Lab 6
Analysis of Shelf Filters

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1 Introduction

Objective

The objective of this lab was to look at shelf filters and apply them to balancing and mixing music signals.

1.1 Filters

Shelf filters alter all frequencies beyond a specific cutoff point. High shelf filters will modify all frequencies above a cutoff and low shelf filters will modify all frequencies below a specific cutoff. This can be used in balancing audio signals where a particular instrument is too loud compared to the rest. In this lab we constructed these filters, looked at their transfer functions, and applied them to various music signals.

2 Main Body

2.1 Low Shelf Filter

We began by constructing a low shelf filter by constructing its transfer function. This was done by matching the coefficients using the gain and ω_c terms. We plotted the poles and zeros of this filter, as well as response for different gain values of $g = 10$ and $g = 0.1$ The plots are shown below.

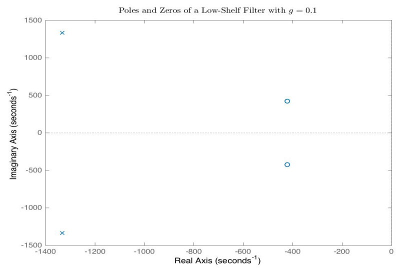

Figure 1: Poles and zeros of a low shelf filter with gain 0.1

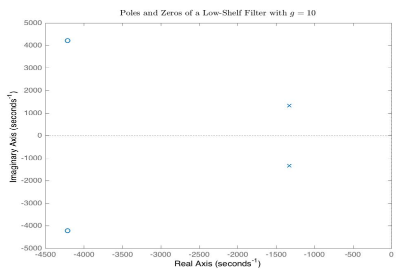

Figure 2: Poles and zeros of a low shelf filter with gain 10

We then plotted the frequency response of both of these cases:

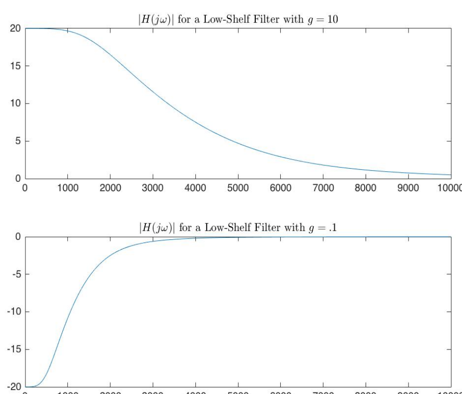

Figure 3: Frequency response of a low shelf filter

Finally, we tested this response by inputing sine waves with different inputs. The plots are given by

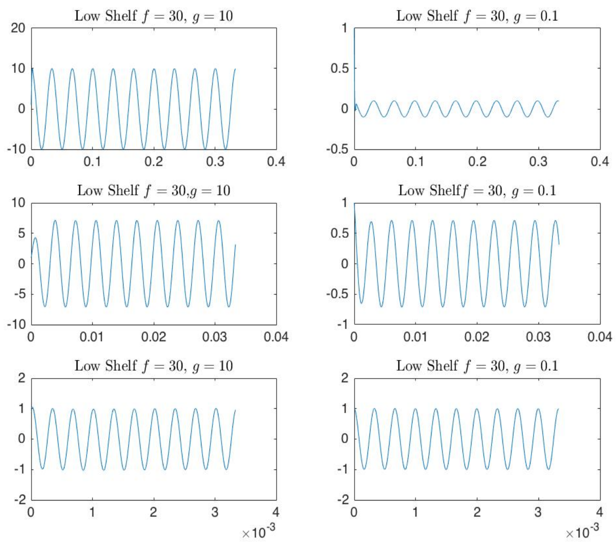

Figure 4: Sine inputs into a low-shelf filter

3 High Shelf Filter

We then repeated the process above for the case of a high shelf filter using the same gain values.

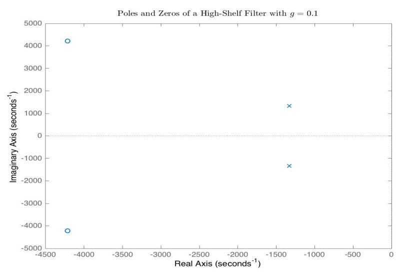

Figure 5: Poles and zeros of a high shelf filter with gain 0.1

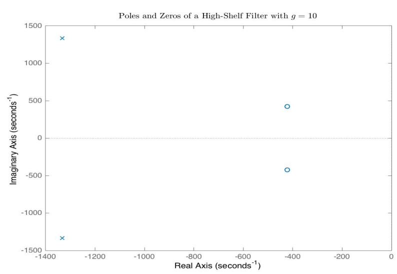

Figure 6: Poles and zeros of a high shelf filter with gain 10

We then plotted the frequency response of both of these cases:

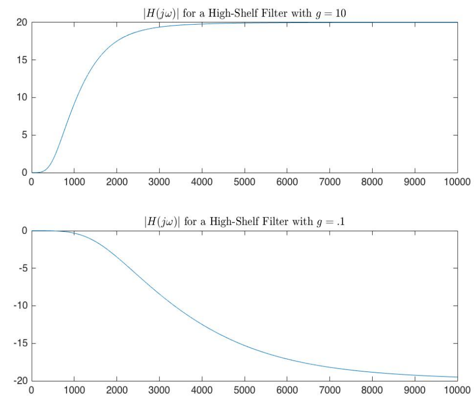

Figure 7: Frequency response of a low shelf filter

Finally, we tested this response by inputing sine waves with different inputs. The plots are given by

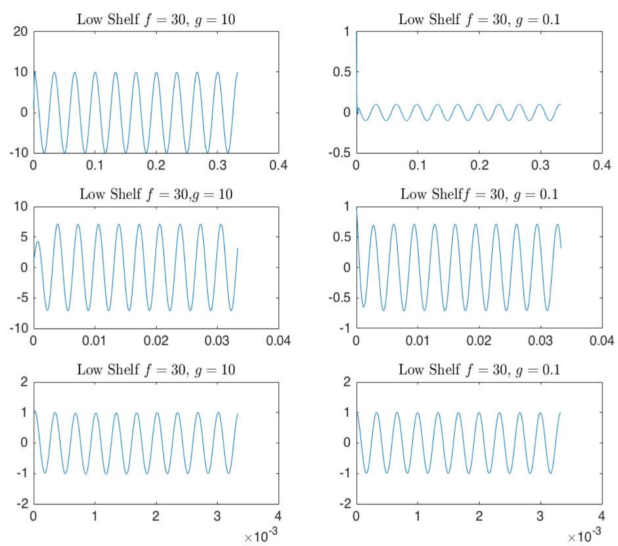

Figure 8: Sine inputs into a high-shelf filter

In this case, we see we get the inverted outputs as with the low shelf case between the $g = 10$ and $g = 0.1$ cases.

4 Music Signals

In this section we used our filter construction algorithm to design filters to alter audio signals. The first signal we looked at was the bass, piano mixture. The spectrogram of this signal is shown below:

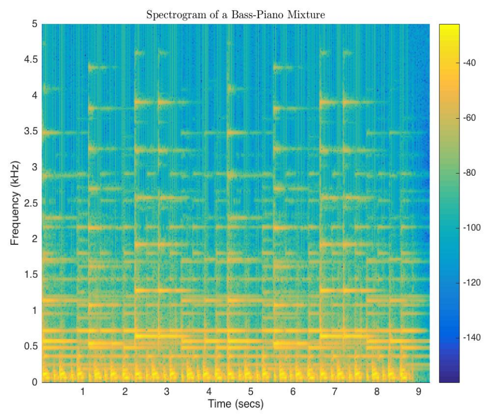

Figure 9: Spectrogram of the unfiltered mixture

We see that from this spectrogram, there is very high power in the low frequency signals. We hear this as the bass in the mixture seems to overpower the piano. In order to compensate for this, we approximated the frequency of the bass to be under 400 Hz. We applied a low shelf filter with a gain of 0.4 to the signal at a radian frequency of $\omega = 2\pi 400$. This reduced the bass in the mixture, as can be heard and seen in the spectrogram.

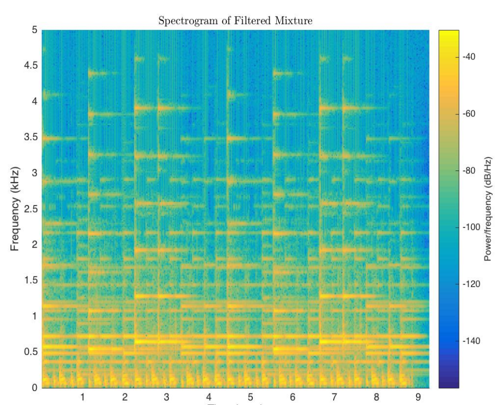

Figure 10: Spectrogram of the filtered mixture

As we can see from the filtered signal, the power of the low frequencies is much lower than initially. This can also be heard audibly using the soundsc command. Finally, we repeated this process for another music signal, which is a C-major chord played arpeggiated, and then simultaneously. Our goal was to reduce the C and E frequencies, and strengthen the G frequency. We did this by using an attenuating low shelf filter with gain 0.01 cutoff frequency at 330 Hz and by passing this output signal into a high shelf filter with gain of 100 with cutoff frequency at 380 Hz. Below are the spectrograms for the original and filtered signal.

