*International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)*
*Volume-3 Number-3 Issue-12 September-2013*

# Performance analysis of adjustable window based FIR filter for noisy ECG Signal Filtering

**N. Mahawar[1], A. Datar[2], A. Potnis[3]**

## Abstract

***Recording of the electrical activity associated to heart functioning is known as Electrocardiogram (ECG). ECG is a quasi-periodical, rhythmically signal synchronized by the function of the heart, which acts as a generator of bioelectric events. ECG signals are low level signals and sensitive to external contaminations. Electrocardiogram signals are often corrupted by noise which may have electrical or electrophysiological origin. The noise signal tends to alter the signal morphology, thereby hindering the correct diagnosis. In order to remove the unwanted noise, a digital filtering technique based on adjustable windows is proposed in this paper. Finite Impulse Response (FIR) low pass is designed using windowing method for the ECG signal. The results obtained from different techniques are compared on the basis of popularly used signal error measures like SNR, PRD, PRD1, and MSE.***

## Index Terms

***Electrocardiogram (ECG), Finite Impulse Response (FIR), Filter bank, Percentage Root Mean Square Difference (PRD), Percentage root mean square difference1(PRD1), Mean Square Error (MSE), Signal-to-Noise ratio (SNR), Maximum Amplitude Error (MAX), Massachusetts Institute of Technology/Beth Israel Hospital (MIT/BIH).***

## 1. Introduction

An Electrocardiogram (ECG) is a recording of the electrical activity on the body surface generated by the heart. Generally the skin electrodes placed at the designated locations on the body collects ECG information. The ECG signal is characterized by the six peaks and valley labeled with successive letters of the alphabets P, Q, R, S, T, and U as shown in Figure 1. [9] The front end of the ECG must be able to deal with extremely weak signals ranging from 0.5mV to 5mV, combined with DC component of up to ±300mV resulting from electrode skin contact plus common mode component of up to 1.5V, resulting from the potential between ground.[5][8][9], ECG gets corrupted due to different kinds of the artifacts like power line interference, motion artifacts, base line drift and instruments noise.

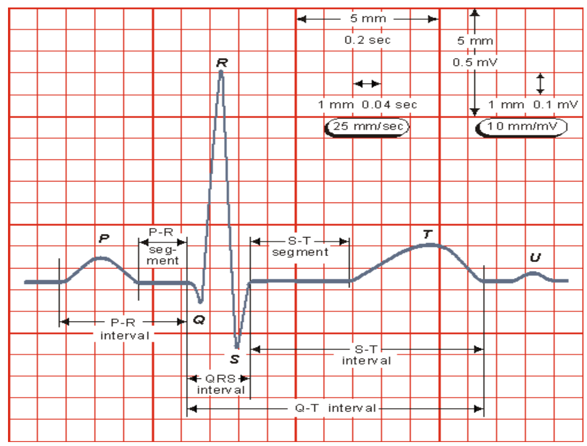


**Fig.1: Basic ECG signal.**

In order to remove unwanted noise, a digital filtering technique using adjustable windows is suitable. The present work deals with the design of window based FIR low pass filters to reduce the interference present in the ECG signal. ECG signals from MIT-BIH database are used and corrupted with Gaussian noise. This corrupted signal then filtered using designed FIR filter. The obtained results are compared on the basis of popularly used signal error measures like Signal-to-Noise Ratio (*SNR)*, Percentage root mean square difference *(PRD)*Percentage root mean square difference1*(PRD1)*, Mean Square Error (*MSE) and* Maximum Amplitude Error*(MAX)* .

This paper is organized as follows: section 2 describes the FIR filters design, section 3 discusses the ECG error measuring parameters, section 4 shows the experimental results and section 5 is the conclusion.[1]

**N. Mahawar,** Assistant Professor in Department of Biomedical Engineering, SATI (Engg.) Vidisha (M.P.).
**A. Datar,** Associate Professor in Department of Biomedical Engineering, SATI (Engg.) Vidisha (M.P.).
**A. Potnis,** Associate Professor in Electronics and Communication Engineering department, NITTTR Bhopal.

