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Comparison of Different Types of IIR Filters

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***Abstract*- In the field of DSP, filter plays a important role of extracting meaningful data from the signal and hence before designing, it is important to know the type of response needed . This Paper describes the comparative analysis of comparison a of different types of infinite impulse response (IIR) filters such as Butterworth, chebyshev1, chebyshev2 and Elliptical each for low pass, high pass band pass and band reject, we have used few parameters such as magnitude response, phase response, zero-pole response, group delay & phase delay.**

***Keywords*- IIR, Impulse response, Group delay**

I. INTRODUCTION

The procedure of converting an analog signal into digital signal is performed using sampling with a finite frequency f_s. This frequency is known as sampling frequency. If a filter contains $f_s/2$ frequency component, it will cause a distortion or noise in the original signal spectrum. Therefore it is necessary to use a low pass filter in the input to reduce the effects of noise. This filter basically referred as anti-aliasing filter. After the aliasing and sampling a digital signal is generated that is called filtering using a digital filter, and the output signal is a digital signal. Digital filter is highly immune to noise and comparatively stable. Digital filters can be implemented using convolution and recursion. Filters can be classified into different groups based on the requirement. Mainly finite impulse response (FIR) and infinite impulse response (IIR) filters are used. Both types of filters have their own advantages and disadvantages, that play an vital role while designing a filter. FIR filters provide linear phase, always stable and can be used for more complex circuits. On the other hand the IIR filter provides non-linear phase characteristics, unstable and they are used for less complexity. Practical Characteristic of a filter is not similar to the ideal characteristics response therefore the approximation of analog filter is needed. Approximation is required to achieve ideal characteristics whereas transformation methods are used to design filters. There are three types of approximation we use; they are butterworth filter approximation, using chebyshev filter approximation and lastly performed by elliptic filter approximation. All the simulation and designing can be done by using the MATLAB [4][5][6][7].

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The objective of this paper is to design IIR filter with the butterworth, chebyshev, elliptic and compare all and determine which one is better in terms of ripple, speed etc.

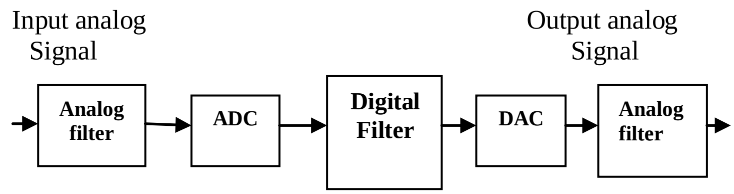

Fig.1. Basic Digital Filter

II. IIR FILTER

The digital filter that has an impulse response of infinite duration (infinite number of non zero terms) is known as infinite impulse response filter. IIR filters are also known as recursive filters. There is always feedback needed. Where phase distortion can be tolerated, IIR are generally favored.
Because here parameters requirement is lesser to achieve sharp cutoff filters, and therefore less complexity. Only problems occur during implementation are stability and difficult design.
IIR filter consists of present and past values which is described in the form of equations,

$$y(n) = \sum_{i=0}^{N} b_i x(n-i) - \sum_{i=0}^{M} a_i y(n-i) \qquad (1)$$

$$H(z) = \frac{y(z)}{x(z)} = \frac{b_0 + b_1 z^{-1} + \cdots + b_N z^{-N}}{1 + a_1 z^{-1} + \cdots + a_M z^{-M}} \qquad (2)$$

Where,
y(n) is output and x(n) is input.
b and a coefficients.

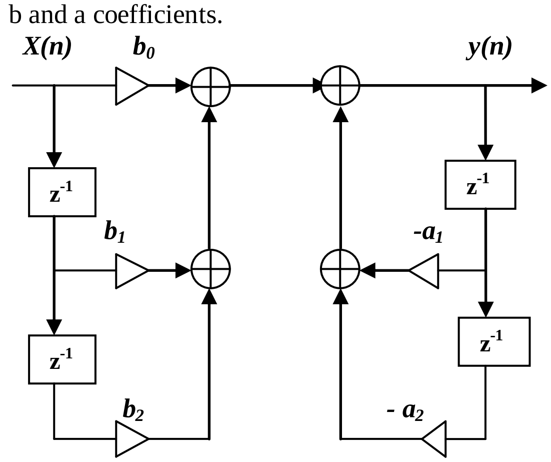

Fig.2. IIR Filter of order N

III. ADVANTAGES OF IIR FILTER OVER FIR FILTER

The main advantages of IIR filter have over FIR filter is their efficient implementation, in order to meet system requirement in terms of pass-band, stop-band, ripple, or/ and roll-off. Such a specification can be achieved with a lower order. This implies a correspondingly lesser number of calculations for every step and the computational saving is often a large concern.

- IIR filters can achieve a desired filtering characteristic using less memory elements and calculations than a FIR filter.
- With high computational efficiency and short delays IIR filters, often make the IIR filter preferred as an alternative. Whereas FIR filters have become too long in digital feedback systems, that cause problems.
- FIR cannot implement analog filter responses, but IIR is used to design that accurately.
- IIR filters are more susceptible to noise.
- Less mathematical operations are performed.
- Time delay is less.
- It Contains less number of side lobes in the stop-band [6][7].

IV. BUTTERWORTH FILTER

The classical method that is used to design analog filters is butterworth approximation. It is also referred as maximally flat filters. The calculations and other mathematical operations are simpler than the other filters. It also has poor phase characteristics. Higher the butterworth filter order, higher the number of cascaded stages required. Practically butterworth filter frequency response is unattainable because it produces excessive passband ripple. Mainly butterworth is used from RF to audio active filter. It has more linear phase response compared to others filters. As well as we increase the N the butterworth filter becomes more non linear [2].

Low pass Butterworth filter magnitude response is presented by

$$|H(\omega)|^2 = \frac{1}{1+\left(\frac{\omega}{\omega_c}\right)^{2N}} \tag{3}$$

Attenuation,

$$A = -10\log(1+\left(\frac{\omega}{\omega_c}\right)^{2N}) \tag{4}$$

Where,

ω_c= Cutoff frequency of 3 dB

N = Filter order

Butterworth filter has slower roll-off compared to chebyshev and elliptic filters.

V. CHEBYSHEV FILTER

There are two types of chebyshev filter they are called chebyshev type 1 and chebyshev type 2. Generally type 1 referred as regular filter and it is most common chebyshev filter. It has the steepest roll-off but it presents in band ripple.

