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# Performance Analysis of Various Windows in The Reduction Of Powerline Interference In Ecg Signal

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## ABSTRACT

Filtering of powerline noise is very significant in the measurement of biomedical events recording, specifically in the recording of ECG signal which is very weak in nature, about 1mV. If this powerline noise and the biomedical signals that mix up with the ECG signal are not filtered out interpretation of the recorded ECG signal may be difficult. Digital finite impulse response (FIR) filters are able to filter out these contaminating signals if properly designed and implemented. The propriety of the design includes the suitability of the window function used in weighting the digital FIR filter with respect to ECG signal processing. This work examines the effectiveness of six different types of window functions in the design and development of digital FIR notch filters for reduction of powerline interference in ECG. Results are obtained with matlab and recorded.

**Keywords:** *ECG, Noise reduction, powerline, windows, Signal to noise ratio.*

## 1. INTRODUCTION

The field of biomedical signal processing and analysis has advanced to the stage of practical application of signal processing and analysis techniques for efficient and improved diagnosis and monitoring of critical patients. Electrocardiogram (ECG) is an important clinical signal for investigating the activities of heart. Interpretation of the details provides for diagnosis of a wide range of heart conditions. Incidentally this ECG signal is mixed with other biomedical signals and the powerline noise signal from the power source supplying the recording equipment or electrocardiograph, also abbreviated ECG. These signals mixing with the ECG effectively contaminate it and degrade its quality. For correct interpretation of the features and frequency of the ECG signal, these contaminating signals must be removed from it, and digital filters are used to remove these contaminating signals.

In [1] Chinchkhede et al implemented FIR digital filters with four different windows and tested their strengths in enhancement of ECG signal. Yatindra and Gorav [2] did a performance analysis of three different types of digital filters to reduce powerline interference in ECG. The filters are notch filter for frequency domain filtering, Wiener filter for optimal filtering and adaptive filter for adaptive filtering. Aung et al [3] did a step by step analysis of how digital filters can be used to cancel powerline interference in ECG. In [4] the authors designed and implemented Butterworth, Chebyshev type I, chebyshev type II and elliptic digital filters and compared their performances in removing power supply noise in ECG. The authors in [5] used LMS-based adaptive filter to filter off the 50Hz powerline interference. In [6] Manpreet and Birmohan exploited the effectiveness of the combination of moving average method and IIR notch filter to reduce powerline interference and baseline wander in ECG. In [7] Sonal and Uplane designed and developed digital Chebyshev Type II low pass, high pass and notch filters for removing the Electroencephalogram, baseline wander and powerline noise contaminating signals respectively. Mbachu et al in [8] used rectangular window-based FIR filter to filter off artifacts in ECG signal. The authors designed and implemented low pass, high pass and notch filter to remove the high frequency, low frequency and powerline interferences in the ECG signal respectively. Mbachu et al [9] investigated the performance of Kaiser Window-based FIR digital filters in processing ECG Signal. Mbachu et al [10] designed and implemented an adaptive filter for suppression of powerline interference in ECG and the filter performed satisfactorily. Sarkar [11] in his book examined in general terms different types of windows that can be used in the design of FIR filters. The windows include Hamming, H` anning, triangular, rectangular, Blackman and Kaiser windows. In [12] Kaiser J. F. designed a non-recursive digital filter using the sine window function.

In this paper the author proposes to compare the performances of Hanning, Hamming, Blackman and Kaiser windows with two other windows, Height Adjustable Triangular (HAT) and Height Adjustable Sine (HAS) windows developed by the author of this paper in designing and implementing FIR digital filters for reduction of powerline interferences in ECG.

## 2. WINDOW FUNCTIONS

With M as the number of filter coefficients or samples and L, the order of the filter, in which case M= L+1, the mathematical models of the six windows for the design are presented below.

### i. Hanning Window

From [11] the Hanning window is given as in eqn (1)

$$w(k) = 0.54 - 0.46\cos\left[2\pi k \big/ (M-1)\right]$$

$0 \le k \le M-1$

(1)

A 101-sample Hanning window is plotted in fig 1. In this case k varies from 0 to 100 at an increment of 1, giving rise to 101 samples.

