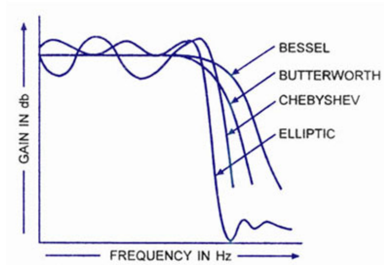
EE 419 - Project 10
Optimal FIR and Alternative IIR Filter Designs With Matlab



Frequency Response Curve

Names: Aiku Shintani & Chris Adams **Lab Date: 3/5/19**

Bench #: 9 **Section: 2**

1) [Matlab] FIR vs. IIR Filter Design Comparison

Filter Design Specifications:

Filter Order: *As needed to meet specs*

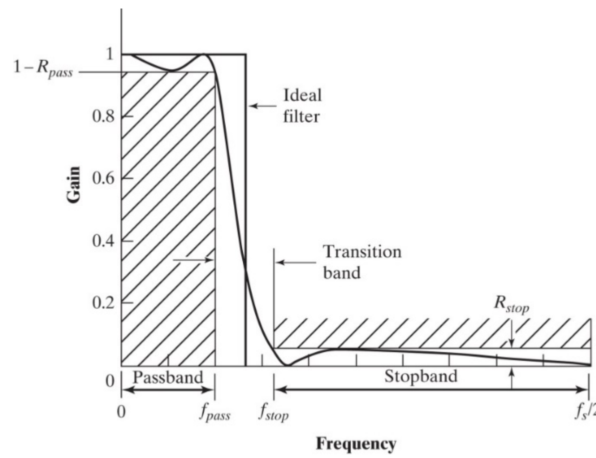
Real Filter Coefficients

Maximum Ripples: δ_p (R_{pass}) = δ_s (R_{stop}) = 0.013

Passband Edge Frequency: F_{pass} = 0.1333 cyc/sample

Stopband Edge Frequency: F_{stop} = 0.2667 cyc/sample

Transition Bandwidth: ΔF_T = 0.1333 cyc/sample



Alternative Filter Designs to be designed, evaluated, and compared are:

a) FIR Parks-McClellan
b) IIR Butterworth Filter
c) IIR Chebyshev Type 1 Filter
d) IIR Chebyshev Type 2 Filter
e) IIR Elliptical Filter

Matlab Filter Design Commands

a) **Listing of the Matlab commands** used to create each design. (Analysis steps do not need to be shown).

```
%% Part 1 Optimal FIR Design Via Parks-McClellan
[N, Fo, Ao, W] = firpmord([0.1333, 0.2667], [1 0], [0.013, 0.013], 1);
b = firpm(N, Fo, Ao, W);
[poles, zeros, HF, Fd, hn, n] = show_filter_response([1], b, 1e3, 100e3, 40, 1);
```

```
%% Part 2 Butterworth
[n, Wn] = buttord(0.1333*2, 0.2667*2, 0.1137, 37.721);
[butter_b, butter_a] = butter(n,Wn);
[poles, zeros, HF, Fd, hn, n] = show_filter_response(butter_a, butter_b, 1e3,
100e3, 40, 1);


%% Part 3 Chebyshev 1
[N, Wp] = cheb1ord(0.1333*2, 0.2667*2, 0.1137, 37.721);
[cheb1_b, cheb1_a] = cheby1(N, 0.1137, Wp);
[poles, zeros, HF, Fd, hn, n] = show_filter_response(cheb1_a, cheb1_b, 1e3, 100e3,
40, 1);

%% Part 4 Chebyshev 2
[N, Ws] = cheb2ord(0.1333*2, 0.2667*2, 0.1137, 37.721);
[cheb2_b, cheb2_a] = cheby2(N, 37.721, Ws);
[poles, zeros, HF, Fd, hn, n] = show_filter_response(cheb2_a, cheb2_b, 1e3, 100e3,
40, 1);

%% Part 5 Elliptical
[N, Wp] = ellipord(0.1333*2, 0.2667*2, 0.1137, 37.721);
[ellip_b, ellip_a] = ellip(N, 0.1137, 37.721, Wp);
[poles, zeros, HF, Fd, hn, n] = show_filter_response(ellip_a, ellip_b, 1e3, 100e3,
40, 1);
```

