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A Finite Impulse Response (FIR) Filtering Technique for Enhancement of Electroencephalographic (EEG) Signal

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Abstract: *Electroencephalographic (EEG) signal is electrical record generated by the brain. It is a vital signal as far as the monitoring, diagnosis and treatment of some health conditions that relate to the human brain are concerned. EEG artifact contaminants have the capability to distort he usefulness of this important bio-electrical signal. Such noises include power line interference, baseline wander, eye blink and eye movement (electro oculogram, EOG) as well as muscle artifacts also called electromyogram (EMG and electrocardiogram (ECG). These are identified as artifacts obtained alongside with EEG by the electrodes of the electroencephalograph which are placed on the scalp of the subject in the EEG procedures. This work focuses on the removal of 10mV 50Hz power line noise from EEG signal using Finite Impulse Response (FIR) filter which is based on a Nuttal window. This technique was simulated in MATLAB/Simulink environment for a real EEG signal that was contaminated with MATLAB generated 10mV 50Hz sine wave signal (power line artifact). The power line noise was seen to have been successfully cancelled out from the EEG with the use of the Nuttall window-based FIR filter modeled with filter order equal to 137 with a band stop filter format of lower sideband and upper sideband frequencies of 40Hz and 60Hz respectively. The filter gives a signal-to-noise ratio (SNR) equal to 2.49dB which is comparable to FIR filters modeled with Hamming, Kaiser, Hann, Gaussian and Bartlett windows.*

Keywords: *EEG, Noise reduction, Nuttall window, Power line artifact, Signal-to-noise ratio.*

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I. Introduction

Electro-biomedical machines have in no small measure aided the diagnosis, monitoring, management and treatment in the modern neurological medicine. Electroencephalograph is one of those electro-biomedical machines. Electroencephalogram (EEG), a signal obtained from Electroencephalograph is a neuro-physiological measurement of the electrical activity of the brain which is recorded from electrodes that are strategically placed on the scalp or, in special cases, subdurally placed in the cerebral cortex for clinical analysis [1]. In 1929 the first EEG procedure was conducted on human being and since then, it has been useful in diagnosis and in scientific research work. Example of such scientific research work is in the Brain Computer Interface (BCI) [2]. In an EEG procedure, electrodes are placed on the scalp to measure the electrical impulse generated by the nerves in the brain. But these electrodes also obtain electrical signals generated from other sources like the eye, muscle, heart and even from the power source that supplies electricity to the electrodes. By this, the brain signals available for the electrodes are contaminated by the presence of these artifacts. The physical properties of the brain signals, like frequency and voltage amplitude which are vital components in the clinical analysis of the subject's brain activity are affected at this point and can easily be recognized by its periodic appearance by mere observation. Because of the presence of these artifacts, the clinical analysis of the subject's neural activity carried out by the physician, so as to determine and treat any neural disorder and cerebral pathologies are hampered. In this condition, wrong analysis and interpretation are inevitable. One can imagine the difficulty a physician may encounter analyzing EEG data of a patient suffering from epileptic seizure which also is contaminated with high frequency artifacts. More so, high amplitude EEG waveform due to seizure may be confusing with high amplitude waveform of ocular artifact [1][3]. In such a case, wrong decisions might be taken by the physician. Although artifacts like the Electrocardiogram (ECG) can be identified by their shapes and patterns, and Electro-Oculogram (EOG) by their spikes, yet some brain conditions can generate wave form that may be in resemblance with these artifacts. Therefore EEG should be made artifact free for its effective use.

EEG contaminants can be biologically (internally) originated such as; Electro-Oculogram (EOG), Electrocardiogram (ECG) and Electromyogram (EMG) or physically (externally) originated such as; 50/60Hz Power Line artifact. Artifacts like eye blink have amplitude much higher than the endogenous brain signal, a voltage amplitude of about 100microVolts (μV) while the endogenous brain signal has voltage level ranging from -50µV to 50µV [2]. Importantly, EEG signal has frequency of 0.1 to 100Hz [4]. It is of great importance; hence it is geared towards delivering EEG results that are free from contamination for sound and accurate physiological analysis of the subject. This study tends to design and implement a Finite Impulse Response (FIR) filter which is based on a Nuttall window to filter 50Hz power line noise from EEG signal. The design is implemented with a band stop filter procedure.