The absolute difference between the idealized response and actual response over the whole pass-band region can be minimized using the chabyshev type 1 filter by including equi-ripple in the passband. It has more rapid transition from passband to stopband rather than butterworth filter. Type 1 has equi-ripple in passband whereas no ripple in stopband.

Type 2 filter is inversion of type 1 filter because it has equi-ripple in stopband and no ripple in passband. It is not commonly used unlike type 1 because it does not roll-off as fast. It requires more components [3].

Magnitude of the chebyshev type 1 filter is given following:

$$|H(\omega)|^2 = \frac{1}{1+s^2C_N^2(\frac{\omega}{\omega_c})} \tag{5}$$

$$|H(\omega)|\, dB = -10\log(1+\varepsilon^2C_N^2\frac{\omega}{\omega_c}) \tag{6}$$

Where, ε is amount of ripple in magnitude.

C_N is chebyshev coefficient.

$$c_N\left(\frac{\omega}{\omega_c}\right) = \begin{cases} \cos[N\cos^{-1}\left(\frac{\omega}{\omega_c}\right)] & for\ \omega \le \omega_c \\ \cosh[N\cosh^{-1}\left(\frac{\omega}{\omega_c}\right)] & for\ \omega \ge \omega_c \end{cases} \tag{7}$$

When $c_N\left(\frac{\omega}{\omega_c}\right) = 0$, it represents magnitude response at its peak. Then

$$H(j\omega) = \frac{1}{1+\varepsilon^2}$$

Similarly to design the chebyshev type 2 filter equation , as equi-ripple presents in type 2 in stop band.

$$H(j\omega) = \frac{\varepsilon^2}{1+\varepsilon^2}$$

Lower order filter is required to permits the higher percentage of ripple.

VI ELLEPTIC FILTER

Elleptic filter is also known as cauer filter. It has equalized ripple in both the bands. As the ripple in stopband is zero it becomes the chebyshev type 1 filter and alternatively when ripples in passband are zero it becomes chebyshev type 2 filter.The amount of ripple in each band is adjustable independently. There are no other filter of same order that can have faster transition in gain between the pass-band and stop-band. Transition bandwidth is minimum. It’s difficult to design and not easy to analysis by basic tools.

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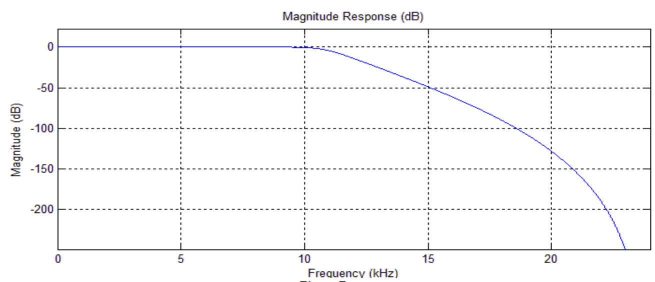
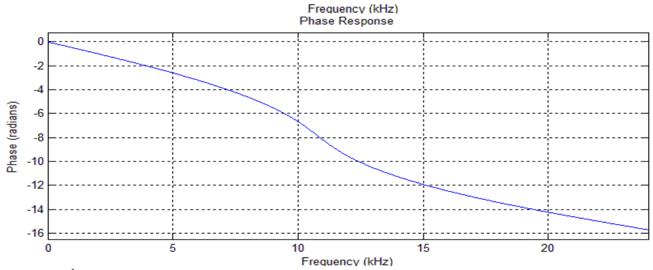
$$|H(j\omega)|^2 = \frac{1}{1 + \varepsilon^2 J_N(\frac{\omega}{\omega_c})} \tag{8}$$

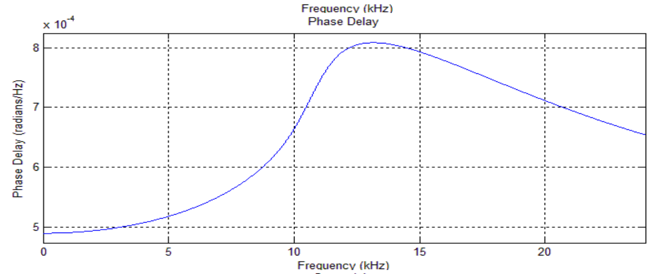
Where, J_N is Jacobean elliptic function.
N= number of order
ε= Ripple factor

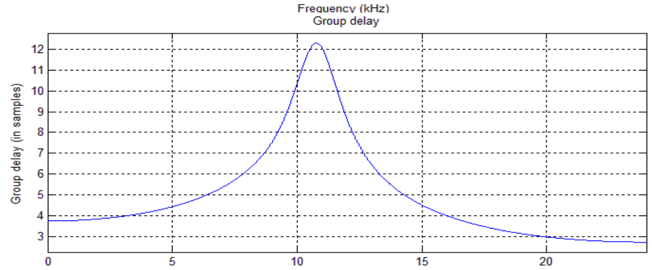
VII. SIMULATION RESULTS

For the purpose of comparison a of different types of Infinite impulse response (IIR) filters such as Butterworth, chebyshev1,chebyshev2 and Elliptical each for low pass, high pass band pass and band reject, we have used few parameters such as magnitude response, phase response, zero-pole response, group delay & phase delay. The MATLAB codes for all the above IIR filters were successfully simulated in MATLAB R2014a . The simulation results were obtained for filter length 10 and sampling frequency 48 kHz [4].