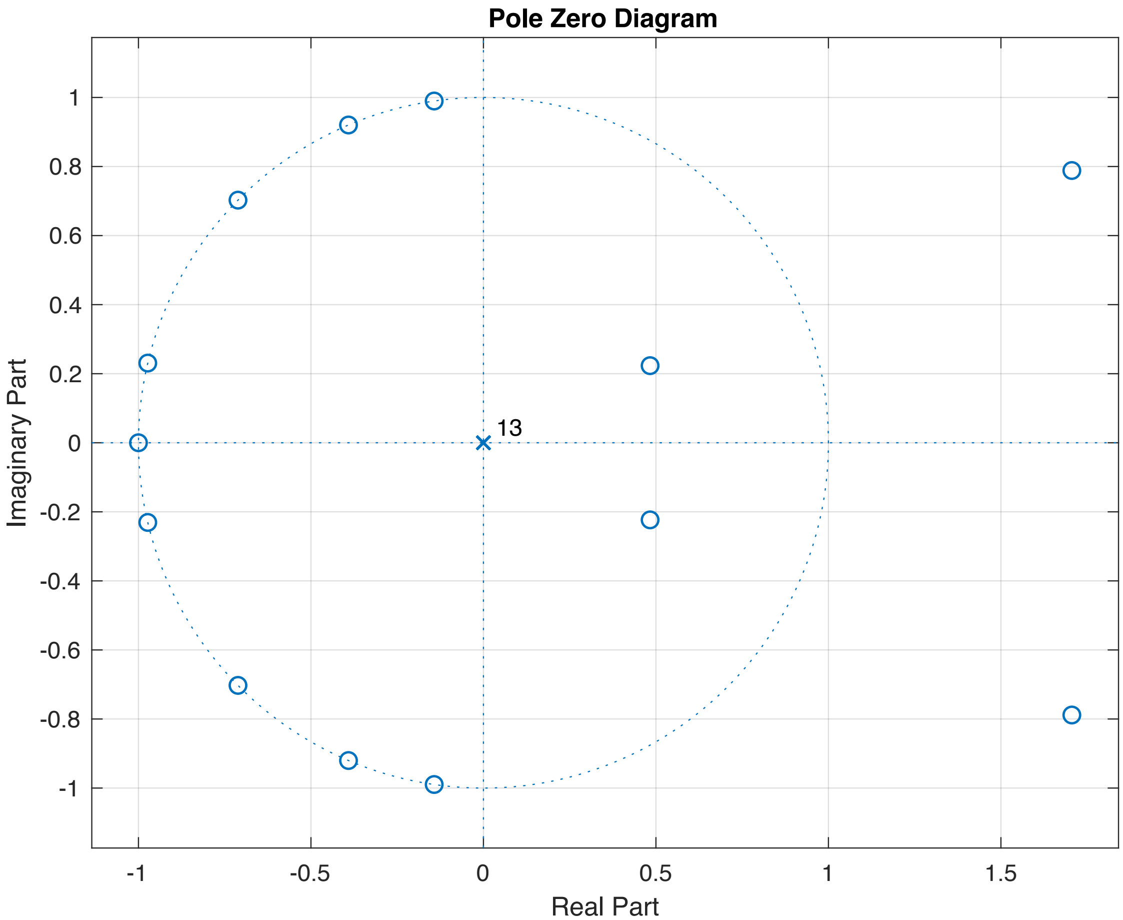
b) Filter Design Results: (assuming a Direct-Form 1 implementation with a single section for all filters).

Filter Coeff	FIR Parks-McClellan	Filter Coeff	IIR – Butterworth	IIR – Chebyshev 1	IIR – Chebyshev 2	IIR – Elliptical
B_0	0.0166	B_0	0.002	0.0026	0.0732	0.0435
B_1	0.0176	B_1	0.0143	0.0131	0.1781	0.0372
B_2	-0.0276	B_2	0.043	0.0263	0.2766	0.0715
B_3	-0.0646	B_3	0.0717	0.0263	0.2766	0.0372
B_4	-0.0000499	B_4	0.0717	0.0131	0.1781	0.0435
B_5	0.1927	B_5	0.043	0.0026	0.0732	
B_6	0.3715	B_6	0.0143			
B_7	0.3715	B_7	0.002			
B_8	0.1927	B_8	N/A			
B_9	-0.0000499	B_9	N/A			
B_{10}	-0.0646					
B_{11}	-0.0276	A_0	1.0	1.0	1.0	1.0
B_{12}	0.0176	A_1	-2.186	-2.9028	-0.73	-2.0364
B_{13}	0.0166	A_2	2.794	4.0054	0.9615	2.1095
B_{14}	N/A	A_3	-2.152	-3.0849	-0.2389	-1.0796
B_{15}	N/A	A_4	1.0981	1.3105	0.1115	0.2423
B_{16}	N/A	A_5	-0.3546	-0.2441	-0.0034	
B_{17}	N/A	A_6	0.0673			
B_{18}	N/A	A_7	-0.0057			
		A_8				
A_0	1.0	A_9				
Minimum # of Multiplies Needed	6	Minimum # of Multiplies Needed	11	8	8	7

