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COMPARING WINDOWING METHODS ON FINITE IMPULSE RESPONSE (FIR) FILTER ALGORITHM IN ELECTROENCEPHALOGRAPHY (EEG) DATA PROCESSING

[1]NOVA EKA DIANA, [2]UMI KALSUM, [3]AHMAD SABIQ, [4]WISNU JATMIKO, [5]PETRUS MURSANTO

[1,2,3]E-Health Research Center, Faculty of Information Technology, YARSI University, Indonesia

[4,5]Faculty of Computer Science, University of Indonesia

E-mail: [1]nova.diana@yarsi.ac.id

ABSTRACT

Electroencephalography (EEG) data contains electric signal activities on a cerebral cortex to record brain electrical activities. EEG signal has some characteristics such as non-periodic, non-standardized pattern, and small voltage amplitude. Hence, it is lightly heaped up to noise and difficult to recognize and extract meaningful information from EEG data. Finite Impulse Response (FIR) with various windowing methods has been widely used to mitigate noise and distortions. This paper compares and analyzes the windowing techniques in resulting the most optimal results in EEG filtration process. The experiment results show that Blackman Window gives the best result in term of the most negative value in stop-band attenuation, the widest transition bandwidth, and the highest cutoff frequency compares to Rectangular Window, Hamming Window, and Hann Window.

Keywords: *Electroencephalography (EEG), Finite Impulse Response, Windowing Methods, Signal Filtering, Blackman Window*

1. INTRODUCTION

Electroencephalography (EEG) data signal consists of electric signal activities on a cerebral cortex with some characteristics, such as non-periodic, non-standardized pattern, and small voltage amplitude. These attributes evoke EEG signal to be swiftly mixed up with noise and difficult to recognize [1]. Many factors can generate noise and distortions, e.g. room exposure, energetic radiation, heart, muscles, and eyes movement. Noise and other parameters such as a sudden change in signal phase and loss of signal amplitude can briefly stimulate distortion in the signal [2].

Data filtering is used to mitigate noise or distortions in EEG data. Many techniques have been proposed to process data signal filtering, such as Finite Impulse Response (FIR) digital filter. In many cases, a bad filter design can induce signal distortions to occur. Windowing methods are usually employed to extract and repair impulse responses in FIR filter. Many researchers had proposed different windowing methods, but only some can give a good result in filtering EEG data. This paper focuses on comparing four windowing methods to get the best outcome in EEG signal filtering process.

We organized this article as follow: Section II discusses literature reviews, Section III explains the methods used in this research, and Section IV provides results and discussion. Finally, Section V presented the conclusion and future works.

2. MOTIVATION

Electroencephalographic (EEG) is a measurement procedure using electro-medical equipment to record electrical activities of the brain and its interpretation. Neurons in the cerebral cortex issue electric waves with a minimum voltage (mV) which then passed through an EEG machine to do an amplification process. After it is amplified, the recorded EEG size will be enough to be captured by the reader's eyes as an alpha, beta, and theta wave [3]. EEG signal is used to diagnose diseases related to brain and psyche, such as epilepsy, brain tumors, detect the position or location of the injured brain and diagnose mental disorders.

Many researchers have proposed various methods to filter EEG data. Surface Laplacian (SL)

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filter is used to emphasize the electrical activities that are spatially located near the electrode which currently being recorded, and to sift out signals that may come from outside of the skull. SL filter also muffles EEG activities which are common to dedicated channels hence increasing the spatial resolution of the recorded signal [4]. However, SL filter can only be applied to EEG data with the number of 64 electrodes or more [5].

Another researcher, Guerrero-Mosquera and Vazquez used Independent Component Analysis (ICA) and Recursive Least Squares (RLS) method to eliminate the eye movement artifacts in EEG data. The method uses separate electrodes that tightly localized to the eyes, in which register to vertical and horizontal eye movements for extracting a reference signal. This procedure projects each reference input into ICA domain, and then RLS algorithm estimates the interference that may occur in this data. This proposed method efficiently rejected artifacts produced by eyes movements by relying on ICA and RLS adaptive filtering [6]. Miyazaki et al. also utilized Infinite Impulse Response (IIR) filter to eliminate the artifacts from EEG data. Their research results showed that the IIR filter can remove artifacts in EEG data quite well. However, IIR has poles that lead the filter to be unstable [7].

Different with the aforementioned methods, FIR filter does not require many electrodes and not only focus on the noise of eye movements. Hence, FIR is more stable than other filters above. In this research, we utilize FIR filter to process EEG data that is captured using Emotiv EPOC device with 14 electrodes.

3. METHODOLOGY

3.1 Finite Impulse Response (FIR)

Finite Impulse Response (FIR) has a finite response and no poles compare with IIR filter. FIR is more stable than other digital filter and preferably used by researchers. In general, the output of FIR filter *y[k]* can be expressed mathematically as Equation 1.

$$y[k] = \sum_{n=0}^{M-1} h[n]x[k-n] \quad (1)$$

where M is the filter length, *h[n]* is the impulse response's coefficient, *x[n]* is the input filter and *y[k]* is the output filter.

The transfer function of FIR filter is approximately ideal following the increasing of filter order. Equation 2 expressed this process, where m is the order of the filter, ΔF is the transition width normalization, Δf is the transition width, and fs is the sampling frequency. Some windowing types to implement FIR filter are Blackman, Hamming, Hann, and Rectangular window. Each windowing type has a different value of normalized transition width (ΔF), as depicted in Table 1.

$$m = \frac{\Delta F}{\Delta f / fs} \quad (2)$$

Table 1: Normalization of Transition Width.

