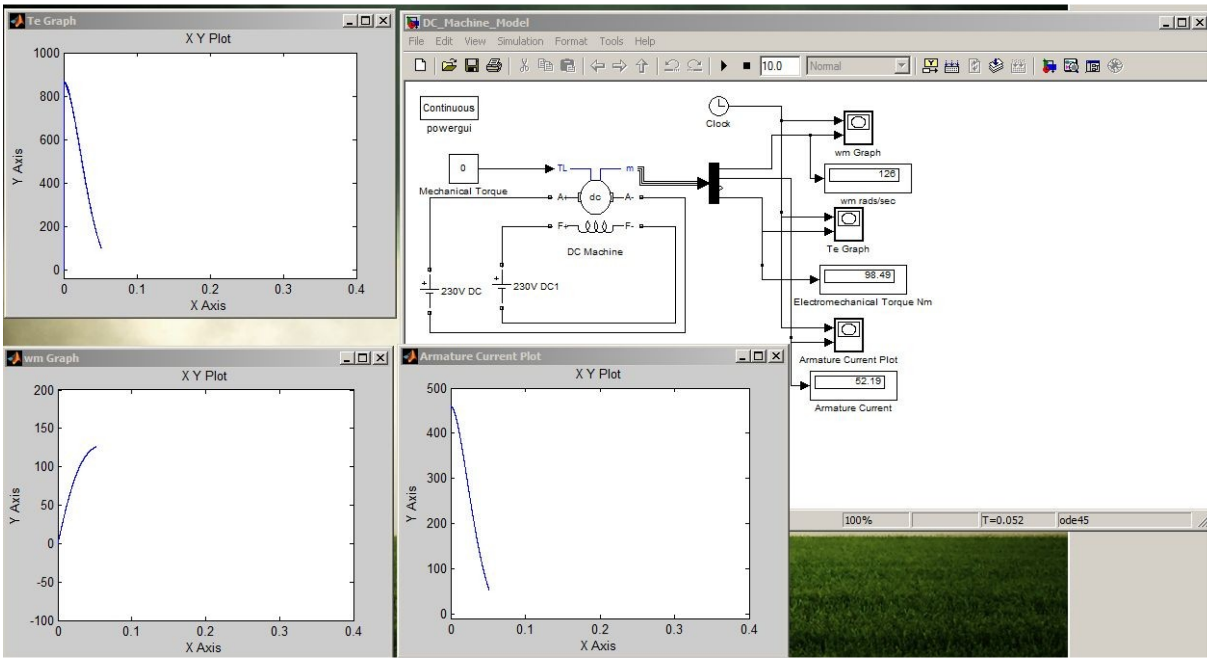
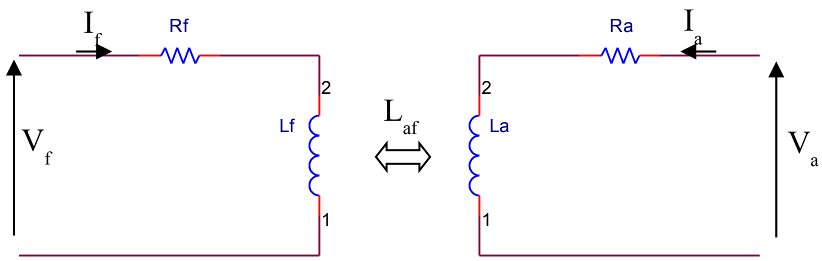
Simulation of DC and Induction Machines

Part 1A

Model created in Simulink



Part 2A



To compute the speed of a DC machine from the load it carries during its steady state operation, a total of two equations will be used. The first gives the relationship between the magnitude of the back EMF at the armature, the speed of the machine, and the field current.

$$E_a = L_{af} I_f \omega \qquad (1)$$

It is also known that at steady state, torque is equal to the mechanical load. Therefore, the following equation:

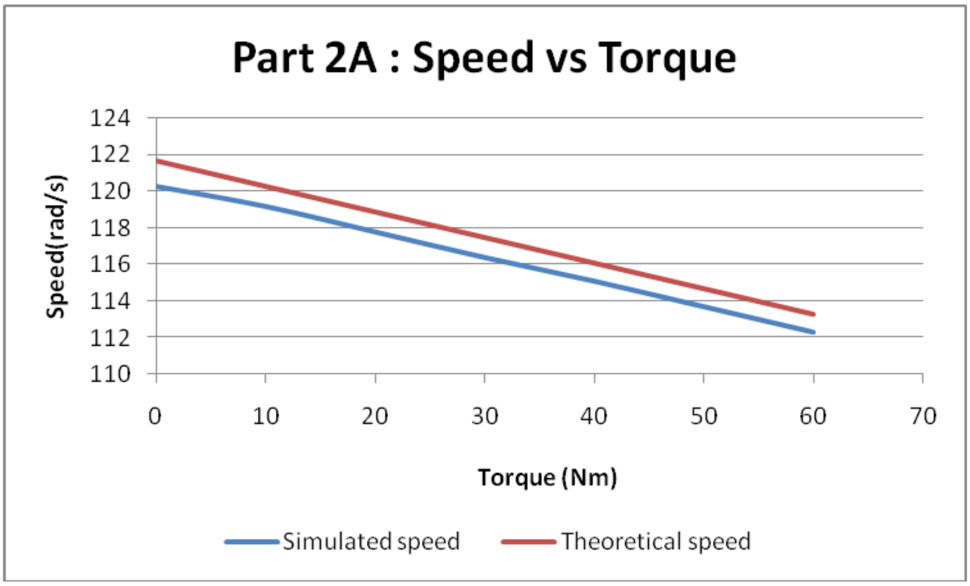
$$T = L_{af} I_f I_a \qquad (2)$$

can be used to obtain a value for I_a since at steady state, I_f is constant because the back EMF at the field drops to zero, making I_f simply equal to (V_f/R_f). Laf as well is a constant figure.

Knowing the value of the armature current, the magnitude of the armature back EMF can be solved through Kirchoff's voltage law at the armature circuit. Knowing the value of the armature back EMF would then give the value of the motor speed according to (1). The values for the theoretical and simulated speeds are given below.

Torque (Nm)	Speed from simulation (Rad/s)	Theoretical
0	120.3	121.6931217
10	119.2	120.2933848
20	117.8	118.893648
30	116.4	117.4939111
40	115.1	116.0941743
50	113.7	114.6944374
60	112.3	113.2947006

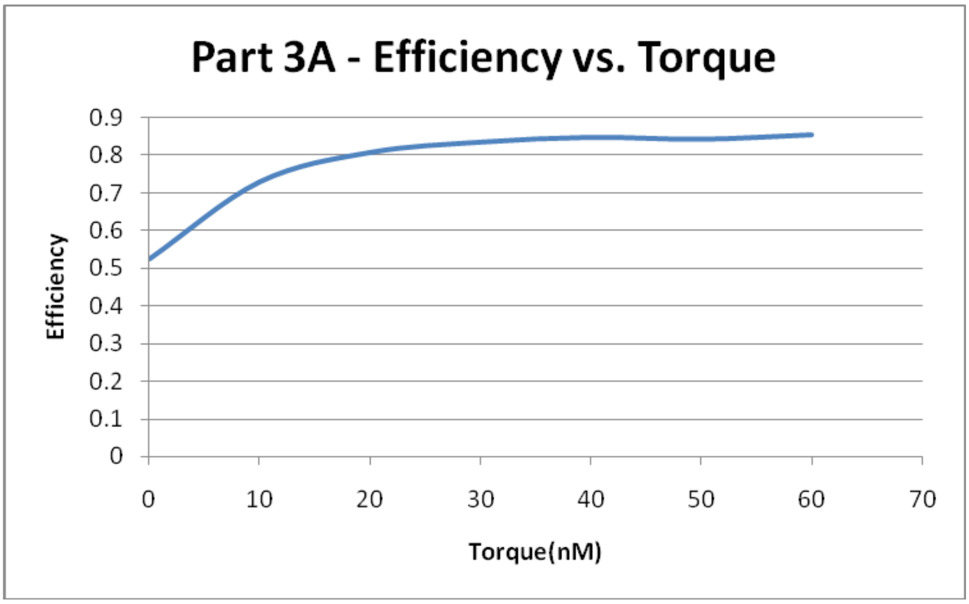
The speed decreases in an almost linear fashion as the mechanical load torque increases. This is evident in the plot below. Additionally, the simulated speeds are lower than the speeds predicted by theoretical analysis. This may be explained by the fact that the simulation takes much more factors into consideration than the simplified analysis performed.



Part 3A

To solve for the efficiency of the machine, the amount of power output and input should be solved. Power input is simply a matter of multiplying the field and armature currents with the DC source voltage, giving the power in watts through VI. To get the output power, the torque generated by the machine should be multiplied with the machine's speed of rotation. Efficiency is then a simple matter of dividing the output power with the input power. The data from the simulation is given below.

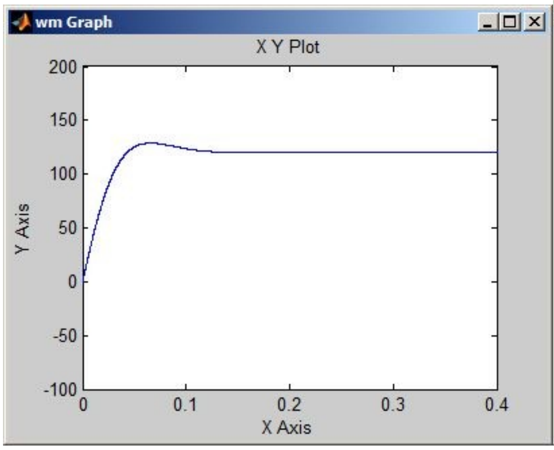
Load Torque	Speed	Em Torque	If	Ia	Input Power	Output Power	Efficiency
0	120.3	5.77	2.7	3.055	1323.65	693.6498	0.524043
10	119.2	15.54	2.7	8.335	2538.05	1852.368	0.729839
20	117.8	25.78	2.7	13.64	3758.2	3036.884	0.808069
30	116.4	35.68	2.7	18.91	4970.3	4153.152	0.835594
40	115.1	45.63	2.7	24.22	6191.6	5252.013	0.848248
50	113.7	54.77	2.7	29.41	7385.3	6227.349	0.843209
60	112.3	65.55	2.7	34.73	8608.9	7361.265	0.855076