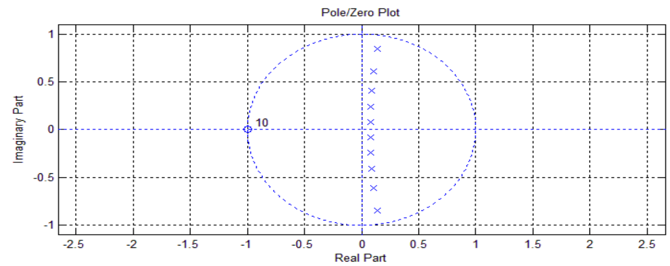
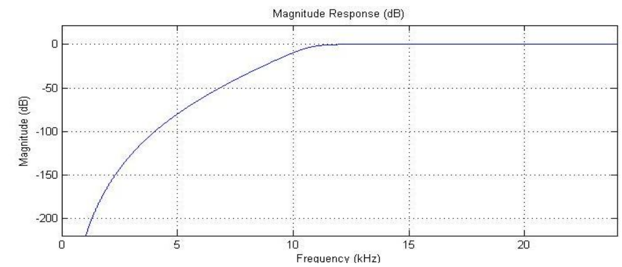
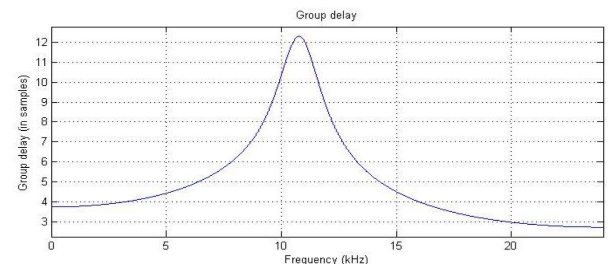
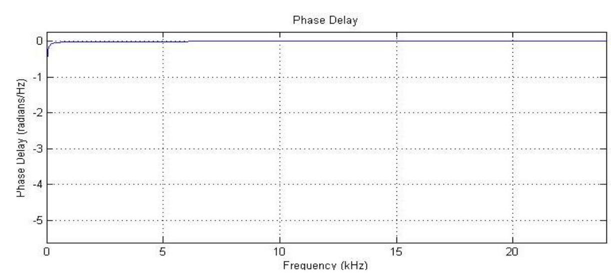
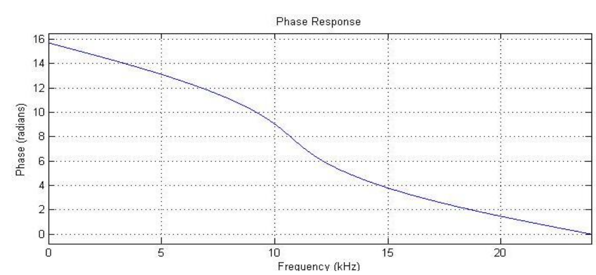


Fig.3 Butterworth Low-pass Filter









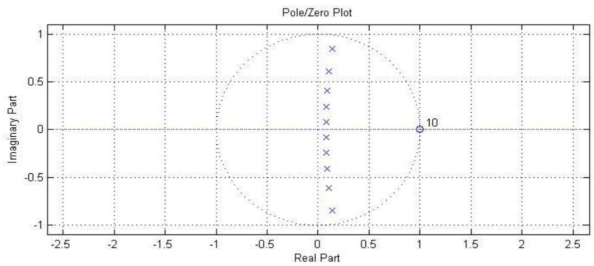


Fig.4 Butterworth High-pass Filter

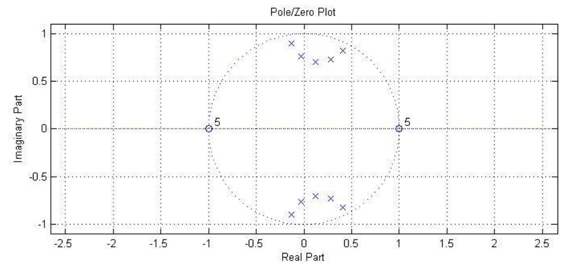
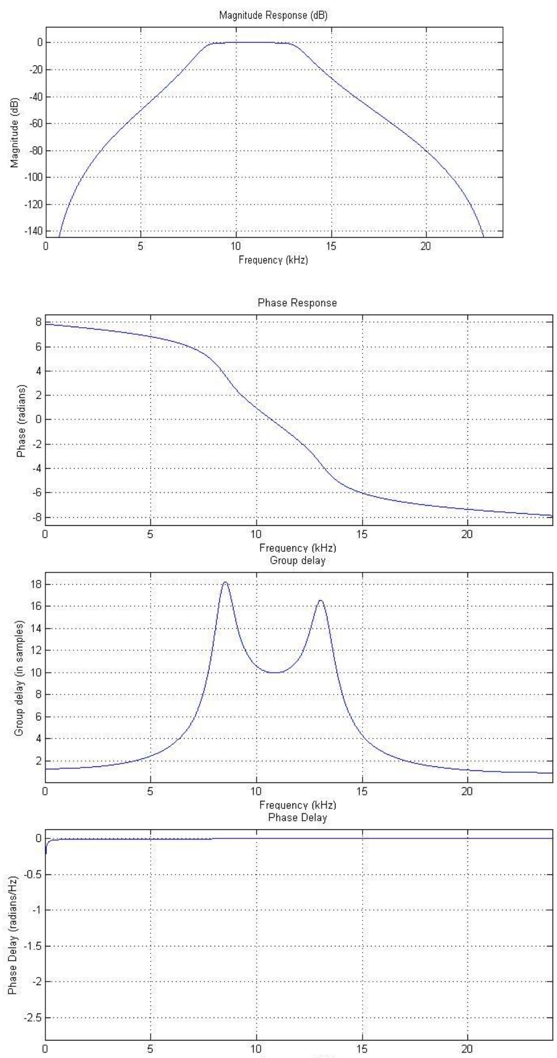


