
0.021855		0.003515	3.8
0.025696		0.003792	4.2
0.029746		0.004036	4.4
0.0329		0.0042	4.6
0.03582		0.004333	4.8
0.04215	2.51	0.004576	5
0.05147		0.00485	5.3
0.05642		0.004965	5.5
0.07562		0.00529	5.8
0.10093		0.005539	6.1
0.1256		0.005685	6.3
0.14		0.005745	6.4
0.175		0.005838	6.6
0.272		0.005961	6.8
0.362		0.006005	6.9
0.437		0.006024	7

0.52435	2.39	0.006039	7.1
V_2 = 3.5			
0	3.529	0	0
0.001031		0.000453	0.5
0.002087		0.000896	1
0.003433		0.001432	1.5
0.004812		0.00195	2.1
0.00578		0.002295	2.5
0.007202		0.002773	3
0.0087		0.003243	3.5
0.010256	3.168	0.003698	4
0.01178		0.004109	4.5
0.013772		0.004605	5
0.015804		0.005061	5.5
0.017988		0.005503	6
0.02065		0.005981	6.5
0.023232		0.00639	7
0.025277		0.00679	7.3
0.027638		0.00698	7.6
0.031021		0.00736	8
0.03345		0.007603	8.3
0.036443		0.00786	8.6
0.039538		0.008102	8.9
0.04297		0.008333	9
0.043585		0.008376	9.2
0.048322		0.00865	9.5
0.0535		0.00901	9.7
0.0586		0.009112	10
0.06457		0.00932	10.2
0.07214		0.009538	10.5
0.08604		0.009842	10.8
0.09787		0.010034	11
0.105207		0.01013	11.1
0.11085		0.010196	11.2
0.11492		0.01023	11.3
0.2		0.01024	
0.3		0.01025	
0.5		0.01025	
V_2 = 4			
0		0	0
0.000999		0.000516	0.5
0.001913		0.000976	1
0.002787		0.001402	1.5
0.003787		0.001873	2

0.004712		0.002294	2.5
0.005718		0.002738	3
0.006858	3.63	0.003219	3.5
0.008014		0.003687	4
0.009046		0.004089	4.5
0.010352		0.004575	5
0.011771		0.005074	5.5
0.013128		0.005527	6
0.014405		0.005929	6.5
0.015989		0.006402	7
0.017685		0.006872	7.5
0.019385		0.007316	8
0.02143		0.007807	8.5
0.023338		0.008227	9
0.025628		0.008688	9.5
0.028376		0.009186	10
0.031054	3.0166	0.00962	10.5
0.034445		0.010103	11
0.037393		0.010474	11.5
0.041842		0.010955	12
0.04389		0.011152	12.2
0.04596		0.011337	12.4
0.05095		0.011726	12.8
0.05359		0.011906	13
0.05634		0.012078	13.2
0.060022		0.012286	13.4
0.063839		0.012478	13.6
0.068025	2.72	0.012663	13.8
0.07234		0.012835	14
0.07575		0.012956	14.2
0.08186		0.013147	14.4
0.08846		0.01323	14.6
0.0984		0.013541	14.8
0.1065		0.01369	15
0.1102		0.01375	15.1
0.1172		0.01385	15.2
0.12617		0.013961	15.3
0.1324		0.014029	15.4
0.14464		0.014137	15.5
0.2		0.014138	
0.35		0.014139	
0.5		0.014139	

Table 5. Mode Characteristics

Vgs	Id (mA)
0	0
1	0.1
1.5	0.12
1.95	0.175
2.15	1.61
2.2	2.68
2.24	3.65
2.28	4.96
2.34	7.38
2.37	9.01
2.4	10.969
2.45	12.67
2.5	15.75
2.54	17.927
2.56	18.865
2.596	20.016
2.64	20.172
2.71	20.204