Window Type	Transition Width Normalization ΔF
Blackman Window	5.5/M
Hamming Window	3.3/M
Hann Window	3.1/M
Rectangular Window	0.9/M

FIR filter is usually employed to process the digital signal, e.g. sound and digital image, to find a clear message without any disruptions. Puspasari et al. implemented FIR filter for pedestrians' location monitoring system captured by Global Positioning System (GPS). When an unstable GPS received the signal, FIR filter would remove the noises which may occur, such as multipath effect. Before applying FIR filter, the coordinate points of the pedestrian are scattered because of the noise. But, after being processed by FIR, only one coordinate point was obtained from these distributed data [8].

FIR also can be utilized for digital signal processing in Field Programmable Arrays (FPGA) equipment. FPGA has an ability to handle heavy loads of works in parallel mode. FIR implementation in FPGA can generate an output which suitable for the specification of 20 KHz cutoff frequency. For sinusoidal input within frequency range 20-22000Hz, FIR filter will suppress the signal above 20,000Hz [9].

3.2 Windowing Method

In EEG data processing, we should consider the impulse response of the data. Finite impulse response may generate an excessive ripple in the pass-band and create low stop-band attenuation. Windowing techniques could overcome this problem during a filtering process. Given a window function (*w[n]*) and an impulse response of the ideal filter ($h_d[n]$), then the impulse response of the actual filter can be expressed in Equation 3.

$$h[n] = h_d[n] * w[n] \quad (3)$$

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Windowing methods employed with FIR filter to mitigate disruptions during filtration process are Rectangular, Hamming, Hann and Blackman Window.

1. Rectangular Window

Researchers rarely employed the rectangular window due to its low stop-band attenuation result. The first lobe of this window has an attenuation of 13dB and the narrowest transition region among all window methods. Hence, a filter designed using this window should have minimum stop-band attenuation of 21 dB. Coefficient of Rectangular Window is defined as follows:

$$w(n) = \begin{cases} 1, 0 \le n \le M-1 \\ 0, other \end{cases} \quad (4)$$

2. Hamming Window

Hamming window is one of the most popular windowing methods. A filter designed with the Hamming window has minimum stop-band attenuation of 53dB, which is sufficient for most implementations of digital filters. Unlike minimum stop-band attenuation, transition region can be changed by altering the filter order. The transition area will become narrow and minimum stop-band attenuation remains unchanged as the filter order increases. Coefficient of Hamming Window is defined as follows:

$$w(n) = \begin{cases} 0.54 - 0.46\cos\left(\frac{2\pi n}{M-1}\right), 0 \le n \le M-1 \\ 0, other \end{cases} \quad (5)$$

3. Hann Window

Researchers usually use Hann window to lessen ill effects on frequency characteristic produced by the final samples of a signal. The first side of a lobe in the frequency domain of this window has 31dB of attenuation value, whereas it amounts up to 44dB in the designed filter. The advantage of this window is its ability to increase the stop-band attenuation of the posterior lobes swiftly. Coefficient of Hann Window is defined as follows:

$$w(n) = \begin{cases} 0.5\left[1 - \cos\left(\frac{2\pi n}{M-1}\right)\right], 0 \le n \le M-1 \\ 0, other \end{cases} \quad (6)$$

4. Blackman Window

Blackman window is considered as the most popular window technique for data signal filtering. Relatively high attenuation value makes this window is very convenient for almost all applications. The first side of a lobe in the frequency domain of this filter has 51dB of attenuation value, and the designed filter has stop-band attenuation up to 75dB. Coefficient of Blackman Window is defined as follows:

$$w(n) = \begin{cases} 0.42 - 0.5\cos\left(\frac{2\pi n}{M-1}\right) + \\ \quad 0.08\cos\left(\frac{4\pi n}{M-1}\right), 0 \le n \le M-1 \\ 0, other \end{cases} \quad (7)$$

3.3 Characteristics of a Good Filter

A transition bandwidth, stop-band attenuation, and cutoff frequency determine the quality of a good filter. Figure 1 illustrates the magnitude response for these parameters in the domain spectrum.

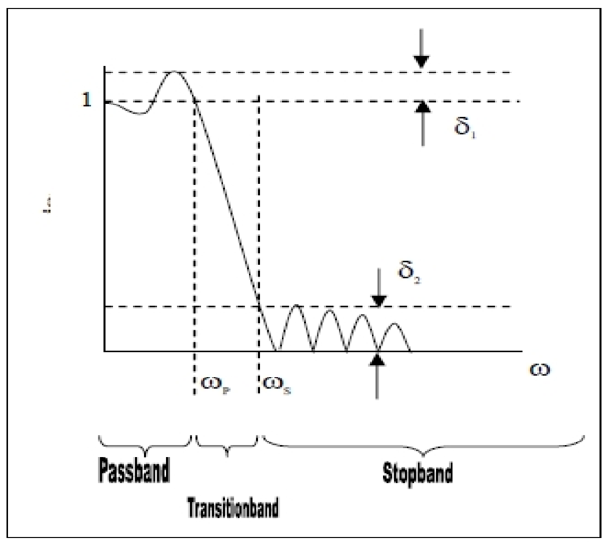

Figure 1: Magnitude response in domain frequency [11]

1. Transition Bandwidth

Transition band is an area that lies between stopband and passband. Narrow transition bands lead to a steep filter roll-off and wide transition bands allow a shallow roll-off. Filter roll-off is a function of filter order (number of filter coefficients/filter length minus one), more accurately the effective impulse response duration. Filters with a steep roll-off can better separate signal and noise components in adjacent frequency bands than filters with a shallow roll-off. But, it makes the filter has a longer impulse response than filters with a wide transition bands or shallow roll-off. Sharper and more extended filters produce

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stronger signal distortions and broader temporal smearing of distortions and ringing artifacts [10]. Therefore, to reduce or attenuate signal distortion, it is more advisable to choose a filter that has a broad transition band.