Fig.5 Butterworth Band-pass Filter



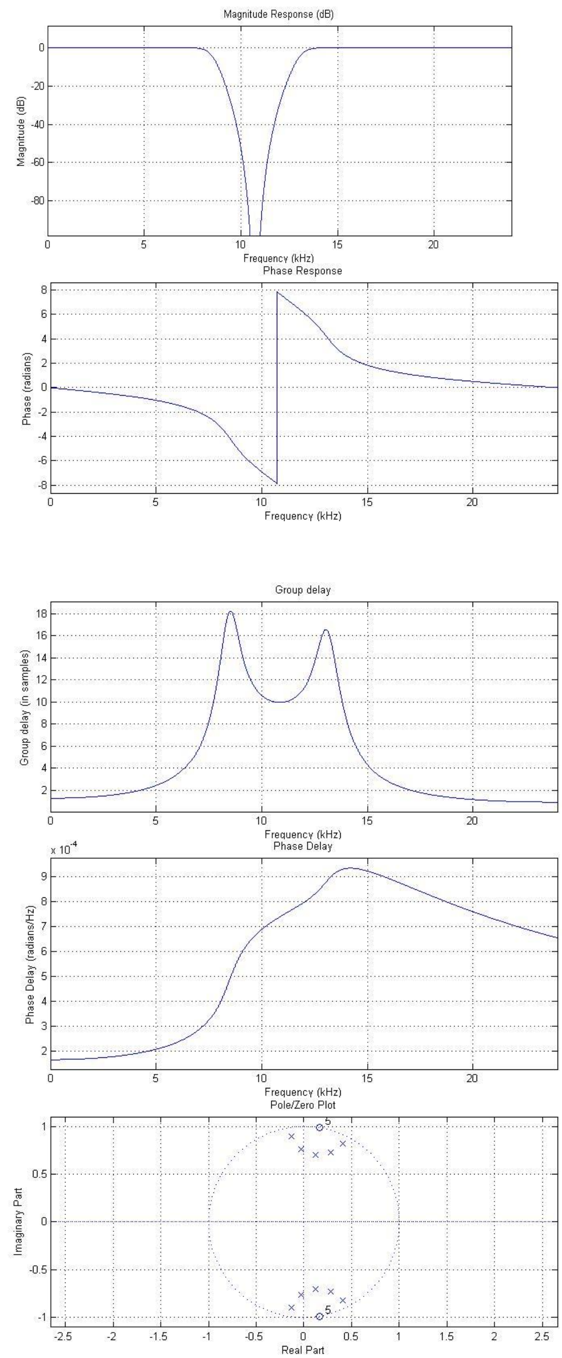


Fig.6 Butterworth Band-reject Filter

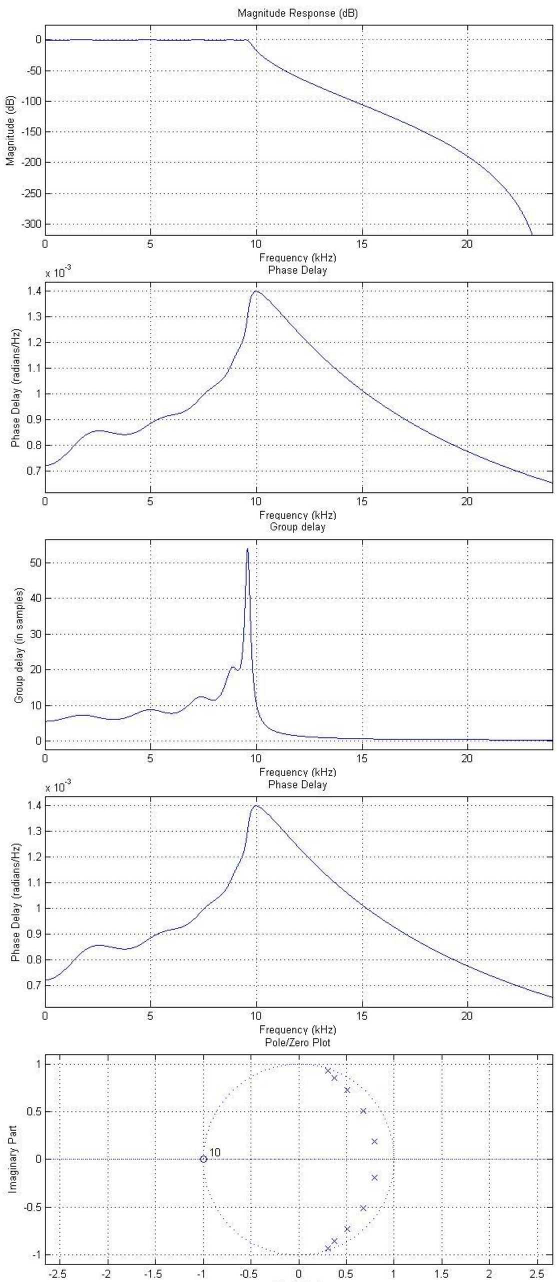


Fig.7 Chebyshev 1 Low pass Filter

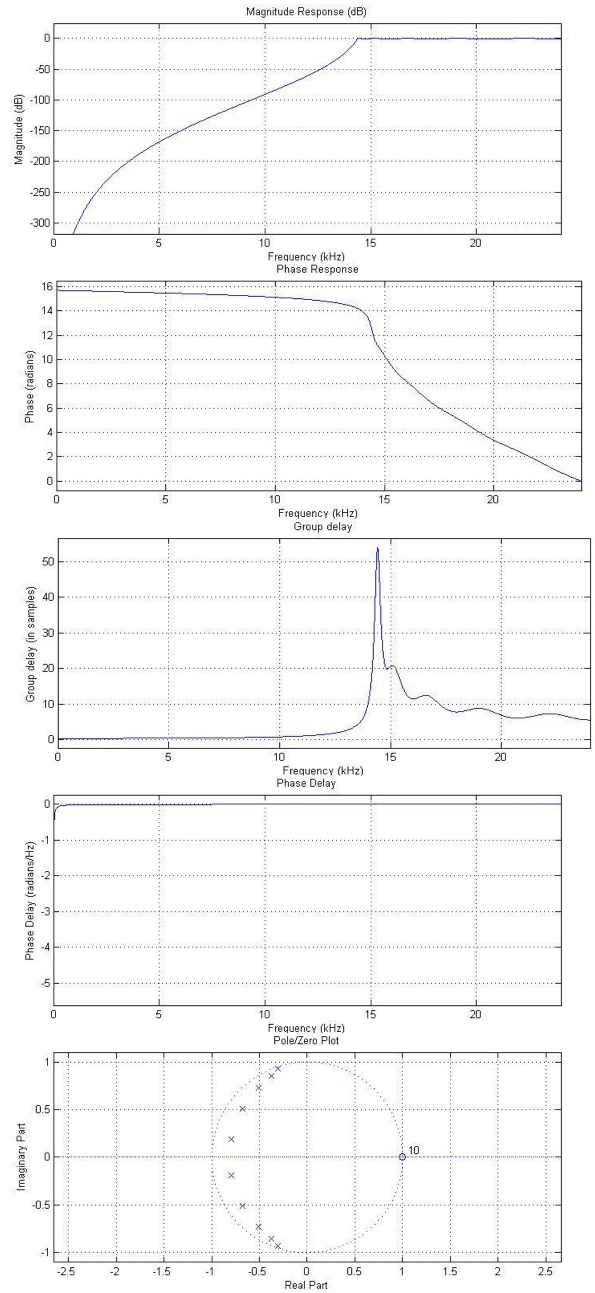


Fig.8 Chebyshev 1 High pass Filter

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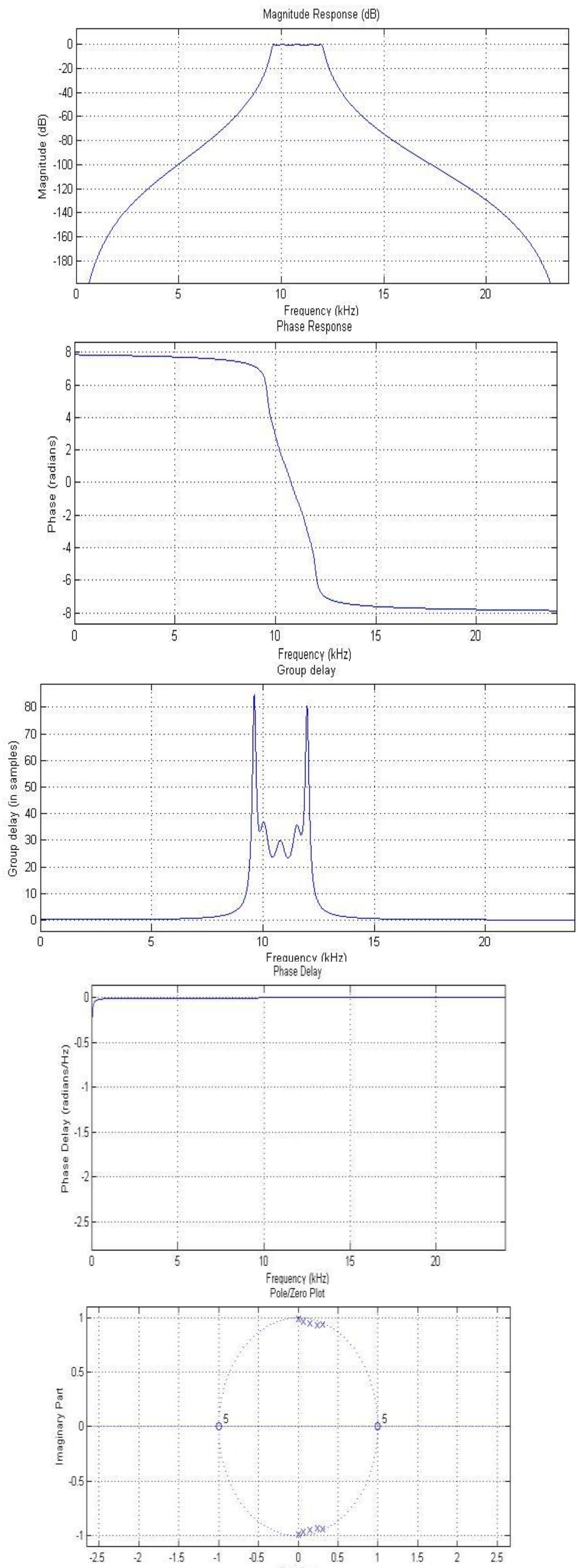

