

# Design and comparison of equiripple bandpass filter for wireless applications at varying bandwidths

## Abstract

This paper presents the design of equiripple programmable bandpass filter for wireless applications. The designed filter covers a wide range of bandwidth compared to what can be achieved by a simple microcontroller. This bandwidth covers a variety of digital wireless applications like TETRA, IS-95, GSM to TACS. The responses of the designed filter are discussed and compared at varying bandwidths. Also the time required to evaluate the performance of designed filter also reduces drastically compared to a simple MAC unit.

## Keywords

*Attenuation, digital filters, bandpass filter, sampling frequency, transition frequency, filter coefficients, response*

## 1. Introduction

The communication technology has experienced various stages of its progress since its beginning. The first stage was from the 1920s and 40s where mobile communication was mainly used on ships, planes, cars and military communication system. Second stage was from the 1940s to the 60s when mobile phone systems came into existence, with the emerging of mobile phone systems. The third stage was from the 1970s to the 80s, where the concept of cellular communication was introduced. Stage 4 started from the 1990s to the present day, with the introduction of digital transmission, CDMA, TDMA technology and many more [1,2]. In all this progress digital filters have always played a very important role in research. The flexibility of a digital filter to change its characteristics, its linearity and stability are some of the advantages which makes it more useful for variety of applications compared to analog filters. Further with the evolution of software defined radio technology the research in the field of telecommunication worldwide has been increased many folds. The advantages of SDR includes multi service, multi band and update feature.

Muhammad et al have proposed a novel design methodology for high performance and low power digital filters. Novel design methodologies which can be used to dramatically reduce the complexity of parallel implementations of digital FIR filters were presented [3]. Saleh et al have proposed an efficient design algorithm of N-band IIR digital filters. Apart from ensuring stability, flexibility of meeting any stringent specifications, the design algorithm resulted in equiripple loss behaviour over its bands of interest [4]. Parikh et al have optimized design of cascaded digital filters in wideband wireless transmitters using genetic algorithms.

The proposed technique was demonstrated for digital WiMAX and WCDMA transmitters, for which near-optimal solutions appeared to have been achieved in a relatively short time compared to the traditional manual design techniques [5]. D'Andrea et al have designed digital filters for data communications. The coefficients in the transmit and receive filters were optimized to meet specified requirements [6]. Out of all the research the complexity and time consumption are two major areas which need to be reduced for fast designing and optimization of designed filters. It was also found that optimal filter design methods to design FIR digital filter are the most suitable ones. Polynomial interpolation solution algorithm for maximal ripple FIR filters proves to be the

most efficient method of filter design as it reduces the complexity and time consumption. In this paper an equiripple bandpass filter is proposed and its performance at varying bandwidths is compared. Equiripple method is chosen because of the following advantages:

1. It meets specifications with the least number of coefficients.
2. It uses less amount of resources on FPGA for implementation.
3. The weighted approximation error between the desired and actual frequency response is spread evenly across the pass-band and stop-band of the filter thereby minimizing error.
4. Pass-band and stop-band deviations can be specified separately.

## 2. Methodology and Design Procedure

MATLAB is used to design equiripple bandpass digital filters for wireless applications. So this paper presents the design of a digital filter using above mentioned approach for achieving specifications like reducing complexity, time consumption along with maintaining the linearity and stability of designed filter. An equiripple filter is the one whose amplitude response oscillates uniformly between the tolerance bounds of each band. It has the smallest maximum deviation from the ideal filter when compared to all other linear-phase FIR filters of the same order. An equiripple filter has following equation:

$$\text{Max } \varepsilon(j2\pi f) = \text{fc}[-0.5, 0.5] \left| Q\{j2\pi f\} [H_d((j2\pi f) - H\{e^{j2\pi f}\}] \right| \quad (1)$$

$H\{e^{j2\pi f}\}$  is the best approximation frequency response;

$H_d((j2\pi f))$  is the ideal frequency response;

$Q\{j2\pi f\}$  is the weighting function;

