RTDSP Week 10 Homework

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1 Design a lowpass IIR filter

1.1 specifications

- sampling frequency $f_s = 8kHz$
- passband cutoff frequency $\Omega_p = 2kHz$
- stopband cutoff frequency $\Omega_s = 2.5kHz$
- passband ripple $\delta_p = 1dB$
- stopband attenuation $1 - \delta_s = 60dB$

MatLab filter designer tool can be activated with command "filterDesigner".

1.2 Butterworth filter

Designer generated a 19th order filter, converted into 10 biquad sections.

Table 1: Butterworth filter SOS Matrix with Scale Values

| stage	b_0	b_1	b_2	a_0	a_1	a_2	scale value
01	1	2	1	1	0.06566729782500881074103205037 3178208247	0.84752869182663104208330651090 363971889	0.47829899741290998749221330399 4503803551
02	1	2	1	1	0.05708255041825958248091765767 6400267519	0.60599953391428706961363559457 8227028251	0.41577052108313666822780874099 4078107178
03	1	2	1	1	0.05072393558555217396577319277 6396172121	0.42710191313800927037647170436 6849735379	0.36945646218089034373832646451 77405327 56
04	1	2	1	1	0.04596309072318885413643840820 4412553459	0.29315704602940945155964413970 650639385	0.33478003418814961111849015651 3871625066
05	1	2	1	1	0.04239286775575004662108824504 6848896891	0.19270995003135343859312911263 2595933974	0.30877570444677582273129701206 9262564182
06	1	2	1	1	0.03974335758896956755092944035 8231659047	0.11816681799236347649717515650 9911175817	0.28947754389533325580785572128 661442548
07	1	2	1	1	0.03783381296507688784647172042 2414364293	0.06444238288059273012109429146 2213732302	0.27556904896141737326686893538 8629324734
08	1	2	1	1	0.03654427156933125891979941002 3188102059	0.02816154284531288687354333433 1770893186	0.26617645360366104512195306597 2775220871
09	1	2	1	1	0.03579859567658911362331153327 4318207987	0.00718218702781375610555425481 6070169909	0.26074519567610071613117384003 9991773665
10	1	1	0	1	0.01777727486732793085733028703 9985705633	0	0.50888863743366385961053310893 4760093689
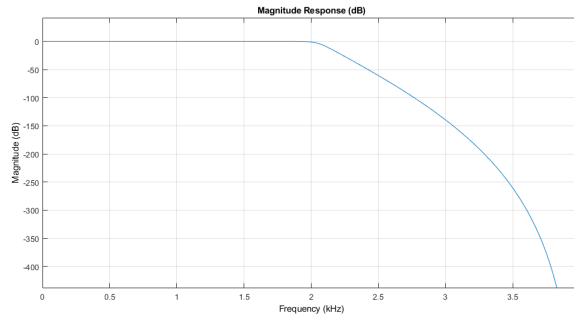
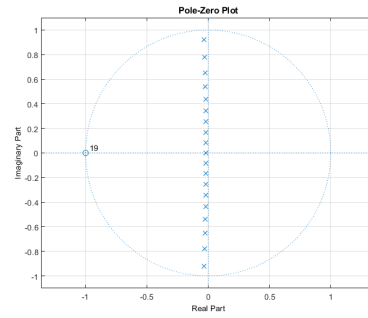Figure 1: Butterworth Magnitude Response
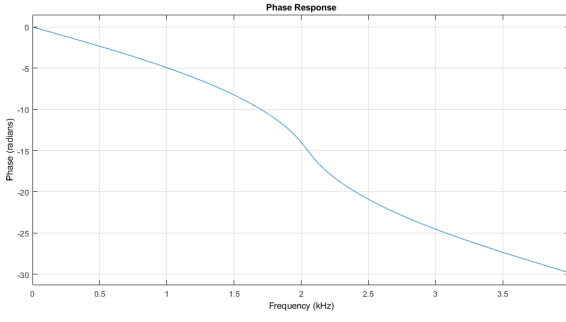