2. Stop-band Attenuation

Stopband attenuation is the highest gain value (in dB) in stopband area. Theoretically, smaller or more negative stopband attenuation may generate a better filtering result because the unwanted frequencies can be eliminated or attenuated [11]. Equation 8 express stopband attenuation:

$$A_s = -20\log_{10}\frac{\delta_2}{1+\delta_1} \qquad (8)$$

where *As* is stopband attenuation, δ_1 is passband ripple tolerance and δ_2 is stopband attenuation tolerance.

3. Cutoff Frequency

The cutoff frequency is the midpoint of transition bandwidth. The cutoff frequency of less than 0.1 Hz should be avoided because it may generate a very long filter length. Therefore, the selection of cutoff frequency determines how fast the filtered signal centered at zero value following the signal deflection. Higher cutoff frequency, then faster the signal centered at zero value because of the low-frequency attenuation [10].

4. RESULTS AND DISCUSSIONS

4.1 Data Collection

EEG data of three respondents with the age range between 19-21 years old are recorded using Emotiv EPOC device. Emotiv EPOC headset has 14 EEG channels and two references that offering a position for accurate spatial resolution. This device operates with 14 bits resolution or 16* per channel with a frequency response between 0.16 – 43 Hz. Each of participants is given an instruction to watch a video with duration about 3-5 minutes long. The purpose of the given instruction is to assess the EEG data that represent the emotion state of participants during/after watching the video.

EEG data recorded using Emotiv EPOC consists of 36 columns with 14 columns are EEG channels. Those channels are AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. These channels represent electrical activities of the brain. The rest of EPOC columns give information about status or mounting accuracy indicator of electrodes on the scalp. Here, instead of using all the channel data, we focus only on F3 and F4 channel which located on the frontal lobe. These two channels are the most influential in determining emotional changes occur in human brain [12].

4.2 Filter Design

In this research, we utilized EEGLAB to do filtering process. Figure 2 depicts the architecture design of this research approach. There are two primary processes: data preparation and filtering process.

In the data preparation, EDF file of EEG data captured by Emotiv EPOC is loaded to EEGLAB. We selected only two channels: F3 and F4, because these channels responsible for regulating human emotions. And for the sampling rate, we assigned 128 Hz/s value as the default setting from EPOC headset.

The filtering process is the essential task in our research architecture. There are three steps involved in filtering process: (1) digital filter set up (2) filtering execution and (3) quality parameters computation. The first step, we need to decide the type and the specification of the digital filter. We choose band-pass filter following the characteristics of the data signal. According to the literature study, the band-pass filter is the most recommended filter type to eliminate noise in EEG data. In this step, we also need to specify the frequency band, the filter length, and the windowing method to mitigate noise with FIR filter. The second phase, the already prepared EEG data is filtered using the designed digital filter. The last step, we calculate three parameters to determine the best windowing method in mitigating noise in EEG data signal. Table 2 shows the parameter configuration in the filtering process.

Table 2: Parameters Configuration

Parameter	Value
EEG channels	F3, F4
Sampling rate	128 Hz/s
Frequency band	0.16 Hz
Filter length	2481, 2641, 4401, 8801, 17601
Windowing method	Rectangular, Hamming, Hann, Blackman

4.3 Experiments

The aim of this research is to find the best windowing method for eliminating noises of EEG signal using FIR filter. We conducted five experiments with a different filter length of each, as depicted in Table 2. Each experiment follows the same scenario as below:

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a. Choose a windowing method (Rectangular, Hamming, Hann, and Blackman method).
b. Repeat five procedures for each windowing method with a different filter length (2481, 2641, 4401, 8801, and 17601).
c. Calculate the stop-band attenuation, the transition bandwidth and the cutoff frequency for each method.

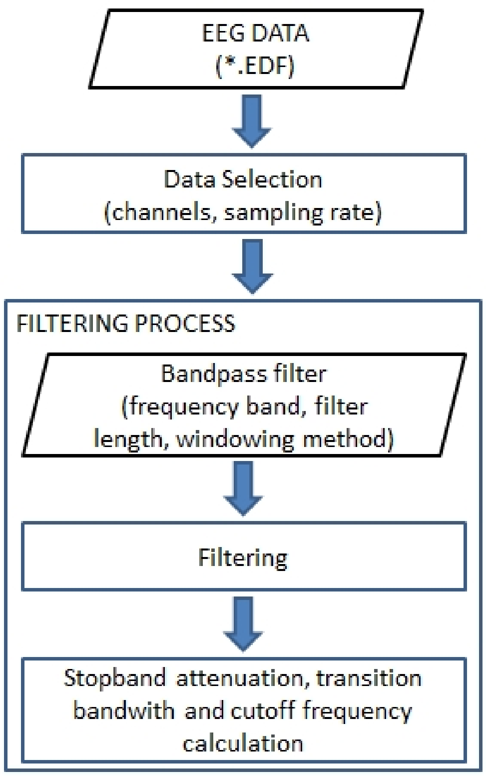

Figure 2: Design Architecture

Figure 3, 4, 5 and 6 shows the filtering result of EEG signal using Rectangular, Hamming, Hann, and Blackman window, in the domain frequency. We examine ripples appearance in either pass-band or stop-band attenuation. Ripples appearance determine the quality of windowing method in term of transition bandwidth, stop-band attenuation, and cutoff frequency. These parameters can be used to decide which windowing method gives the best filtering result.