$\varepsilon(j2\pi f)$  is the Equiripple factor

## 3. Results and Discussion

The designed equiripple bandpass filter covers a wide range of 10 MHz - 40 MHz which covers a variety of digital wireless applications. The wide bandwidth covers multiple wireless standards from TETRA, IS-95, GSM to TACS. The center frequency of the filter (the intermediate frequency of the receiver) was chosen at 100 MHz, while the -3 dB bandwidth (BW) can be programmed within the interval 10 MHz–40 MHz. The filter length  $N$  is calculated by using the following equations:

$$N = C_\infty(\delta_p, \delta_s) / (\Delta\omega/2\pi) + G(\delta_p, \delta_s)(\Delta\omega/2\pi) \quad (2)$$

Where  $\delta_p$  is passband peak deviation,  $\delta_s$  is stopband peak deviation and  $\Delta\omega$  is transition width

$$C_\infty(\delta_p, \delta_s) = \log_{10} \delta_s [a_1(\log_{10} \delta_p)^2 + a_2(\log_{10} \delta_p) + a_3] + [a_4(\log_{10} \delta_p)^2 + a_5(\log_{10} \delta_p) + a_6] \quad (3)$$

Where  $a_1$  to  $a_6$  are filter coefficients. And then,

$$G(\delta_p, \delta_s) = -14.6 \log_{10}(\delta_p / \delta_s) - 16.9 \quad (4)$$

60 The transfer function  $H(Z)$  of FIR equiripple bandpass filter is defined as:

$$H(z) = \sum_{k=0}^{N-1} h(k) z^{-k} \quad (5)$$

64 The output of the filter  $y(n)$  can be determined by using the following equation

$$y(n) = \sum_{k=0}^{N-1} h(k)x(n-k) \quad (6)$$

68 The impulse response  $h(n)$  of the filter can be written as

$$h(n) = \frac{1}{N} \sum_{k=0}^{N-1} H(k) e^{j2\pi nk/N} \quad (7)$$

72 There are three realization structures for FIR filters such as transversal structure or direct form, frequency sampling structure and  
73 fast convolution structure. The most widely used for FIR is the direct form or transversal structure because it is particularly simple to  
74 implement. The block diagram of proposed filter is shown in Fig.(1)

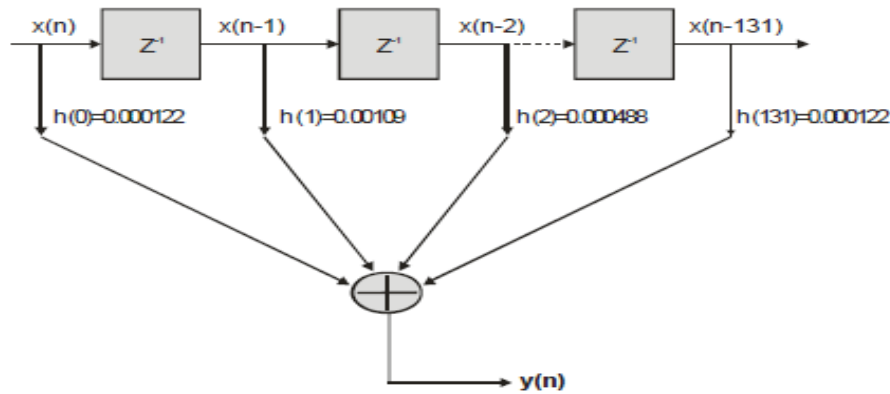


Fig. 1 Block diagram of proposed filter

77 The input and filtered outputs after passing through the proposed filter for 10 MHz-40MHz bandwidth are shown in Fig.(2) and  
78 Fig.(3)