Figure 2: Butterworth Pole-Zero Plot

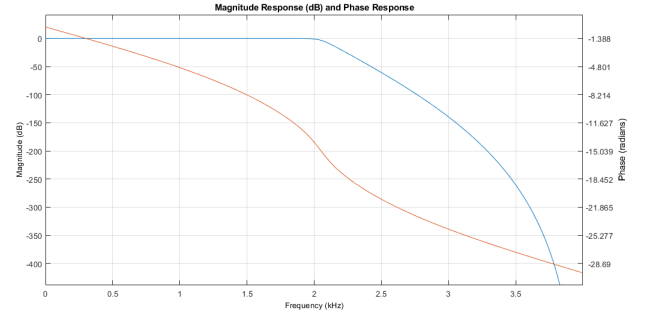Figure 3: Butterworth Phase Response

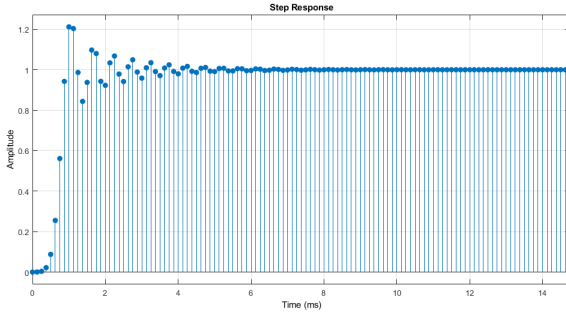Figure 4: Butterworth Magnitude and Phase Response

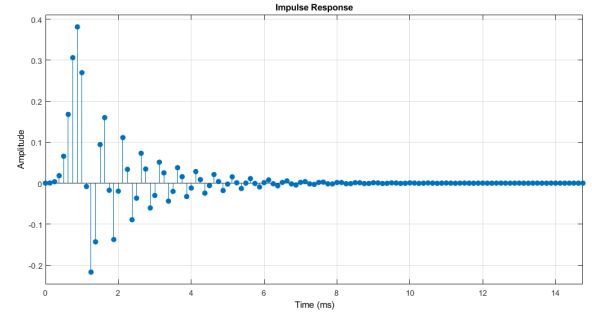Figure 5: Butterworth Step Response

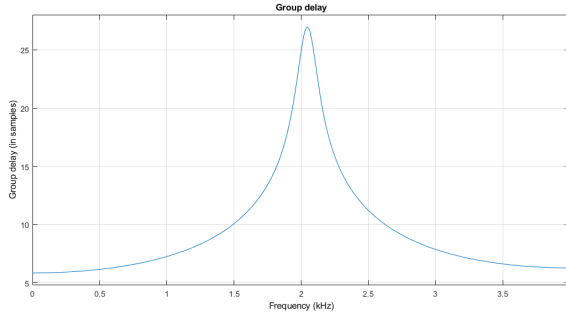Figure 6: Butterworth Impulse Response
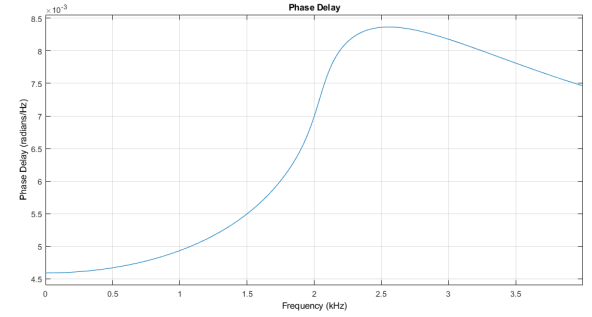

Figure 7: Butterworth Group Delay

Figure 8: Butterworth Phase Delay

1.3 Chebyshev Type II filter

Designer generated a 9th order filter, converted into 5 biquad sections.

Table 2: Chebyshev Type II filter SOS Matrix with Scale Values

| stage	b_0	b_1	b_2	a_0	a_1	a_2	scale value
01	1	0.79134644552604482825586273975204676389	1	1	0.16085676891008904298985271452693266567	0.78575206601309821596858686838345459476113	0.6973727098774147314941274089505897225
02	1	0.99659806905118930586695569218136370182	1	1	0.22225937376313051330178893749689450487	0.46521902469040332661620595899876207113	0.5631313775049715530940375174395740032
03	1	1.3770445894043270573803283696179278194	1	1	0.32362720427270869061331381999480072408	0.24054004712333035276294879167835460975	0.4631763691553568151881847825279692187
04	1	1.8014639316239964283994368088315241038	1	1	0.41286266368546831184715983908972702920	0.09933653966588645856106154496956150978	0.39779391059626306725860445112630259245
05	1	1	0	1	0.22412310651970071551097873907565372064	0	0.61206155325985034387770156172337010502

