E3DSB Miniprojekt B

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Contents

1 Introduction

This project investigates the usage of different digital filters as equalizers. The filter types used are Finite Impulse Respones (FIR) and Infinite Impulse Response (IIR) filters.

FIR filters has a finite memory, and only allows an impulse response to affect the system for a FINITE amount of time. IIR filters allows the impulse response to affect the system for an INFINITE amount of time. There are a few key differences between the FIR and IIR. A FIR filter can run on integer math, whereas IIR requires floating point for the calculations not to blow up. An IIR filter requires fewer coefficients, less memory and is generally faster than a FIR filter.

For this project we are asked to divide the filters into five different bands. Generelly speaking the human hearing is between 20 Hz and 20 kHz The five bands are inspired by the Wikipedia article on Audio frequency[1] and are adjusted to fit our range of five bands in the range of 0 Hz to 22 050 Hz. The used values are seen in table 1.

Table 1: The frequency bands filtered out. 22 050 Hz is the upper limit of frequencies for the analyzed music, which is sampled at 44 100 Hz.

Frequency (Hz)	**Description**
0 to 512	Rhythm frequencies.
512 to 2048	Horn like and tinny quality. Regular speach lies here.
2048 to 8192	Labial and fricative sounds.
8192 to 16 384	Sounds of bells and ringing.
16 384 to 22 050	Beyond Brilliance, nebulous sounds approaching and just passing the upper human threshold of hearing.

2 Expectations

First FIR filters for the bands in table 1 are going to be implemented converted into an .mp4 file for listening. It is expected that the implementation of filters will be most easily heard at frequencies from 512 Hz to 8192 Hz. We are going to do a few speed tests. First testing to see how much faster IIR is compared to FIR at comparable output results (not filter order). Then some testing of the impact of filter order on the computation speed of the two filters. A speed test alone does not give the tools to test the two types speed up against each other, as IIR filters can achieve approximately the same effect as a FIR filter with a much lower order, therefore the effect of the order of the filter on the magnitude of the output signal will also be investigated.

[1]https://en.wikipedia.org/wiki/Audio_frequency

3 Analysis

3.1 Original Signal

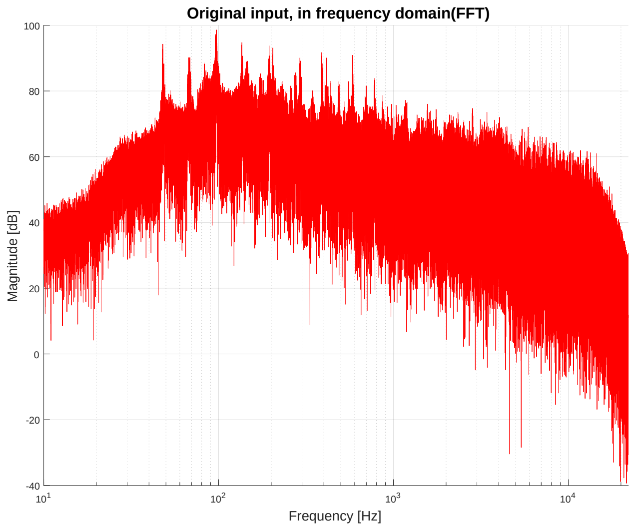

Figure 1: Frequency spectrum of the non-filtered signal.

3.2 Filtered Signals

All frequency bands presented in table 1 will be filtered using FIR. Some of them will also be filtered using IIR to test the expectations presented in section 2.

3.2.1 FIR Frequency Spectrums

The five figs. 2 to 6 demonstrate different kinds of FIR-filtering, which are all implemented using the matlab fir1 function. Figure 2 is a highpass filter with a cutoff frequency of 512 Hz and an order of 70. Figure 3 shows a bandpass with cutoff frequencies of 512 Hz and 2048 Hz and an order of 50. Figure 4 shows a stopband filter with cutoff frquencies of 2048 Hz and 8192 Hz and an order of 50. Figure 5 shows a bandpass filter with cutoff frequencies of 8192 Hz and 16 384 Hz and an order of 50. The last filter, fig. 6 shows a lowpass filter with a cutoff frequency of 16 384 Hz and an order of 5.