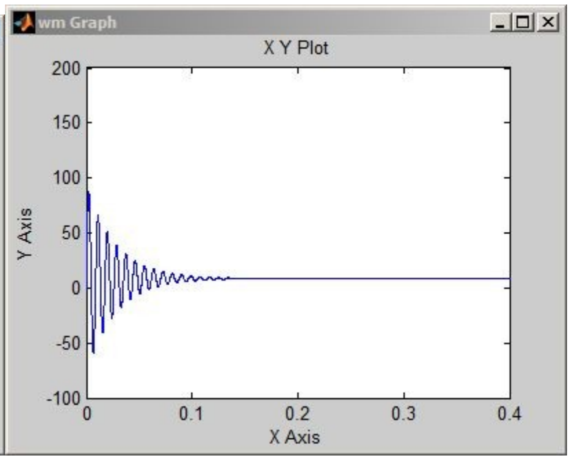


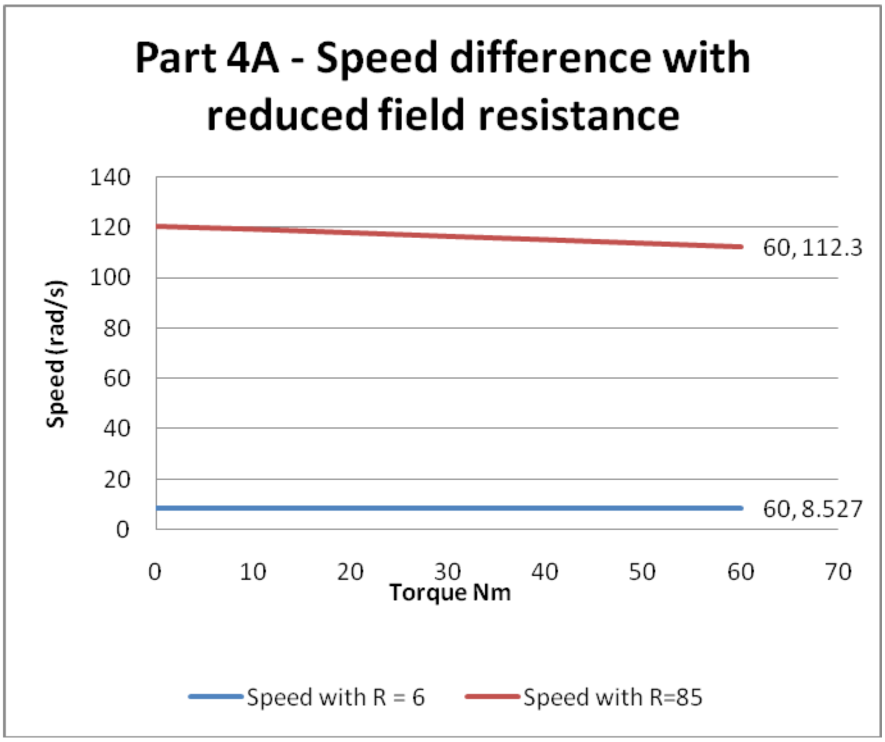
From the plot, it can be seen that efficiency increases as the load torque increases up to a certain limit. At which point, the efficiency of the DC machine reaches a plateau.

Part 4A

The reduction of the resistance of the field winding has had significant effects. First, the speed of the motor has dropped significantly. The efficiency has also dropped by more than one decade. The motor is also more unstable compared to the previous scenario as the speed undergoes more oscillations before reaching a stable speed. The instability can be seen in the plots of the speed before and after the field resistance change. The speed plot before the change is in the left and the speed plot after the change is at the right.