II. Nuttall Window

In FIR filter designed, the length of a unit sample response is normally truncated using a defined window function in other to obtain a finite frequency response. Nuttall window is used to implement the FIR filter function in this study. Mathematically, the Nuttall window function of length N-1 can be represented as w(n) as shown in equation 1.

$$w(n)=a_0-a_1\cos\left(\frac{2\pi n}{N-1}\right)+a_2\cos\left(\frac{4\pi n}{N-1}\right)-a_3\cos\left(\frac{6\pi n}{N-1}\right) \quad (1)$$

where $a_0=0.355768$; $a_1=0.487396$;
$a_2= 0.144232$; $a_3=0.012604$

N-1 = window length or number of window coefficient or samples L = window order, N and L are related as L= N – 1.

More so, the window is given by the expression W(n);

$$W(n) = \begin{cases} w(n) \text{ for } n = 1, 2, 3, \ldots N-1 \\ 0 \quad\quad\quad\quad\quad \textit{elsewhere} \end{cases}$$

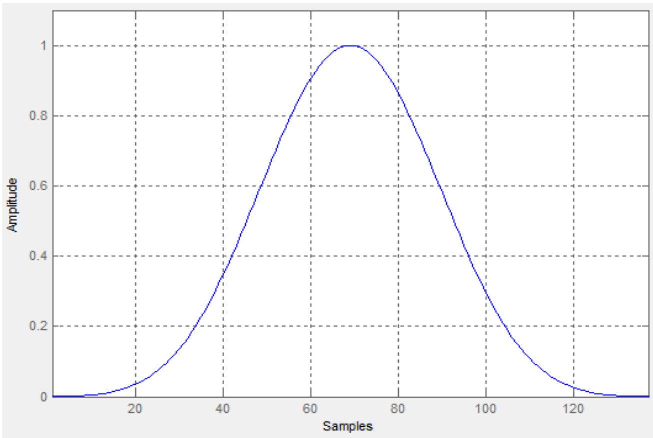

Fig 1. Time domain of 137-Length Nuttall window

Figures 1, 2, 3, 4 and 5 show the time domain, frequency domain, impulse response, magnitude response and phase response of Nuttall window respectively. The good linearity nature of the Nuttall window can be seen in the phase response in fig 5.

