Interfering Tone Filtering (December 2023)

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Abstract— This paper presents a study on interference suppression using digital filters. MATLAB will be used as a support tool to carry out this analysis. We hope that our study will be to your liking. For any doubt or clarification, we are at your disposal through our e-mails.

Keywords — *FIR (Finite Impulse Response), IIR (Infinite Impulse Response).*

I. Introduction

IN this study, the problem of removing an interfering tone from an audio file using digital filters is addressed. The results obtained by applying FIR and IIR filters are compared and analyzed, evaluating their effectiveness in attenuating the interfering tone and preserving adjacent frequencies in the audio file. MATLAB is used to load the audio file and apply digital filters. For the FIR filter, coefficients designed to remove the frequency of the interfering tone are used, while for the IIR filter the modulus of the poles is adjusted to achieve selective attenuation.

II. Problem Statement

In the present study a song is available, whose signal has an interfering tone attached to it at a certain frequency, with a high amplitude which hinders the correct hearing of the original song.

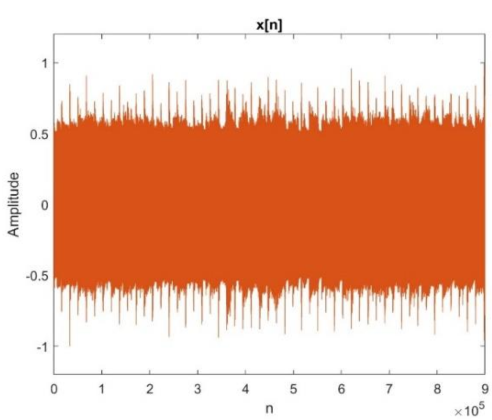

Figure I. Orinal Signal $x[n]$.

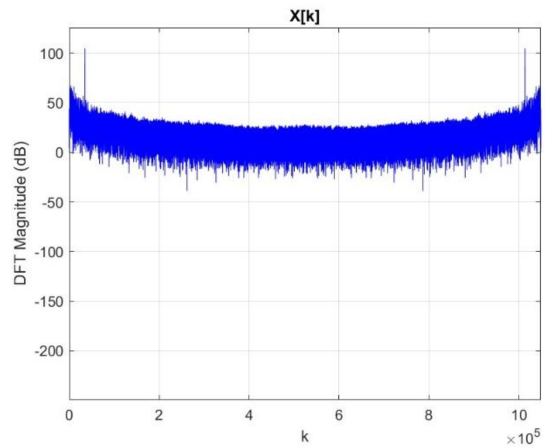

Figure II. $X[k]$.

The previous images show information of the original signal, where, in the time domain, the distinction between the original signal and the interfering tone is practically imperceptible. However, when we perform the DFT of this signal, and we obtain the signal in frequency domain, we can identify at a glance, the frequencies where the interference is.

The following expressions enable us to identify the position of a specific tone within a signal. Once the tone's position is determined, we can extract its digital frequency, relevant in the digital signal processing domain, for subsequent filtering operations.

$$\Omega = 2\pi \cdot \frac{k}{N}$$

Equation I. Digital Frequency Expression.

III. FILTERS & FILTERING

After determining the frequency of interest, the next step involves the design of a specialized device known as a band-stop filter. For our goal it wiil be used an specific band-stop filter called, band-notch, is precisely engineered to selectively attenuate or eliminate a narrow band of frequencies centered around a specified frequency. This filtering process enables the desired frequencies to pass through.

By applying a band-notch filter to the signal with the unwanted interfering tone, that specific unwanted frequency may be selectively reduced or removed, improving signal quality by eliminating noise of interference without significantly affecting other parts of the signal that are important or desirable.

A. FIR Filter

A valid option is to apply a band-notch FIR filter. This filter is characterized by having a finite impulse response, which means that its output depends only on a finite amount of input samples and has no feedback in its structure.

Among the characteristics of this type of filter we have:

- Stability: FIR filters are inherently stable due to their finite impulse response.
- Provide more atenuation.
- Reduced frequency selectivity.
- Ease of design: The design of FIR filters can be simpler and more predictable compared to IIR filters.

$$H(z) = \frac{(z - e^{-j\Omega})(z - e^{j\Omega})}{z^2}$$

Equation II. FIR filter Transfer Function.