## 2. FIR Filter Design

### 2.1. Windowing

Window functions are used to truncate the infinite data series to some finite limits. The data that are beyond the truncation point are simply ignored. This windowed series may be processed more efficiently than the original one. A practical window usually has a trade-off between the width of its main-lobe and attenuation of its side-lobes. No window is the best in all aspects and it should be selected according to the requirements of a particular application. [10]

### 2.2. Kaiser window

In design of a low pass filter using windowing technique, four parameters the passband edge $\omega_p$, the stopband edge $\omega_s$, passband ripple $A_p$and stopband attenuation $A_s$, are required. The prototype filter $h(n)$ is designed using widely used Kaiser window. The Kaiser Window function *w(n)* is given as [12]

$$w(n) = \begin{cases} \dfrac{I_o\left\{\alpha\sqrt{1-\left(\frac{n}{N}\right)^2}\right\}}{I_o(\alpha)} & -N \le n \le N \\ 0 & otherwise \end{cases}$$

(1)

Where $I_0$ (.) the $0^{th}$ order is modified Bessel function, which can be computed as:

$$I_0(x) = 1 + \sum_{k=1}^{\infty}\left(\frac{(0.5x)^k}{k!}\right)^2$$

(2)

The adjustable parameter α can be determined by designed $A_s$

$$\alpha = \begin{cases} 0 & for \quad A_s \le 21 \\ (0.5842(As-21))^{0.4} + 0.07886(As-21) & for \quad 21 < A_s \le 50 \\ 0.1120\ (As\text{-}8.7) & for \quad A_s > 50 \end{cases}$$

(3)

For desired $A_s$and an appropriate chosen transition bandwidth Δω, the order of window *N* can be estimated as: [8][9],

$$D = \begin{cases} 0.9222 & forA_s \le 21 \\ \dfrac{(A_s - 7.95)}{(14.36)}, & orA_s > 21 \end{cases} \qquad (4)$$

### 2.3. Dolph –Chebyshev window (DC window)

The window function expression in discrete time domain for variable Dolph –Chebyshev window is given by [12]-[13],

$$w(n) = \begin{cases} \dfrac{1}{N+1}\left(\dfrac{1}{r} + 2\sum_{i=1}^{\frac{N}{2}} C_N\left[x_o\cos\left(\dfrac{i\pi}{N+1}\right)\cos\left(\dfrac{2ni\pi}{N+1}\right)\right]\right), & for\,|n| \le \dfrac{N}{2} \\ 0, & for\,|n| > \dfrac{N}{2} \end{cases}$$

Where, $r = \dfrac{A_s}{A_p}$, $x_o = \cosh\left[\dfrac{1}{N}\cosh^{-1}\left(\dfrac{1}{r}\right)\right]$,

(5)

$$C_N(x) = \begin{cases} \cos(N\cos^{-1}(x)), & for\,|x| \le 1 \\ \cosh(N\cosh^{-1}(x)), & for\,|x| > 1 \end{cases}$$

Here $A_s$is the pass band ripple.

The empirical design equation (4) given by Kaiser for computation of D for DC window. The modified equation is given by

$$D = \begin{cases} 0.9222 & forA_s \le 21 \\ \dfrac{(A_s - 5.45)}{(14.36)}, & orA_s > 21 \end{cases}$$

The filter order (N) for both windows may be calculated as

*N=[D/Δf]+1*

Where $\Delta f$is the normalized transition band width is = $(f_s - f_p) = (\omega_s - \omega_p)/2\pi$, $fp = (\omega_p/_{2\pi})$ is the normalized passband frequency and,$fs = (\omega_s/_{2\pi})$ is the normalized stopband frequency.