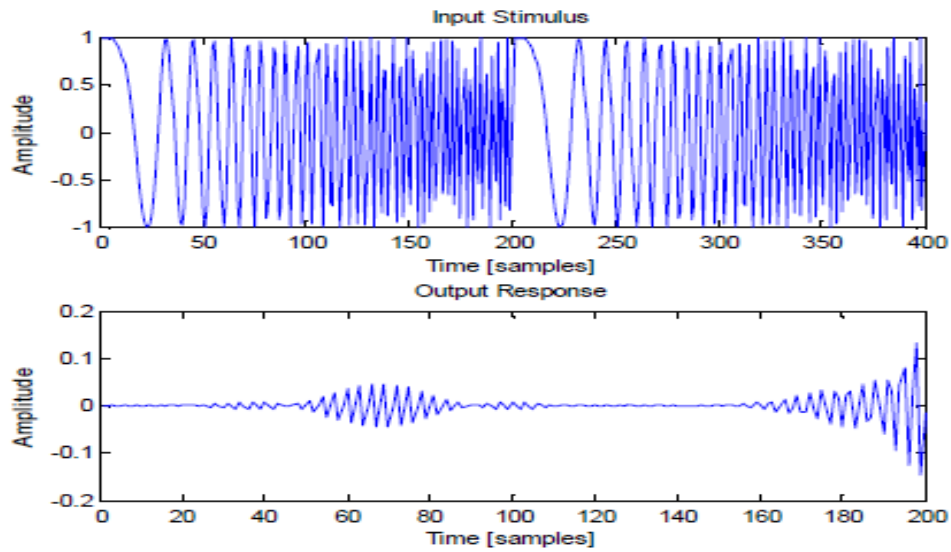


**Fig. 2 Input and filtered output for 10MHz**

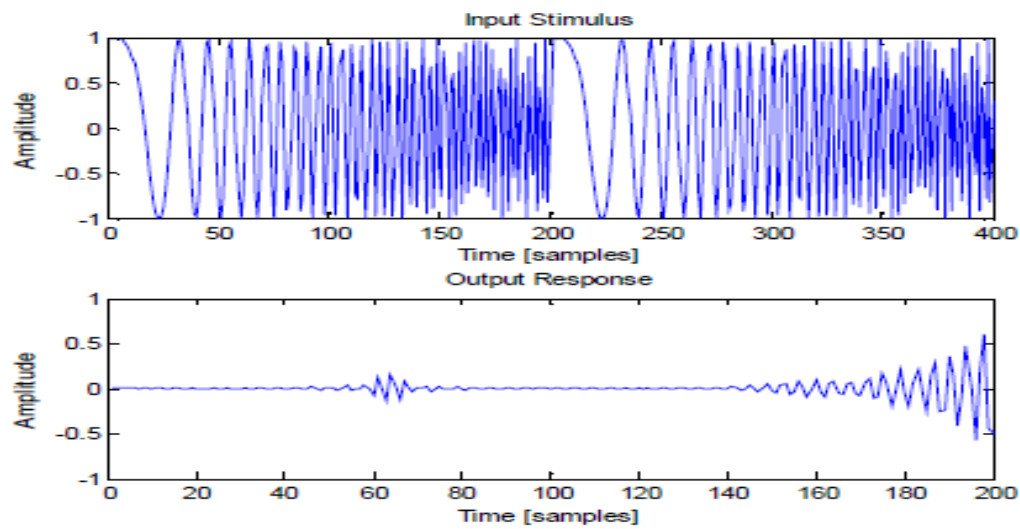


**Fig. 3 Input and filtered output for 40MHz**

The pole zero plots of the proposed filter for 10 MHz-40MHz bandwidths are shown in Fig.(4) and Fig.(5) .