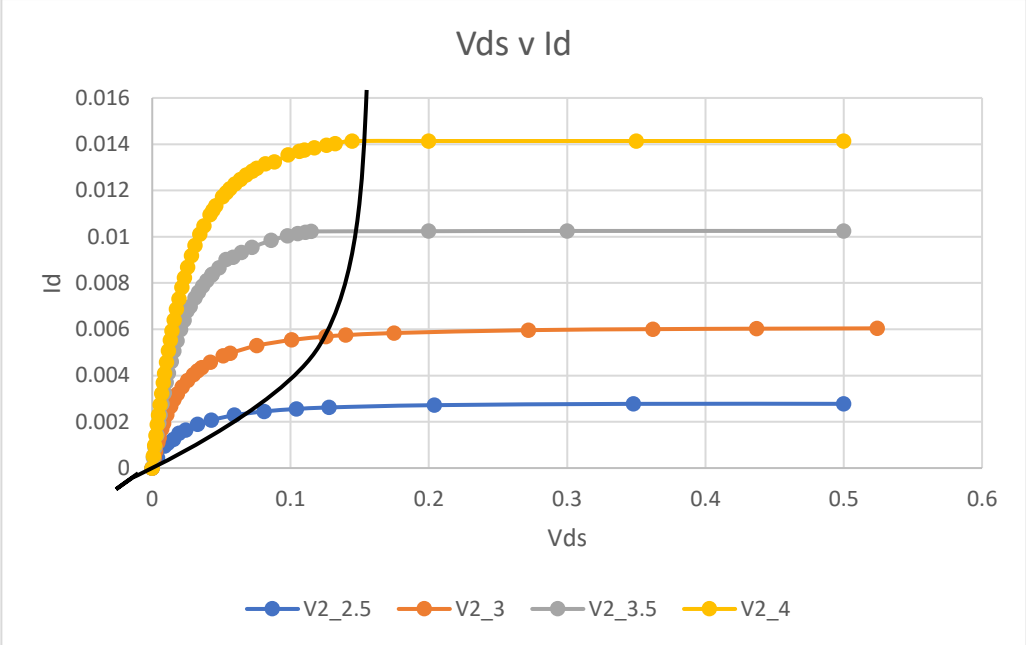


Figure 8. Output Characteristics

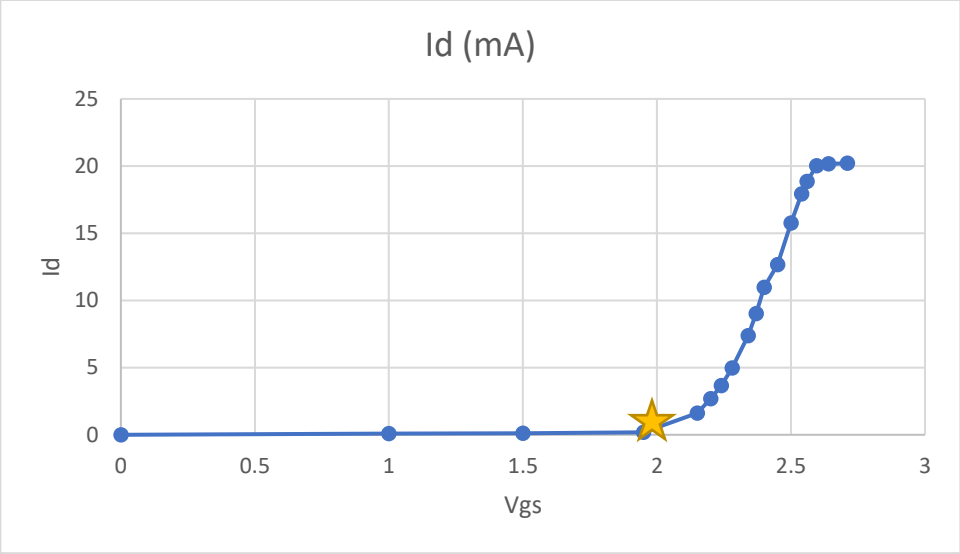


Figure 9. Mode Characteristics

Table 6. Amplification observations

F(HZ)	V_{OUT} (mV)	Gain(db)
20	320	2.462658715
30	380	3.955331081
60	400	4.400858975
100	400	4.400858975
200	420	4.824644956
500	420	4.824644956
1000	420	4.824644956
2000	460	5.614815782
5000	460	5.614815782
10000	460	5.614815782
15000	460	5.331169692
20000	420	4.540998866
50000	380	3.67168499
75000	340	2.705591399
100000	280	1.019173685
150000	240	-0.31976211
200000	200	-1.90338703
500000	100	-7.92398694
750000	80	-9.8621872
1000000	60	-13.1602279
1500000	60	-13.1602279