### 2.4. Impulse response filter design

The frequency response of a digital filter is periodic with period equal to the sampling rate. Using Fourier series any periodic function can be expressed as a linear combination of complex exponentials as given below:

$$H(e^{j\omega T}) = \sum_{n=-\infty}^{\infty} h_d(n)e^{-j\omega nT} \qquad (6)$$

Whose transfer function is

$$H(z) = \sum_{n=-\infty}^{\infty} h_d(n)z^{-n} \qquad (7)$$

Where, $h_d(n)$is the desired impulse response of filter, T is the sampling interval, and ω is the frequency in radians.

### 2.5. Low pass filter design

The impulse response required to implement the ideal lowpass filter is infinitely long it is impossible to design an ideal FIR lowpass filter. Finite length approximation to the ideal impulse response leads to the presence of ripples in both the passband $\omega<\omega_c$and the stopband of th $\omega>\omega_c$e filter, as well as to a nonzero transition width between the passband

and stopband of the filter so $h_d(n)$ is modified impulse response to implement low pass FIR filter. It is based on the above concept and the cut-off frequency of lowpass filter is varied in a linear manner after initializing the filter coefficients, the values of which are decided by initial passband and transition band. The window method is used to find the initial values of $h_0(n)$. Depending on the transition band width, filter order is obtained and then window coefficients $w(n)$ are calculated. In window method, the initial value ofimpulse response $h_0(n)$ is calculated as[11]
For prototype filter,

$$h_0(n) = w(n).h_d(n) \qquad (8)$$

Where,

$$h_d(n) = \frac{\sin\left(\omega_c\left(n - \frac{N}{2}\right)\right)}{\pi\left(n - \frac{N}{2}\right)} \qquad (9)$$

## 3. ECG Error Measuring Parameter

The quality measurement of the reconstructed ECG signal is obtained by the most widely used parameters like the percentage root-mean square difference (PRD), Signal-to-Noise Ratio (SNR), Mean Square Error (MSE) for the filtered output signal. [6]

### 3.1. Percentage root mean square difference (PRD)

Let $x[n]$ and $\hat{x}[n]$ be the original and the reconstructed signal, respectively, of $L$ samples. The *PRD*forula is defined as: [1],[3],[6].

$$PRD = \sqrt{\frac{\sum_{n=1}^{L}\left(x[n] - \hat{x}[n]\right)^2}{\sum_{n=1}^{L}\left(x[n]\right)^2}} \times 100 \qquad (10)$$

This parameter as quality measurement can mask the real performance of an algorithm since the *PRD* depends a lot on the mean value of the original signal. When using the *PRD* care must be taken to remove the baseline, or at least, to eliminate the DC level. To avoid this problem, *PRD*1which independent of the mean value, is used.

$$PRD1 = \sqrt{\frac{\sum_{n=1}^{L}\left(x[n] - \hat{x}[n]\right)^2}{\sum_{n=1}^{L}\left(x[n] - \bar{x}[n]\right)^2}} \times 100 \qquad (11)$$

Where $\bar{x}[n]$ is the mean value of the signal $x[n]$

### 3.2. Mean square error (MSE)

The average of the square of the difference between the original and the reconstructed signal output,respectively, of L samples.The MSE formula is defined as: [1].

$$MSE = \frac{1}{L}\sum_{n=1}^{L}\left|x[n] - \hat{x}[n]\right|^2 \qquad (12)$$

### 3.3. Signal-to-noise ratio (SNR)

The performances of the ECG signal in the presence of the noise can beevaluated for different signal-to-noise ratio (SNR) defined as

$$SNR = -20\log_{10}(0.01PRD1) \qquad (13)$$

### 3.4. Maximum amplitude error (MAX)

The measure of maximum differences has been added too by means of the maximum amplitude error (MAX) which is expressed as

$$MAX = \max_n\left\{\left|x[n] - \hat{x}[n]\right|\right\} \qquad (14)$$

## 4. Experimental Results

### 4.1. FIR filtering results

Low pass filter is designed using parameters as Pass band ripple is 1, Pass band frequency is 45Hz, Stop band frequency 50 Hz and Sampling frequency is 360 Hz, Required Stopband attenuation is -60dB and Filter order of 263 and 275 respectively are obtained for Kaiser Window and Dolph-Chebyshev Window. The frequency response of designed filter is shown in fig. 2 and fig. 3.[2]

