

Speech Signal Analysis Using Windowing Techniques



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ABSTRACT

In Speech Processing and Digital Signal Processing applications, window techniques are widely used. A function which is a mathematical function that is zero-valued outside the chosen interval is considered as window function. In this paper, the performance of Hamming, Hanning and Blackman windows are mainly compared considering their magnitude responses, phase responses, using MATLAB. The responses of an FIR low pass, high pass filters can be obtained from its design. The results obtained are same as stated in the theory. In this paper, on comparing the simulation results using different windows, we observed that Blackman window produces better results among them. The analysis of windows with speech signal is also simulated using MATLAB and observes the same expected result.

Keywords

FIR filter, Impulse response, Frequency response, Window.

1. INTRODUCTION

In signal processing and Communication Systems a filter removes the unwanted signal and allows the desired signal. Different forms of filters available based on applications. Low pass filters allows only low frequency band. High pass filters allows only high frequency band. Digital filters are

broadly classified in to two types. They are Finite Impulse Response (FIR) filter and Infinite Impulse Response (IIR) filter [1] [2]. FIR system has finite impulse response where as IIR system has infinite impulse response. While implementation of these filters, FIR filter has no feedback and it is also called non- recursive filter. Because of this, FIR filter structure can easily be implemented as compared to the IIR filter [3][4][5]. FIR filters can be designed using, Fourier series method ,Frequency sampling method and Window methods are used [4][6]. FIR filters implementation using Fourier series method encounters some problems i.e. If the Fourier series is truncated abruptly, it results in oscillations in the pass band and stop band. These oscillations are due to slow convergence of the Fourier series, This Phenomenon is called Gibb's Phenomenon. We can overcome this by using an appropriate window function. In this paper, we discussed Blackman, Hanning and Hamming windows for designing the FIR low pass, high pass filters. FIR filters using different windows are simulated.

2. FIR FILTER

A filter whose impulse response is finite can be considered as an FIR filter. The Basic Prototype FIR filter types are

- 1.Low pass filter
- 2.High pass filter
- 3.Band pass filter
- 4.Band stop filter

The benefits of FIR filter over IIR filter are given below [4][6][7]:

1. FIR filters have better stability.
2. They can have an exact linear phase.
3. They can be realized efficiently in hardware.

3. FIR FILTER

For a discrete-time FIR filter, the output is a weighted sum of the current and a finite number of previous values of the input. The following equation describes the operation, which defines the output sequence $y[n]$ in terms of its input sequence $x[n]$ [8]:

$$y(n) = b_0 x[n] + b_1 x[n-1] + \dots + b_N x[n-N]$$

$$= \sum_{i=1}^n b_i x[n-i]$$

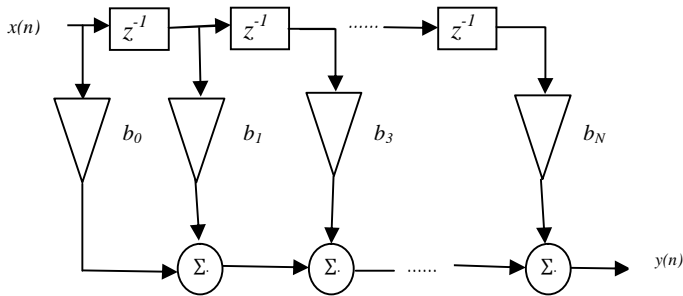


Fig 1: Transversal structure of FIR filter

4. Frequency Response

The frequency response of a system is nothing but the discrete-time Fourier transform (DTFT) of the system's impulse response $h[n]$:

$$H(\omega) = \sum_{n=-\infty}^{\infty} h[n] e^{-j\omega n} \dots\dots\dots(1)$$

Similarly, DTFT of the sequence $x[n]$ is

$$X(\omega) = \sum_{n=-\infty}^{\infty} x[n] e^{-j\omega n} \dots\dots(2)$$

If finite sequence $x[n]$ is considered then its spectrum is given by

$$X(\omega) = \sum_{n=0}^{N-1} x[n] e^{-j\omega n} \dots\dots\dots(3)$$

5. Windowing Techniques

The basic approach of the windowing techniques is to multiply the sequence $x[n]$ by a 'window sequence $w[n]$ that is non-zero only for $n= 0 \dots L-1$, where L , the length of the window, is smaller than the length N of the sequence $x[n]$.