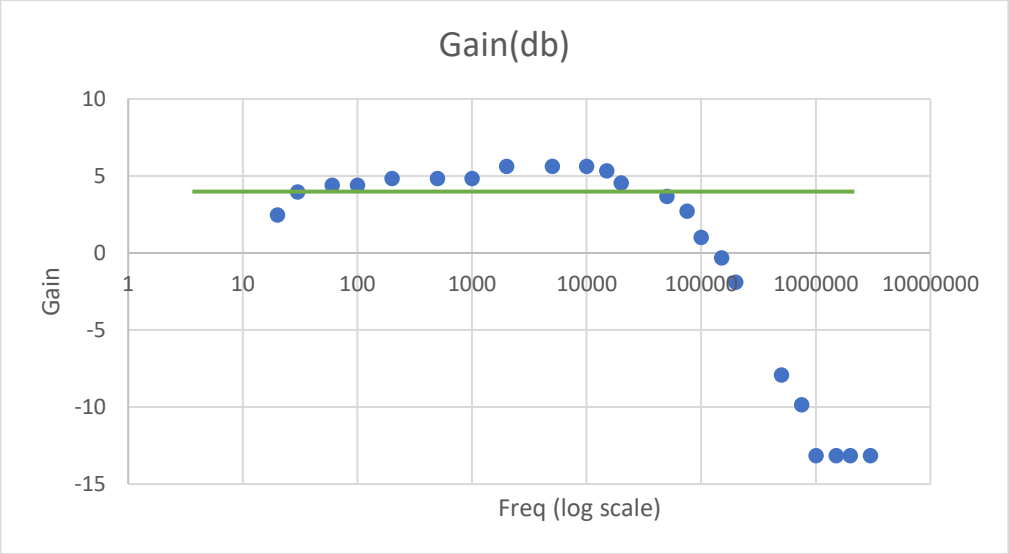


Figure 10. Gain vs Frequency

Results and Discussion:

As far the look of the plots, the outputs and lines were as we expected. Given the plots we collected, we had a n-channel MOSFET in enhancement mode with a threshold voltage of 2. The results gathered for the first portion for both experimental and simulation were pretty close with each other. They both saturated at the same I_d with a little discrepancy due to lab equipment vs software.

The gain portion of the lab differ a lot between the experimental and simulation sections because the oscilloscope in the lab was not working correctly. After every change of frequency if you auto scaled the output it gave back around 420 mV every time. From the data I could collect it seemed to be acting in reverse, which was not correct, so I did reverse the data for the graph so that it would come out to the correct shape. The bandwidth for the experimental portion is shifted by about 50 to the left compared to the simulation. The amplitude that determines the bandwidth is also about half that of what was seen in the simulation portion.

Conclusion

Overall, the results of lab where in line with what we expected from the information gathered from the theoretical sections. Our results for the experimental and simulation matched for the first portion of the lab with discrepancies due to real equipment and components versus

