In-Lecture Assignment #1 on March 2, 2020

Design of a bandstop IIR filter to relieve symptoms of tinnitus ("ringing of the ears").

This assignment relates to parts (a) and (b) of homework problem 3.3.

Here are the bandstop filter specifications for your design:

- For frequencies 0 Hz to $0.6 f_c$, passband ripple should be no greater than 1 dB.
- For frequencies $(2/3) f_c$ to $(4/3) f_c$, stopband attenuation should be at least 80 dB.
- For frequencies above $1.4 f_c$, passband ripple should be no greater than 1 dB

Please use a tinnitus frequency f_c of 3000 Hz and a sampling rate f_s of 44100 Hz.

Use the filter design and analysis tool (fdatool) or filter designer in Matlab.

(a) Use the Elliptic (equiripple) design method to design an IIR filter to meet the specification.

1. Give the filter order. **20** How many biquads? **10 biquads in cascade.**

2. Are all of the poles inside the unit circle for bound-input bounded-output (BIBO) stability? **Yes. Fdatool indicates that the design is BIBO stable. Also, one can plot the poles and zeros to show that the poles are inside the unit circle.**

3. Describe the pole-zero plot and connect poles/zeros to filter passbands/stopbands. **Angles of the poles near the unit circle indicate passband frequencies; angles of zeros on/near the unit circle indicate stopband frequencies.**

4. Give the minimum and maximum value of group delay over 0-1 kHz. **10 & 21 samples.**

5. At what frequency does the peak group delay value occur? **Maximum values of group delay are at the edges of the passband, i.e. at 1.8 kHz and 4.2 kHz**

(b) Convert the IIR filter structure to be a single direct form section. In fdatool, this accomplished via the "Convert to a Single Section" under the Edit menu.

1. Are any poles outside the unit circle? **Yes.** If so, how many? **4** Why? **Poly expansion.**

$$H(z) = C \frac{(1 - z_0 z^{-1})(1 - z_1 z^{-1})}{(1 - p_0 z^{-1})(1 - p_1 z^{-1})} = C \frac{1 - (z_0 + z_1)z^{-1} + z_0 z_1 z^{-2}}{1 - (p_0 + p_1)z^{-1} + p_0 p_1 z^{-2}}$$

When converting the transfer function from factored form (cascade of biquads) to unfactored form (direct form), each multiplication and addition involving the poles is converted back to the original precision of the poles, which causes loss of accuracy in the feedback coefficients and perturbs the pole locations. Four poles move outside the unit circle to indicate a BIBO unstable filter.

2. Describe any differences in the magnitude response vs. part (a). **As shown below on the right, the single section implementation does not the specification in the passband.**
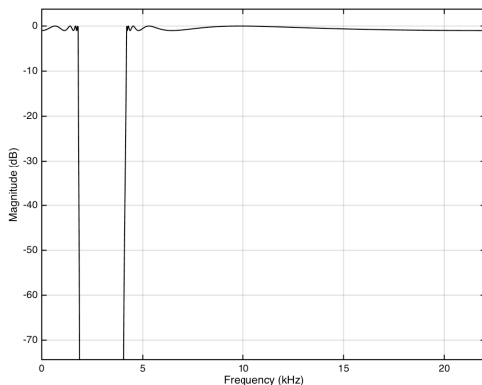
Magnitude Response for the IIR Bandstop Filter as a Cascade of Biquads
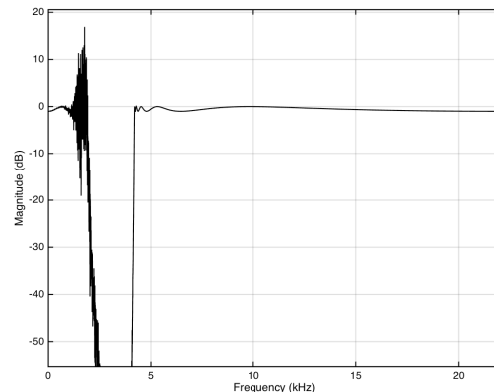
*Magnitude Response for the IIR Bandstop Filter as a Single Section (**Direct Form**)*