3
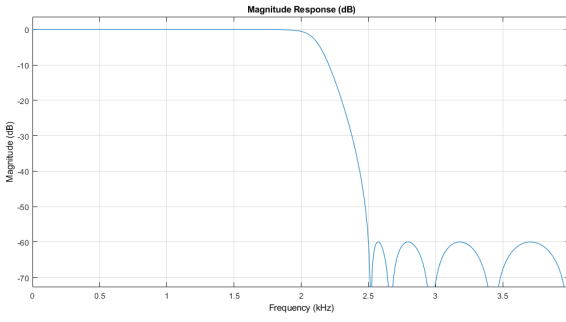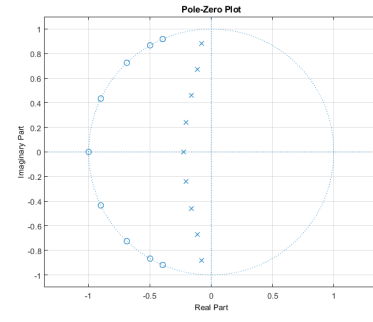
Figure 9: Chebyshev II Magnitude Response

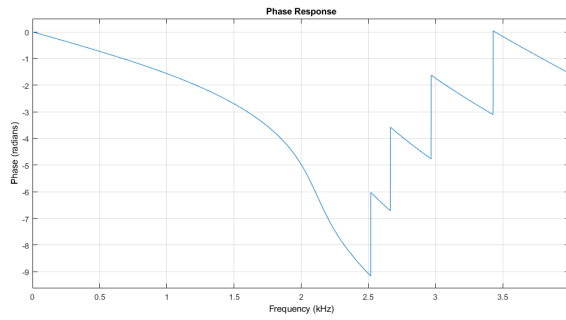Figure 10: Chebyshev II Pole-Zero Plot

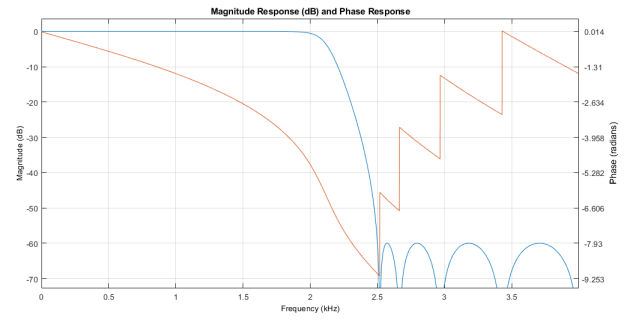Figure 11: Chebyshev II Phase Response

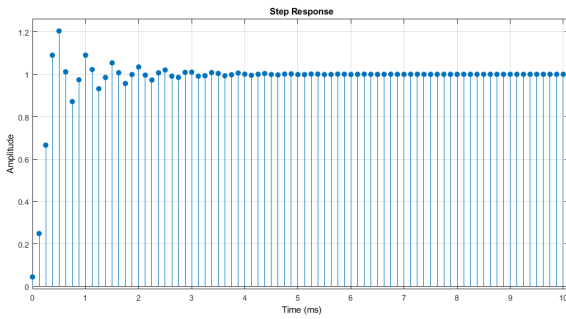Figure 12: Chebyshev II Magnitude and Phase Response

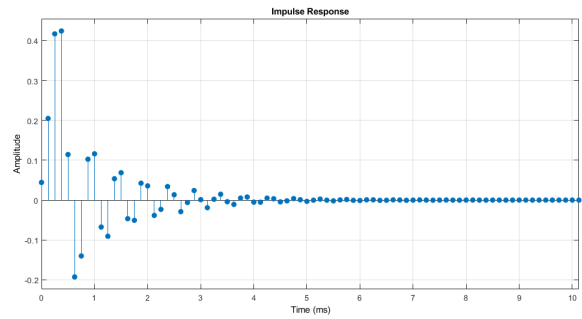Figure 13: Chebyshev II Step Response

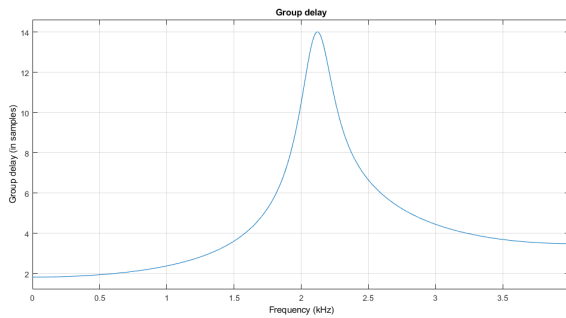Figure 14: Chebyshev II Impulse Response
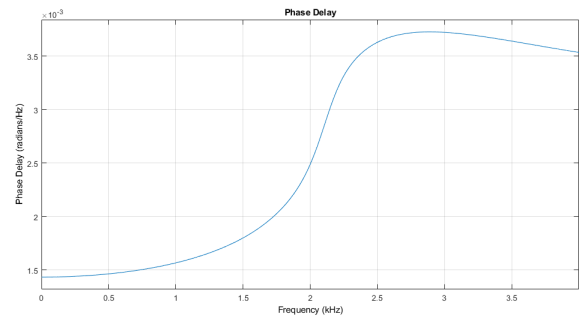