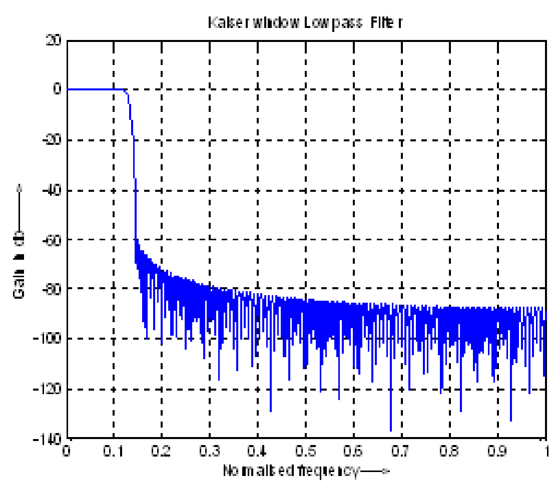


**Fig. 2: Low Pass Filter using Kaiser Window.**

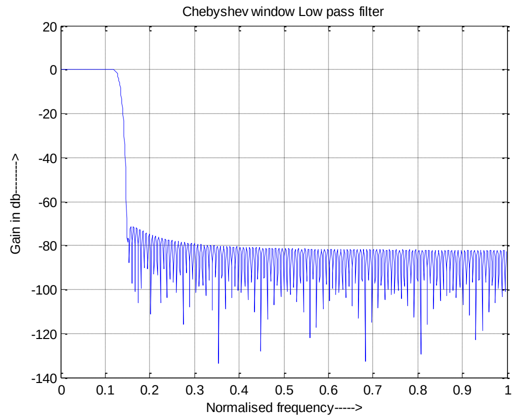


**Fig. 3: Low Pass Filter using Dolph-Chebyshev Window.**

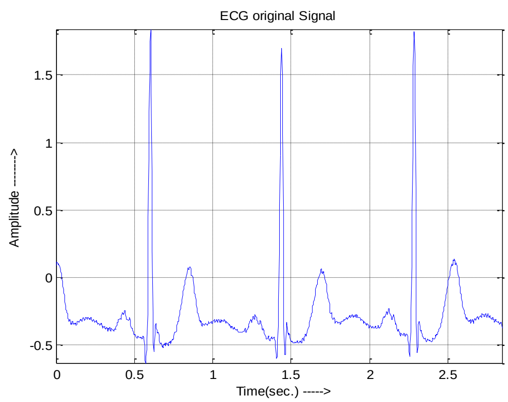


**Fig.4: ECG original Signal in Time (sec).**

MIT-BIH arrhythmia database is used to carry out tests. Fig. 4shows the initial 1024 signal samples of record 103 from MIT-BIT database.