Fig.9 Chebyshev 1 Band pass Filter

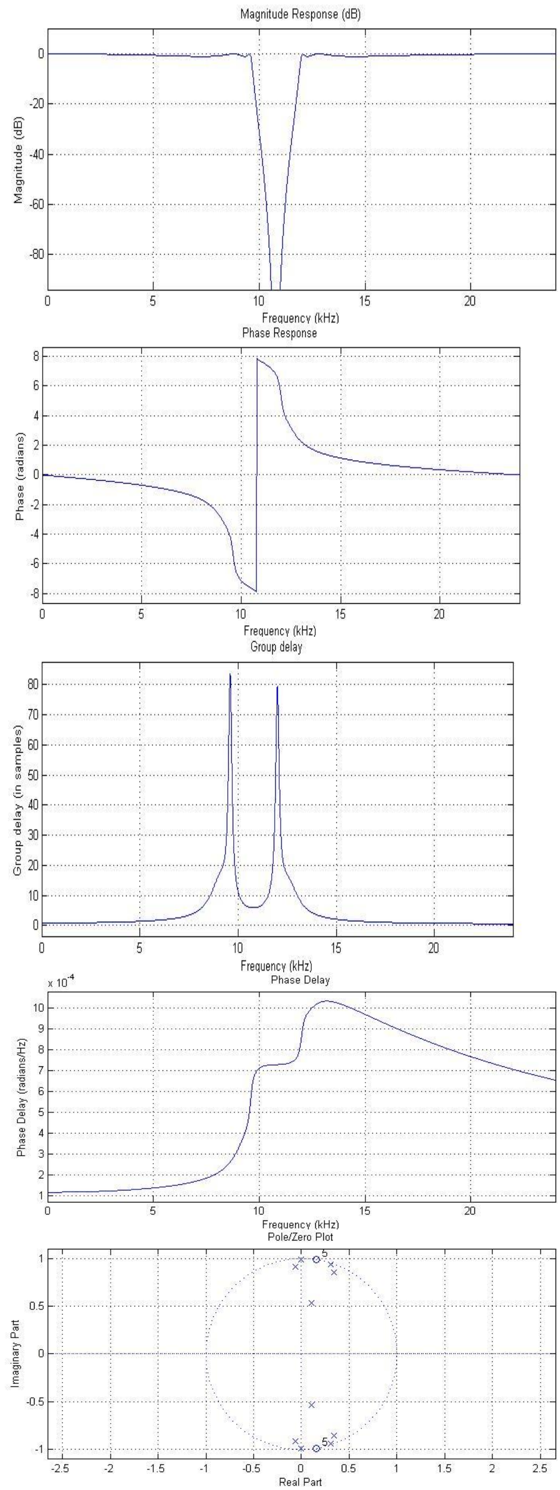

Fig.10 Chebyshev 1 Band reject Filter

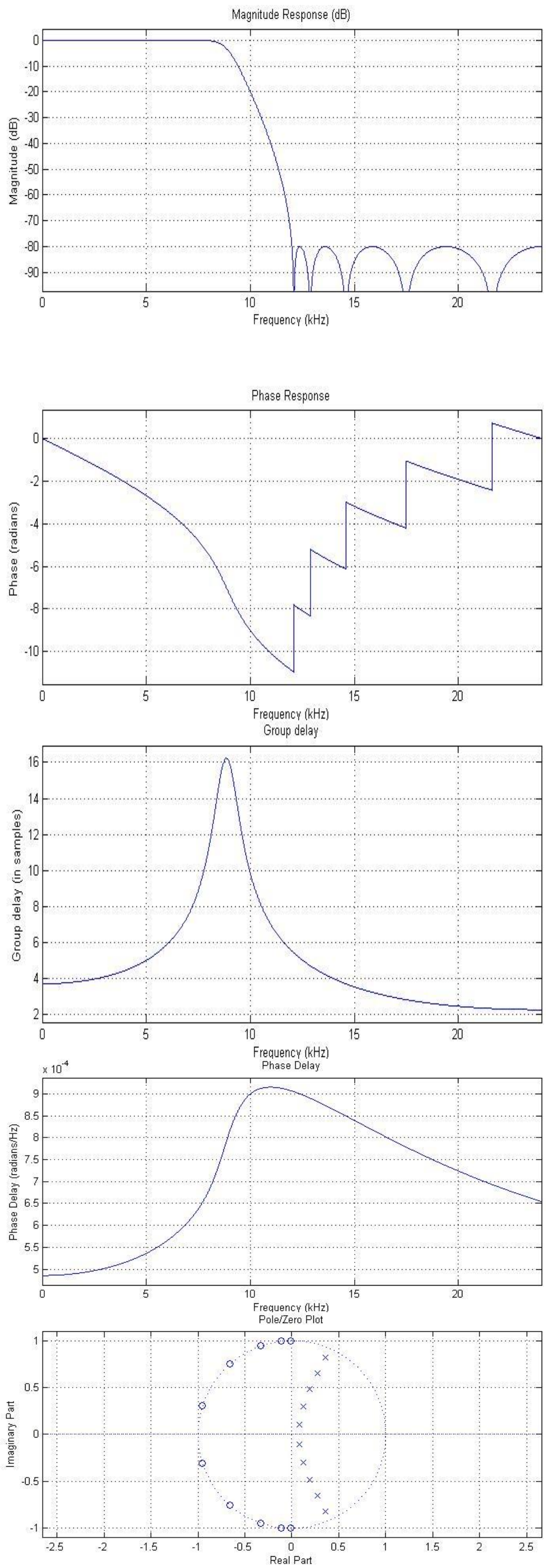

Fig.11 Chebyshev 2 Low pass Filter

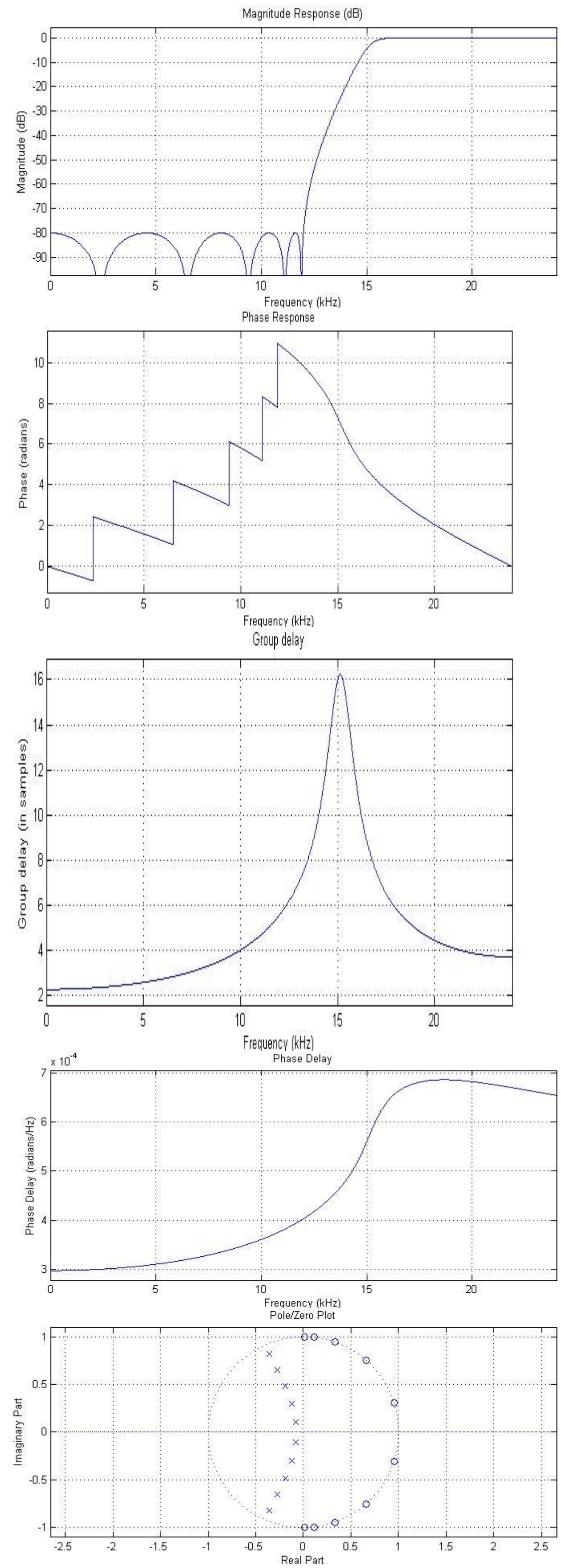

Fig.12 Chebyshev 2 High pass Filter

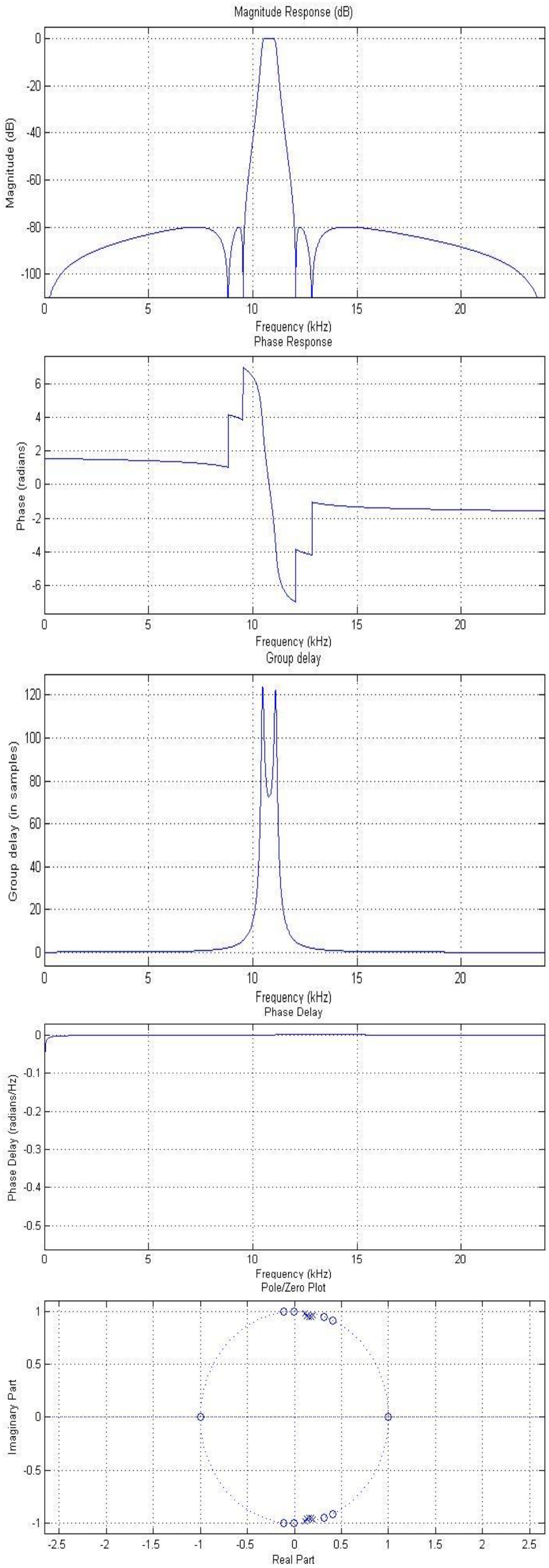

Fig.13 Chebyshev 2 Band pass Filter