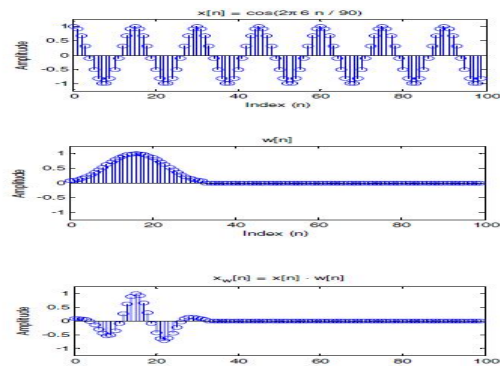
$$x_w[n] = x[n] \cdot w[n] \dots\dots\dots (4)$$

Then we compute the spectrum of the windowed sequence $x_w[n]$ as usual

$$X_w(\omega) = \sum_{n=0}^{N-1} x_w[n] e^{-j\omega n} = \sum_{n=0}^{N-1} x[n] \cdot w[n] e^{-j\omega n}$$

\dots\dots\dots (5)

The following figure describes how a window sequence $w[n]$ is applied to the sequence $x[n]$:



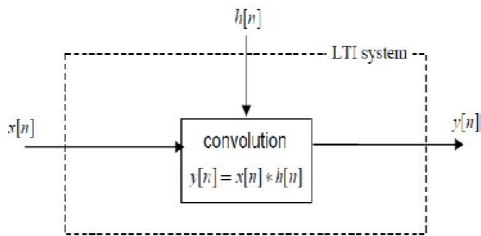
The DTFT of the windowed sequence is:

$$X_w(\omega) = \sum_{n=0}^{L-1} x_w[n] e^{-j\omega n} \dots\dots (6)$$

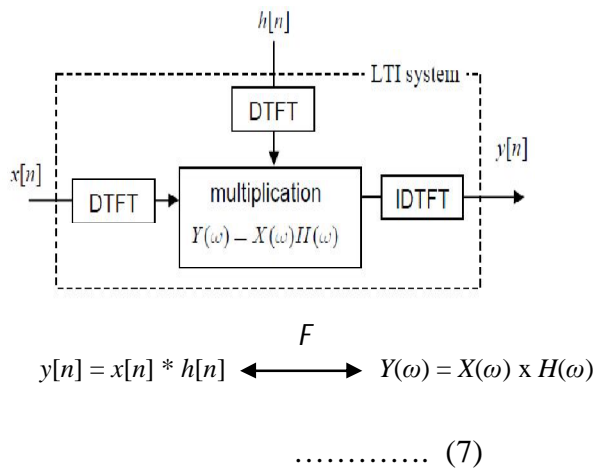
Windowing Effects

To illustrate the effect, we introduced some of the important properties of the Fourier transform. The figure below describes the property graphically:

I. Response of LTI system in the time domain.



Response of LTI system in frequency domain.



the time domain and the frequency domain are dual's in the Fourier transform, we also know that multiplication in the time domain is equal to convolution in the frequency domain [9]:

$$x_w[n] = x[n] * w[n] \xleftrightarrow{F} X_w(\omega) = X(\omega) x W(\omega)$$

The two implementations of an LTI system are equivalent: they will give the same output for the same input. Hence, convolution in the time domain is equal to multiplication in the frequency domain: This shows that multiplication of the sequence $x[n]$ with the window sequence $w[n]$ in the time domain is equivalent to convolving the spectrum of the sequence $X(\omega)$, with the spectrum of the window $W(\omega)$. The result of the convolution of the spectra in the frequency domain is that the spectrum of the

sequence is 'smeared' by the spectrum of the window.

Types of Window for designing FIR filters:

- 1.Hamming window
- 2.Hanning window
- 3.Blackman window
- 4.Rectangular window
- 5.Bartlett window
- 6.Kaiser window etc.

II.

5.1 Hamming Window

The Hamming window sequence is defined by

$$w[n] = a - b \cos\left(\frac{2\pi n}{N-1}\right) \text{ for } -\frac{N-1}{2} \leq n \leq \frac{N-1}{2} \dots (9)$$

With $a = 0.54$ and $b = 1 - a = 0.46$

The non-causal hamming window function related to the rectangular window function.

$$w_H(e^{j\omega T}) = 0.54 \frac{\sin(\frac{\omega NT}{2})}{\sin(\frac{\omega T}{2})} + 0.46 \frac{\sin(\frac{\omega NT}{2} - \frac{N\pi}{N-1})}{\sin(\frac{\omega T}{2} - \frac{\pi}{N-1})} + 0.46 \frac{\sin(\frac{\omega NT}{2} + \frac{N\pi}{N-1})}{\sin(\frac{\omega T}{2} + \frac{\pi}{N-1})} \dots (11)$$