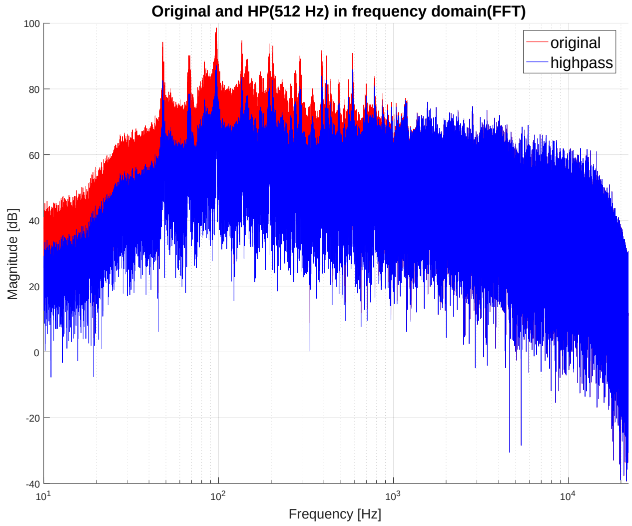

Figure 2: Frequency spectrum of the non-filtered signal(red) and the highpass filtered signal(blue).

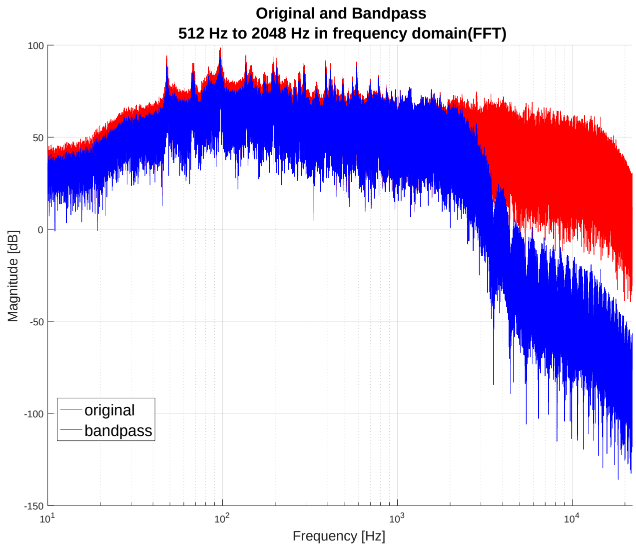

Figure 3: Frequency spectrum of the non-filtered signal(red) and the first bandpass filtered signal(blue).

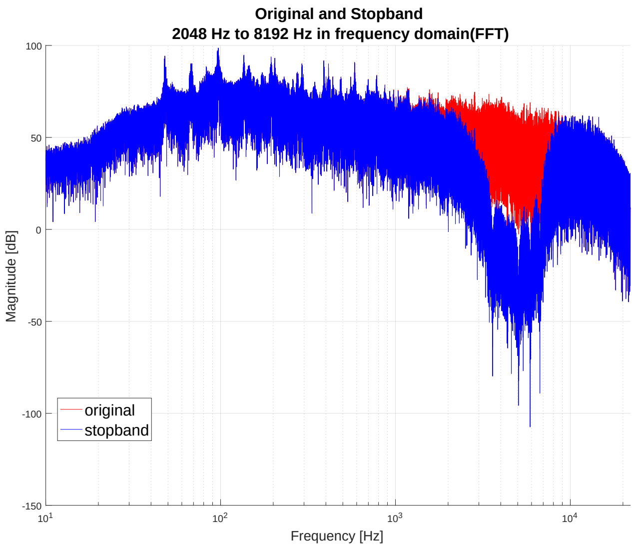

Figure 4: Frequency spectrum of the non-filtered signal(red) and the stopband filtered signal(blue).