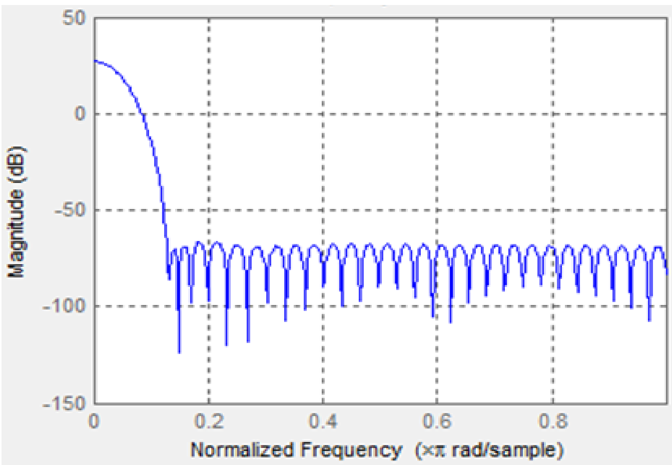

Fig 2. Frequency domain of 137-Length Nuttall window

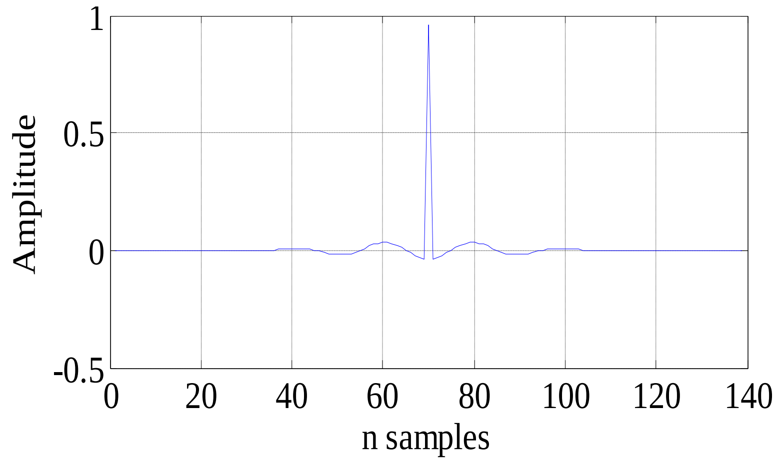

Fig 3. Impulse Response of Nuttall window

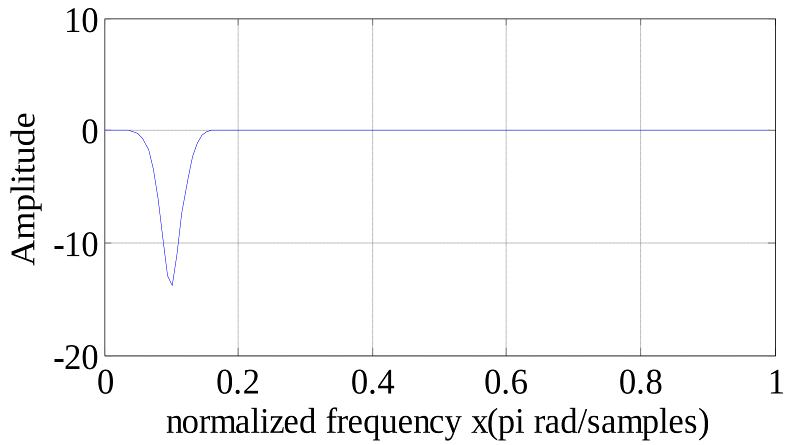

Fig 4. Magnitude Response of Nuttall window

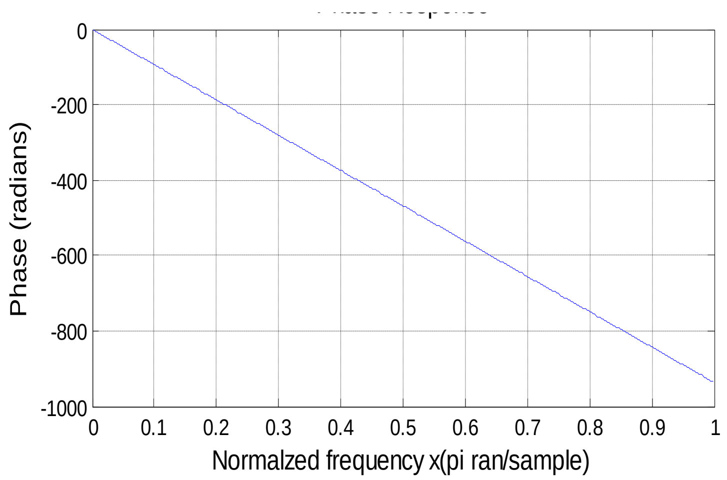

Fig 5. Phase Response of Nuttall Window

III. Design Of Fir Window-Based Nuttall Filter

In the design of FIR filters using window method, a window function is usually used to truncate the equation of ideal impulse response of the implementing filter by multiplying the function of the window by that of the implementing filter. A 137-point Nuttall window is used in this study to truncate the implementing filter. In this case, the implementing filter is the stop band filter. Since the goal of this study is to attenuate 50Hz power line signal from EEG signal of 0.1Hz to 100Hz, the suitable implementing filter is the stop band filter, in this case it can be called the filter handle.

Signal used in this research is a 1200 numbers of iteration samples (g) out of 2000 numbers of iteration samples of a 10-second EEG signal of an 18 year old lady obtained on March 13, 2012 at Federal Medical