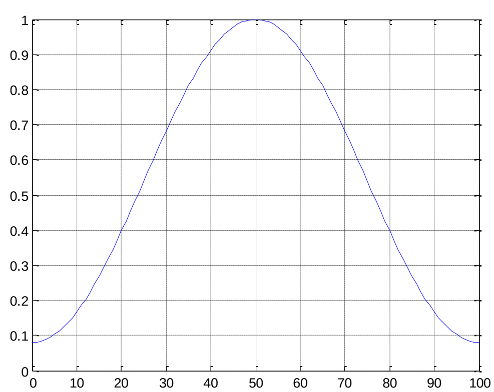


**Fig. 1: 101-Sample Hanning Window Function**

### ii. Hamming Window

From [11] the Hamming window is given as in eqn (2)

$$w(k) = \frac{1}{2}\left[1 - \cos\left(2\pi k \big/ (M-1)\right)\right], 0 \le k \le M-1$$

(2)

A 101-sample Hamming window is depicted in fig. 2.

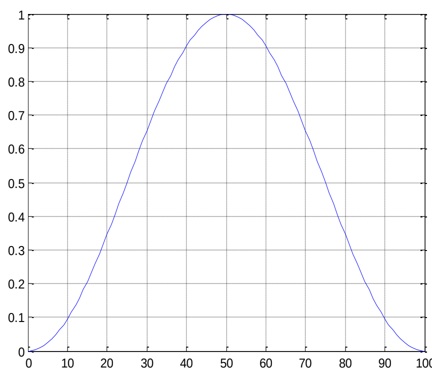


**Fig 2: 101-Sample Hamming Window**

### iii. Blackman Window

As contained in [1,11] the Blackman window is as shown by eqn (3). A 101-sample Blackman window is as presented in fig. 3.

$$w(k) = 0.42 - 0.5\cos\left(\frac{2\pi k}{M-1}\right) + 0.08\cos\left(\frac{4\pi k}{M-1}\right)$$

$$0 \le k \le M-1 \qquad (3)$$

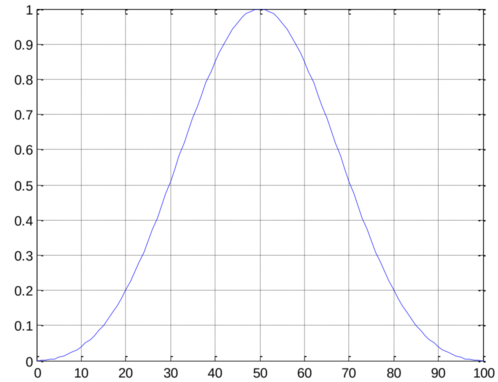


**Fig. 3: 101-Sample Blackman Window**

### iv Kaiser Window

The Kaiser window function is expressed as [1, 9, 11, 12] in eqn (4). A 101 sample Kaiser window is shown in fig. 4

$$\begin{cases} \omega_n(\beta,k) = \dfrac{J_o\left[\beta\left[1-\left(\dfrac{2k}{M-1}\right)^2\right]^{\frac{1}{2}}\right]}{J_o\beta}, \\ for \\ \qquad -\dfrac{(M-1)}{2} \le k \le \dfrac{(M-1)}{2} \\ = 0, \; otherwise \end{cases}$$

(4)

where $J_o(x)$ is the modified Bessel function of the first kind of order zero.

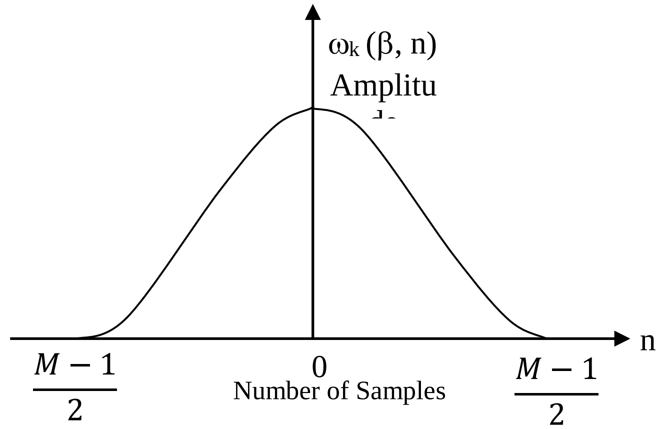


**Fig. 4: 101-sample Kaiser Window**

### v. Height Adjustable Triangular (HAT) Window

The mathematical model of HAT window is shown as eqn (5). A HAT window function is presented in fig. 5

$$w(k) = \begin{cases} \alpha + (2-2\alpha)k/(M-1), & 0 \le k \le \dfrac{M-1}{2} \\ 2 - [\alpha + (2-2\alpha)k/(M-1)], & \dfrac{M-1}{2} \le k \le M-1 \end{cases}$$

(5)

where $\alpha$ varies from 0 to 1.