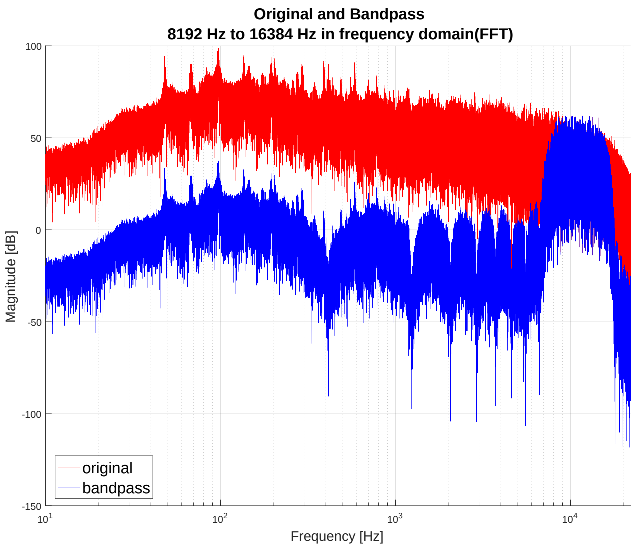

Figure 5: Frequency spectrum of the non-filtered signal(red) and the second bandpass filtered signal(blue).

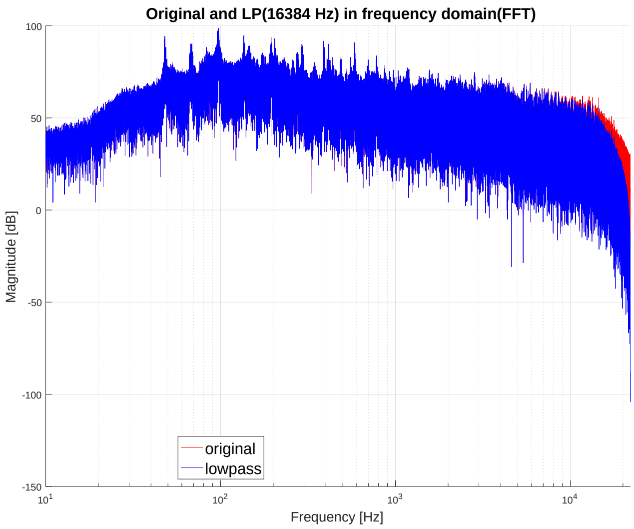

Figure 6: Frequency spectrum of the non-filtered signal(red) and the lowpass filtered signal(blue).

3.2.2 IIR Frequency Spectrums

Figure 7 and fig. 8 shows the effect of a few IIR filters on the original frequency spectrum. Figure 7 is a high pass filter at 512 Hz with an order of 1. Figure 8 is a bandpass filter at the frequencies 512 Hz and 2048 Hz with an order of 1.

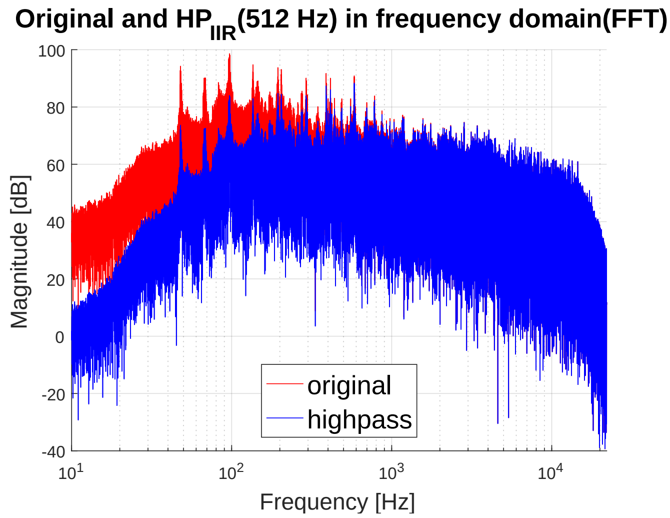

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Figure 7: Frequency spectrum of the non-filtered signal(red) a highpass IIR filtered signal(blue).