Figure 15: Chebyshev II Group Delay

Figure 16: Chebyshev II Phase Delay

1.4 Elliptic filter

Designer generated a 6th order filter, converted into 3 biquad sections.

Table 3: Elliptic filter SOS Matrix with Scale Values

| stage	b_0	b_1	b_2	a_0	a_1	a_2	scale value
01	1	1.0026439794980208652930286916671320796011	1	1	-0.3390558493838707332379556191881420090791	0.6982727922287973454373855020094197243451	0.9594200584710349533068551863834727555511
02	1	1.798927466167703048682824373827315866947	1	1	-0.9492666882848023179874985544302035123111	0.3703316003040151294101178791606798768041	2.556431085694567784116770781110972166061
03	1	0.615981808299446154109091366990469396114	1	1	-0.0037801673350602448160640012275734989091	0.9210674865110901610165683450759388506411	0.0133623420771176344701292038052997668271
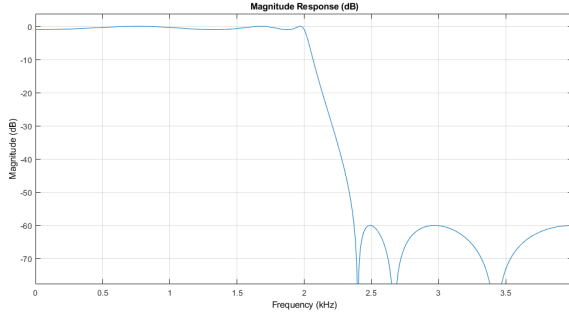
Figure 17: Elliptic Magnitude Response
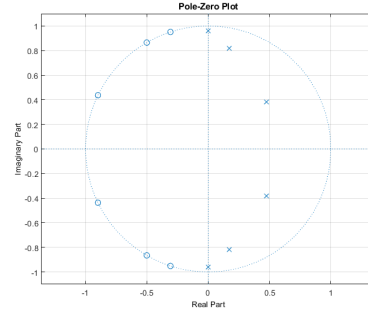
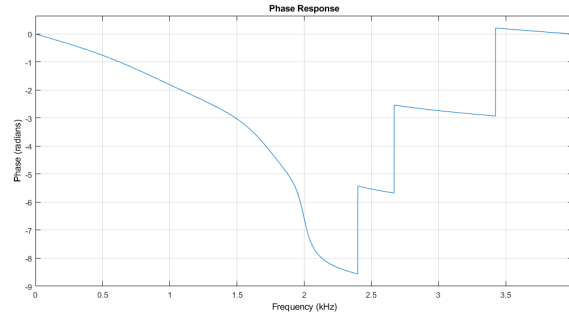Figure 18: Elliptic Pole-Zero Plot

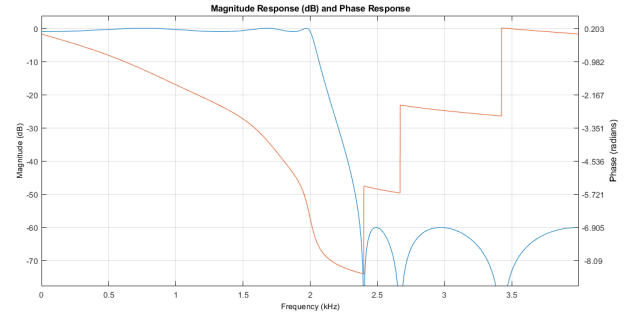Figure 19: Elliptic Phase Response

Figure 20: Elliptic Magnitude and Phase Response
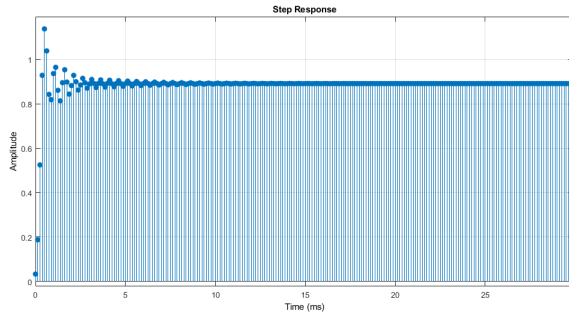