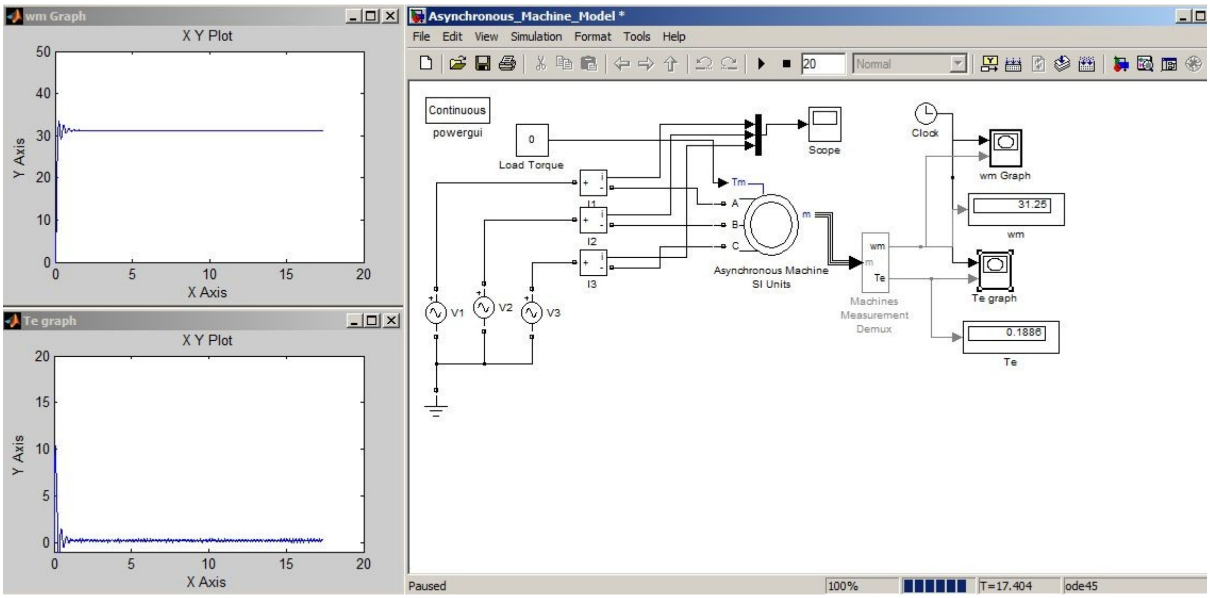

wm Graph
X Y Plot
200
150
100
50
0
-50
-100
0
0.1
0.2
0.3
0.4
Y Axis
X Axis


wm Graph
X Y Plot
200
150
100
50
0
-50
-100
0
0.1
0.2
0.3
0.4
Y Axis
X Axis


Part 4A - Speed difference with reduced field resistance
Speed (rad/s)
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Torque Nm
60, 112.3
60, 8.527
Speed with R = 6
Speed with R=85

Part 1B

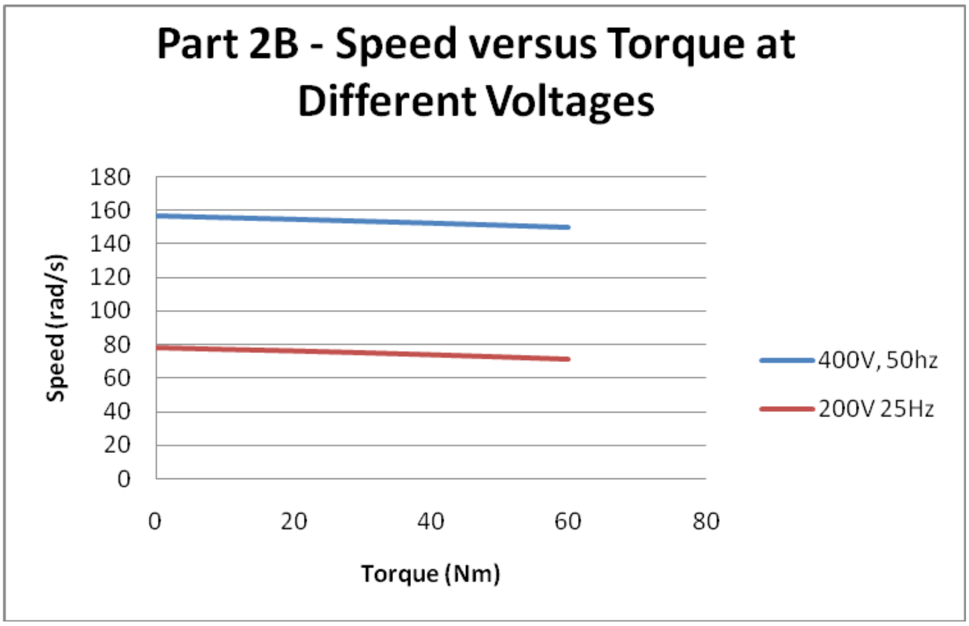
Model created in Simulink



Part 2B

From the results of the simulation, it can be seen that having a lower voltage and frequency results in lower steady state motor speeds. For a particular voltage, the speed appears to decline linearly as torque increases. This linear decline can be seen in the plot below.