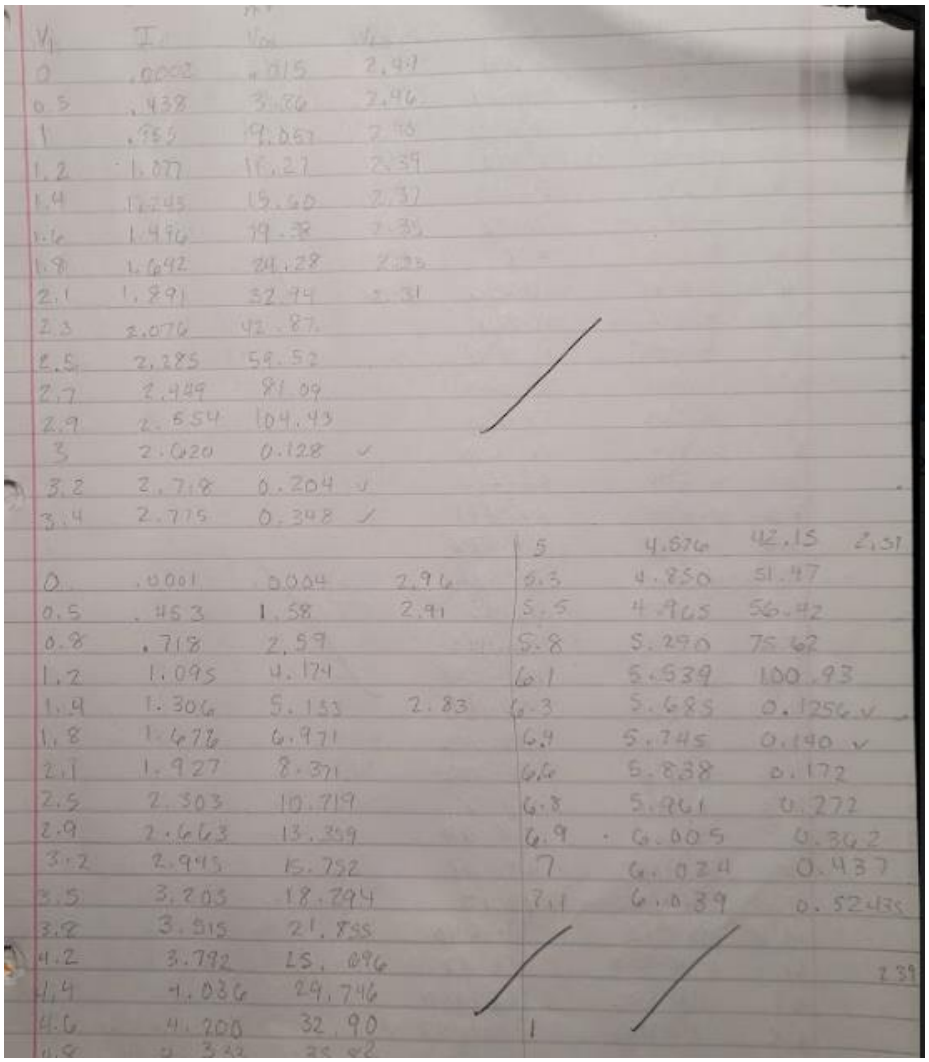
software. The amplification portion of the lab differed greatly due to in lab equipment not working correctly or possibly a component/circuit problem. This lab showed us the behavior for MOSFET and allowed us to identify mode and type based on behavior. It also gave us the information to compare the MOSFET to BJTs and JFETs.

