

In-Lecture Assignment #2 on Oct. 5, 2020

Design bandstop IIR filter to apply to audio signals before they are played to relieve symptoms of tinnitus (“ringing of the ears”).

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

Here are the bandstop filter specifications for your design:

- From 0 Hz to $0.6 f_c$, passband ripple is not greater than 1 dB.
- From $(2/3) f_c$ to $(4/3) f_c$, stopband attenuation is at least 80 dB.
- Above $1.4 f_c$, passband ripple is not greater than 1 dB

Use tinnitus frequency f_c of 3000 Hz & sampling rate f_s of 44100 Hz.

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

(a) Use elliptic method to design an IIR filter to meet specification.

1. Give the filter order. **20** How many biquads? **10 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 poles near unit circle indicate passband frequencies and angles of zeros on/near unit circle indicate stopband frequencies, provided poles/zeros separated in angle.**
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 passbands, 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.

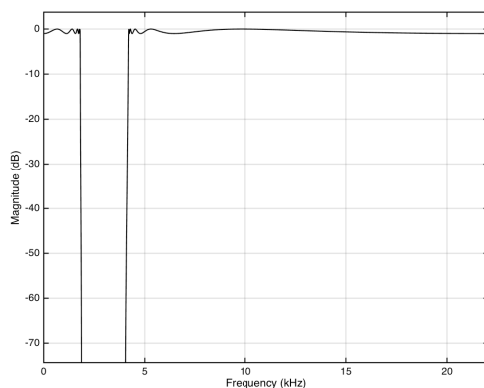
1. Are any poles outside the unit circle? **Yes.** If so, how many? **4** Why? **Poly expansion:**

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

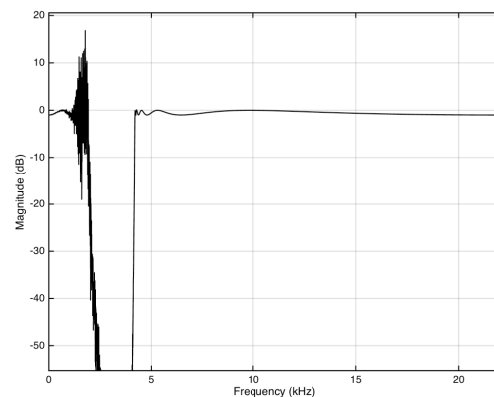
When converting the transfer function from factored form (cascade of biquads) to unfactored form (direct form), each two-argument multiplication and addition involving the poles is converted back to the original precision of the poles, which causes loss of accuracy in the feedback coefficients and perturbs 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 meet 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)

Bandstop selectivity
IIR filter
Elliptic design of pole
and zero locations
Minimum order design
Sampling rate 44100 Hz
 $f_{pass1} = 1800$ Hz
 $f_{stop1} = 2000$ Hz
 $f_{stop2} = 4000$ Hz
 $f_{pass2} = 4200$ Hz
 $A_{pass1} = 1$ dB
 $A_{stop} = 80$ dB
 $A_{pass2} = 1$ dB