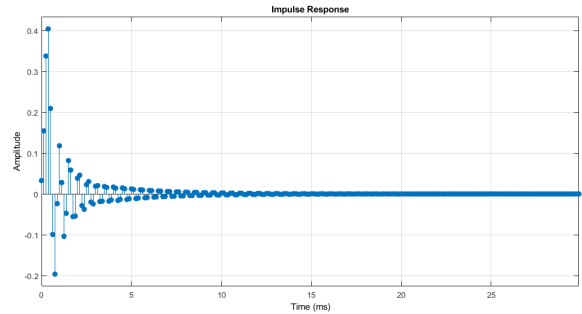Figure 21: Elliptic Step Response

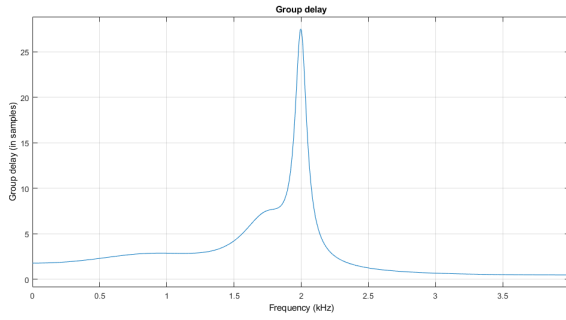
Figure 22: Elliptic Impulse Response
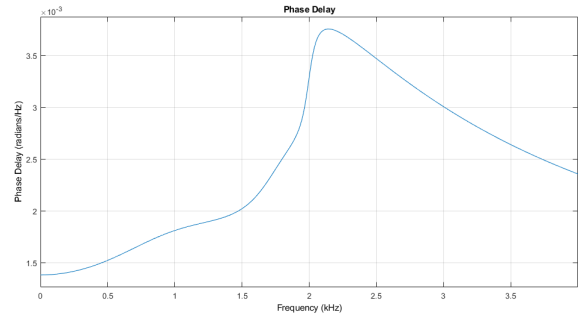
Figure 23: Elliptic Group Delay

Figure 24: Elliptic Phase Delay

1.5 Bessel filter

Since Filter Designer in MatLab doesn't have the option to design Bessel filter, I used my own code to try to design a Bessel filter that satisfies the requirements. My code is available at `https://github.com/belongtothenight/RTDSP_Code/blob/main/src/w10_bessel.m`.
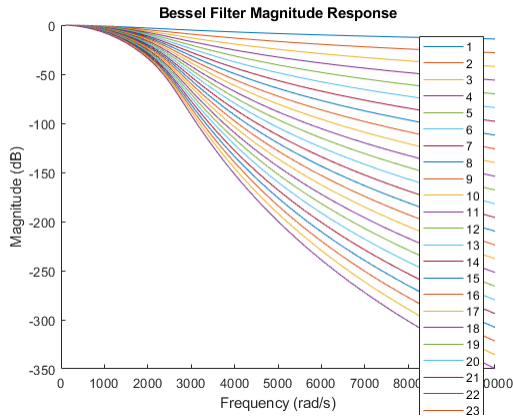

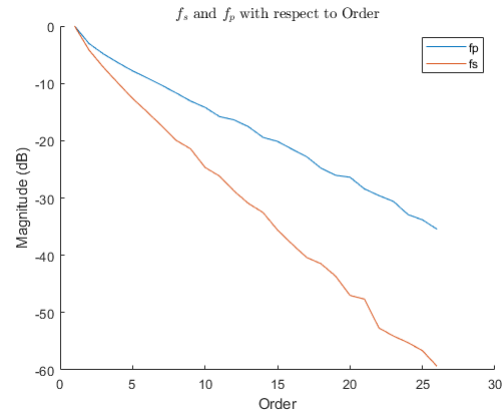Figure 25: Bessel filter Magnitude Response with different orders

Figure 26: f_s and f_p with different orders

From figure 25, we can see that as the filter order increases, the magnitude response decrease faster. From figure 26, we can see that as the filter order increases, the f_s and f_p both decrease.

However, since MatLab limits the maximum order of Bessel filter to 25, I can't design a Bessel filter that satisfies the requirements. Also, the magnitude response at f_p drops way too fast as the order increases, so I don't think Bessel filter is a good choice for this problem.