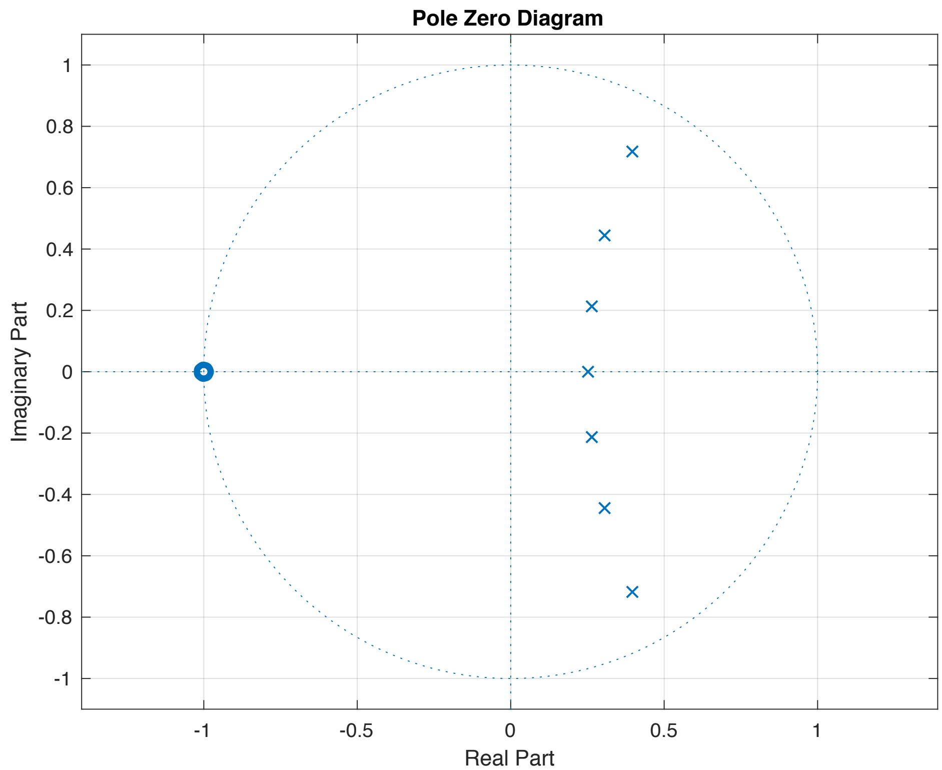
Table 1 – Filter Difference Equation Coefficients
(Fill in only those blocks needed for your filter designs)

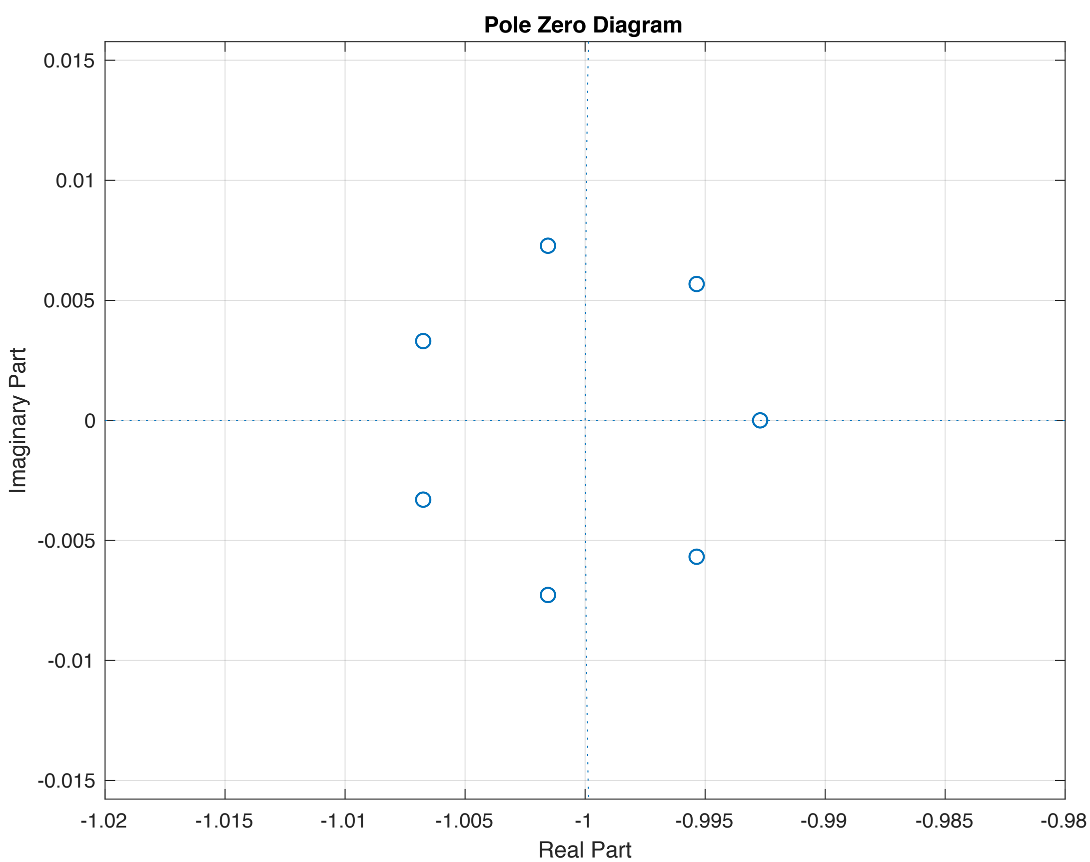
c) Pole-Zero Plots for each design (individual plot for each design).