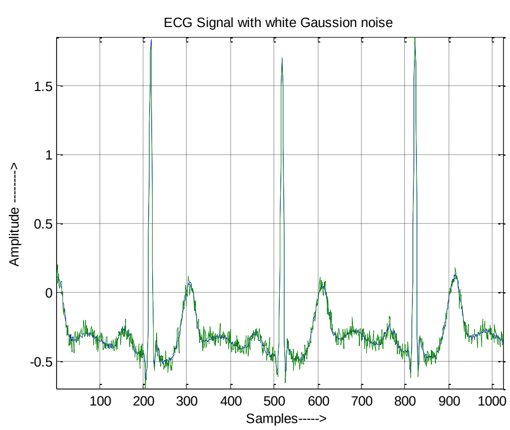


**Fig. 5: ECG Signal with SNR = 20 dB**

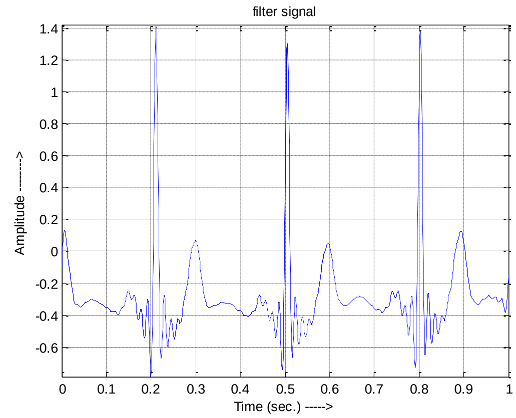


**Fig. 6: Filtered ECG Signal.**

The signal is filtered using the designed low pass filter. The filtered ECG signal is shown in fig. 5. The results of filtering are shown in Table – I.

**Table 1: Noise removal performance of filter with various levels of noise.**

| SNR (dB) | Window | PRD1 | MSE | MAX |
|---|---|---|---|---|
| - 5 | Kaiser | 81.6321 | 0.0585 | 0.9827 |
| | Chebyshev | 93.7868 | 0.0772 | 0.9855 |
| 0 | Kaiser | 57.9896 | 0.0295 | 0.8077 |
| | Chebyshev | 63.2907 | 0.0352 | 0.8290 |
| 5 | Kaiser | 40.7472 | 0.0146 | 0.6569 |
| | Chebyshev | 40.5262 | 0.0144 | 0.5251 |
| 10 | Kaiser | 31.9183 | 0.0089 | 0.5450 |
| | Chebyshev | 32.7087 | 0.0094 | 0.5560 |
| 15 | Kaiser | 30.3859 | 0.0081 | 0.5478 |
| | Chebyshev | 30.0817 | 0.0079 | 0.5533 |
| 20 | Kaiser | 29.2756 | 0.0075 | 0.5311 |
| | Chebyshev | 29.3069 | 0.0075 | 0.5264 |
| 25 | Kaiser | 29.0864 | 0.0074 | 0.5505 |
| | Chebyshev | 28.9785 | 0.0074 | 0.5312 |
| 30 | Kaiser | 28.9485 | 0.0074 | 0.5436 |
| | Chebyshev | 28.9560 | 0.0074 | 0.5395 |
| 35 | Kaiser | 28.9613 | 0.0074 | 0.5404 |
| | Chebyshev | 28.9299 | 0.0073 | 0.5490 |
| 40 | Kaiser | 28.9568 | 0.0074 | 0.5463 |
| | Chebyshev | 28.8902 | 0.0073 | 0.5427 |

**Table 2: Noise removal performance of filter with various levels of Attenuation ($A_s$) and fixed adding noise in 30db.**

| $A_s$ | N | Window | PRD1 | MSE | MAX |
|---|---|---|---|---|---|
| 25 | 87 | Kaiser | 28.6488 | 0.0072 | 0.5504 |
| | 125 | Chebyshev | 28.4112 | 0.0071 | 0.5319 |
| 30 | 113 | Kaiser | 28.5848 | 0.0072 | 0.5423 |
| | 125 | Chebyshev | 28.3776 | 0.0071 | 0.5438 |
| 35 | 137 | Kaiser | 28.6937 | 0.0072 | 0.5435 |
| | 149 | Chebyshev | 28.4422 | 0.0071 | 0.5370 |
| 40 | 163 | Kaiser | 28.7337 | 0.0072 | 0.5380 |
| | 175 | Chebyshev | 28.5589 | 0.0072 | 0.5409 |
| 45 | 187 | Kaiser | 28.7902 | 0.0073 | 0.5495 |
| | 199 | Chebyshev | 28.7139 | 0.0072 | 0.5453 |
| 50 | 213 | Kaiser | 28.8425 | 0.0073 | 0.5412 |
| | 225 | Chebyshev | 28.7742 | 0.0073 | 0.5368 |
| 55 | 237 | Kaiser | 28.9367 | 0.0074 | 0.5444 |
| | 249 | Chebyshev | 28.8974 | 0.0073 | 0.5357 |
| 60 | 263 | Kaiser | 29.0108 | 0.0074 | 0.5417 |
| | 275 | Chebyshev | 28.9369 | 0.0074 | 0.5433 |
| 65 | 287 | Kaiser | 29.0184 | 0.0074 | 0.5446 |
| | 301 | Chebyshev | 28.9965 | 0.0074 | 0.5530 |
| 70 | 313 | Kaiser | 29.1120 | 0.0074 | 0.5400 |
| | 325 | Chebyshev | 29.0209 | 0.0074 | 0.5433 |
| 75 | 337 | Kaiser | 29.1155 | 0.0074 | 0.5385 |
| | 351 | Chebyshev | 29.0906 | 0.0074 | 0.5383 |