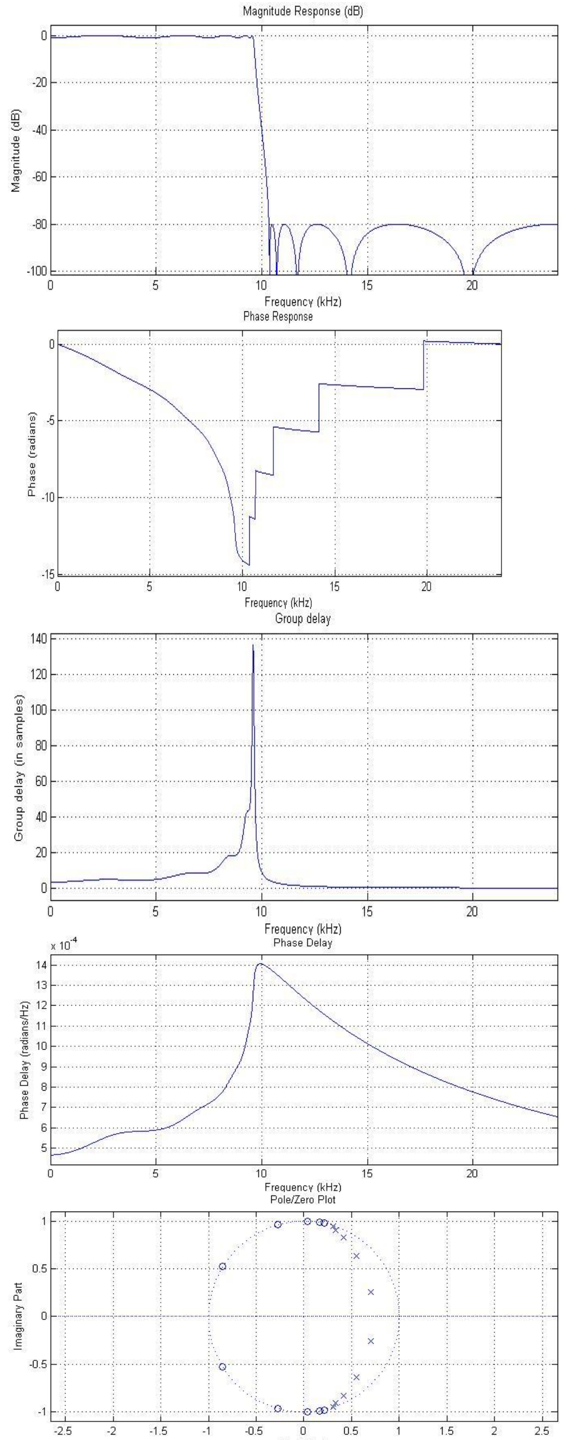

Fig.14 Elliptical Low pass Filter

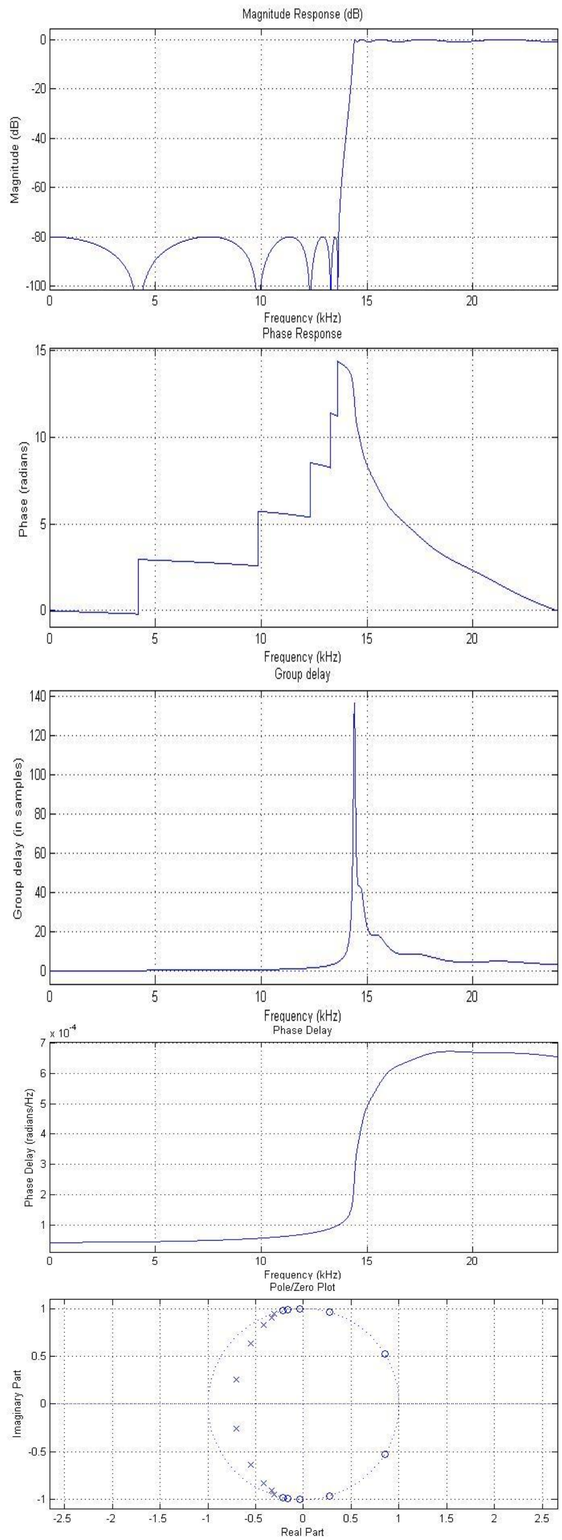

Fig.15 Elliptical High pass Filter

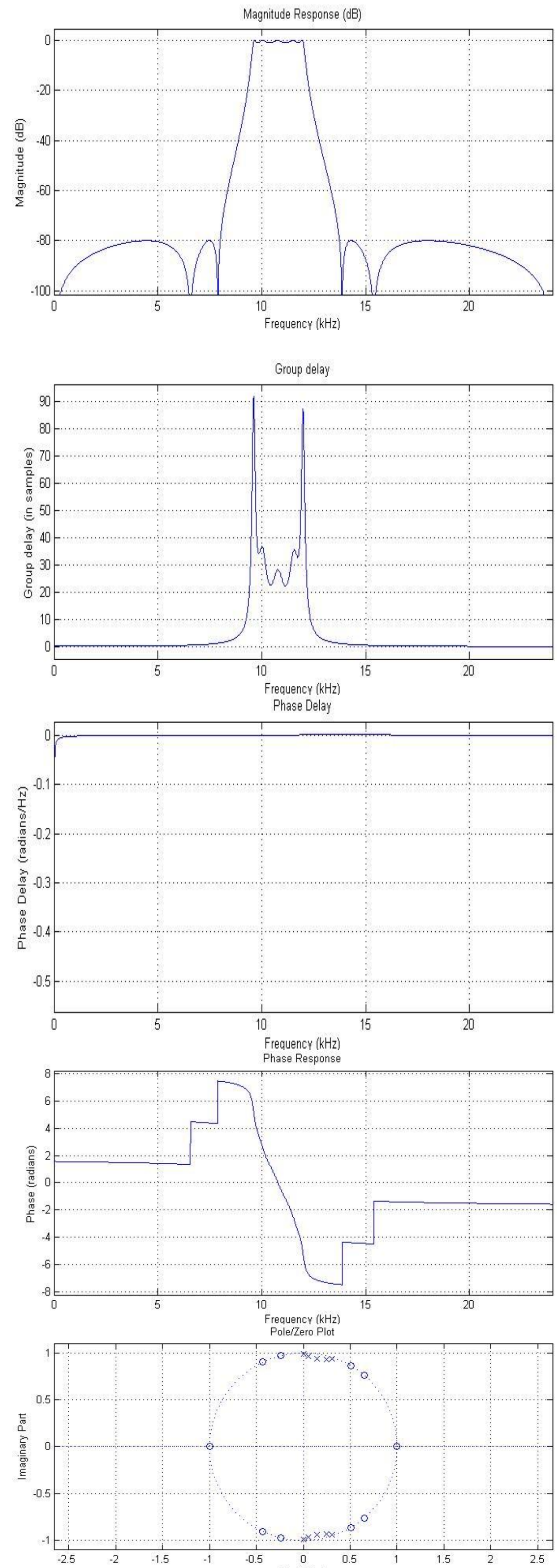

Fig.16 Elliptical Band pass Filter

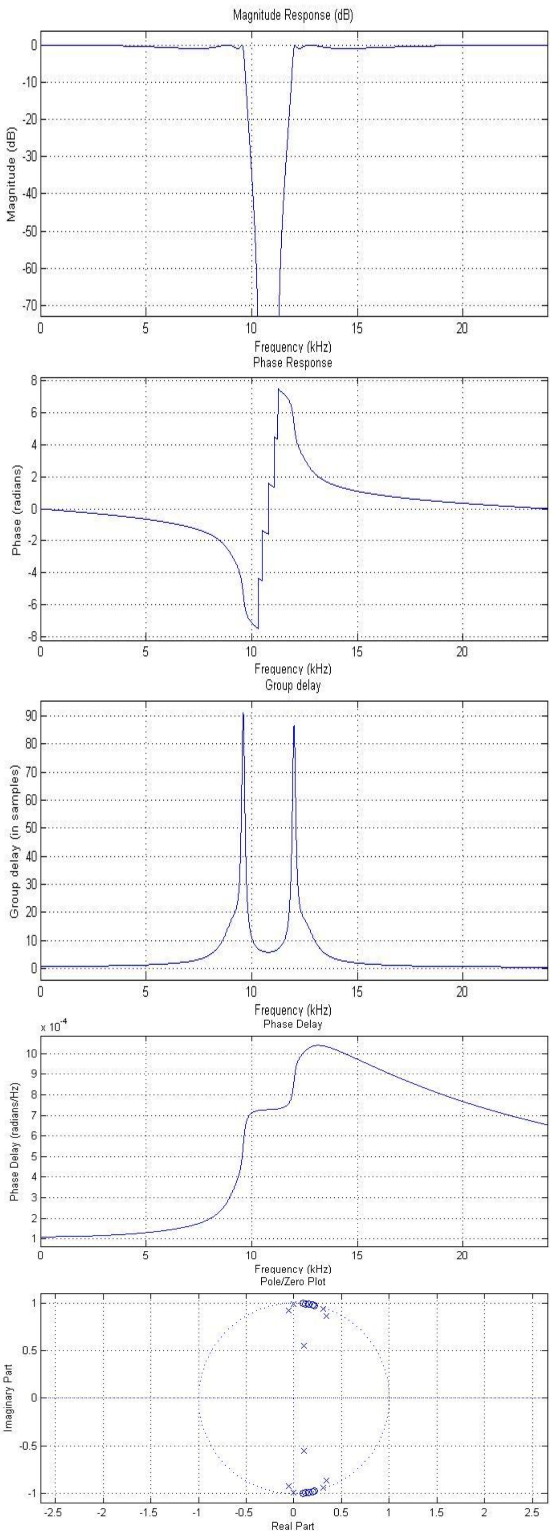

Fig.16 Elliptical Band Reject Filter

VIII CONCLUSION

From fig. 3,4…,15 and 16 it is concluded that;

Table No. 1 Comparison b/w Butterworth, Chebyshev & Elliptical Filter

Type	Pass band	Stop Band	Roll-off	Step response
Butterworth	Flat	Monotonic	Poor	Good
Chebyshev1	Rippled	Monotonic	Good	Poor
Chebyshev2	Flat	Rippled	Very good	Good
Elliptical	Rippled	Rippled	Best	Poor

Each filter has its advantage and disadvantages, when a pass band is needed, butterworth and Chebyshev 2 filter will be good choice and hence helpful for designing of filters.

IX. FUTURE WORK

By utilizing the above conclusion, further research work will be extended for FIR filters, which will be helpful for designing work dependent filters.

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