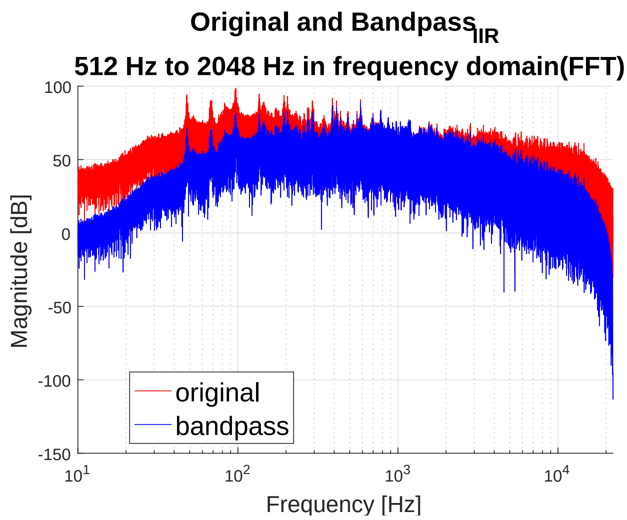

Figure 8: Frequency spectrum of the non-filtered signal(red) a bandpass IIR filtered signal(blue).

3.3 FIR - Different Window Types

Here the effect (shown as impulse response) of different window types on a 50th order FIR bandpass filter will be investigated.

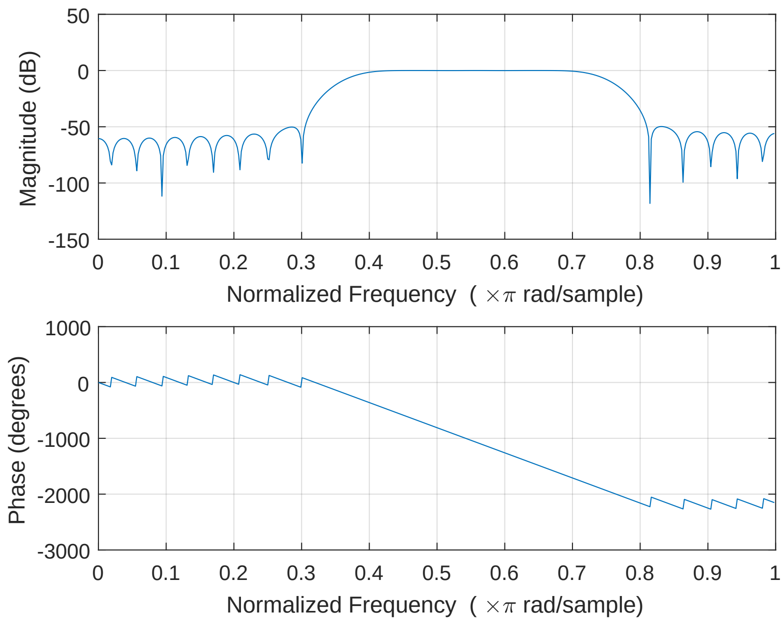

Figure 9: Impulse Response of using a Hamming Window.

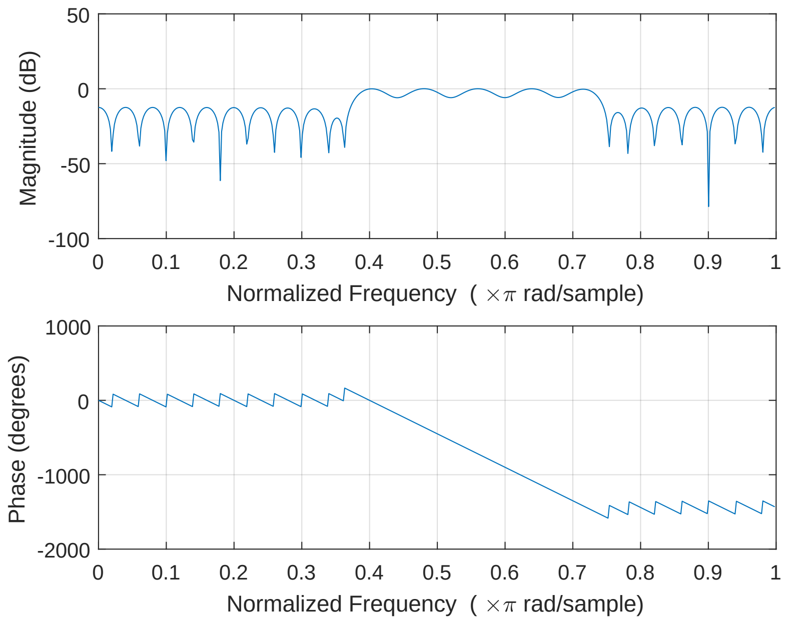

Figure 10: Impulse Response of using a Chebyschev Window.