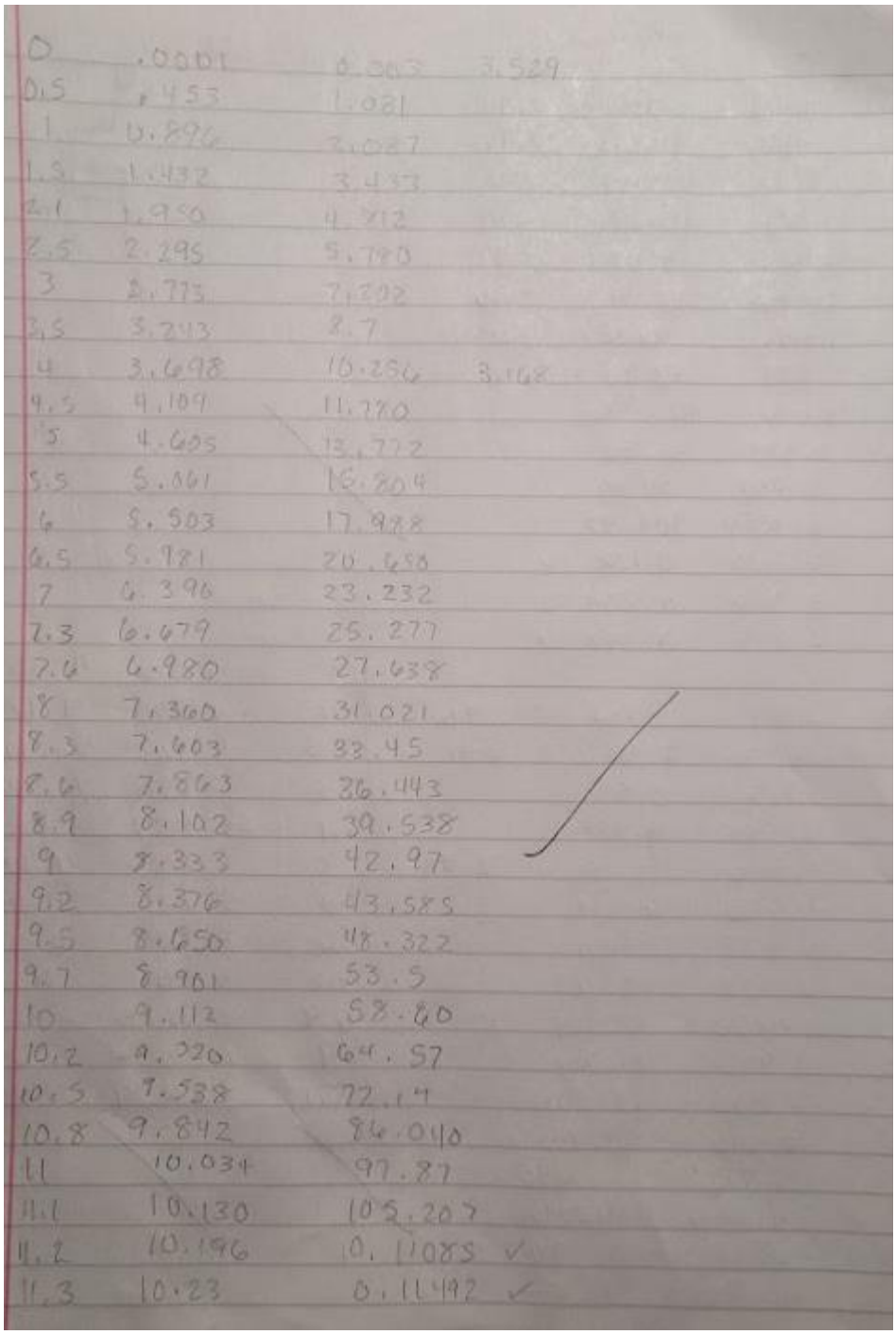
Appendix 1:

N/A

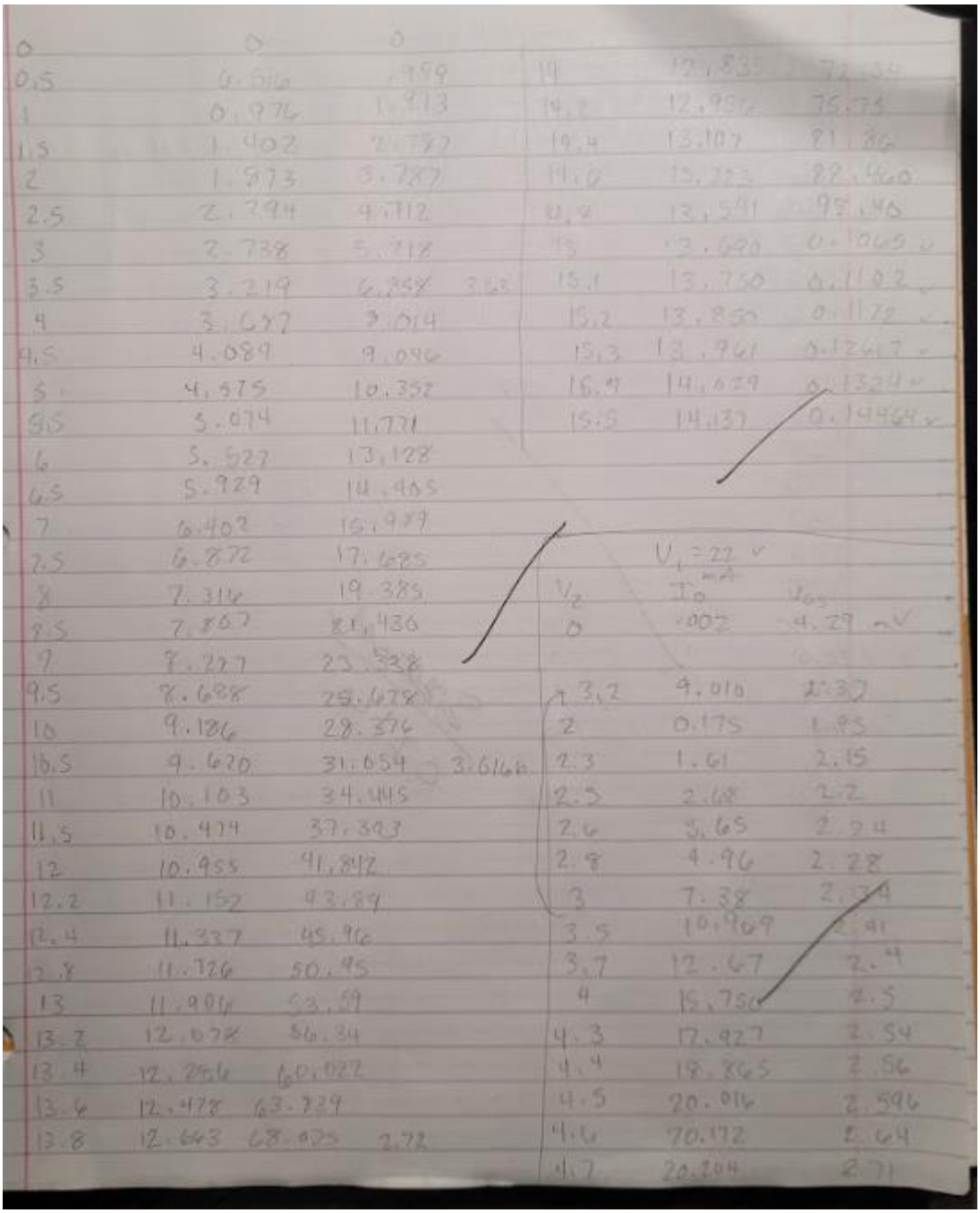
Appendix 2:

Signed lab results

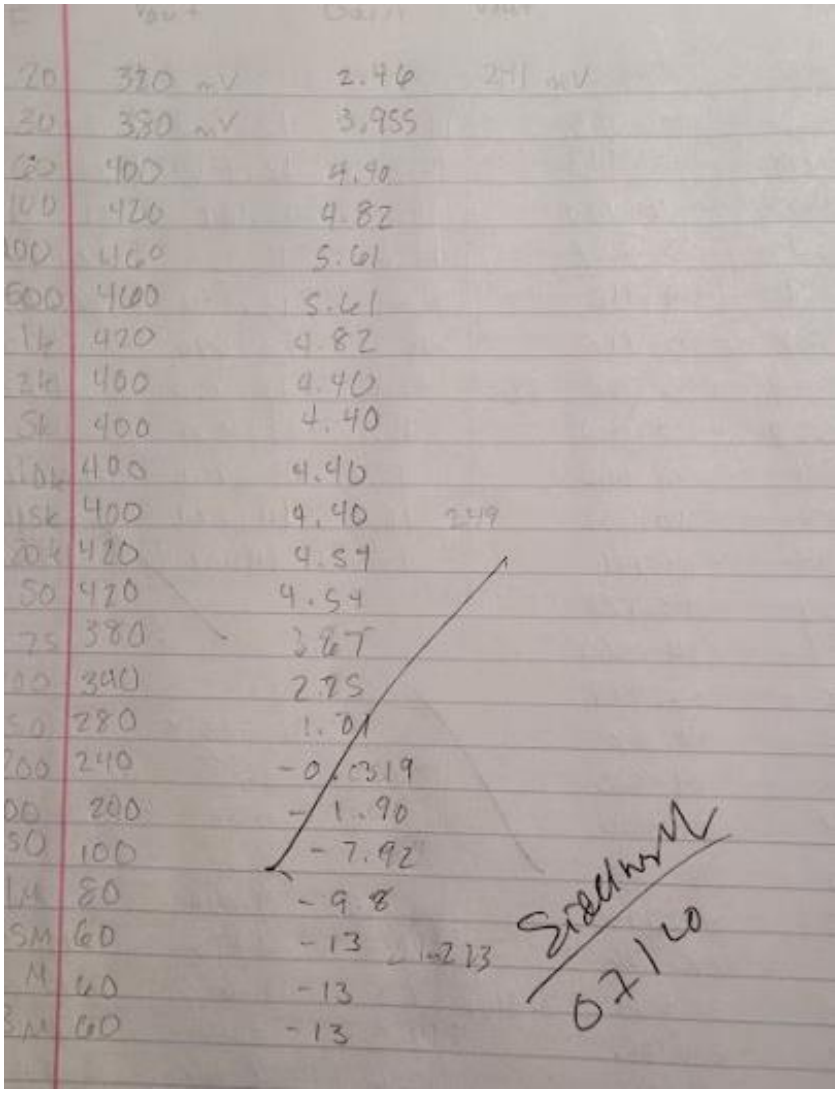




0	.0001	0.063	3.529
0.5	.453	1.021	
1	0.896	2.027	
1.5	1.432	3.433	
2.1	1.950	4.912	
2.5	2.295	5.720	
3	2.773	7.202	
3.5	3.243	8.7	
4	3.698	10.256	3.168
4.5	4.109	11.270	
5	4.605	13.772	
5.5	5.061	16.304	
6	5.503	17.988	
6.5	5.981	20.650	
7	6.396	23.232	
7.3	6.679	25.277	
7.6	6.980	27.638	
8	7.360	31.021	
8.3	7.603	33.45	
8.6	7.863	36.443	
8.9	8.102	39.538	
9	8.333	42.97	
9.2	8.376	43.585	
9.5	8.650	48.322	
9.7	8.901	53.5	
10	9.112	58.80	
10.2	9.220	64.57	
10.5	9.538	72.19	
10.8	9.842	86.040	
11	10.034	97.87	
11.1	10.130	105.207	
11.2	10.196	0.11085 ✓	
11.3	10.23	0.11492 ✓	



0	0	0				
0.5	0.516	.999		14	12.835	72.34
1	0.976	1.913		14.2	12.956	75.73
1.5	1.402	2.787		14.4	13.107	81.86
2	1.873	3.787		14.6	13.323	89.460
2.5	2.294	4.712		14.8	13.541	98.46
3	2.738	5.718		15	13.690	0.1065 v
3.5	3.219	6.758	3.68	15.1	13.750	0.1102 v
4	3.687	7.814		15.2	13.850	0.1172 v
4.5	4.089	9.046		15.3	13.961	0.12617 v
5	4.575	10.352		16.9	14.629	0.1324 v
5.5	5.074	11.771		15.5	14.137	0.14464 v
6	5.527	13.128				
6.5	5.929	14.905				
7	6.403	15.989				
7.5	6.872	17.685			$V_1 = 22$ V	
8	7.316	19.385		V_2	I_D mA	V_{out}
8.5	7.807	21.430		0	.007	4.29 mV
9	8.227	23.338				
9.5	8.688	25.678		3.2	9.010	2.37
10	9.186	28.376		2	0.175	1.95
10.5	9.620	31.054	3.6166	2.3	1.61	2.15
11	10.103	34.445		2.5	2.68	2.2
11.5	10.474	37.393		2.6	3.65	2.24
12	10.955	41.842		2.8	4.96	2.28
12.2	11.152	43.89		3	7.38	2.34
12.4	11.337	45.96		3.5	10.969	2.41
12.8	11.726	50.95		3.7	12.67	2.4
13	11.901	53.59		4	15.750	2.5
13.2	12.078	56.34		4.3	17.927	2.54
13.4	12.256	60.027		4.4	18.865	2.56
13.6	12.428	63.729		4.5	20.016	2.596
13.8	12.643	68.025	2.72	4.6	70.172	2.64
				4.7	20.204	2.71