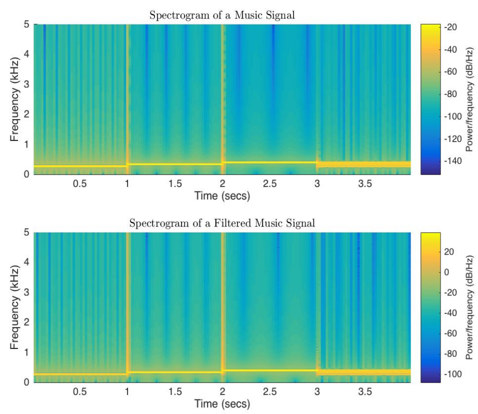

Figure 11: Spectrogram of a filtered and unfiltered music signal

As we can see the spectrogram of the filtered signal has less power in the two lowest frequencies as compared to the higher frequency. This, audibly, was only slightly noticeable despite the extreme choices in gain. This is likely because we are using a non-ideal shelf filter and the choice of cutoff frequency needs to be be distant from the frequency that is actually being amplified. Additionally, the notes that were being altered were very close to each other and there may have been an overlap in the filters.

5 Conclusion

In this lab we looked at shelf filters and applied them to music signals. We tend to see that low shelf filters and high shelf filters have opposing effects, and have frequency response diagrams that reflect this. When applying sinusoids of varying frequencies to these systems we saw, as expected, that in a low shelf filter, the frequencies further below the cutoff were altered, and for the high shelf the frequencies above the cutoff were altered. In the case of music, we were able to use our filter design to alter both music signals, with the case of the piano mixture to be more audibly noticeable than the chord.