Based on those figures, the rectangular window creates a high number of ripples either on pass-band or stop-band. At a glance, we can deduce that Rectangular window will give the worst result in EEG signal filtering. Otherwise, the Blackman window may give the best result because it has a small number of ripples and narrow transition bandwidth. Discussion section will explore more about the filtering result analysis.

4.4 Discussion

Based on the characteristics of a good filter, we compare the value of stop-band attenuation, transition bandwidth, and the cutoff frequency of the filtering results using four windowing methods. Figure 7, 8, and 9 illustrate the average yield of EEG data obtained from three participants.

Figure 7 compares the stop-band attenuation value of Rectangular, Hamming, Hann, and Blackman window method. In three experiments with a different filter length for each, Hann window generates the most negative stop-band attenuation value when the filter length value is 2641, 4401, and 8801. The smaller stop-band attenuation value, then the more unwanted frequencies can be eliminated. Hence, it can generate a better filtering result.

Figure 8 illustrates the comparison of the transition bandwidth characteristic for each windowing method. As mentioned in section 3.4, it is advisable to have a wide transition bandwidth to get an ideal filter with little as possible distortions. From this figure, we can see that Blackman window has the largest transition bandwidth in all experiments. Hence, we can conclude that Blackman window is the best method for attenuating noise and distortions compare to the others windowing methods.

Figure 9 shows the cutoff frequency results of five filter lengths' experiment over three participants EEG data. Higher cutoff frequency value, then faster the signal centered at zero because of the low-frequency attenuation. Analysis results indicate that Blackman window method gives the constant highest cutoff frequency value for all tests. Hence, the digital filter which employed with Blackman window will enormously make EEG signals to be centered on zero value.

Table 3: Windowing Method Comparison

Criteria	Windowing method	
	1st	2nd
Stop-band attenuation	Hann	Blackman
Transition bandwidth	Blackman	Hann
Cutoff frequency	Blackman	Hann

Table 3 summarizes the comparison between Rectangular, Hamming, Hann, and Blackman window based on three criteria: stop-band attenuation, transition bandwidth, and cutoff frequency. From all experiments, the Blackman window excels in term of transition bandwidth and

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cutoff frequency. And it also comes second to having the most negative stop-band attenuation. Therefore, we can conclude that the best windowing method which provided the most optimal result in EEG data filtering is Blackman Window.

5. CONCLUSIONS AND FUTURE WORKS

5.1 Conclusion Discussion

FIR digital filter was employed to process EEG data signal which recorded using Emotiv EPOC device. Poles absence characteristics made FIR filter more stable in processing data signal. A band-pass filter is recommended to process signal data in electrophysiology, e.g. EEG data. FIR filter needs to employ windowing techniques to repair the impulse responses resulted from filtering process. Four windowing methods can be utilized to process data filtering; Rectangular, Hamming, Hann, and Blackman window method.

Experiments were conducted to find the best windowing method that provides the optimal filtering results. The results show that Blackman window gives the most optimal outcome in EEG data filtering based on stop-band attenuation, transition bandwidth, and cutoff frequency measurements. Blackman window provides the second most negative value of stop-band attenuation, the widest transition bandwidth, and the highest cutoff frequency. Hence, we conclude that to better process EEG data with 14 electrodes, it is advisable to employ FIR filter equipped with Blackman window technique to eliminate noise and distortions during the filtering process.

5.2 Future Works

In the future, windowing techniques comparison can be further developed to find the optimal value of transition bandwidth in EEG data filtration. Great design of filtering method can generate an optimal output of data signal filtering. Thus, it can contribute to process the next steps in EEG data processing, such as to extract and classify data efficiently and also to simply gather the meaningful information in EEG data.

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REFRENCES:

[1] Kemalasari, M. H. P, R. W, and N. S, "Pengolahan sinyal elektroensephalogram (EEG) sistim peletakan 8 elektrode dengan metode wavelet," Proceeding of Industrial Electronic, Surabaya, 2003.

[2] Repovš G., "Dealing with noise in EEG recording and data analysis," Informatica Medica Slovenica, vol. 15, no. 1, pp. 18-25, 2010.

[3] Murugappan M., Ramachandran N., and Sazali Y., "Classification of human emotion from EEG using discrete wavelet transform," J. Biomed. Sci. Eng., vol. 03, no. 04, pp. 390–396, 2010.

[4] Cohen M. X., "Analyzing neural time series data: theory and practice," Illustrate. MIT Press, p. 600, 2014.

[5] Guerrero-mosquera C. and Vazquez A. N., "Automatic removal of ocular artifacts from eeg data using adaptive filtering and independent component analysis," 17th Eur. Signal Process. Conf. (EUSIPCO 2009), no. Eusipco, pp. 2317–2321, 2009.