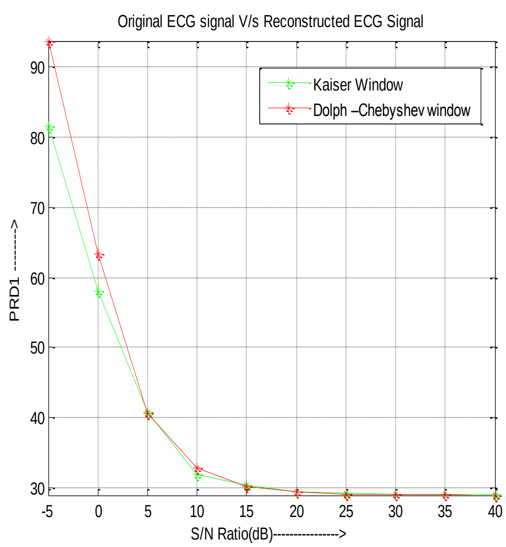


**Fig. 7: Comparison of PRD1 V/s SNR for Kaiser and DC window filtered signals.**

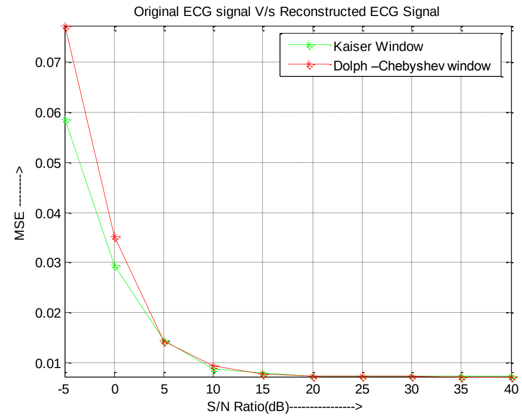


**Fig. 8: Comparison of MSE V/s SNR for Kaiser and DC window filtered signals.**

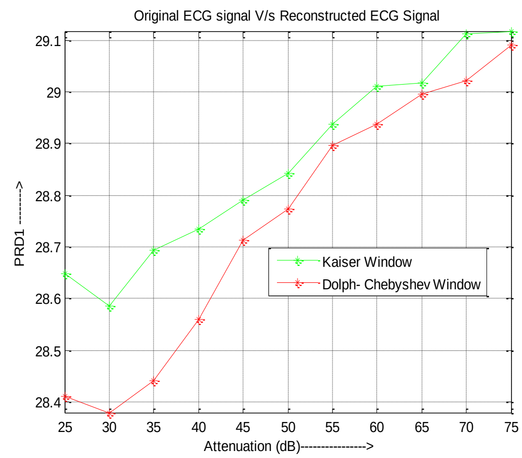


**Fig. 9: Comparison of PRD1 V/s attenuation for Kaiser and DC window filtered signals.**

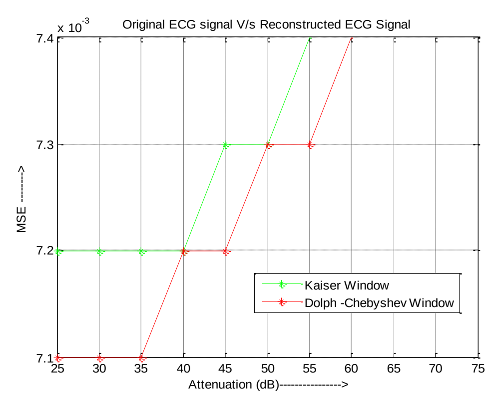


**Fig. 10: Comparison of MSE V/s attenuation for Kaiser and DC window filtered signals.**

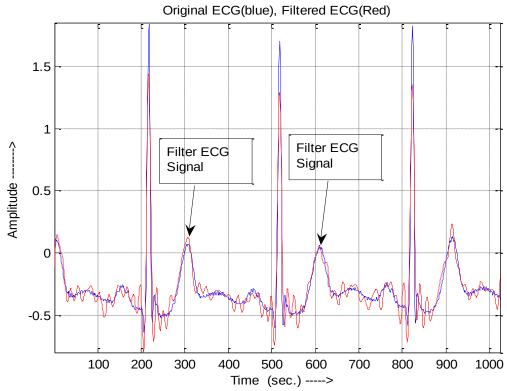


**Fig. 11: Comparison of ECG signals (Original Signal and Filtered) at SNR = 15dB.**

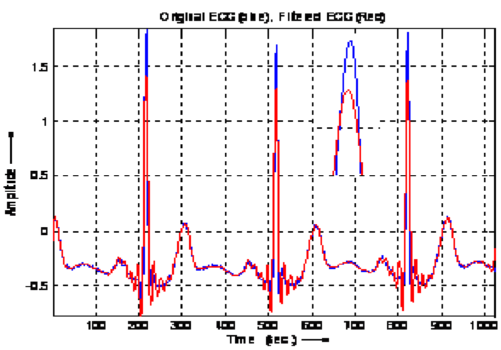


**Fig. 12: Comparison of ECG signals (Original Signal and Filtered) at SNR = 35 dB. Inset: Zoom view of R peak.**

## 5. Conclusion

In this work FIR based filtering techniques for ECG signal is presented; windowing techniques are used to develop various FIR filters. Popular adjustable window- Kaiser Window and DC window are used to developed low pass filter. It has been well established that ECG signal are low frequency signals, low amplitude periodic signals. However these signals are susceptible to external electrical contamination as well as artifacts. This may seriously affect the clinical diagnosis. In this work we have experimented with the response of FIR filter in suppressing the high frequency noise. It can be