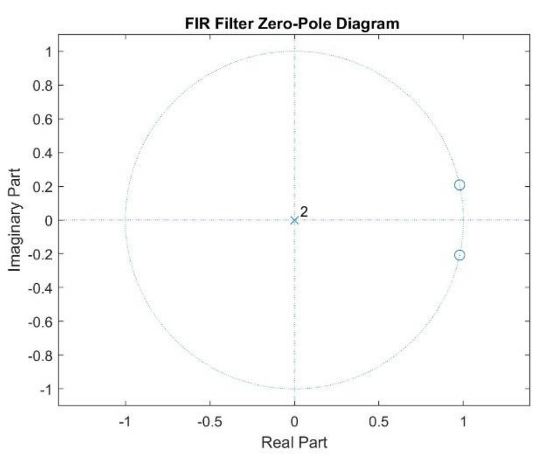

Figure III. FIR filter Zero-Pole Diagram.

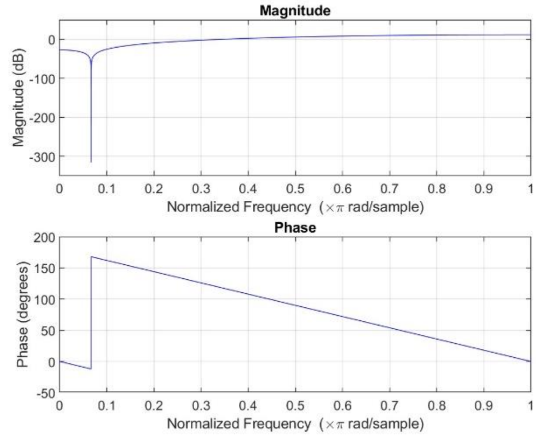

Figure IV. FIR filter Frequency Response.

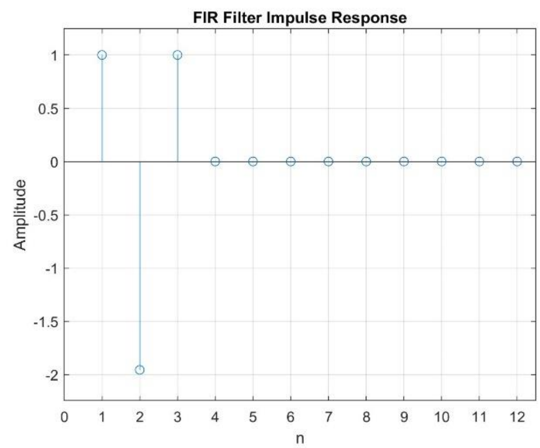

Figure V. FIR filter Impulsional Response.

B. IIR Filter

On the other hand, we have IIR filters, which have an infinite impulse response and present feedback in their structure.

The characteristics of a band eliminated IIR filter are as follows:

- High frequency selectivity.
- Less atenuation.

$$H(z) = \frac{(z - e^{-j\Omega})(z - e^{j\Omega})}{(z - \rho e^{-j\Omega})(z - \rho e^{j\Omega})}$$

Equation III. IIR filter Transfer Function.

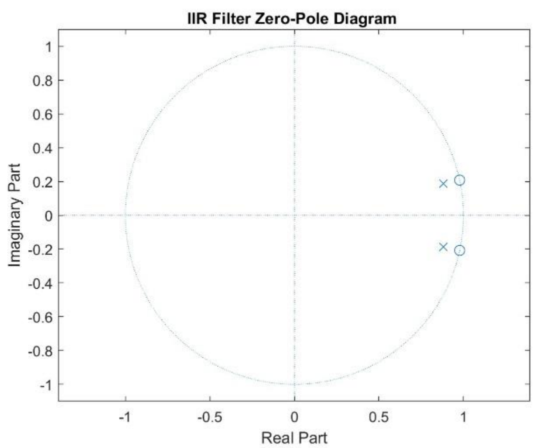

Figure VI. IIR filter Zero-Pole Diagram Response ($\rho = 0.9$).