Centre (FMC) Owerri, Nigeria, as shown in fig 6. A 50Hz sine wave is generated in MATLAB sampled at 1000Hz to serve as 50Hz power line noise as shown in fig 7. This is used to corrupt the EEG signal resulting in a contaminated EEG in fig 8. Impulse response of the stop band filter of lower cut-off frequency f_1 = 40Hz and upper cut-off frequency f_2 = 60Hz are used. The FIR Nuttall window-based filter is modeled and used in filtering the corrupted EEG using the following MATLAB commands [5].

```
E=[eeg(:,1);eeg(:,2);eeg(:,3);eeg(:,4);eeg(:,5);eeg(:,6);eeg(:,7);eeg(:,8);eeg(:,9);eeg(:,10);
eeg(:,11);eeg(:,12);eeg(:,13);eeg(:,14);eeg(:,15);eeg(:,16);eeg(:,17);eeg(:,18);eeg(:,19);
eeg(:,20)];
load E;
ntr = 1200;  % Number of iterations
v = E (1:1200)'; % EEG signal
fs = 1000; % sampling
f1 = 40; f2 = 60;% lower and upper cutoff frequencies in Hz
w1 = 2*f1/fs; % computes normalized digital lower cutoff frequency;
w2 = 2*f2/fs; % computes normalized digital upper cutoff frequency;
L = 137; % order of the filter;
Wn = [w1  w2];  %  using on symbol to define the two cutoff frequencies;
b = fir1(N,Wn,'stop',nuttallwin(L+2)); % creates the object of the notch filter weighted with nuttall window;
Impz(b) % plots the impulse response of the filter;
k = 1:1200; t = k-1/fs
x1 = 10*sin(2*pi*50*t); % sampled 10Mv 50Hz power line noise;
x = v(1:ntr)+x1(1:ntr);  % contaminated EEG signal;
y = filter(b,1, x); % filters the EEG signal;
subplot(2,2,1),plot(v),title('EEG Signal')% displays the EEG signal in the first quadrant;
subplot(2,2,2),plot(x1),title('10mV 50Hz Noise')% displays the noise in the second quadrant;
subplot(2,2,3),plot(x),title('Noise + EEG Signal')% displays the contaminated EEG signal in the third quadrant;
subplot(2,2,4),plot(y),title('Filtered EEG Signal')% displays filtered EEG signal in the fourth quadrant;
```

IV. Results

The result of the simulation process executed using the MATLAB codes is a noise free EEG signal. The FIR Nuttall window filter was observed to have removed the power line artifact leaving a clean EEG signal shown in fig 9.