concluded, quantitatively as well as by visual inspection that ECG waveform shows (table – I) significant improvement in quality with the use of high attenuation low pass filter. This can extract the ECG signal from noise, thus enabling cardiac experts for reliable and dependable clinical diagnosis.

## References

[1] Ashutosh Datar, Alok Jain and PC Shama, "Performance of Blackman window family in M channel Cosine Modulated Filter Bank for ECG signals", IMPACT-2009.

[2] C. N. Mead, K. W. Clark, S. J. Patter, S. M. Moore and L. J. Thomas, " Recent Process in Frequency – domain Analysis of the ECG". IEEE Transaction as Computers in Cardiology,PP-43-47, 1979.

[3] Wei Zhang, Xu Wang, LinlinGe2 ,*et .al*, "Noise Reduction in ECG Signal Based on Adaptive Wavelet Transform" **,** Proc. 27th IEEEConf. Engineering in Medicine and Biology (EMB)Shanghai, China, September 1-4, 2005.

[4] Manuel Blanco-Velasco, Fernando Cruz-Roldan, Ignacio Godino-Llorenteet. al., "On the use of PRD and CR parameters for ECG compression" Medical Engineering & Physics, 27 (2005), pp. 798–802.

[5] Renumadhavi, C. H., S. Madhava Kumar, A. G. Ananth, and Nirupama Srinivasan. "A new approach for evaluating SNR of ECG signals and its implementation." In Proceedings of the 6th WSEAS International Conference on Simulation, Modelling and Optimization, pp. 202-205. World Scientific and Engineering Academy and Society (WSEAS), 2006.