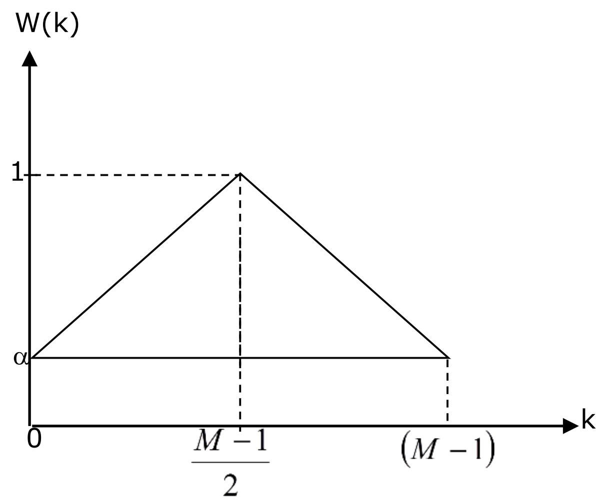


**Fig. 5: HAT Window**

 

### vi. Height Adjustable Sine (HAS) Window

The HAS model is as expressed by eqn (6). The diagram of a HAS window function is depicted in fig. 6.

$$w(k) = \begin{bmatrix} \alpha + \sin\left[\dfrac{2\sin^{-1}(1-\alpha)}{L}\right]k, 0 \le k \le \dfrac{L}{2} \\ \alpha + \sin\left[\dfrac{(L-k)2\sin^{-1}(1-\alpha)}{L}\right]\dfrac{L}{2} \le k \le L \end{bmatrix} \quad (6)$$

where α varies from 0 to 1.

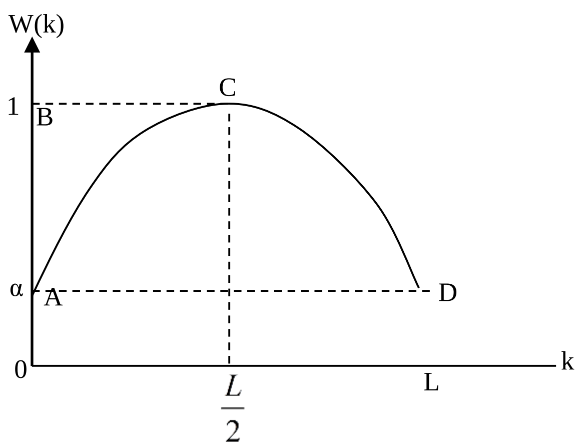


**Fig. 6: HAS Window**

## 3. EVALUATION MEASURE

The output signal to noise ratio ($SNR_o$) is the figure of merit that will be used to measure the performance of the filters.

$$SNR_o = 10Log\frac{\sum S_F^2}{\sum N_o^2} \quad (7)$$

where No, the output noise power, is the noise power present in the filtered signal power, while $S_F$ is the power of the filtered signal. Output noise power No is given by

$$No = S - S_F \quad (8)$$

where S is the power of the corrupt signal. Using (8) in (7) gives (9)

$$SNR_o = 10Log\frac{\sum S_F^2}{\sum (S - S_F)^2} \quad (9)$$

For a three level noise the output signal to noise ratio from (9) is given as in (10)

$$10\log\frac{S_{F1}^2+S_{F2}^2+S_{F3}^2}{(S_1-S_{F1})^2+(S_2+S_{F2})^2+(S_3-S_{F3})^2} \quad (10)$$

If the noise level is only one the noise ratio from (10) condenses to (11)

$$10\log\frac{S_{F1}^2}{(S_1-S_{F1})^2} \quad (11)$$

## 4. DESIGN OF NOTCH FILTERS

Each of the six windows stated above is used to design a notch filter for reducing powerline interference in ECG. With powerline frequency of 50Hz, sampling frequency of 1000Hz and filter order of 100 the magnitude responses of the notch filters designed with Hanning, Hamming, Blackman and Kaiser windows are depicted in figures 7, 8, 9 and 10 respectively. Additionally, with the value of α as 0.02 in (5) and 0.005 in (6) the magnitude responses of the notch filters designed with HAT and HAS windows are equally depicted in fig. 11 and fig. 12 respectively.