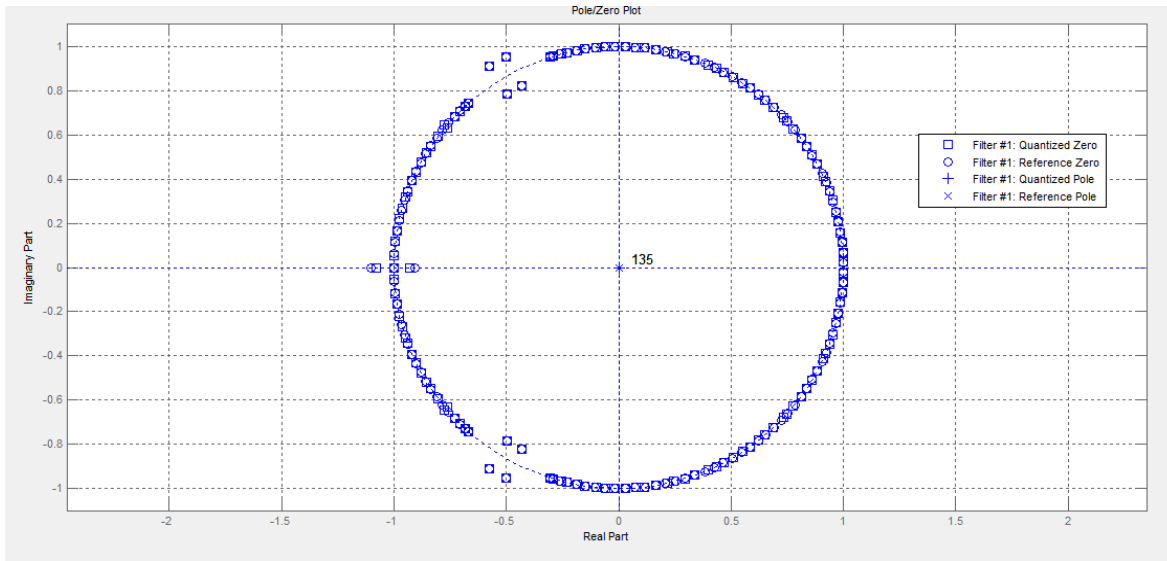


**Fig. 4 Pole zero plot of proposed filter for 10MHz**

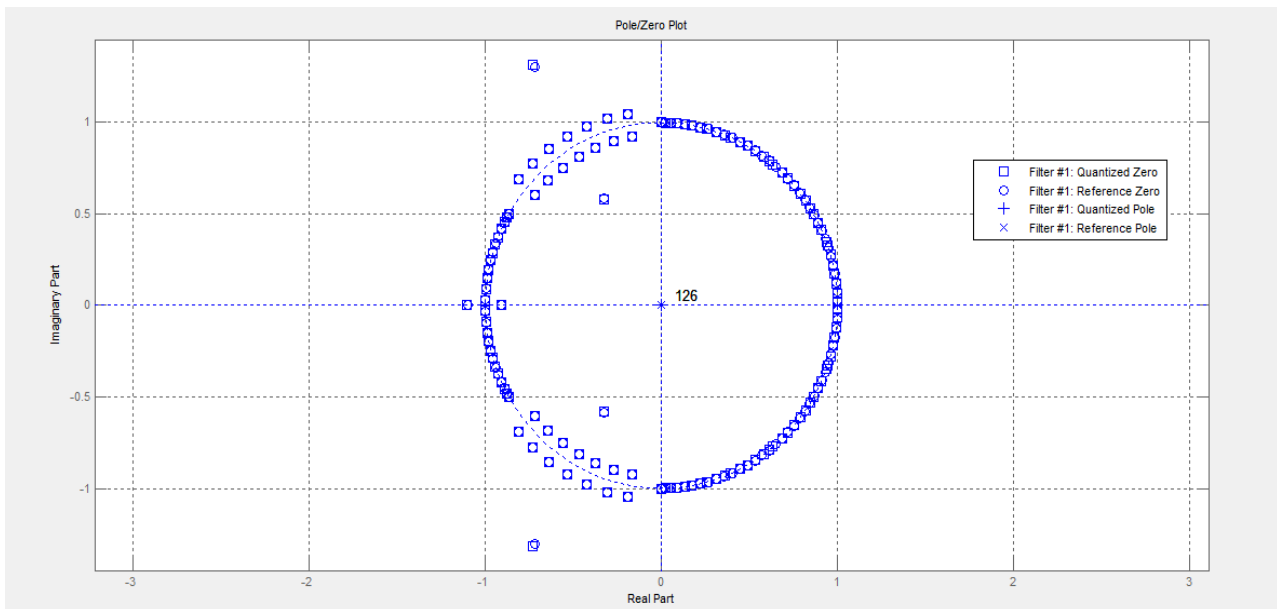


**Fig. 5 Pole zero plot of proposed filter for 40MHz**

It is clear that as there are no zeros on the unit circle so the designed filter is stable at various bandwidths. Also the filter coefficients are reduced from 136, 132, 130 to 127 for varying ranges and hence the complexity of design is greatly reduced. The magnitude and phase responses of the proposed filter for 10 MHz-40MHz bandwidths are shown in Fig.(6) and Fig.(7)

