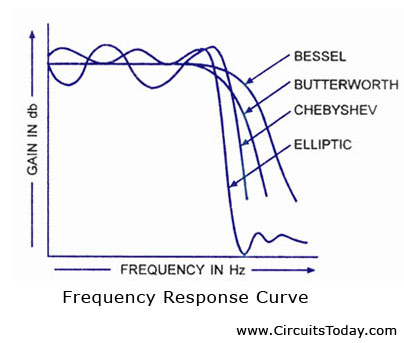
EE 419 - Project 10

Optimal FIR and Alternative IIR Filter Designs With Matlab

[](http://www.google.com/url?sa=i&rct=j&q=&esrc=s&frm=1&source=images&cd=&cad=rja&docid=KG1ioWE1mJ2yZM&tbnid=EjKGMs5pH2lEAM:&ved=0CAUQjRw&url=http://www.circuitstoday.com/active-filter-types&ei=VfwyUaDEJcXmiwLQn4HQCw&bvm=bv.43148975,d.cGE&psig=AFQjCNFnKSEXOOJ_JdrwCLxyeYKdq689fw&ust=1362382248744025)

|  |  |
| --- | --- |
| **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:p (*Rpass*) = s (*Rstop*) = 0.013  Passband Edge Frequency: *Fpass* = 0.1333 cyc/sample  Stopband Edge Frequency: *Fstop* = 0.2667 cyc/sample  Transition Bandwidth: FT = 0.1333 cyc/sample | FG_06_014.jpg |

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

1. FIR Parks-McClellan
2. IIR Butterworth Filter
3. IIR Chebyshev Type 1 Filter
4. IIR Chebyshev Type 2 Filter
5. IIR Elliptical Filter

**Matlab Filter Design Commands**

1. **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);

1. **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** |
| **B0** | **0.0166** | **B0** | **0.002** | **0.0026** | **0.0732** | **0.0435** |
| **B1** | **0.0176** | **B1** | **0.0143** | **0.0131** | **0.1781** | **0.0372** |
| **B2** | **-0.0276** | **B2** | **0.043** | **0.0263** | **0.2766** | **0.0715** |
| **B3** | **-0.0646** | **B3** | **0.0717** | **0.0263** | **0.2766** | **0.0372** |
| **B4** | **-0.0000499** | **B4** | **0.0717** | **0.0131** | **0.1781** | **0.0435** |
| **B5** | **0.1927** | **B5** | **0.043** | **0.0026** | **0.0732** |  |
| **B6** | **0.3715** | **B6** | **0.0143** |  |  |  |
| **B7** | **0.3715** | **B7** | **0.002** |  |  |  |
| **B8** | **0.1927** | **B8** | **N/A** |  |  |  |
| **B9** | **-0.0000499** | **B9** | **N/A** |  |  |  |
| **B10** | **-0.0646** |  |  |  |  |  |
| **B11** | **-0.0276** | **A0** | **1.0** | **1.0** | **1.0** | **1.0** |
| **B12** | **0.0176** | **A1** | **-2.186** | **-2.9028** | **-0.73** | **-2.0364** |
| **B13** | **0.0166** | **A2** | **2.794** | **4.0054** | **0.9615** | **2.1095** |
| **B14** | **N/A** | **A3** | **-2.152** | **-3.0849** | **-0.2389** | **-1.0796** |
| **B15** | **N/A** | **A4** | **1.0981** | **1.3105** | **0.1115** | **0.2423** |
| **B16** | **N/A** | **A5** | **-0.3546** | **-0.2441** | **-0.0034** |  |
| **B17** | **N/A** | **A6** | **0.0673** |  |  |  |
| **B18** | **N/A** | **A7** | **-0.0057** |  |  |  |
|  |  | **A8** |  |  |  |  |
| **A0** | **1.0** | **A9** |  |  |  |  |
| **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)*

1. **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.**

H1(z)

H2(z)

H3(z)

H4(z)

1. **Two Composite Magnitude Response Plots using a linear magnitude scale**
   1. full frequency range and details of the stop band ripple
   2. passband ripple details

**

1. **Two Composite Magnitude Response Plots using a dB magnitude scale** 
   1. full frequency range and details of the stop band ripple
   2. passband ripple details

****

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

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Design Method** | **Filter**  **Order** | **Maximum**  **Passband Attenuation**  **Ap (dB)**  |H|max /(1-pmax)  @F < Fp | **Passband Ripple**  **p**  @Fp=.133 | **Stopband Ripple**  **s**  @Fs=.267 | **Minimum**  **Stopband Attenuation**  **As (dB)**  |H|max/(s max)  @F > Fs | **Passband**  **Edge Freq. Fp**  **(cyc/spl)**  @|H|=1-p (p=.013) | **Stopband**  **Edge Freq. Fs**  **(cyc/spl)**  @|H|=s (s=.013) | **Transition**  **Band**  **Width**  **FT**  **(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 2nd 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 2nd order sections should have the most gain and therefore more potential for overflow.**

1. **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.