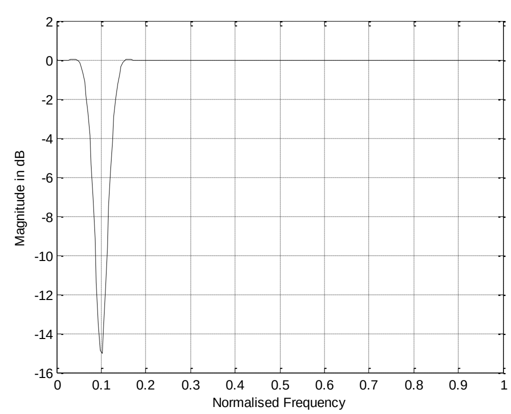


**Fig. 7: Magnitude Response of Notch Filter Designed with Hanning Window**

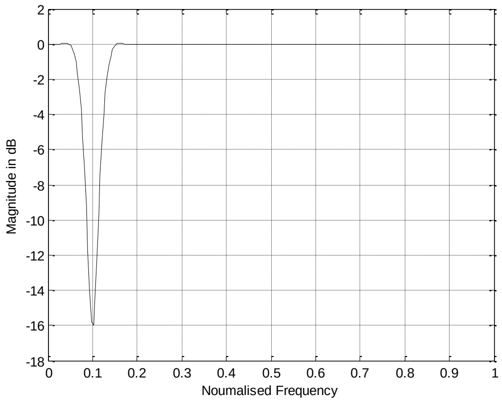


**Fig. 8: Magnitude Response of Notch Filter Designed with Hamming Window**

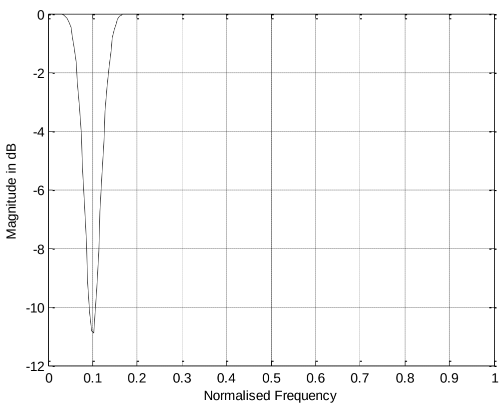


**Fig. 9: Magnitude Response of Notch Filter Designed with Blackman Window**

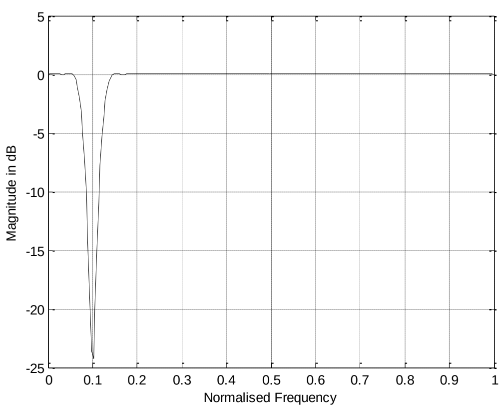


**Fig. 10: Magnitude Response of Notch Filter Designed with Kaiser Window**

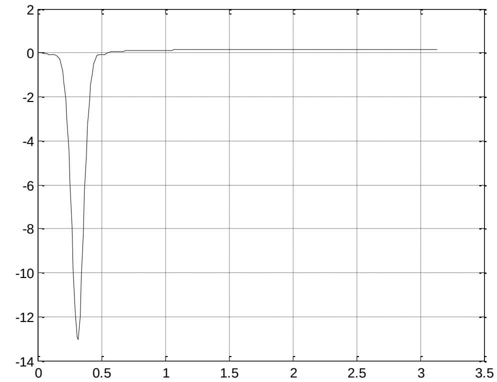

**Fig. 11: Magnitude Response of Notch Filter Designed with HAT Window**

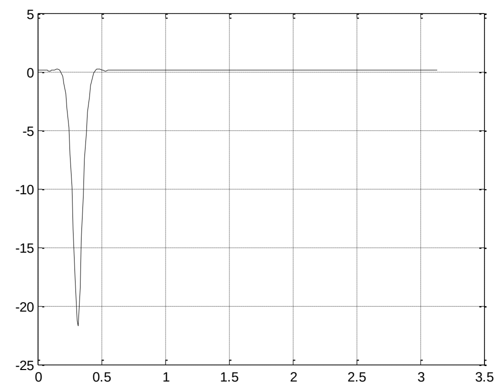

**Fig. 12: Magnitude Response of Notch Filter Designed with HAS Window**

## 5. RESULTS

A clean ECG signal containing 4 cycles from a heart beat of about 89 bps is presented in fig 13. The clean ECG signal is contaminated with a 50Hz powerline interference and the contaminated signal is presented in fig 14. The contaminated ECG signal is filtered separately with the notch filters designed with the six different windows in sequence and the filtered signals are presented figures 15, 16, 17 , 18, 19 and 20. The signal to noise ratios of the contaminated and filtered ECG signals are calculated, using the expression of eqn (9) and the values are tabulated as in table 1.