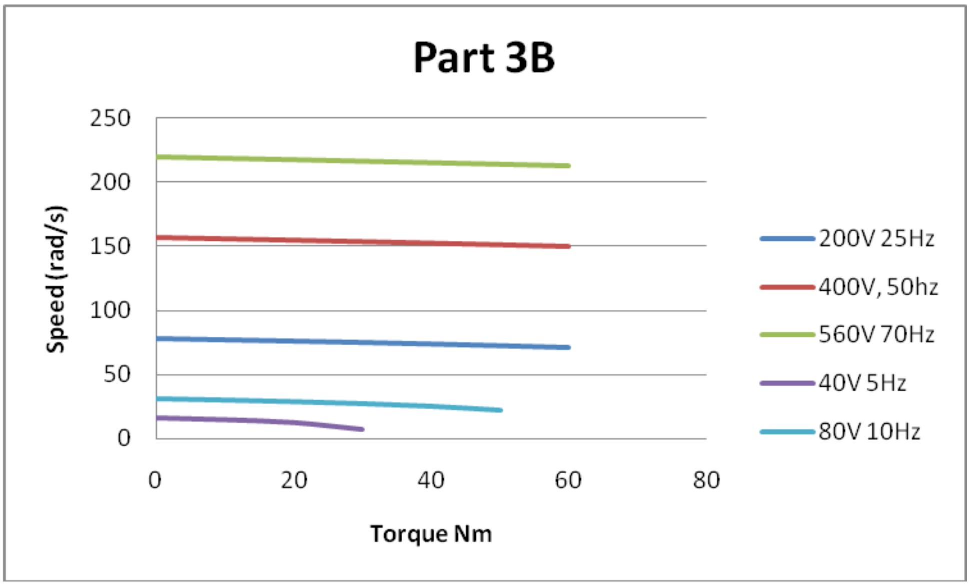
	Speed	
Torque	400V, 50hz	200V 25Hz
0	156.9	78.47
10	155.9	77.42
20	154.9	76.38
30	153.8	75.19
40	152.7	73.91
50	151.5	72.51
60	150.2	70.95



Part 3B

In extending simulation to even lower voltage and frequency combinations, an interesting scenario occurs. At combinations of low voltages and high load torques, the simulation tends to become unstable, and the speed declines continuously without reaching steady state. For all other working voltage and frequency combinations, the speed still appears to decline linearly as the amount of torque is increased.

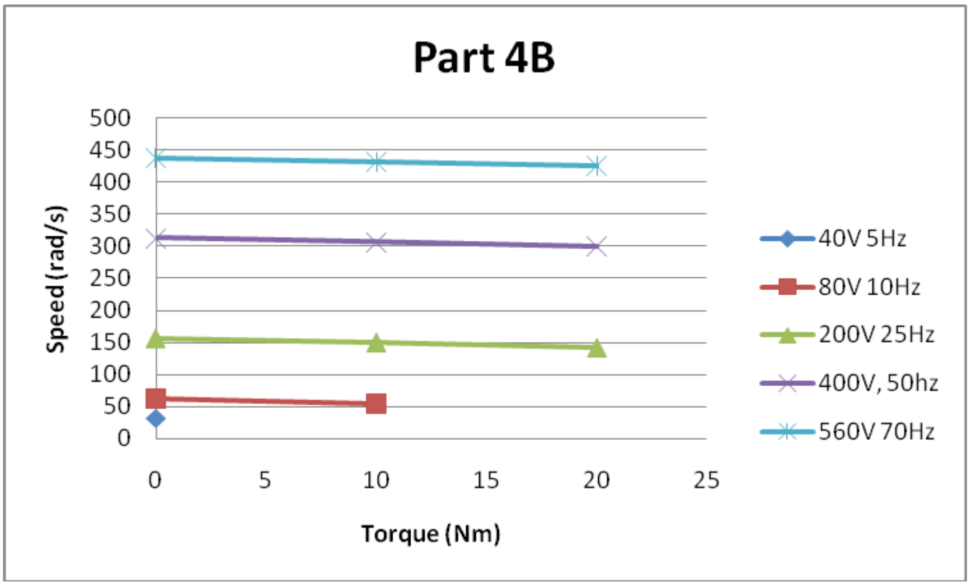
	Speed				
Torque	40V 5Hz	80V 10Hz	200V 25Hz	400V, 50hz	560V 70Hz
0	15.7	31.36	78.47	156.9	219.7
10	14.4	30.29	77.42	155.9	218.7
20	12.43	28.99	76.38	154.9	217.7
30	7.508	27.39	75.19	153.8	216.6
40	Does not stabilize	25.26	73.91	152.7	215.5
50	Does not stabilize	22.02	72.51	151.5	214.4
60	Does not stabilize	Does not stabilize	70.95	150.2	213.2



Part 4B

The new machine is even more unstable. With the same set of voltages and load torques as in the previous part, the machine reaches instability much more often. This can be seen in the table and plot below.

	Speed				
Torque	40V 5Hz	80V 10Hz	200V 25Hz	400V, 50hz	560V 70Hz
0	31.25	62.58	156.5	312.9	438.1
10	DNS	54.57	150.1	307	432.2
20	DNS	DNS	141.7	300	425.6
30	DNS	DNS	DNS	DNS	DNS
40	DNS	DNS	DNS	DNS	DNS
50	DNS	DNS	DNS	DNS	DNS
60	DNS	DNS	DNS	DNS	DNS


Part 4B
Speed (rad/s)
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
Torque (Nm)
40V 5Hz
80V 10Hz
200V 25Hz
400V, 50hz
560V 70Hz