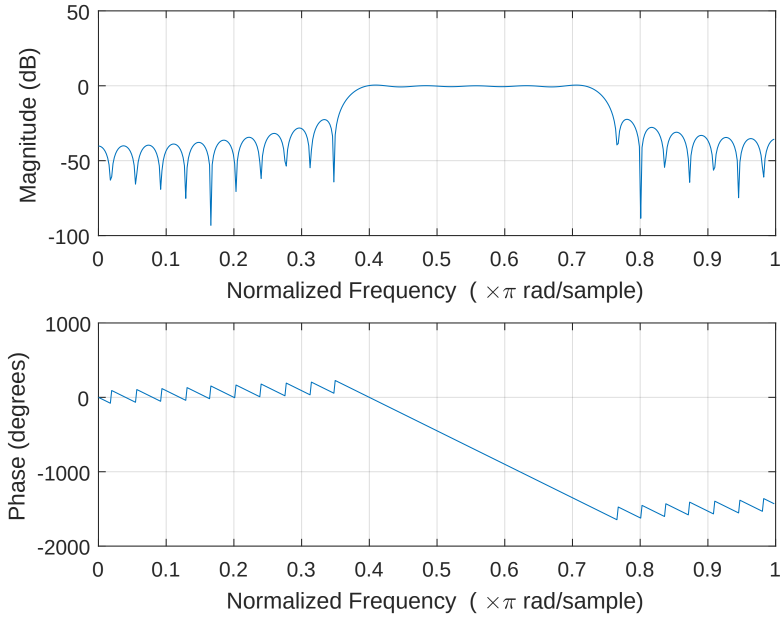

Figure 11: Impulse Response of using a Kaiser Window. $\beta = 0.5$.

4 Results

4.1 FIR vs IIR speed

The speed of the filters was found by using the built in matlab tic toc function around the filter function as shown in listing 1. The filters are attempted to have the same frequency characteristics, which result in different filter orders for the FIR and IIR filters.

```
    tic
    yBP = filter(b,a,y);
    toc
```

Listing 1: Demonstration of the code used to find the calculation time of the filters.

Table 2: Comparing the calculation speed of FIR and IIR filters.

Type of filter	Time(s)
FIR low pass	2.275 644
IIR low pass	0.404 421
FIR band pass	2.283 198
IIR band pass	0.463 531

4.2 FIR and IIR speed dependency of filter order

To test this a band pass from 2048 Hz to 8192 Hz will be created using different orders of filters. It is important to note that you cannot compare FIR and IIR filters with the same order in this table, as IIR filters can achieve the same effect on the output as the FIR, but with a much lower filter order. The results are shown in table 3.

Table 3: Comparing the calculation speed of FIR and IIR filters with different orders.

Order of filter	FIR time (s)	IIR time (s)
1	0.199 696	0.406 552
5	0.443 048	0.875 347
10	0.500 542	3.545 236
100	2.461 655	6.413 526
500	6.044 611	21.773 430

4.3 Windows Effect on the FIR Impluse Response

Figures 9 to 11 demonstrates three different windows and their effect on the impulse response. Comparing the magnitudes response, the Hamming window has a less sharp cutoff at the cutoff frequencies than both the Chebyshev and the Kaiser filter. The Chebyshev filter has a noticable ripple in the passband, whereas the ripple in the Kaiser filter is almost invisible. The phase in all three windows appears almost constant outside of the passband, but as an effect of the Hamming window not having as sharp a cutoff at the cutoff frequencies, it's linear phase is a lot longer than the linear phases for both the Chebyshev and Kaiser windows.