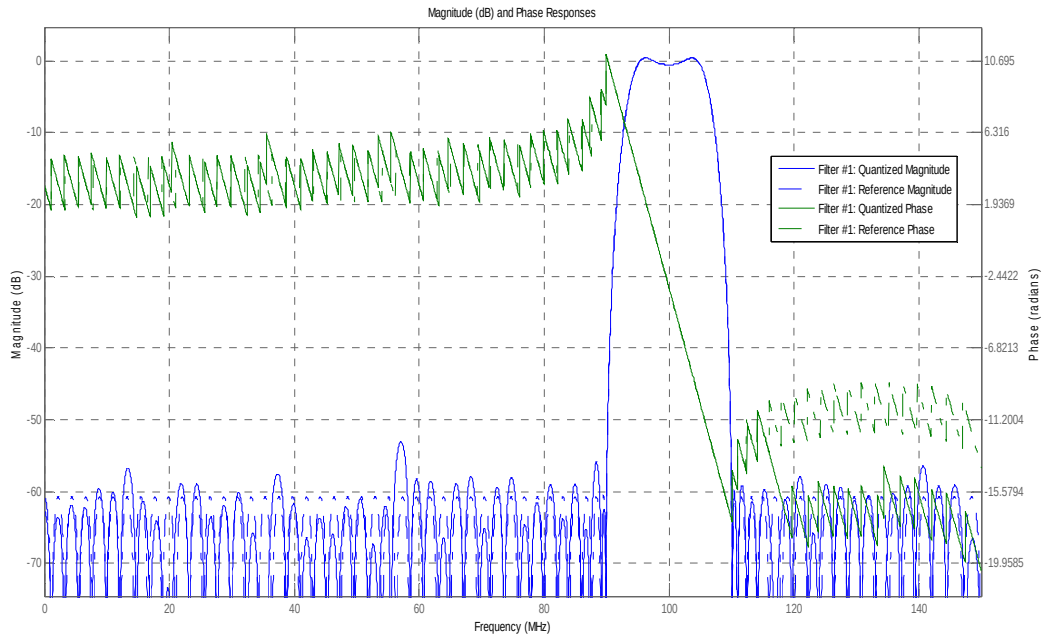


**Fig. 6 Magnitude and Phase response of proposed filter for 10MHz**

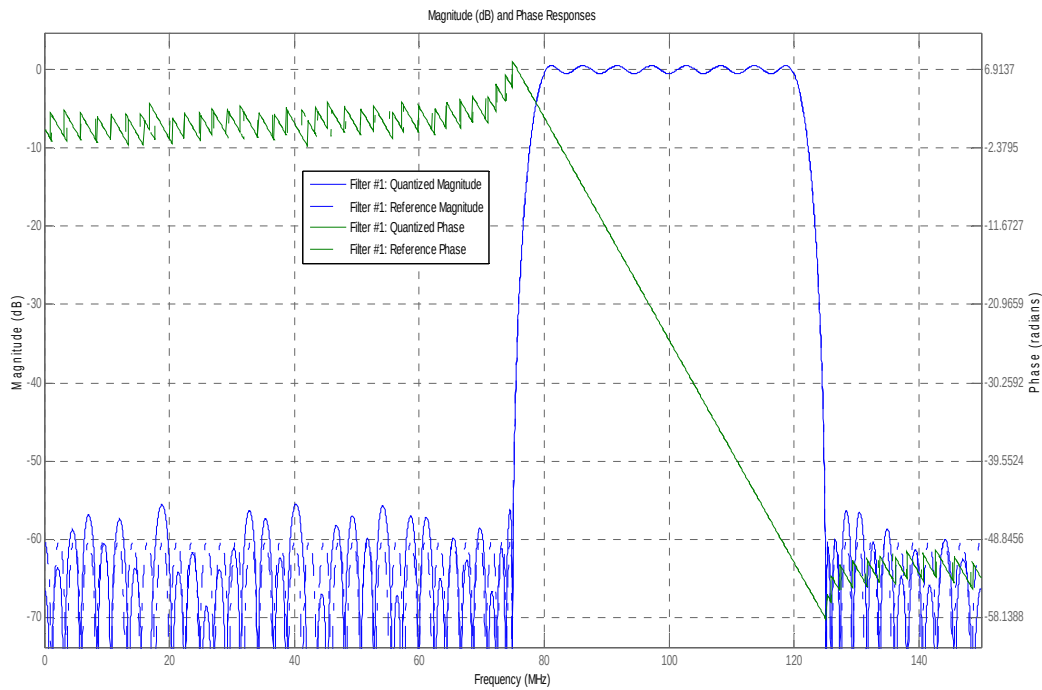
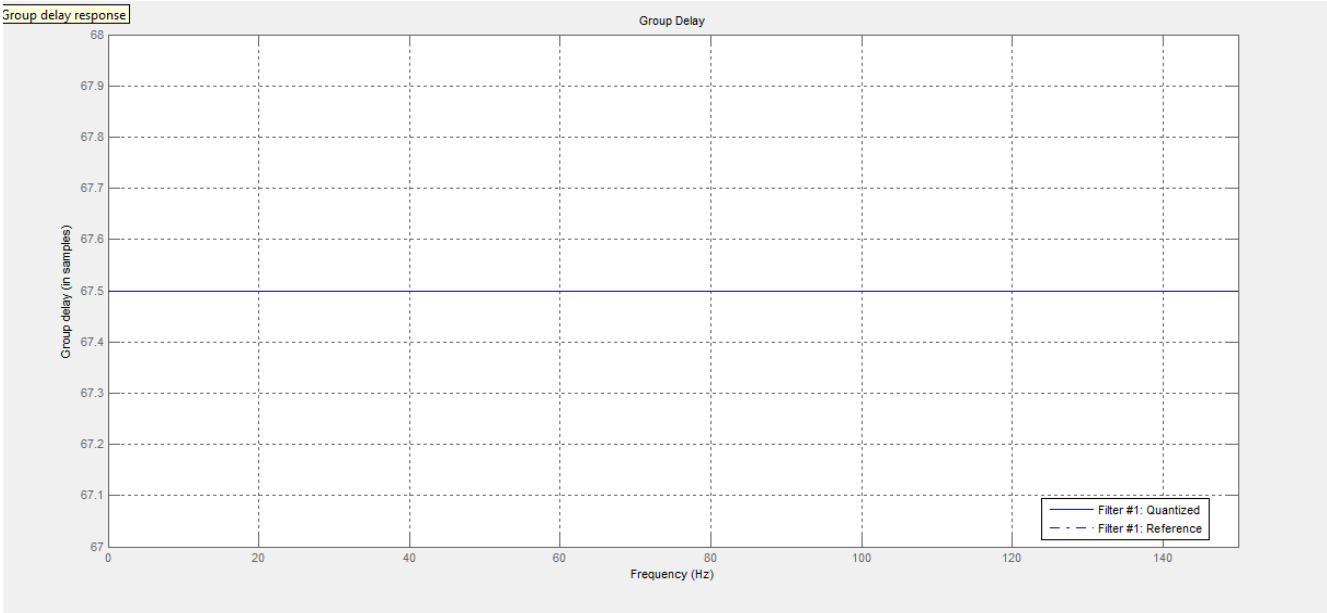


**Fig. 7 Magnitude and Phase response of proposed filter for 40MHz**

It is clear that smooth slope line between the pass band ranges is obtained which shows that the designed filter is linear. The linear phase response increases with increasing bandwidth. The group delay responses of the proposed filter for 10 MHz-40MHz bandwidths are shown in Fig.(8) and Fig.(9)