Simulation of Filter Networks

Part 1 – Design of a 3rd order LP Butterworth Filter

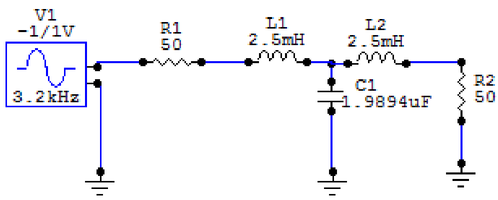
The table gives element values of 1.00, 2.00 and 1.00 for a 3rd order Butterworth Filter. Since we want to place the filters 3dB point at 3.2kHz, we have to apply appropriate scaling to our elements. This gives us the following values for our inductors and capacitors.

$$L_1 = \frac{50L_p}{2\pi(3200)} = \frac{50(1.00)}{2\pi(3200)} = 2.5mH$$

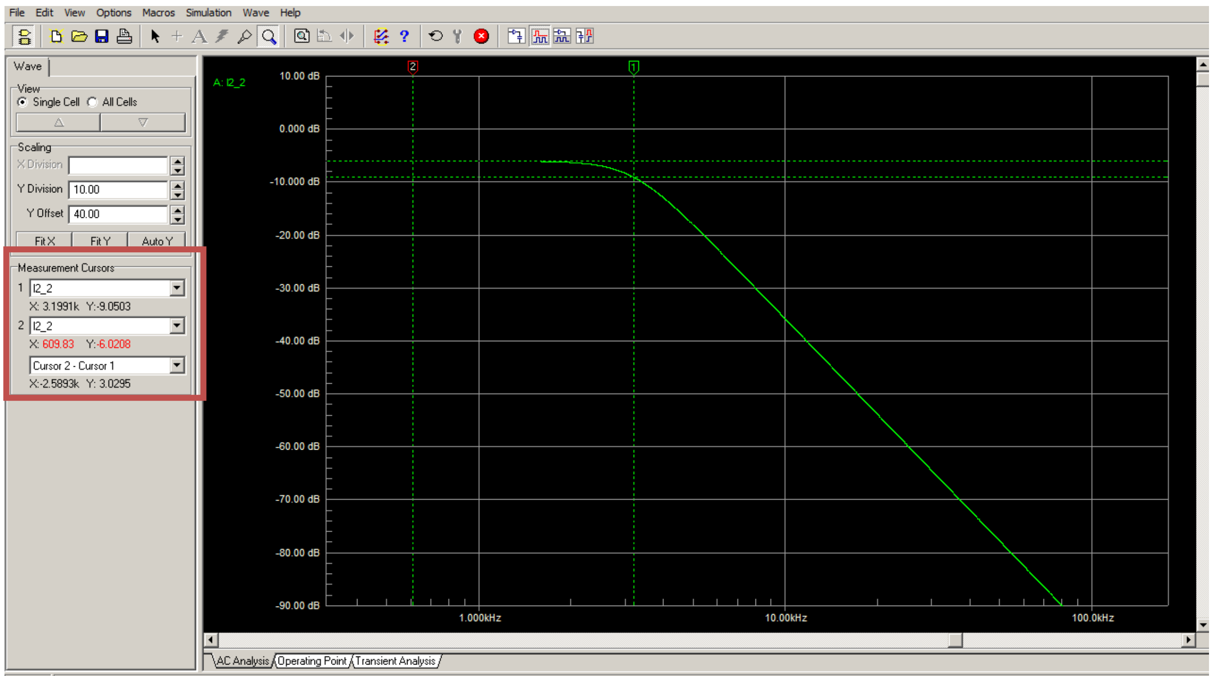
$$C_2 = \frac{C_p}{50(3200)(2\pi)} = \frac{(2.00)}{50(3200)(2\pi)} = 1.9894uF$$

$$L_3 = \frac{50L_p}{2\pi(3200)} = \frac{50(1.00)}{2\pi(3200)} = 2.5mH$$

These values are summed up by the circuit diagram below.



Performing an AC sweep on the circuit via Circuitmaker, we get the following Bode plot.



We see that the 3dB point of our circuit occurs around the 3.2kHz frequency.

Part 2 – Designing a 5th order Chebyshev Lowpass Filter

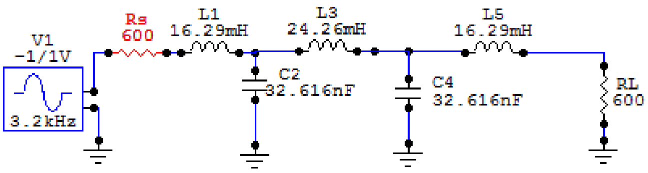
From the table, we obtain the following values for a 5th order Chebyshev filter with a 0.5dB ripple.