The width of the main lobe is approximately $8\pi/N$ and the peak of the first side lobe is at -43dB. The side roll off is 20 dB/decade. For a causal window,

$$w_H(e^{j\omega T}) = 0.54 \frac{\sin(\frac{\omega NT}{2})}{\sin(\frac{\omega T}{2})} - 0.46 \frac{\sin(\frac{\omega NT}{2} - \frac{N\pi}{N-1})}{\sin(\frac{\omega T}{2} - \frac{\pi}{N-1})} - 0.46 \frac{\sin(\frac{\omega NT}{2} + \frac{N\pi}{N-1})}{\sin(\frac{\omega T}{2} + \frac{\pi}{N-1})} \dots (12)$$

5.2 Hanning Window

The window function of a causal Hanning window is given by,

$$w_{Hann}[n] = \begin{cases} 0.5 - 0.5 \cos\left(\frac{2\pi n}{N-1}\right) & \text{for } 0 \leq n \leq \frac{N-1}{2} \\ 0 & \text{Other wise} \end{cases} \dots (13)$$

The window function of a non-causal Hanning window is given by,

$$w_{Ham} [n] = \begin{cases} 0.5 + 0.5 \cos \left(\frac{2\pi n}{N-1} \right) & \text{for } 0 \leq |n| \leq \frac{N-1}{2} \\ 0 & \text{Other wise} \end{cases} \dots\dots (14)$$

The main lobe width is $8\pi/N$ and first side lobe peak is at -32dB.

5.3 Blackman Window

This window sequence is defined by,

$$W_{Black}[n] = p_0 + p_1 \cos \left(\frac{2\pi n}{N-1} \right) + p_2 \cos \left(\frac{4\pi n}{N-1} \right) \text{ for } -\frac{N-1}{2} \leq n \leq \frac{N-1}{2}$$

Where p_0, p_1, p_2 are constants.

$$p_0 = \frac{1-a}{2}, p_1 = \frac{1}{2}, p_2 = \frac{a}{2}$$

Generally, the value of a for Blackman window is static and it is a =0.16. Now, putting the value of a into p_0, p_1, p_2 , the actual value of the coefficients for the Blackman window sequences can be achieved and they are,

$$p_0 = 0.42, p_1 = 0.5, p_2 = 0.08.$$

6. GENERATION OF WINDOW SEQUENCE AND ITS DESIRED IMPULSE RESPONSE

In FIR filter, the magnitude function is given by,

$$H_d(e^{j\omega}) = \begin{cases} 1 & \text{for Pass band} \\ 0 & \text{Otherwise} \end{cases} \dots\dots\dots (15)$$

The desired impulse response is given by,

$$h_d(n) = \frac{\sin(n\pi) - \sin(\frac{n\pi}{4})}{n\pi} \dots\dots\dots (16)$$

If $h(n)$ exhibits symmetry about $n=0$ i.e

$$h_d(-n) = h_d(n) \dots\dots\dots (17)$$

Table 1. Filter Coefficients

Desired Impulse Response of $h_d(n)$	Value of $h_d(n)$	Symmetry of $h_d(n)$
$h_d(0)$	0.75	$h_d(0)$
$h_d(1)$	-0.225	$h_d(-1)$
$h_d(2)$	-0.159	$h_d(-2)$
$h_d(3)$	-0.075	$h_d(-3)$
$h_d(4)$	0.000	$h_d(-4)$
$h_d(5)$	0.045	$h_d(-5)$