320 mV
2.46
380 mV
3.955
400
4.90
420
4.82
460
5.61
400
5.61
420
4.82
400
4.40
400
4.40
400
4.90
400
4.90
420
4.54
420
4.54
380
2.67
390
2.75
280
1.01
240
-0.0319
200
-1.90
100
-7.92
80
-9.8
60
-13
60
-13
Stockwell
07/20

Pictures of Circuits

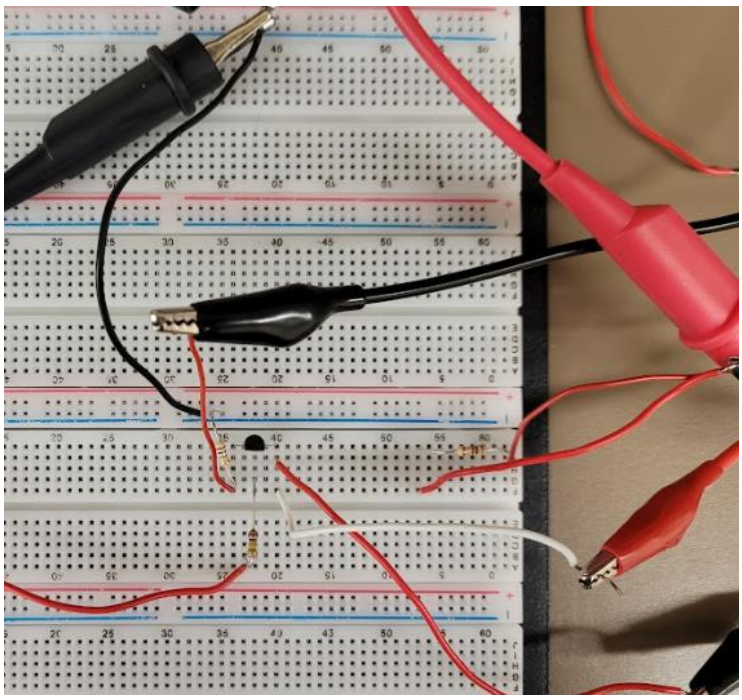


Figure 1. Characteristic Circuit (ref Figure 3)

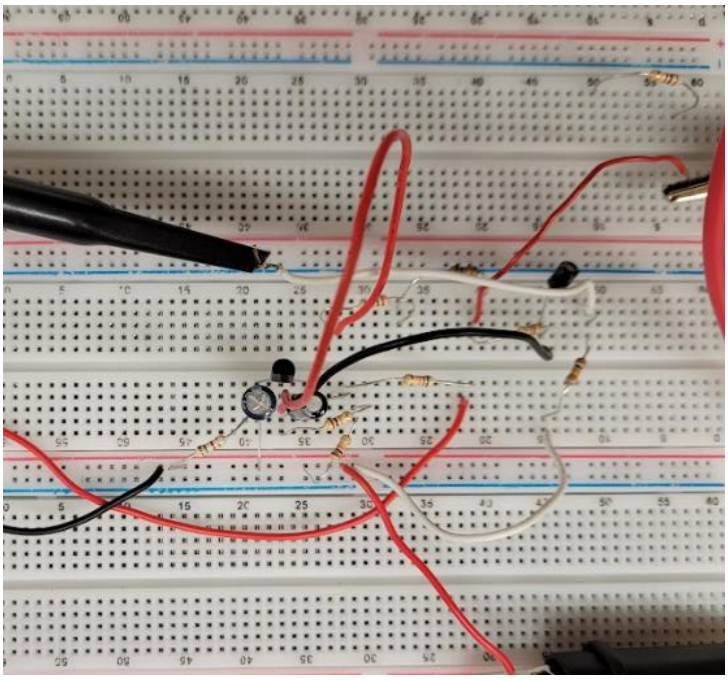


Figure 2. Amplification Circuit (ref Figure 4)