6 Appendix

6.1 Lab Code

```
%Part 2: Design of a Low-Shelf Filter
[lnum1, lden1] = design_shelf(10, 2*pi*300,0);
Hls1 = tf(lnum1,lden1);
figure
pzplot(Hls1)
title('Poles and Zeros of a Low-Shelf Filter with $g =
    10$','Interpreter','LaTex')

[lnum2, lden2] = design_shelf(0.1, 2*pi*300,0);
Hls2 = tf(lnum2,lden2);
figure
pzplot(Hls2)
title('Poles and Zeros of a Low-Shelf Filter with $g =
    0.1$','Interpreter','LaTex')

w = linspace(0,10000,100000);

[A1,B1] = freqs(lnum1,lden1,w);
[A2,B2] = freqs(lnum2,lden2,w);

figure
subplot(2,1,1)
plot(B1,20*log10(abs(A1)))
title('$|H(j\omega)|$ for a Low-Shelf Filter with
    $g=10$','Interpreter','LaTex')

subplot(2,1,2)
plot(B2,20*log10(abs(A2)))
title('$|H(j\omega)|$ for a Low-Shelf Filter with
    $g=.1$','Interpreter','LaTex')

%Part 2 High Shelf Filter

[lnum3, lden3] = design_shelf(10,2*pi*300,1);
Hhs1 = tf(lnum3,lden3);
figure
pzplot(Hhs1)
title('Poles and Zeros of a High-Shelf Filter with $g =
    10$','Interpreter','LaTex')

[lnum4, lden4] = design_shelf(0.1, 2*pi*300,1);
Hhs2 = tf(lnum4,lden4);
figure
pzplot(Hhs2)
```

```
title('Poles and Zeros of a High-Shelf Filter with $g =
    0.1$','Interpreter','LaTex')


[A3,B3] = freqs(lnum3,lden3,w);
[A4,B4] = freqs(lnum4,lden4,w);

figure
subplot(2,1,1)
plot(B3,20*log10(abs(A3)))
title('$|H(j\omega)|$ for a High-Shelf Filter with
    $g=10$','Interpreter','LaTex')

subplot(2,1,2)
plot(B4,20*log10(abs(A4)))
title('$|H(j\omega)|$ for a High-Shelf Filter with
    $g=.1$','Interpreter','LaTex')

%Part 2d

t1 = linspace(0,(1/3),10000);
x1 = cos(2*pi*30*t1);

t2 = linspace(0,(10/300),10000);
x2 = cos(2*pi*300*t2);

t3 = linspace(0,(10/3000),10000);
x3 = cos(2*pi*3000*t3);

y11 = lsim(Hls1,x1,t1);
y21 = lsim(Hls1,x2,t2);
y31 = lsim(Hls1,x3,t3);

y12 = lsim(Hls2,x1,t1);
y22 = lsim(Hls2,x2,t2);
y32 = lsim(Hls2,x3,t3);

figure
subplot(3,2,1)
plot(t1,y11)
title('Low Shelf $f = 30$, $g=10$','Interpreter','LaTex')

subplot(3,2,3)
plot(t2,y21)
title('Low Shelf $f = 30$,$g=10$','Interpreter','LaTex')

subplot(3,2,5)
plot(t3,y31)
title('Low Shelf $f = 30$, $g=10$','Interpreter','LaTex')
```

```
subplot(3,2,2)
plot(t1,y12)
title('Low Shelf $f = 30$, $g=0.1$','Interpreter','LaTex')

subplot(3,2,4)
plot(t2,y22)
title('Low Shelf$f = 30$, $g=0.1$','Interpreter','LaTex')

subplot(3,2,6)
plot(t3,y32)
title('Low Shelf $f = 30$, $g=0.1$','Interpreter','LaTex')

u11 = lsim(Hhs1,x1,t1);
u21 = lsim(Hhs1,x2,t2);
u31 = lsim(Hhs1,x3,t3);

u12 = lsim(Hhs2,x1,t1);
u22 = lsim(Hhs2,x2,t2);
u32 = lsim(Hhs2,x3,t3);

figure
subplot(3,2,1)
plot(t1,u11)
title('High Shelf $f = 30$, $g=10$','Interpreter','LaTex')

subplot(3,2,3)
plot(t2,u21)
title('High Shelf $f = 30$,$g=10$','Interpreter','LaTex')

subplot(3,2,5)
plot(t3,u31)
title('High Shelf $f = 30$, $g=10$','Interpreter','LaTex')

subplot(3,2,2)
plot(t1,u12)
title('High Shelf $f = 30$, $g=0.1$','Interpreter','LaTex')

subplot(3,2,4)
plot(t2,u22)
title('High Shelf $f = 30$, $g=0.1$','Interpreter','LaTex')

subplot(3,2,6)
plot(t3,u32)
title('High Shelf $f = 30$, $g=0.1$','Interpreter','LaTex')

%Part 4: Music Equalization

%a
%The sound of the two is combined. The bass is slightly
%dominant in the mixture
```

```
%To improve mixture, I would attenuate the bass by using a high shelf

load('lab6.mat')
figure
win = 512; noverlap = 256; nfft = 512;
spectrogram(mixture2, win, noverlap, nfft, fs, 'yaxis');
colorbar
title('Spectrogram of a Bass-Piano Mixture','Interpreter','LaTex')

%bass is approximately 250 Hz

[num, den] = design_shelf(0.4,2*pi*400,0);


hls = tf(num,den);

maxt = length(mixture2)/fs;
tmix = linspace(0,maxt,92834);
tmix = tmix';

Y = lsim(hls,mixture2,tmix);

figure
spectrogram(Y, win, noverlap, nfft, fs, 'yaxis');
title('Spectrogram of Filtered Mixture','Interpreter','LaTex')

%soundsc(Y,fs)
%This sounds better

%Last Part
%I will use a low shelf and high shelf filter.

[r1, r2] = design_shelf(0.0001,2*pi*330,0);
shelf1 = tf(r1,r2);
[s1,s2] = design_shelf(100,2*pi*380,1);
shelf2=tf(s1,s2);
%This is a C-major chord. I will attenuate the C and E frequencies


tmus = linspace(0,4,40000);

Y1 = lsim(shelf1,music,tmus);
Y2 = lsim(shelf2,Y1,tmus);
soundsc(Y2,fs)

figure
subplot(2,1,1)
spectrogram(music, win, noverlap, nfft, fs, 'yaxis');
title('Spectrogram of a Music Signal','Interpreter','LaTex')
```

```
subplot(2,1,2)
spectrogram(Y2, win, noverlap, nfft, fs, 'yaxis');
title('Spectrogram of a Filtered Music Signal','Interpreter','LaTex')
```

6.2 Filter Function

```
function [A,B] = design_shelf(g,wc,a);
%g: The gain of the system
%wc: The cutoff frequency
%a: A boolean 0/1. 0 indiactes a low shelf and 1 indicates a high shelf
%Output: Two vectors corresponding to the transfer function
%       of a low_shelf filter that meets the spec.
if a ~= 1 & a ~= 0
    error('a must be either 1 or 0!')
elseif a == 0
    A = [1, wc*sqrt(2*g), g*wc^2];
    B = [1, wc*sqrt(2), wc^2];

elseif a==1
    A = [g, wc*sqrt(2*g), wc^2];
    B = [1, wc*sqrt(2), wc^2];
end
```

7 References

Lathi, B. P. Linear Systems and Signals. New York: Oxford UP, 2005. Print.