n=5	1.7058	1.2296	2.5408	1.2296	1.7058

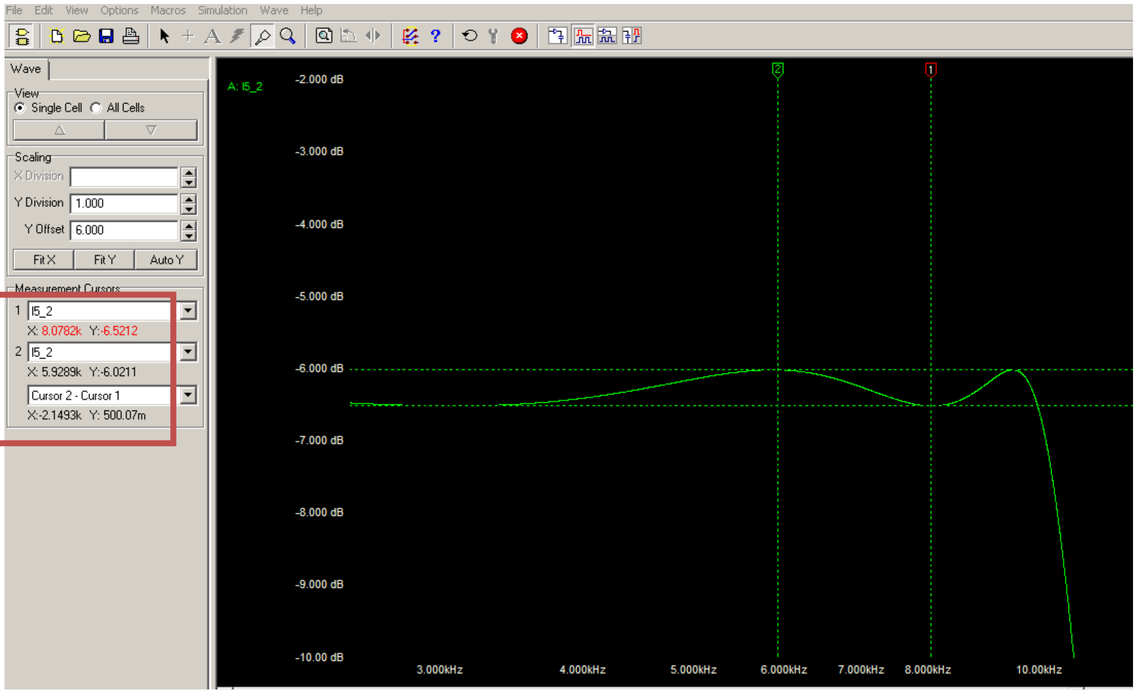
As with the Butterworth filter, these normalized values would have to be scaled appropriately to put the corner frequency at 10kHz.

$$L_1 = \frac{600L_p}{2\pi(10000)} = \frac{600(1.7058)}{2\pi(10000)} = 16.29mH$$
$$C_2 = \frac{C_p}{600(10000)(2\pi)} = \frac{(1.2296)}{600(10000)(2\pi)} = 32.616nF$$
$$L_3 = \frac{600L_p}{2\pi(10000)} = \frac{600(2.5408)}{2\pi(10000)} = 24.26mH$$
$$C_4 = \frac{C_p}{600(10000)(2\pi)} = \frac{(1.2296)}{600(10000)(2\pi)} = 32.616nF$$
$$L_5 = \frac{600L_p}{2\pi(10000)} = \frac{600(1.7058)}{2\pi(10000)} = 16.29mH$$

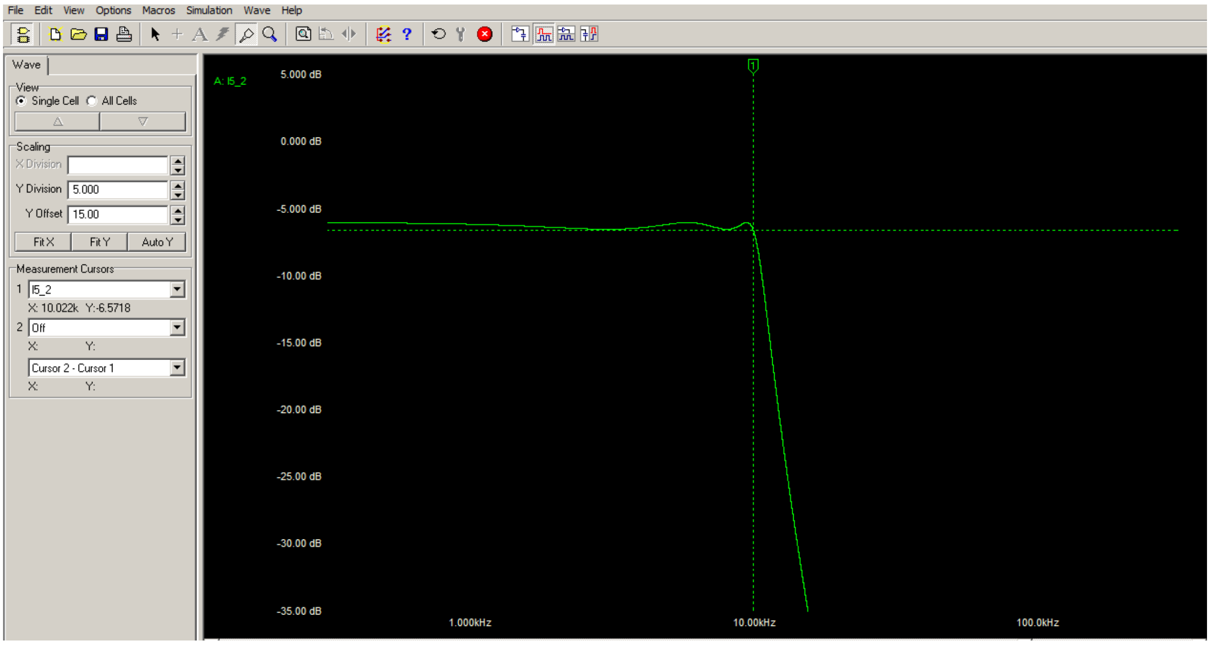
Therefore, the circuit for our filter would be the following:



Performing an AC sweep on the circuit via Circuitmaker, we get the following Bode plot showing the Ripple magnitude of our circuit.