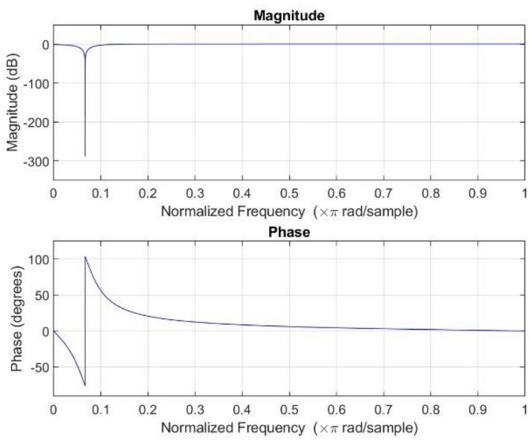

Figure VII. IIR filter Frequency Response ($\rho = 0.9$)

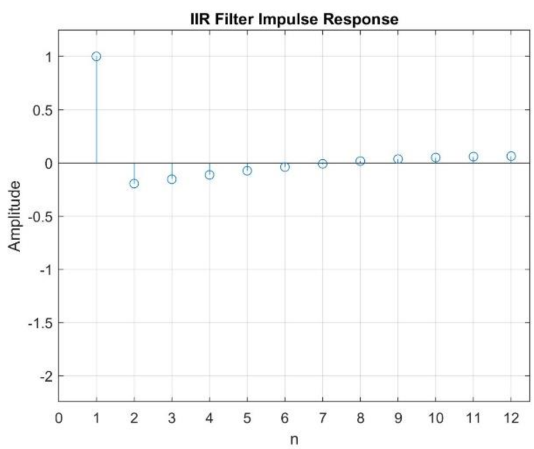

Figure VIII. IIR filter Impulsional Response.

C. Filtering

To remove the interfering tone, it must be applied de filter designed to the original signal which in Discrete-Time is seen like a convolution.

$$y[n] = x[n] * h[n]$$

Equation IV. Discrete-Time Filtering Expression.

And viewed from the frequency Domain.

$$Y(z) = X(z) \cdot H(z)$$

Equation IV. Frequency Filtering Expression.

IV. FIR VS IIR

When we apply the FIR filter to our original signal to remove the interfering tone, we notice an attenuation in the target tone frequency. However, since FIR filters have a finite frequency response and tend to have smoother transition characteristics compared to IIR filters, we can see how the adjacent frequencies are also affected by the attenuation.

In the spectrum of the original signal, a peak at the frequency corresponding to the interfering tone is clearly visible. After applying the FIR filter, this frequency will be attenuated, but you may still notice a decrease in the adjacent frequencies due to the frequency response of the filter.

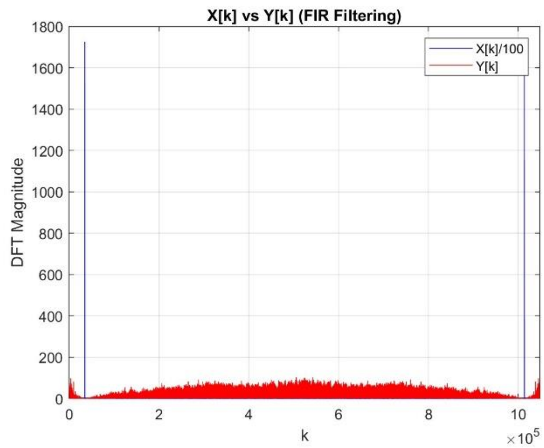

Figure IX. $X[k]$ vs $Y[k]$ (FIR Filtering).

Viewed in attenutation :

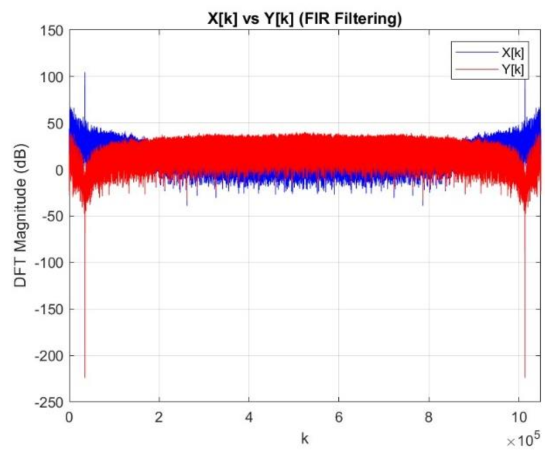

Figure X. $X[k]$ vs $Y[k]$ (FIR Filtering) (dB).

If instead of a FIR filter, an IIR filter is applied, a selective attenuation of the interfering tone is obtained, i.e., a lower impact on adjacent frequencies, since IIR filters usually have a higher selectivity in the attenuation of specific frequencies compared to FIR filters.

It can be seen how the frequencies adjacent to the target frequency have been attenuated to a lesser extent than using the FIR filter. It can also be seen that the frequencies farther away from the target frequency are practically indistinguishable from the original signal. This feature allows preserving the original signal to a large extent without modifying it excessively, which contributes to a better user experience.