Optimal FIR – Parks McClellan Design

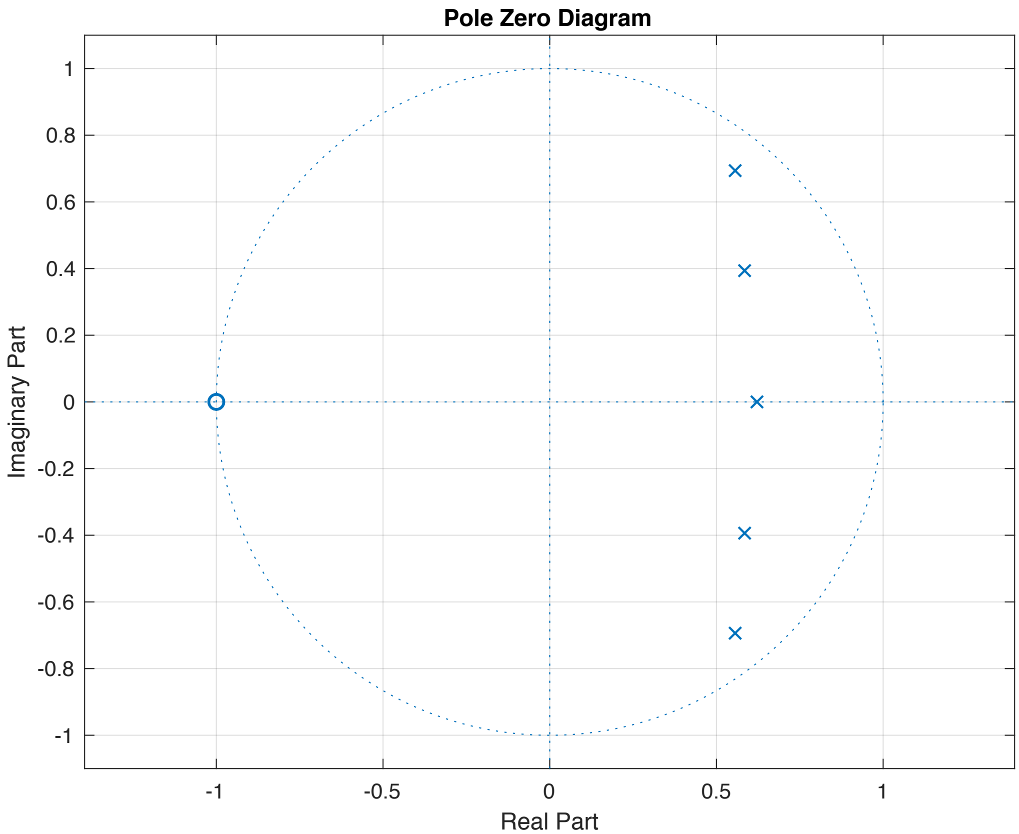


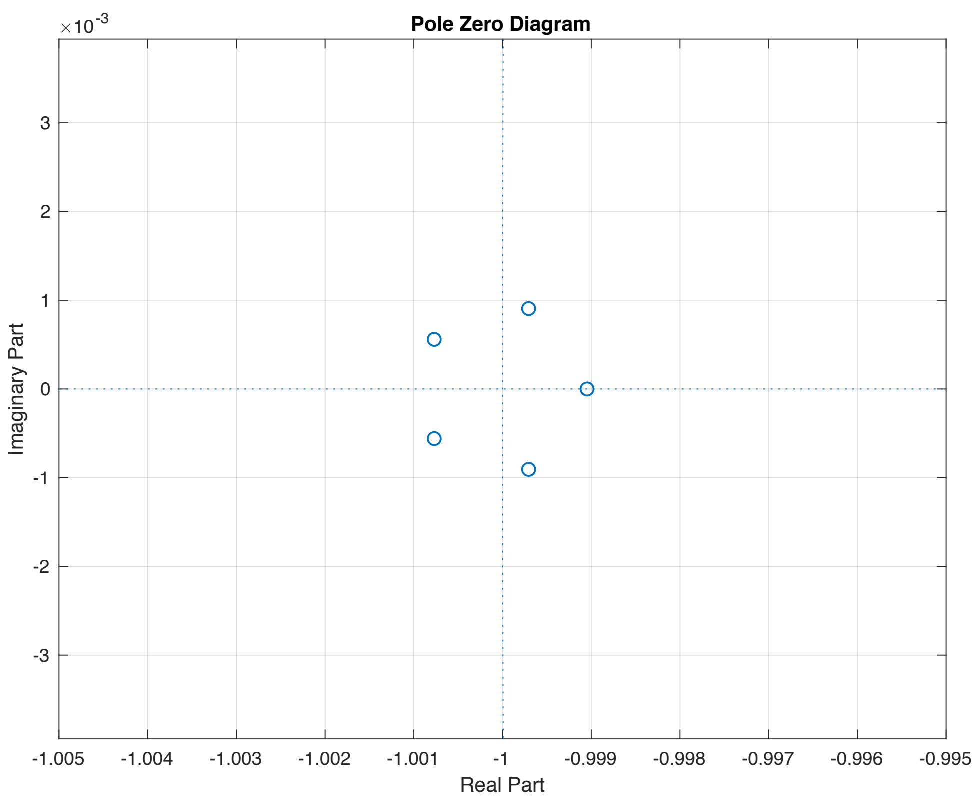
IIR – Butterworth Design



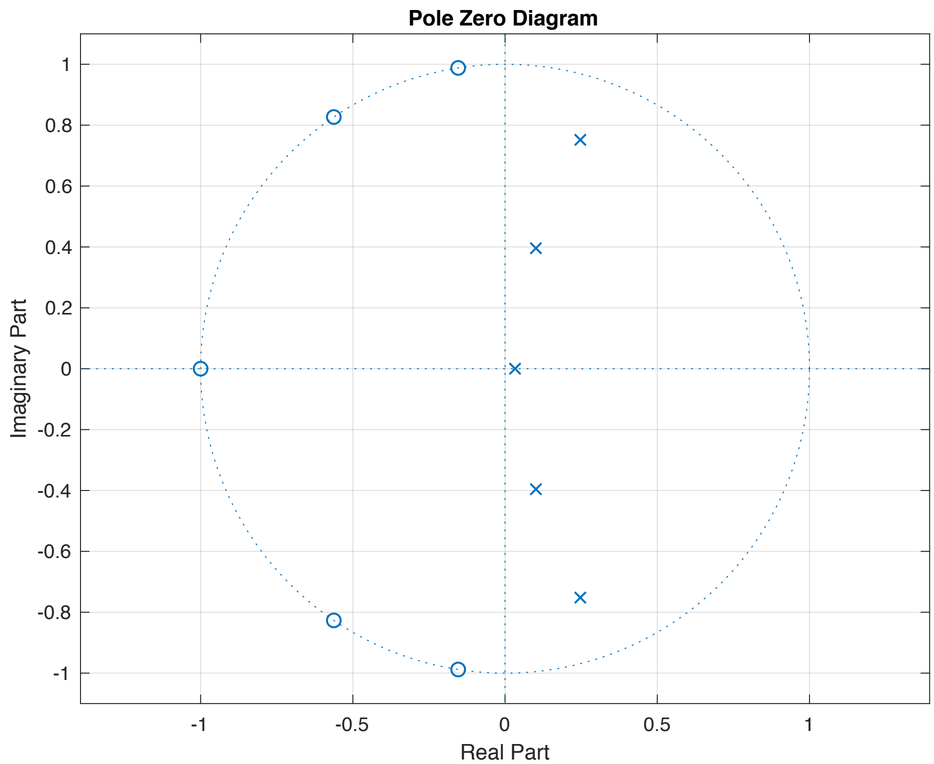