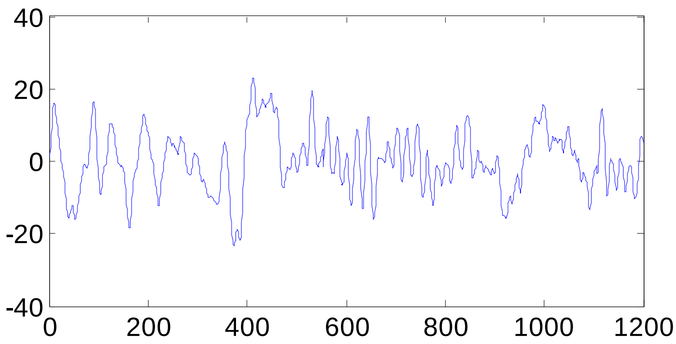

Fig 6.EEG signal

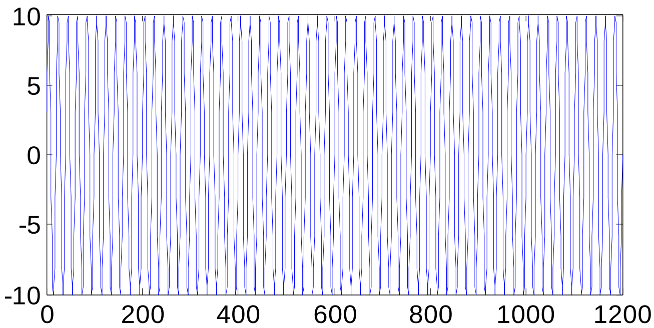

Fig 7. Sampled 10mV, 50Hz power line noise

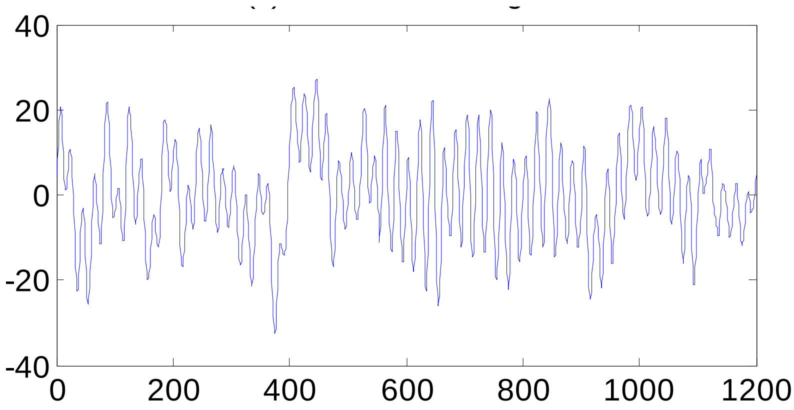

Fig 8. Corrupted EEG signal

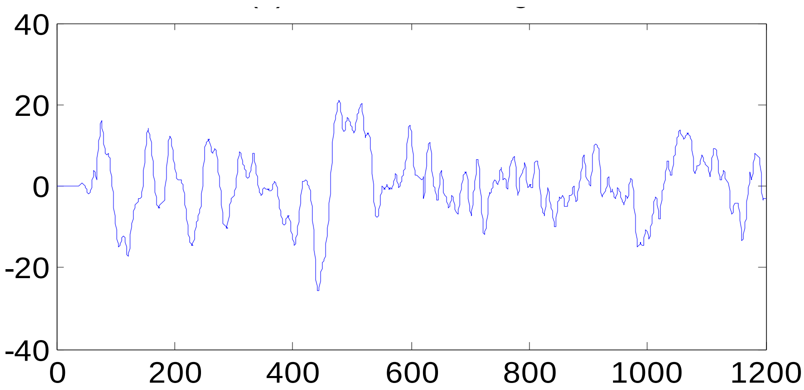

Fig 9. Filtered EEG signal

Fig 11 shows the magnitude response of the 50Hz power line noise. The spike of value seen represents the value of the noise. It can be seen that the power value of the noise at 50Hz is equal to 75.563dB corresponding to normalizing frequency of 0.1 xπ rad/sample which depicts the frequency of 50Hz. The magnitude response of EEG in fig 10 corresponding to normalizing frequency of 0.1 xπ rad/sample (depicting 50Hz) equal to power value of 62.0477dB. But in fig 12 that shows a corrupted EEG, the magnitude response at frequency of 50Hz (corresponding to normalizing frequency of 0.1xπ rad/sample) now becomes 76.314dB. This shows that the noise actually corrupted the EEG. After filtration, the magnitude response now drops from 62.048dB to 62.044 (fig 13). This shows that the Nuttall window-based FIR filter has successfully and effectively attenuated the noise.