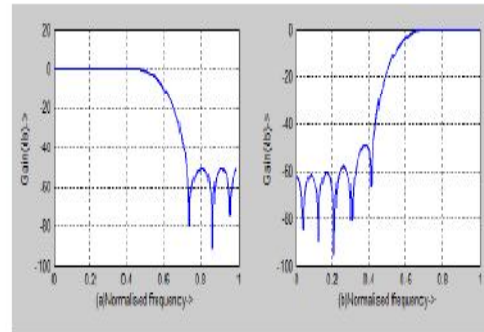


Fig 2 . Filters Using Hamming window
 (a) Low Pass Filter (b) High Pass Filter

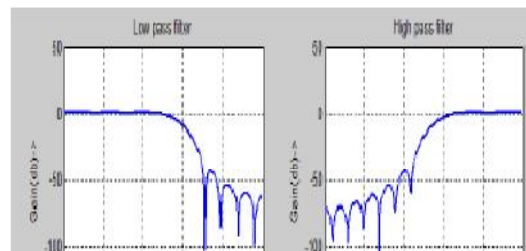


Fig 3 . Filters Using Hanning window
 (a) Low Pass Filter (b) High Pass Filter

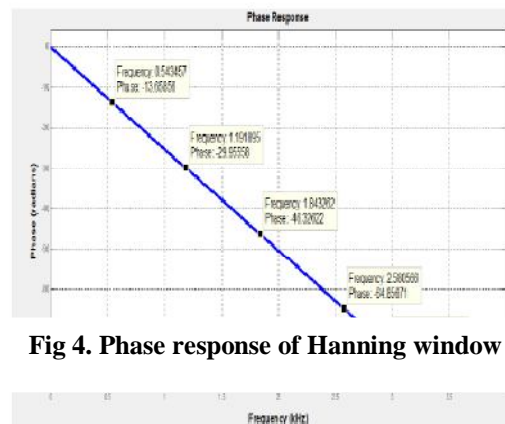


Fig 4. Phase response of Hanning window (N=64)

Table .2. Filter Coefficients $h(n)$ Using Blackman Window

Filter Coefficients $h(n)$	Value of Coefficient	Symmetry of $h(n)$
$h(0)$	0.75	$h(0)$
$h(1)$	-0.2111	$h(-1)$
$h(2)$	-0.1229	$h(-2)$
$h(3)$	-0.0416	$h(-3)$

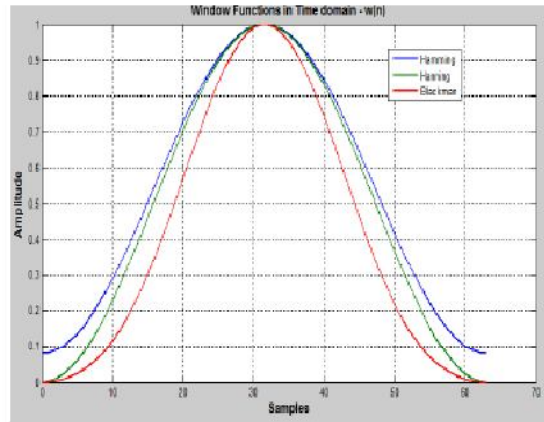
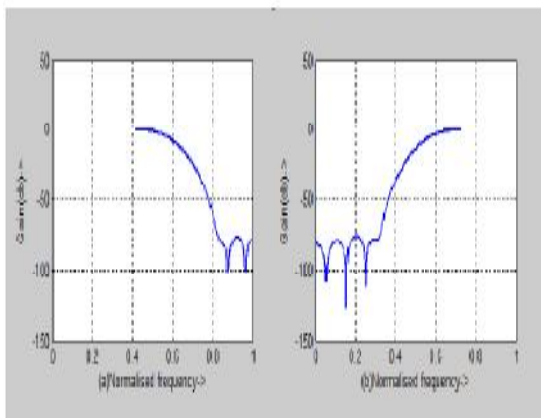


Fig 7: Responses of Window function in time domain



**Fig 5: Filters using Blackman window
 (a) Low Pass Filter (b) High Pass Filter**

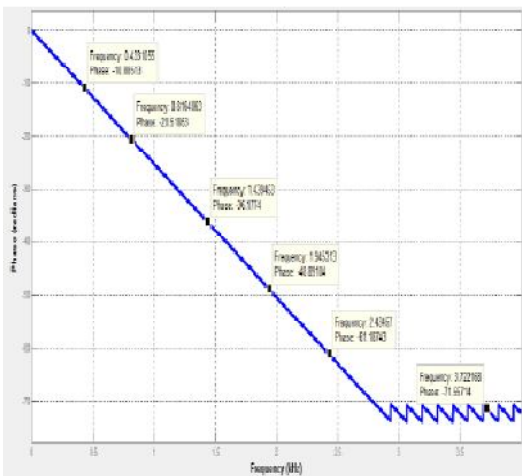


Fig 6. Phase response of Blackman window (N=64)