The corner frequency of our filter is shown in the plot below.



Part 2 – Designing a 5th order Butterworth Lowpass Filter

From the table, we obtain the following values for a 5th order Chebyshev filter with a 0.5dB ripple.

n=5	0.618	1.618	2.000	1.618	0.618

To achieve a -3dB point at our corner frequency of 108MHz, the passive components should be scaled appropriately.

$$L_1 = \frac{50L_p}{2\pi(108M)} = \frac{50(0.618)}{2\pi(108M)} = 45.536nH$$

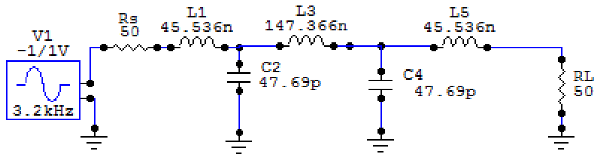
$$C_2 = \frac{C_p}{50(108M)(2\pi)} = \frac{(1.618)}{50(108M)(2\pi)} = 47.69nF$$

$$L_3 = \frac{50L_p}{2\pi(108M)} = \frac{50(2.0)}{2\pi(108M)} = 147.366nH$$

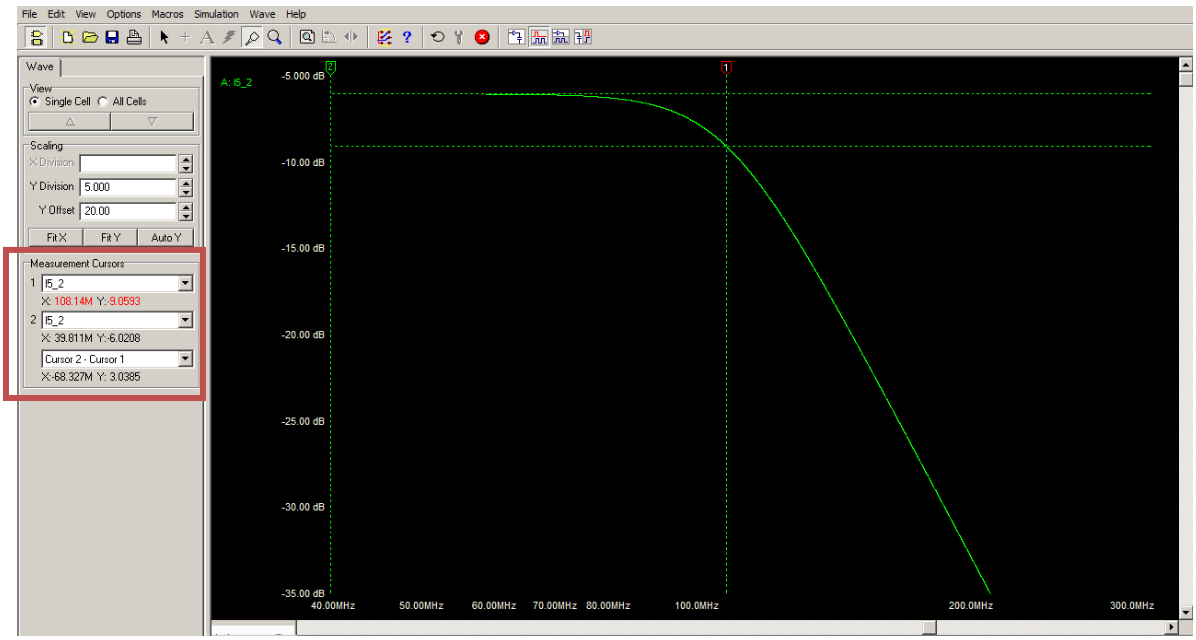
$$C_4 = \frac{C_p}{50(108M)(2\pi)} = \frac{(1.618)}{50(108M)(2\pi)} = 47.69nF$$

$$L_5 = \frac{50L_p}{2\pi(108M)} = \frac{50(0.618)}{2\pi(108M)} = 45.536nH$$

The circuit for the filter is the following:



The frequency characteristics for the circuit are given by the following frequency sweep.



Reference List

Williams, A.B. and Taylors, Fred, J. (1988) Electronic Filter Design Handbook. New York: McGraw-Hill.

Gottlieb, I.M. (1994) Electric Motors & Control Techniques. 2nd ed. TAB Books.