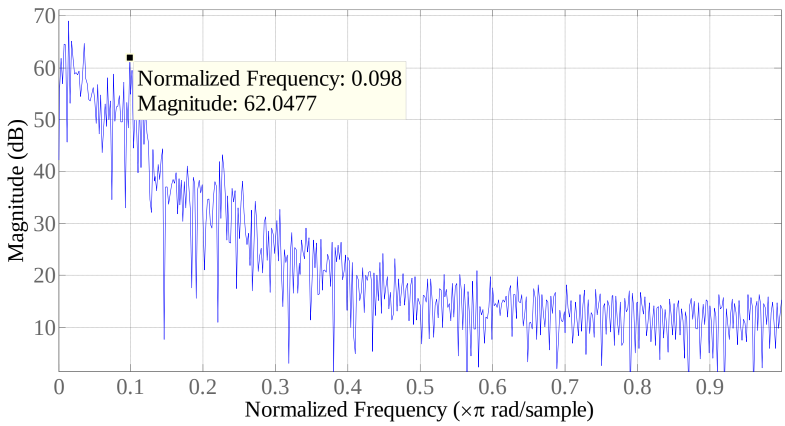

Fig 10. Magnitude response of EEG signal

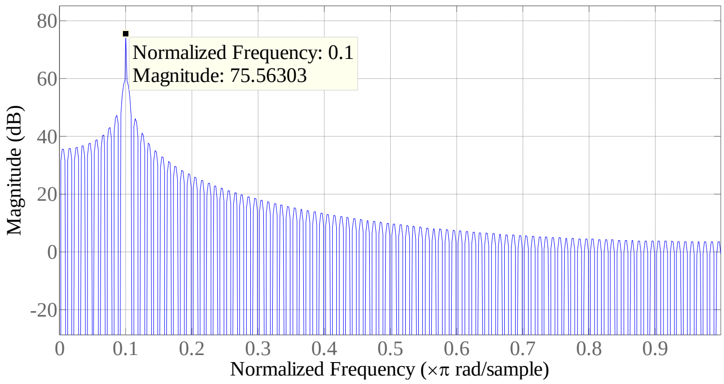

Fig 11. Magnitude response of 10mV 50Hz Noise signal

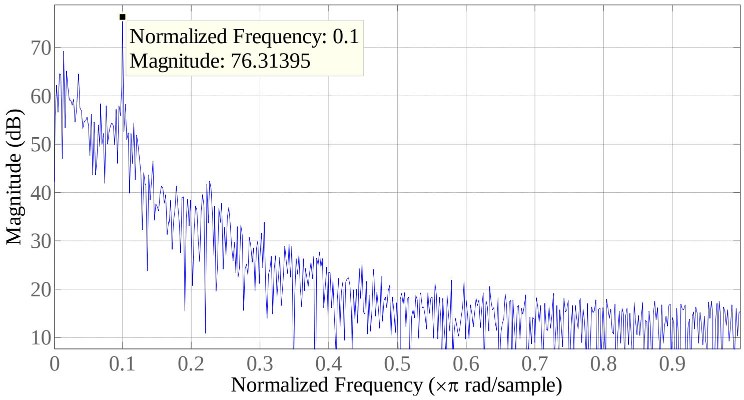

Fig 12. Magnitude response of contaminated EEG signal

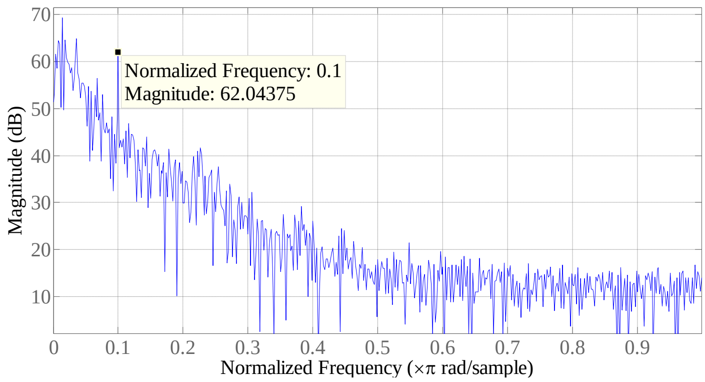

Fig 13 Magnitude response of Filtered EEG signal when, f1=40, f2=60 & L=137

V. Conclusion

Results obtained using the modeled filter with sampling frequency (fs) = 1000Hz and various sets of lower sideband cutoff frequency (f1), upper sideband cutoff frequency (f2) and filter order (L) is shown in table 1. Comparing the findings in table 1 and figures of the magnitude responses of filtered EEG using the sets of specification in table 1 shows that f1=40, f2=60 and L=137 is the best set of specification for the filter.

Table 1 Magnitude responses of filtered EEG with different values of f1, f2 and L

Filter Order (L)	Magnitude Response (dB) of Filtered EEG at Different Cutoff Frequencies		
	f1=40Hz and f2=60Hz	f1=41Hz and f2=59Hz	f1=42Hz and f2=58Hz
131	62.970	64.780	66.464
133	62.658	64.519	66.247
135	62.350	64.261	66.024
137	62.044	64.005	65.821
139	61.739	63.756	65.612
141	61.437	63.500	65.406
143	61.140	63.252	65.203
145	60.847	63.009	65.004

147	60.557	62.768	64.805
149	60.260	62.520	64.602
151	59.944	62.258	64.386
153	59.602	61.975	64.155
155	59.243	61.679	63.914
157	58.881	61.382	63.672
159	58.437	61.092	63.436
161	58.190	60.816	63.211
163	57.874	60.555	62.999
165	57.584	60.312	62.800
167	57.320	60.088	62.615
169	57.081	59.881	62.440
171	56.851	59.679	62.269
173	56.617	59.473	62.094
175	56.361	59.250	61.907

In addition, the researcher compared the signal-to-Noise ratio (SNR) of the FIR Nuttall window-based filter with some window-based FIR filters commonly used in signal processing namely Bartlett, Gaussian, Hann, Kaiser and Hamming. The result tabulated in table 2 shows that the FIR Nuttall window-based filter is comparable. Therefore the filter is valid.

Table 2. SNR of some FIR window based filters

Signal to noise ratio of FIR (windowing) filtered EEG signal (dB)					
Nuttall	Hamming	Kaiser	Hann	Gaussian	Bartlett
2.49	2.50	2.47	2.50	2.50	2.47

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