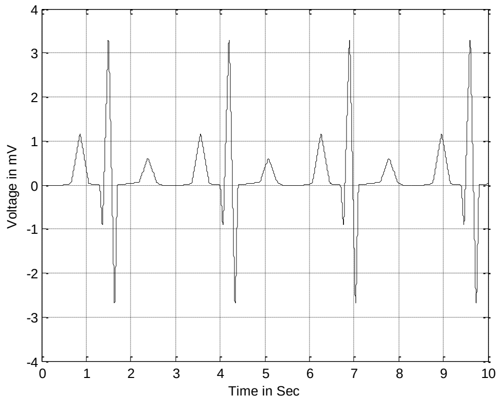


**Fig. 13: ECG Signal Showing Four Cycles**

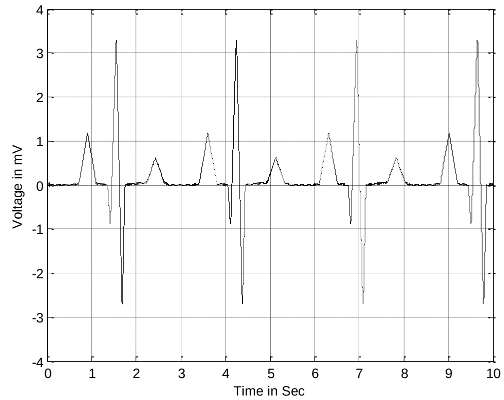


**Fig. 16: ECG signal Filtered with Notch Filter Designed with Hamming Window**

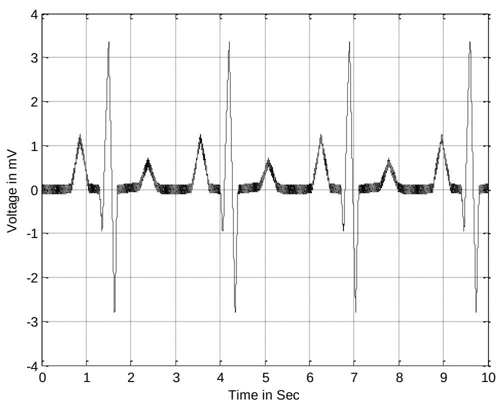


**Fig. 14: ECG signal Corrupt with 50Hz Powerline Noise**

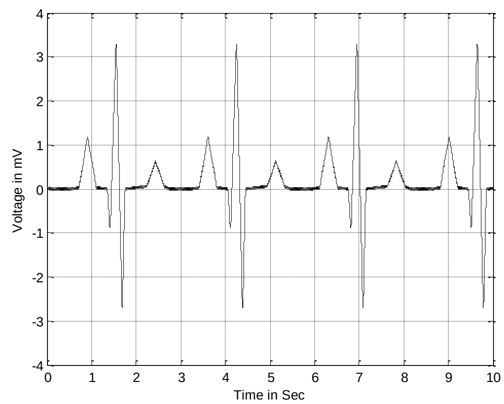


**Fig. 17: ECG signal Filtered with Notch Filter Designed with Blackman Window**

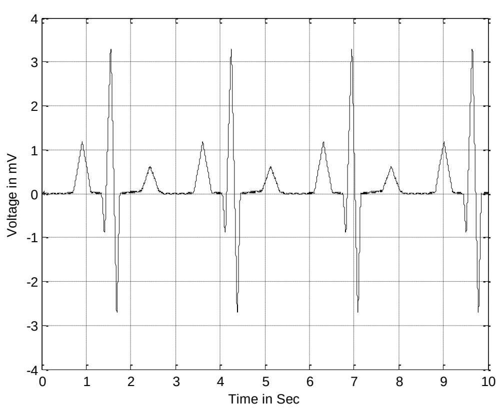


**Fig. 15: ECG signal Filtered with Notch Filter Designed with Hanning Window**

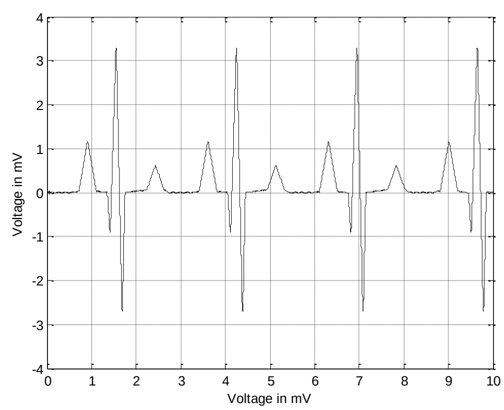


**Fig. 18: ECG Signal Filtered with Notch Filter Designed with Kaiser Window**

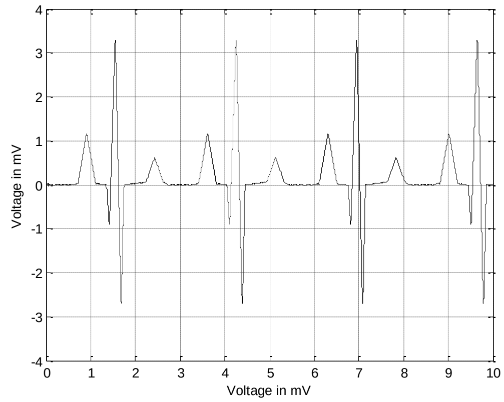


**Fig. 19: ECG signal Filtered with Notch Filter Designed with HAT Window**

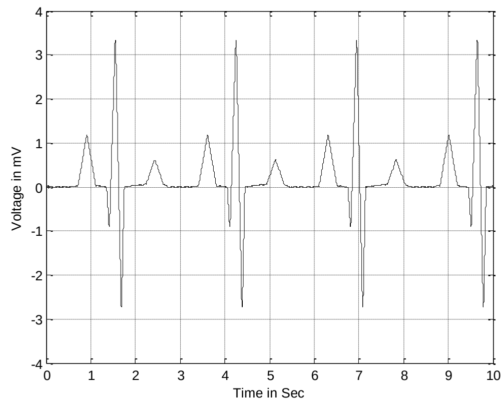


**Fig. 20: ECG signal Filtered with Notch Filter Designed with HAS Window**

By invoking equation (11) since only one noise level is being considered, the signal to noise ratios of the ECG signals at 50Hz filtered with FIR notch filters designed with six different windows, for removing powerline interference are computed and presented in table 1. The signal to noise ratio of the corrupt ECG signal is **15.03dB.**

**Table 1: Signal to Noise Ratios of ECG Signals at 50Hz Filtered with Notch Filters Designed with Different Windows**

| Different Windows Used in the Notch Filter Design | Signal to Noise Ratio ($SNR_O$) of the Filtered ECG Signals in dB |
|---|---|
| Hanning Window | 29.88 |
| Hamming Window | 32.08 |
| Blackman Window | 16.82 |
| Kaiser Window | 49.36 |
| HAT Window | 25.89 |
| HAS Window | 44.12 |

## 6. DISCUSSION

Analysis of the magnitude responses of figures 7 to 12 for the six notch filters designed with the six different windows suggests that the Kaiser window will relatively reduce the 50Hz powerline interference most followed by the HAS window because of their comparative high attenuation levels of -24.22dB and -21dB respectively, while the Blackman window is the least because of its low attenuation level of -10.71dB. Observation of the corrupt signal of fig. 14 and filtered signals of figures 15 to 20 and comparing them with the clean signal of fig. 13 shows that each of the six filters reduced the 50Hz powerline noise in the ECG. The signal to noise ratios in/ table 1 confirms that the Kaiser window is comparatively the most effective in reducing powerline interference in ECG followed by the HAS window, while the Blackman window is the least effective. It is therefore recommended that in consideration of the six windows Kaiser window should be used in designing notch filters for the removal of powerline interferences in ECG.

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