[6] Miyazaki R., Ohshiro M., Nishimura T., and Tsubai M., "A novel neural network with Non-Recursive IIR Filters on EEG Artifacts Elimination," Eng. Med. Biol. Soc. 2005, pp. 2048–2051, 2005.

[7] Sakato M., "Alat pengukur gelombang otak," 2014. [Online]. Available: http://sentramedis.com/?sentra-medis=newsdetail&id=292. [Accessed: 17-Jan-2015].

[8] Puspasari B. D., Setiawan I., and Darjat, "Penerapan low pass filter dan finite impulse response menggunakan GPS," Transient, vol. 2, no. 3, 2013.

[9] Putra R. J., Rif'an M., and Setyawan R. A., "Implementasi filter digital FIR (Finite Impulse Response) pada Field Programmable Gate Arrays (FPGA)," Jurnal Mahasiswa TEUB, vol.1, no. 4, 2013.

[10] Widmann A., Schröger E., and Maess B., "Digital filter design for electrophysiological data – a practical a p- proach," J. Neurosci. Methods, pp. 1–16, 2014.

[11] Mooniarsih N. T., "Desain dan simulasi filter FIR menggunakan metode windowing," J. ELKHA, vol. 2, no. 1, pp. 41–47, 2010.

[12] Othman M., Wahab A., Karim I., Dzulkifli M. A., and I. F. T. Alshaikli, "EEG emotion recognition based on the dimensional models of emotions," Procedia - Soc. Behav. Sci., vol. 97, pp. 30–37, Nov. 2013.

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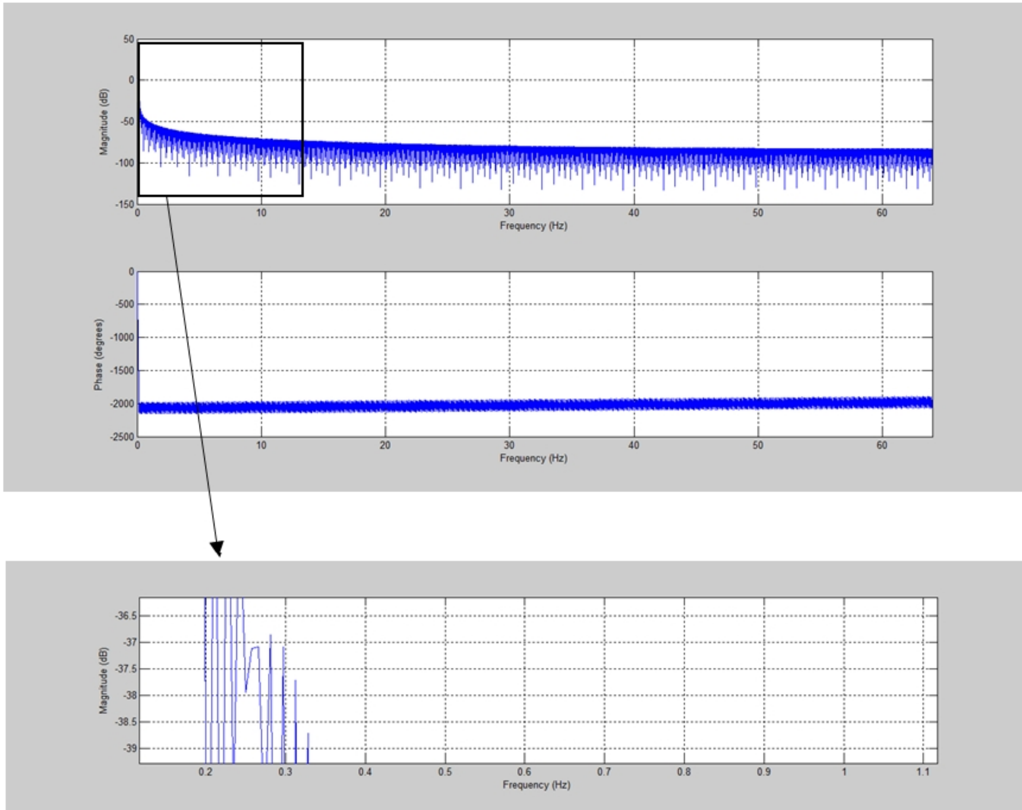