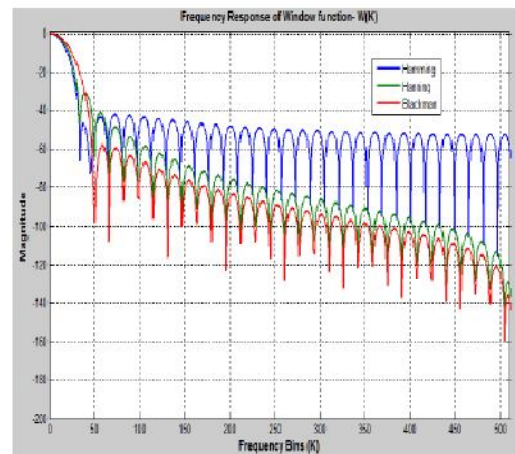


Fig 8: Responses of Window function in the frequency domain

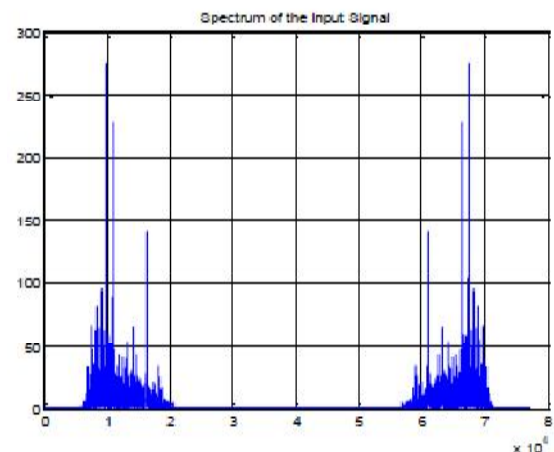


Fig 9: Spectrum of the Speech Signal

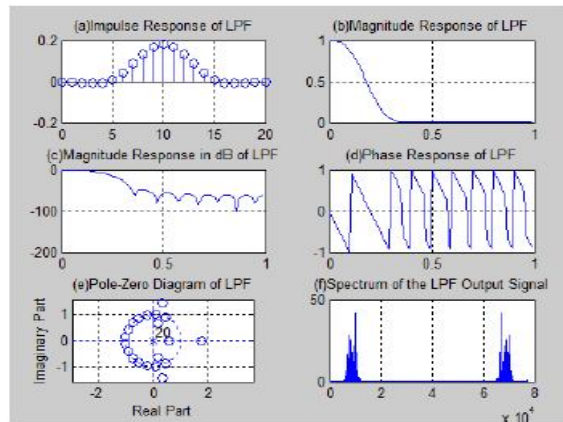


Fig 10: Speech signal analysis for low pass filter

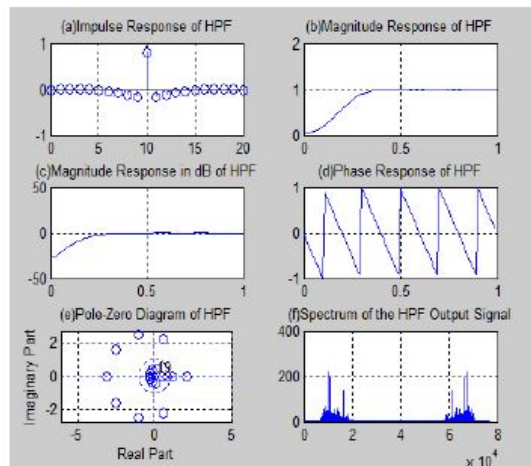


Fig 11: Speech signal analysis for high pass filter

From above figures (Fig.2, 3, 4, 5 and 6), we can be observe that the response of Blackman window are more smooth and perfect when compared to Hamming and Hanning window.

The time domain and frequency domain responses of Blackman window (Fig.7) are better than Hamming and Hanning windows.

From Fig.2(a), we observe that in Hamming window, the peak side lobe is down by 50dB. But in Blackman window, the peak side lobe is down by 78dB. In Fig.5 (a). So, there is a progress in Blackman window of 18dB when compared to the Hamming window.

Fig.9 shows the spectrum of the speech signal whose sampling rate is 22050 and number of bits per sample is 16. Fig.10 indicates the low pass filter characteristics and the change of spectrum of the speech signal using Hamming window where the pass band frequency is 2000 Hz. For deigning high pass filter using Blackman window (Fig.11) pass band frequency 2000 Hz (for HPF). For speech signal analysis to remove undesirable noise window technique can be used. Band separation filter using Hanning window can recover the original speech signal sharply [1][10].

7. CONCLUSION

In this paper, we have designed low pass, high pass FIR filter and compared their responses in time and frequency domain using MATLAB simulation. The application of speech signals using various windows are simulated using MATLAB, and compared the input and output spectrum of the signal. In all cases, we observed that Blackman window out performs among three windows [10].

8. REFERENCES

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