IIR – Chebyshev Type 1 Design

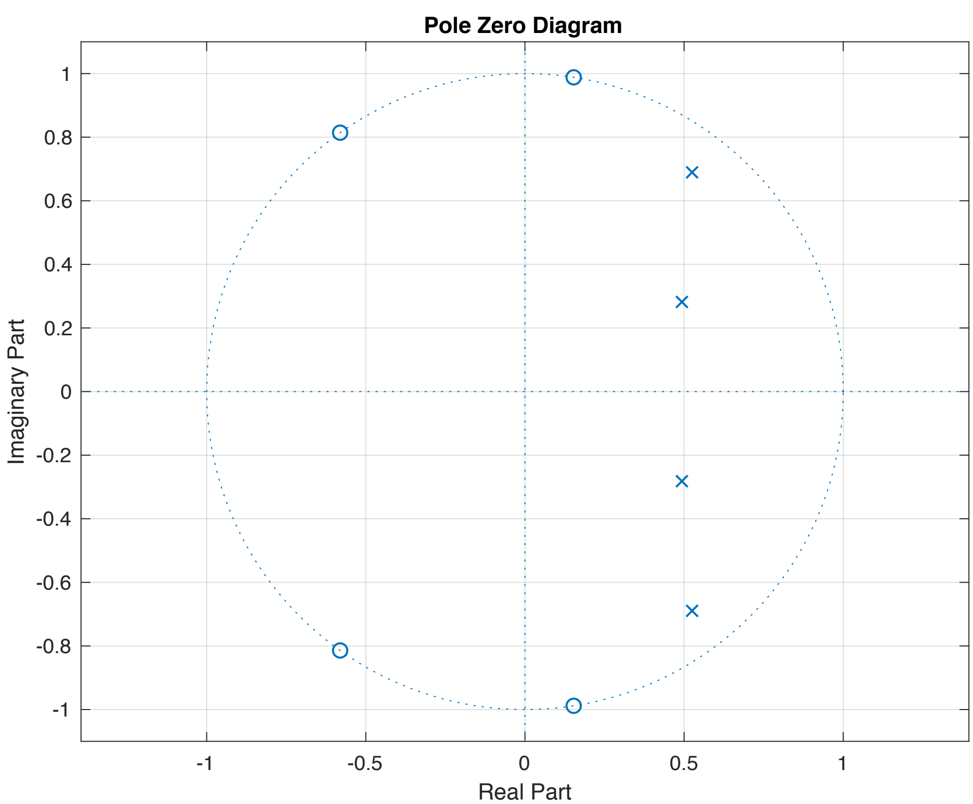




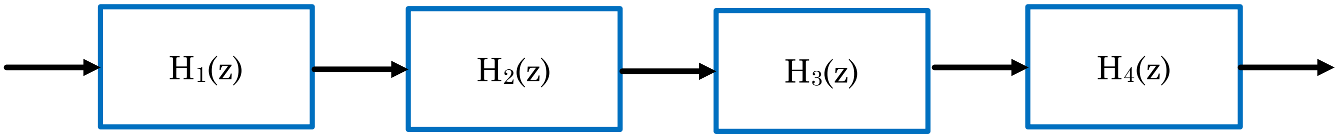
IIR – Chebyshev Type 2 Design



IIR – Elliptical Design



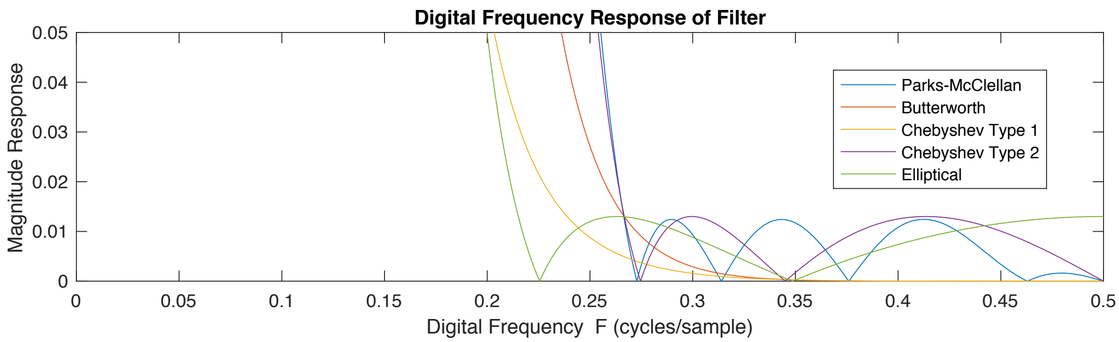
Label the poles and zeros in the Pole/Zero diagrams for the IIR filters with the 2nd–order section number that they would be assigned to in a cascade 2nd-order implementation.