[6] Yong Lian and Jiang Hong Yu"The Reduction of noises in ECG signal using a frequency response masking based FIR filter" IEEE International workshop on Biomedical circuits &system, 2004.

[7] Stuart W.A. Bergen, Andreas Antoniou ,"An efficient closed –form design method for cosine –modulated filter banks using window functions" Department of Electrical and Computer Engineering of Victoria P.O.Box 3055STN CSC Victoria, BC, Canada, 7 August 2006.

[8] Prajakta S Gokhale, "ECG Signal De-noising using Discrete Wavelet Transform for removal of 50Hz PLI noise",International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 2, Issue 5, May 2012.

[9] S.K. Jagtop, M. S. Chavan, R. C. Wagvekar and M.D.Uplane "Application of the digital filter for noise reduction in electrocardiogram"Jl of Instrum. Soc. of India vol.40 No.2, *June* 2010.

[10] T-YM Slonim,MASlonim, EA Ovsyscher "The use of Simple FIR Filters for Filtering of ECG Signals and a NEW method for Post-Filter Signal reconstruction" Electrical and Computer engineering Department ,Cardiology Department Ben–Gurion University of the Negev ,Beer-sheva,Israel, 1993 IEEE.

[11] YanivZigel*, Arnon Cohen, and Amos Katz, **"**ECG Signal Compression Using Analysis by Synthesis Coding", IEEE Transaction on BiomedicalEngineering vol.47, 10, October 2000.

[12] John W. Clark, Michael R. Neuman, Walter H. Olsonet .al, "Medical Instrumentation Application and Design" 3rd edition, John Wiley & Sons Inc., New York, 2001.
[13] C. Ifeachor and B.W. Jervis, Digital Signal Processing-A Practical Approach, Asea Pearson, New Delhi, 2002.
[14] R. M. Rangayyan, "Biomedical Signal Analysis-A case study approach", EMB, WSE, Wiley, 2002.
[15] W. J. Tompkins, "Biomedical Digital Signal Processing", PHI, 2nd edition, 2002.
[16] S. K Mitra, "Digital Signal Processing-A Computer based Approach", McGraw Hill, New Delhi, 2nd edition, 2001.
[17] D. J. Defatta, "Digital Signal Processing-a System design approach",WSE, Wiley and Sons, 1988.

**Narendra Mahawar** has received his B.E. (Biomedical Engineering) degree from Samrat Ashok Technological Institute, Vidisha (M.P.) India in 2006, M. Tech (Digital Communication) part time degree from Barkatullah Universit Institute of Technology, Barkatullah University Bhopal in 2010. He is present working as Assistant Professor in Department of Biomedical Engineering, Samrat Ashok Technological Institute, Vidisha (M.P.) India.

**Dr. Ashutosh Datar** was born in Vidisha, India on 12th October 1967. He has received his B.E. (Electronics & Instrumentation) degree from Samrat Ashok Technological Institute, Vidisha (M.P.) India, and M.Tech. (Biomedical Engineering) degree from Institute of Technology, Banaras Hindu University (BHU) Varanasi, in 1989 and 1998, respectively. He obtained his Doctoral degree from Rajiv Gandhi Proudyogiki Vishwavidyalaya, (State Technological University of Madhya Pradesh), Bhopal India in 2012. He is presently working as Associate Professor in Department of Biomedical Engineering, Samrat Ashok Technological Institute, Vidisha (M.P.) India. Mr. Datar is a life member of IET, IE (I), ISTE, BMESI, Instrumentation Society of India (ISoI). His current research interests include digital signal processing, multirate signal processing, filter banks, Bio-medical signal processing and Medical image processing.

**Dr. (Mrs.) Anjali Ashish Potnis** has done B Tech. and M Tech. from Maulana Azad National Institute of Technology,Bhopal .Her area of interest are signal processing , Image Processing and Communication. She has more than sixteen years of teaching experience at under graduate and post graduate levels. She is also fellow member of IETE. Presently she is working as faculty at National Institute of Technical Teachers Training and Research, Bhopal.