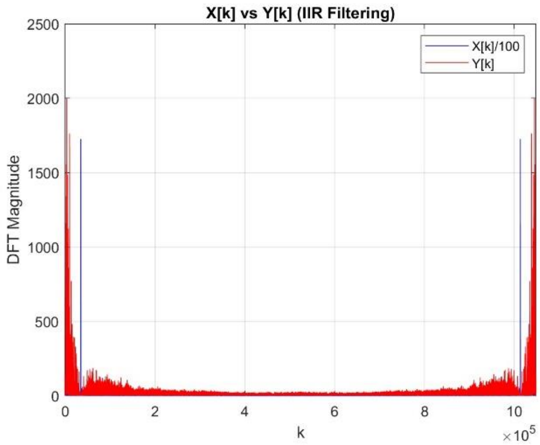

Figure XI. $X[k]$ vs $Y[k]$ (IIR Filtering).

Viewed in dB of atenuation:

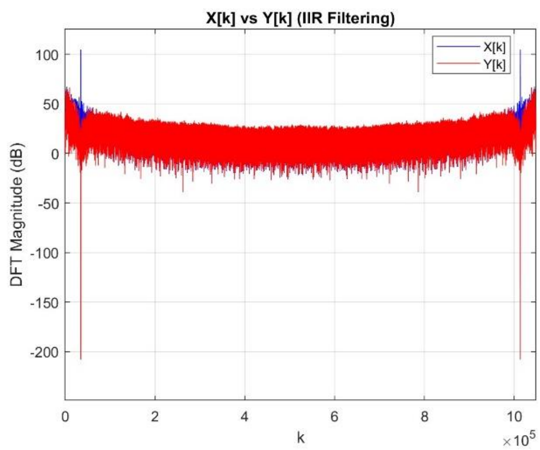

Figure XII. $X[k]$ vs $Y[k]$ (IIR Filtering) (dB).

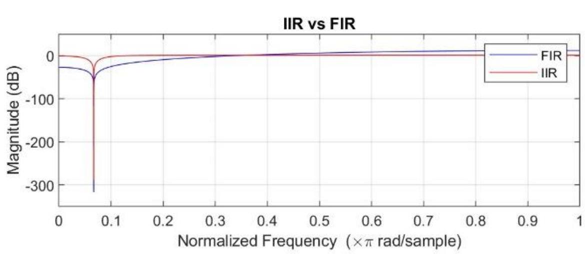

Figure XIII. IIR vs FIR Frequency Response.

Figure XII illustrates that the FIR filter exhibits greater attenuation across a broader range of frequencies compared to the IIR filter. In contrast, the IIR filter offers less attenuation but with greater precision.

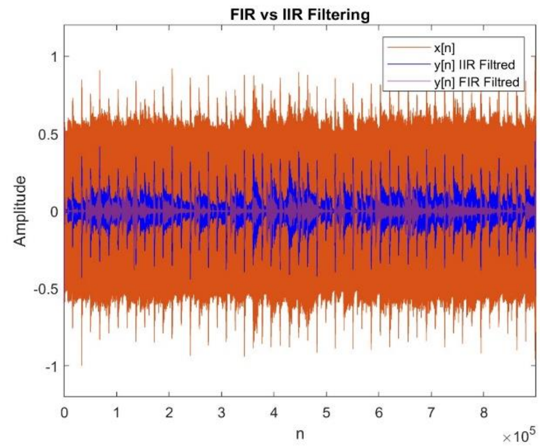

Figure XIV. $x[n]$, $y[n]$ IIR Filtred, $y[n]$ FIR Filtred

V. CONCLUSION

Comparison between FIR and IIR filters reveals significant differences in their attenuation capabilities. While the FIR filter offers robust attenuation of the interfering tone, its effect on nearby frequencies can be dramatic. In contrast, the IIR filter, with the ability to adjust the modulus of the poles, allows more specific attenuation of the interfering tone while better preserving neighboring frequencies.

The choice between a FIR and IIR filter depends on specific design needs. FIR's tend to be easier to design and more stable, but may require more computational resources to achieve the same selectivity as an IIR. On the other hand, IIRs are more resource efficient and can achieve selectivity with fewer parameters, but can be more difficult to design and control due to their feedback and susceptibility to stability issues.