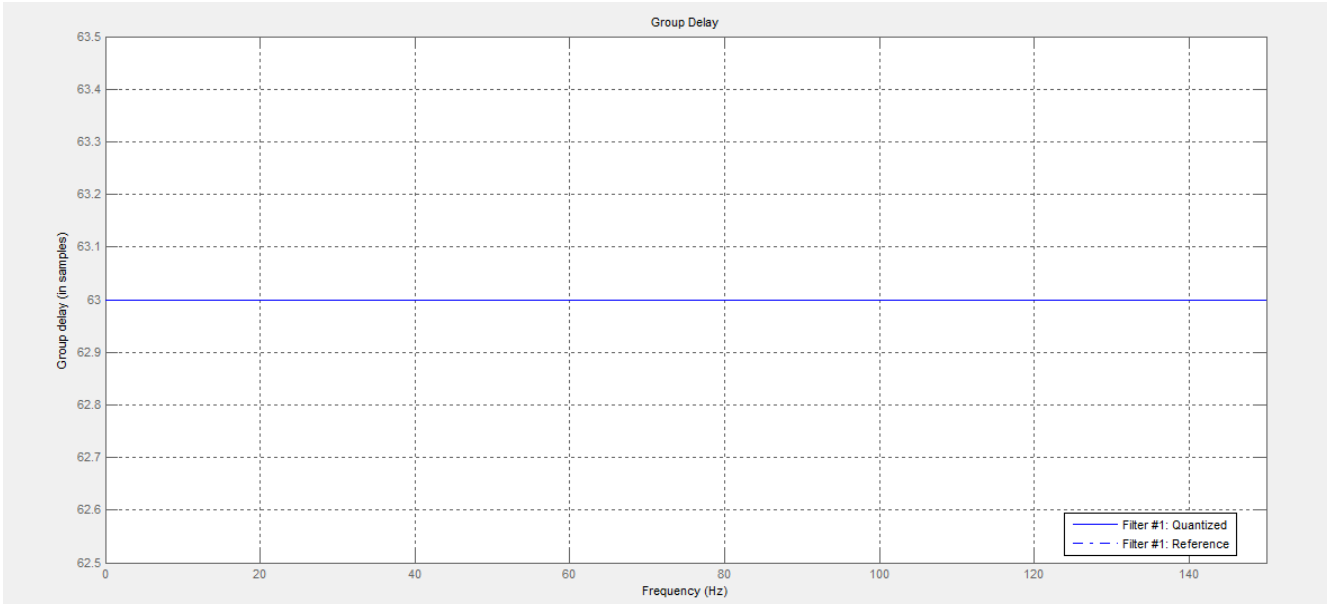
.02



.03

.04

**Fig. 8 Group delay response of proposed filter for 10MHz**



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**Fig. 9 Group delay response of proposed filter for 40MHz**

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The group delay of a system specifies how long it takes a signal group to travel from system's input to output. Here the filter becomes fast in response as the group delay decreases from 67.5, 66.5, 64.5 to 63 in samples for varying bandwidths. The performance comparison of designed filter at varying bandwidths is as shown in table 1.

**Table 1: Performance comparison of proposed filter at varying bandwidths**

| Parameter name                | For 10 MHz<br>Bandwidth | For 20 MHz<br>Bandwidth | For 30 MHz<br>Bandwidth | For 40 MHz<br>Bandwidth |
|-------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Passband Frequency            | 95MHz-105MHz            | 90MHz-110MHz            | 85MHz-115MHz            | 80MHz-120MHz            |
| Lower Stopband edge Frequency | 90 MHz                  | 85MHz                   | 80 MHz                  | 75 MHz                  |
| Upper Stopband edge Frequency | 110 MHz                 | 115MHz                  | 120 MHz                 | 125 MHz                 |
| Filter length                 | 136                     | 132                     | 130                     | 127                     |
| Group Delay(in samples)       | 67.5                    | 66.5                    | 64.5                    | 63                      |
| Run Time(in ms)               | 0.0055                  | 0.0054                  | 0.00538                 | 0.00535                 |

#### 4. Conclusion

The Filter performance is better compared to previous researches as it provides much improved and stable response and less time consumption in its designing. Also the designed filter covers a wide range of bandwidth which can be extended to several Mhz so as to support many wireless applications. The proposed filter has the great advantage providing bandwidth programmability within a wide range to accommodate multiple wireless standards: TETRA (10 MHz bandwidth), PDC (16 MHz bandwidth), IS-95, GSM and IS-54 (with 25 MHz bandwidth), TACS and EGSM with bandwidths of 33 and 35 MHz, respectively. Also wide range of prototype filter banks can also be designed for further studies. Some optimization algorithms may also be implemented to test the results.

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