Figure 3: Bandpass Filter Result For Rectangular Window

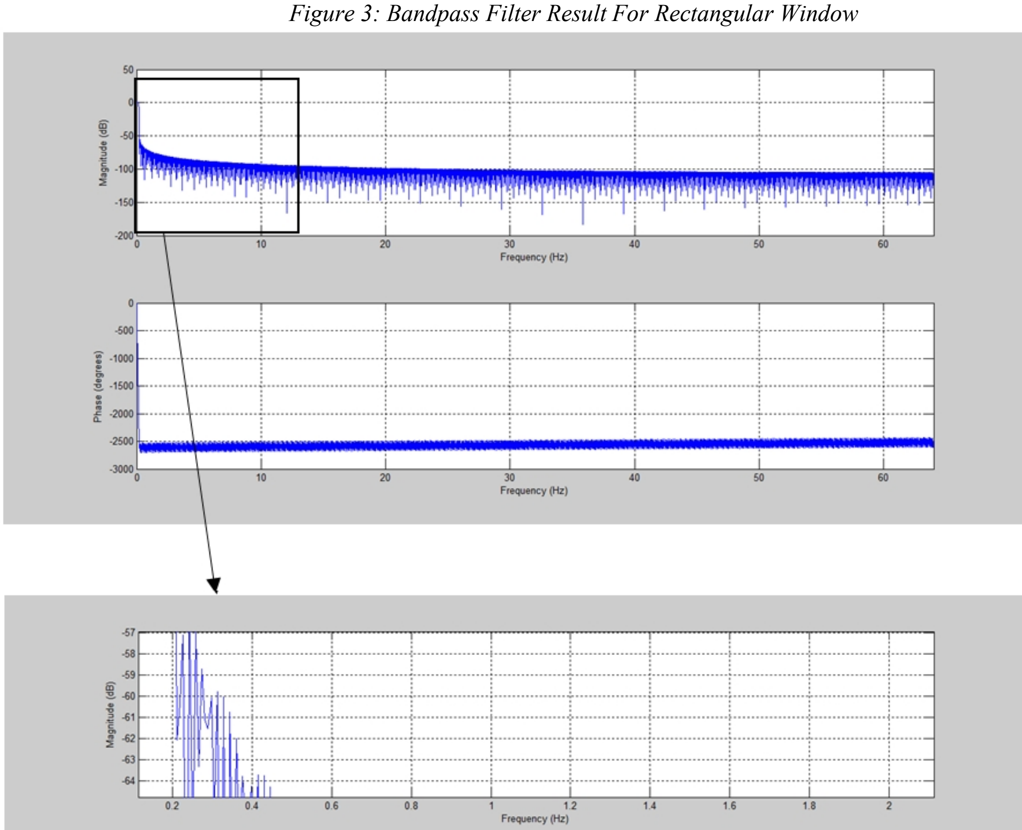

Figure 4: Bandpass Filter Result For Hamming Window

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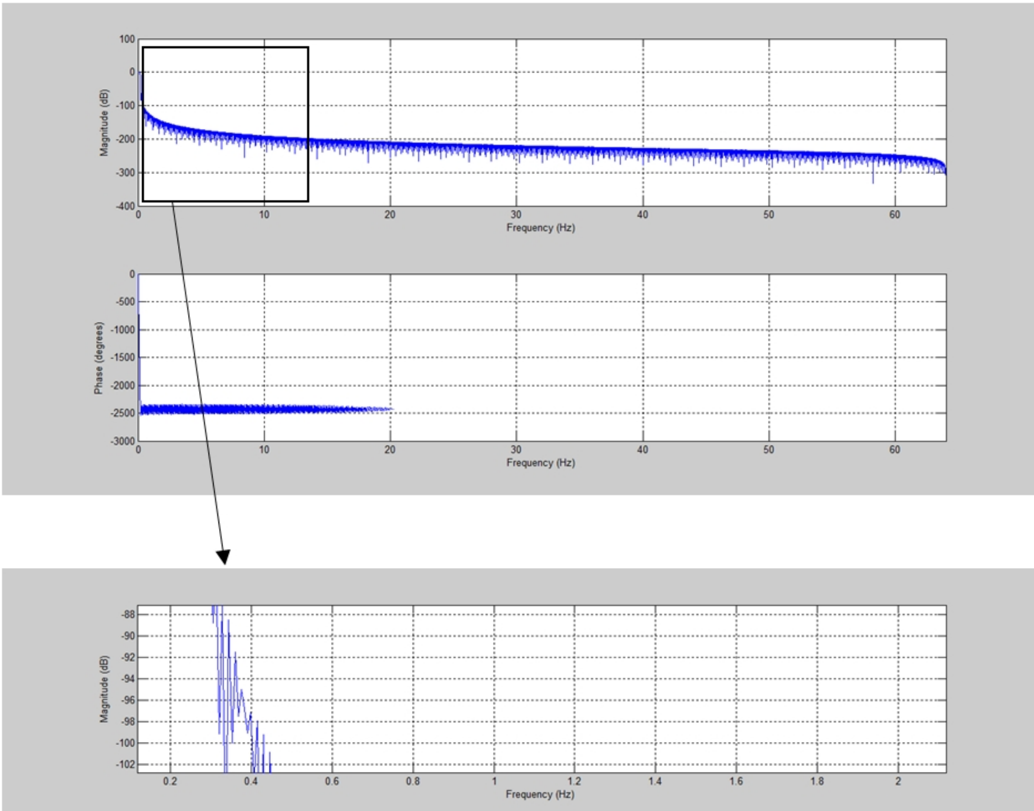