4.4 FIR and IIR filter Order Impact on Phase

As seen in table 4 the FIR filter has a starting phase of 0 and ends at $-90°$ times the filter order. The IIR filter has a more unstable phase, but the difference between the start and end phase is always $2 \times 90° \times$filter order.

Table 4: FIR and IIR filter order impact on phase.

	FIR phase		IIR phase	
Filter Order	Start	End	Start	End
1	$0°$	$-90°$	$90°$	$-90°$
2	$0°$	$-180°$	$180°$	$-180°$
3	$0°$	$-270°$	$-90°$	$-630°$
5	$0°$	$-450°$	$90°$	$-810°$

It should also be noted that the phase of the FIR filter phase is linear, as seen infig. 12, as long as the filter order is low enough as not to cause any ripples (as seen in e.g. fig. 11). On the other hand an IIR filter is not linear, as seen in fig. 13.

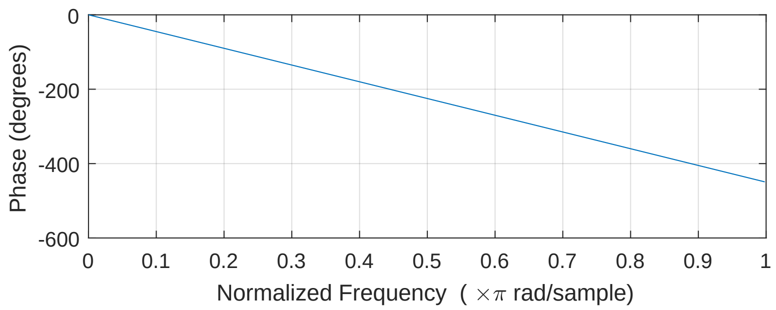

Figure 12: Linearity of a 5th order FIR filter.

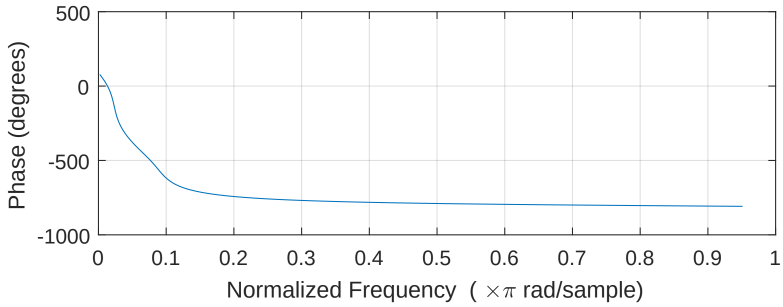

Figure 13: Non-linearity of a 5th order IIR filter.

4.5 FIR Filter Effect on the Sound of the Music

Table 5: FIR filter effect on the sound of the music

Filter	Effect
High pass at 512 Hz	Almost inaudible.
Band pass between 512 Hz and 2048 Hz	Bass and bells stand out a lot. Voice very distorted.
Stop band between 2048 Hz and 8192 Hz	More sound to the bass. Voise less distorted. Small "clicks" during playback.
Band pass between 8192 Hz and 16 384 Hz	Bass sounds like a guitar. General sound level is very low. Hi-hat really comes forward.
Low pass at 16 384 Hz	Some of the hollow noise from hitting the drums has disappeared.

5 Conclusions

An IIR filter is significantly faster at filtering an incoming signal when compared to a similar FIR filter (table 2). This speed enhancement is affected by the fact that a higher order FIR filter is needed to accomplish the same output result as a low order IIR filter, as IIR filters of equivalent order as a FIR filter is significantly slower to implement (table 3).

The use of different windows on a FIR filter strongly affects the output magnitude (section 3.3), and should be taken into consideration when designing filters.

If the phase is important to keep track of, this is much easier to do when using a FIR filter, as seen in table 4 and on the figures 12 and 13, because the FIR phase is linear, but the IIR phase is unpredictable.

The influence of the different filters on the output signal(the music) was, as predicted easiest to notice in the frequency range of 512 Hz to 16 384 Hz (table 5).