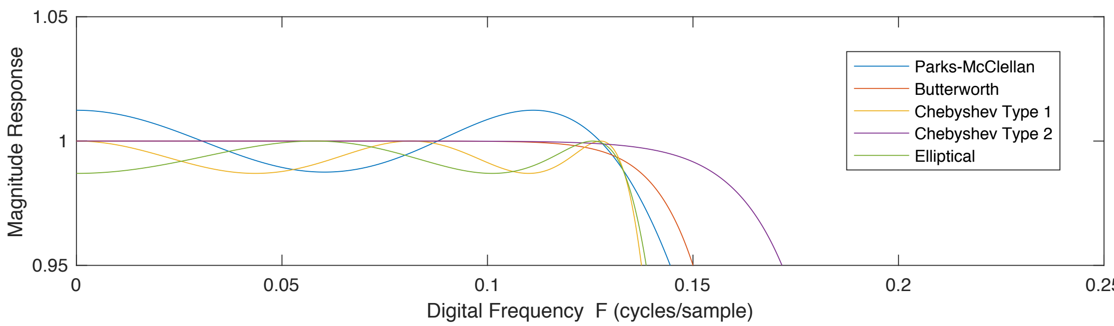


d) **Two <u>Composite</u> Magnitude Response Plots using a linear magnitude scale**

i. full frequency range and details of the stop band ripple

ii. passband ripple details

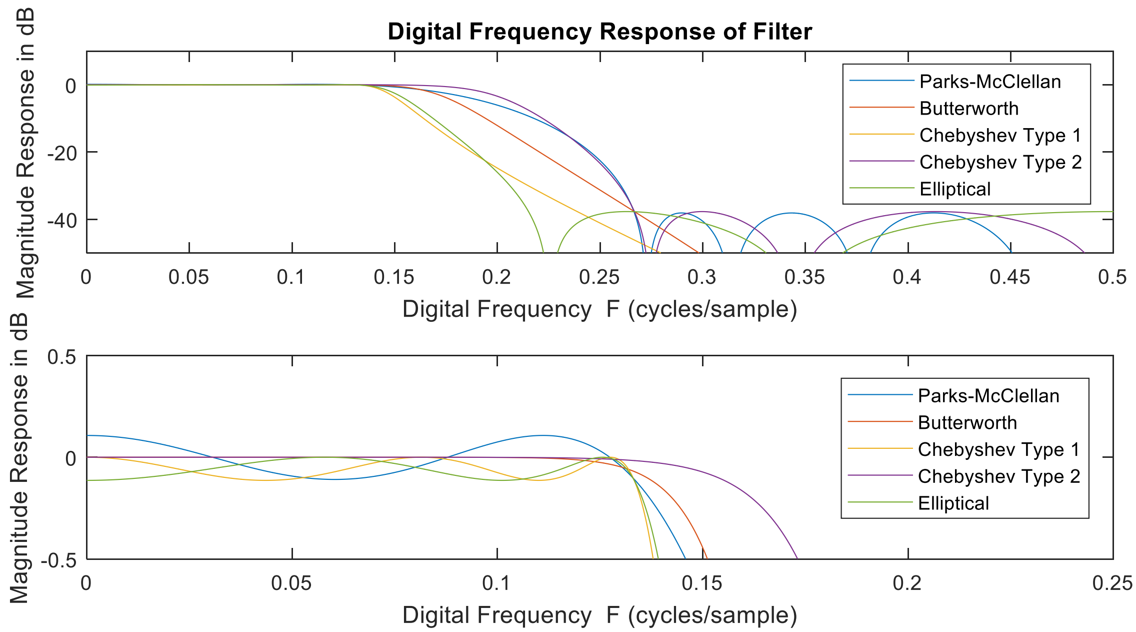




e) Two <u>Composite</u> Magnitude Response Plots using a dB magnitude scale

i. full frequency range and details of the stop band ripple

ii. passband ripple details



f) **Complete Table 2 (below) with the resulting performance for each filter design.**