Figure 5: Bandpass Filter Result For Hann Window

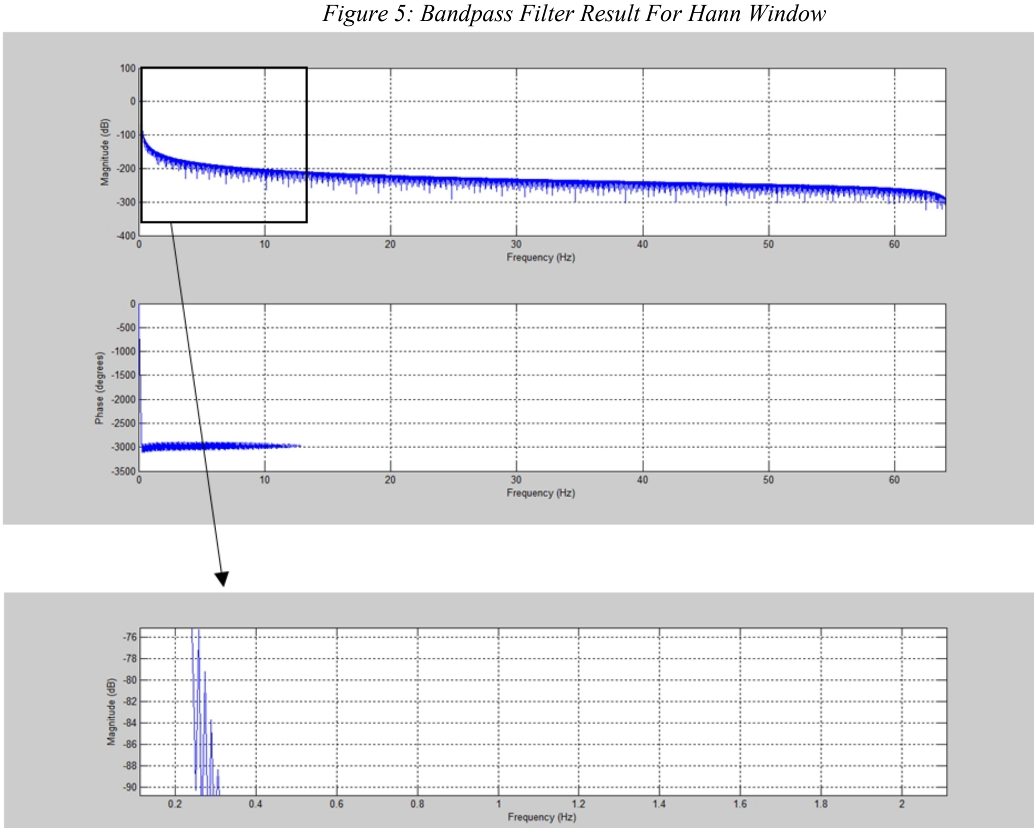

Figure 6: Bandpass Filter Result For Blackman Window

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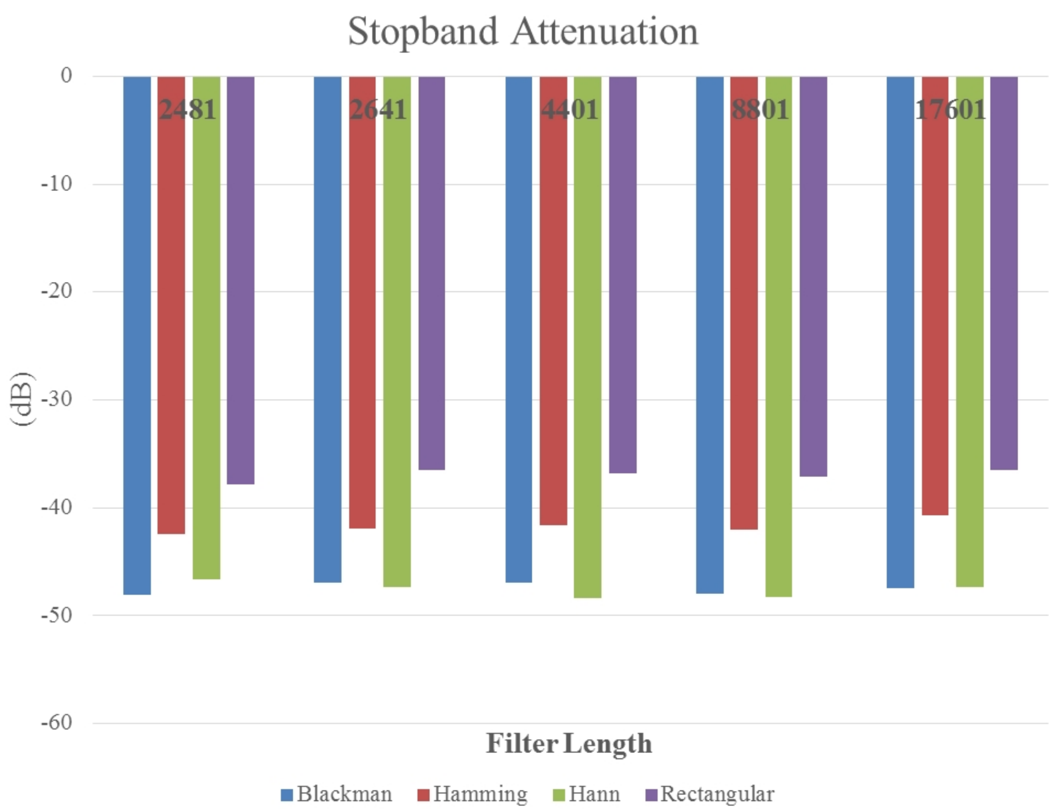

Figure 7: Comparison Of Stopbaand Attenuation

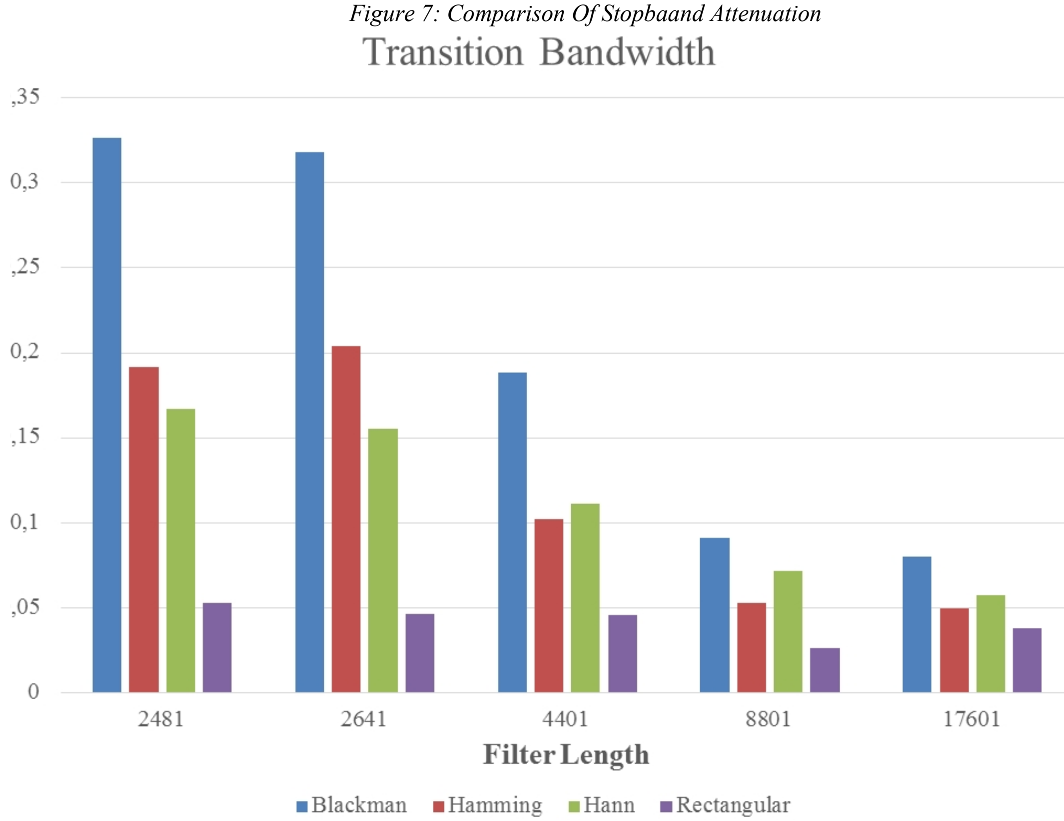

Figure 8: Comparison Of Transition Bandwith

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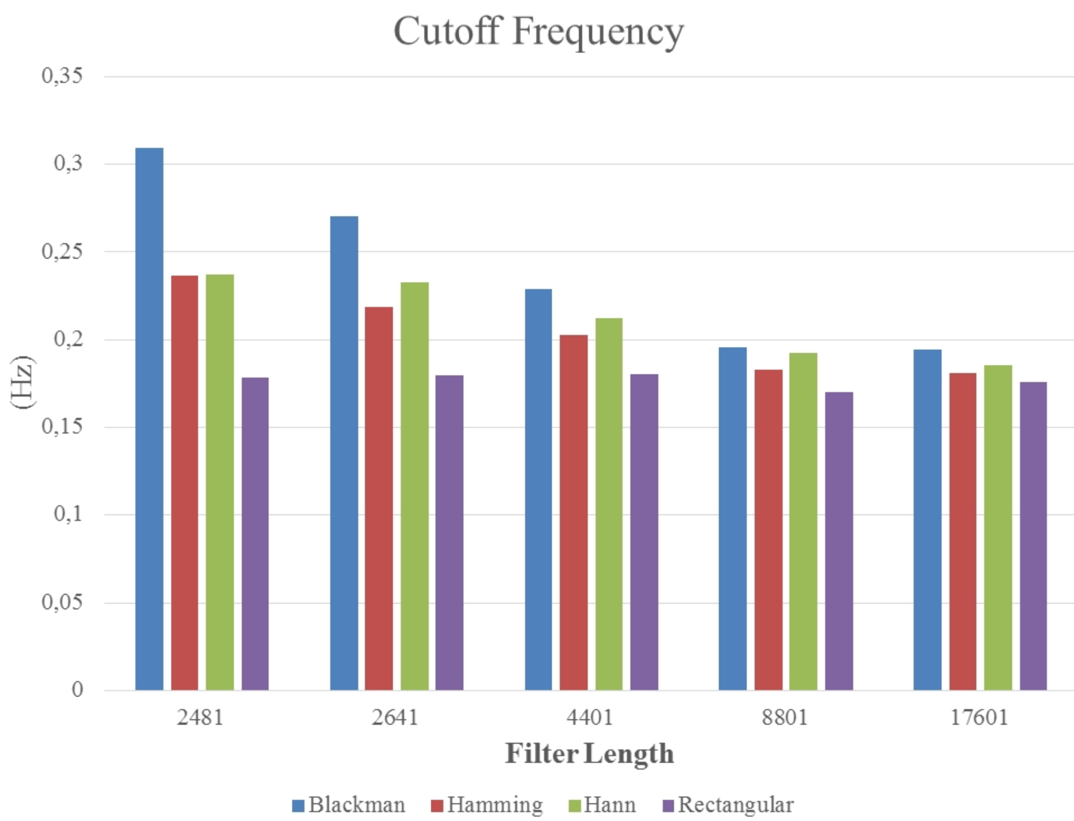

Figure 9: Comparison Of Cutoff Frequency