Design Method	Filter Order	Maximum Passband Attenuation Ap (dB) $\lvert H\rvert_{max}/(1-\delta_{pmax})$ @F < F_p	Passband Ripple δp @F_p=.133	Stopband Ripple δs @F_s=.267	Minimum Stopband Attenuation As (dB) $\lvert H\rvert_{max}/(\delta_{s\,max})$ @F > F_s	Passband Edge Freq. Fp (cyc/spl) @|H|=1-δ_p (δ_p=.013)	Stopband Edge Freq. Fs (cyc/spl) @|H|=δ_s (δs=.013)	Transition Band Width ΔF_T (cyc/spl)
Specification	-	FIR: 0.226 IIR: 0.114	.0130	.0130	FIR: 37.8 IIR: 37.7	.133	.267	.133
FIR Parks-McClellan	13	0.109	0.0125	0.0124	38.12	0.133	0.267	0.133
IIR Butterworth	7	0.069	0.0077	0.013	37.84	0.133	0.267	0.133
IIR Chebyshev 1	5	0.113	0.013	0.005	46.27	0.133	0.267	0.133
IIR Chebyshev 2	5	0.0157	0.0018	0.013	37.72	0.133	0.267	0.133
IIR Elliptical	4	0.114	0.013	0.013	37.72	0.133	0.216	0.083

Table 2 – Filter Performance Comparison

Analysis Questions:

1) **Based on the pole/zero locations, which IIR filter type do you think would be more susceptible to arithmetic overflow problems when implemented with scaled integer filter coefficients in cascaded 2^{nd} order sections? Explain your reasoning.**

   The Chebyshev type I will be the most susceptible to arithmetic overflow because it has poles closest to the unit circle and zeros furthest away from the poles. Therefore, the 2^{nd} order sections should have the most gain and therefore more potential for overflow.

2) **Conclusions (in words) of your comparison between filter types (optimal FIR, Butterworth IIR, Chebyshev 1 & 2 IIR, Elliptical IIR).** Identify relative differences in the performance of each approach, and discuss the tradeoffs involved in selecting each filter type. Consider the filter lengths, specifications achieved, and phase characteristics of each filter design.

   Overall, the Parks-McClellan optimal FIR performs very well in comparison to the IIR filters (similar transition, ripple and attenuation). However, it can only accomplish these specs with a much higher order than the IIR filters (13 vs. 7, 5 and 4). The benefit is that it will always be stable after quantization and will have linear phase and the tradeoff is that it will require more hardware to implement. The Butterworth is the filter of the next highest order but has very good ripple in both the passband and stopband. Both Chebyshev 1 and 2 perform well with all specs with type 1 having practically no ripple in the stopband and type 2 having no ripple in the passband. Depending on whether you care about less ripple in the stop or passband should influence you to pick one of the two types. Finally, the Elliptical filter achieves the specs with the lowest order and the fastest transition band. However, it sacrifices ripple and has the worst stop and passband attenuation of the filters.

Project Conclusions:

Summarize at least two learnings about IIR Filter Design that this project helped you understand better. Also describe any particular challenges that you had to overcome, and at least one suggestion for improvement of this lab in the future.

Name: Aiku Shintani

Conclusions: Through the course of this project, trade-offs for different IIR filter design implementations were studied. At first, an FIR filter was implemented via the Parks-McClellan method; this filter served as a baseline for comparison of performances between IIR filters. The Butterworth, Chebyshev Type I and Type II, and Elliptical IIR filters were implemented via Matlab functions which effectively transform ideal analog filters into optimized digital ones. Understanding the theory behind the analog (s domain) to digital (z domain) transformation was critical to understanding how and why the filters are able to achieve the desired response. The Butterworth filter gives the smoothest transition between pass and stop bands, the Chebyshev Type I filter gives the smallest passband ripple, the Chebyshev Type II filter gives the smallest stopband ripple, and the Elliptical filter gives the narrowest transition width (for a given filter order).

It is clear that when deciding which digital filter to implement, multiple design constraints must be considered. Each of the filters have their pros and cons and it is up to the design engineer to understand these and choose the filter with the best balance. In the future, it may help to offer some comments on how the filter order can reasonably be increased or decreased. The Matlab functions hide a lot of details and I believe this may provide more intuition.

Name: Chris Adams

Conclusions: From this project, a better understanding of the tradeoffs and advantages between well-known IIR filter implementations were better understood. Furthermore, a deeper understanding to how pole-zero placement maps to a filter response was achieved. Comparing the best FIR design to common IIR designs proved that while the FIR filter performed within specs, a much higher order filter is required. The IIR filters all had their own advantages and tradeoffs. Butterworth had the highest order with overall good ripple and transition. Chebyshev I had great stopband attenuation while the Chebyshev II had great passband ripple. Lastly, the elliptical filter had the quickest transition and the lowest order but had the worst ripple all together. Clearly there are certain situation in which one filter implementation is better suited for the application than the others and this lab helped to see that.

Sometimes it was a bit confusing to implement the IIR filters through a couple commands because you don’t know what the functions are doing. But, due to simplicity, it worked out after playing with the inputs a bit. Since this experiment is rather short, in future experiments, I think it would be beneficial to explore more IIR filter types and compare them.