DIGITAL COLOR DOPPLER SIGNAL PROCESSING

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Abstract- **In Color Doppler ultrasound imaging system, digital signal processing is mainly based on Hilbert filter and Clutter rejection filters. Hilbert filter is used to filter out the negative frequency component of the real Doppler signal to produce the analytic signal. Clutter rejection filter are used to filter out the low frequency unwanted tissue signals for measurement of the low velocity blood flow. In this paper, two methods for designing a Hilbert filter are implemented. One of these methods is based on shifting sinc function and the other method is window based. In addition, clutter filters are designed using different types of FIR and IIR design methods. The magnitude response of each of the different designed filters is plotted to select the best filter design with the minimum order that reject clutter signals. The assessment is based on the magnitude response specifications. The Hilbert filters results show that the first method is better than other method. The clutter rejection filters results show that IIR filters offer significantly better performance than FIR at the same order. The FIR requires higher order to achieve comparable narrow transition band to IIR. For IIR; ChebyshevII and elliptic types show the best clutter rejection filters.**

Keywords- Hilbert **filters, real signal, analytic signal, clutter signal, clutter rejection filter, HPF, FIR, IIR.**

I. INTRODUCTION

Doppler ultrasound imaging systems are focused on the visualization and measurement of blood flow in the body. This is a technological achievement because the received echoes from the acoustic scattering from regions of blood, such as those in the chambers of the heart, were at levels so low that they could not be seen or appeared as black in an ultrasound image. Even when blood cannot be seen directly, its movement can be detected. Now images of blood circulation, called color flow imaging (CFI) is routine on imaging systems. The real-time display of the blood velocity and direction is both an outstanding technical achievement. Doppler techniques provide critical diagnostic information noninvasively about the fluid dynamics of blood circulation and abnormalities, such as leaking heart valves, flow reduction, and occlusion from atherosclerotic plaque. Digital signal processing techniques are required to extract, process, and display weak Doppler signals. [1]. Doppler signals are real signals where they consist of an equal contribution of positive and negative frequency components.[2] In Addition, the Doppler signals from blood are much weaker than from tissue. The signal from the tissue arise from vibration of the skeletal muscle tension, muscles in the hand of the operator holding the ultrasound probe, and slowly moving structures like vessel walls in the imaged region of the patient itself. This noise signal is called clutter signals [3]. The clutter signals may be 40-80 dB higher than scattered signal from blood but it has frequencies below 1 KHz [4].It should therefore come as no surprise that signal-processing engineers prefer to convert real signals into analytic signal, signal with positive frequency components only, before further processing this conversion can be achieved by using Hilbert filter in digital signal processing. [2, 5]. Also the clutter signals must be removed to have an accurate estimate of the flow velocities [4]. Clutter rejection filters are used to suppress the clutter signals. The clutter rejection filter is a high pass filter (HPF).The parameters describing the frequency response of a high-pass filter are illustrated in Fig. 1. [6].The stop-band, which refers to those frequencies that are blocked, is limited by stop-band cut-off frequency ω_s, which should be large enough to remove the clutter noise. The deviation from zero in stop-band is given by d_s, which should be as small as possible to get sufficient clutter rejection. In pass-band, all of frequencies should be passed through unaltered, which means that ripple d_p should be minimized. Finally, the pass-band cut-off frequency ω_p should be as close as possible to the stop-band cut-off frequency ω_s i.e. transition band should be narrow to achieve fast roll–off.This insures that a maximal range of blood velocities can be measured and maximal range of clutter frequencies is rejected. The cutoff frequency is the center between the pass-band and stop band frequency [6]. In some systems, the cutoff frequency of the HPF is user selectable to best suit the clinical application [4].

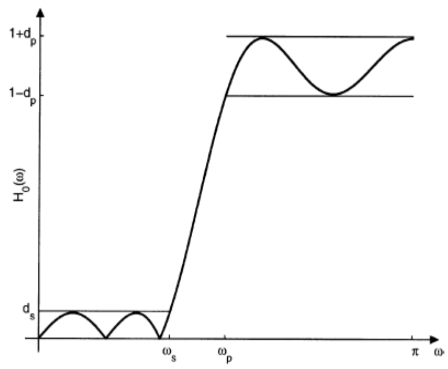

Fig.1. The parameters describing the frequency response of a high-pass filter. [6]

A number of different methods to design HPF have been adopted. The simplest method is finite impulse response (FIR) as the output is derived simply by subtracting each successive echo from its processor. Signal from stationary objects are unchanged and then cancelled, whereas those from moving objects change, and thus are preserved. This filter is non-recursive in the sense that it computes the 'current' output only from the current and past inputs, and not past outputs. The length of non-zero portion of response to an impulse is dictated by the number of coefficient and delays in the filter [4]. The frequency characteristics of digital filters may be dramatically improved by the use of recursive techniques, that is to say filters that derive their inputs not only from the present and past inputs but also from the present and past outputs. Such filters are also known as infinite impulse response (IIR) filters because of their theoretically infinite setting times [4].

In this work, two methods for designing a Hilbert filter are implemented using matlab. In addition, clutter filters, HPF, are designed using different types of FIR and IIR design

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methods using the filter design and analysis tool (fdatool) in matlab program. The fdatool is a powerful user interface used for designing and analyzing filters of matlab. The magnitude response of the different designed filters is plotted using the Fdatool to select the best filter design with the minimum order that reject clutter signals. The assessment is based on the magnitude response specifications, e.g. transition band, stop-band attenuation, and ripples in pass-band….etc

II. METHODOLOGY

Hilbert filter is designed by two methods and implemented using Matlab then the magnitude of the frequency response is plotted.

A. The first method is based on defining a sinc function, which is the continuous inverse Fourier transform of the rectangular pulse of width 2π and height 1 then shift it by phase $-\pi/2$.

B. The second method algorithm based on calculating the fast fourier transform (fft) of the desired response, and then taking a window to represent the Hilbert filter

High pass filters, clutter filters, are designed using different types of FIR and IIR design methods using the fdatool of matlab. Same main frequency and magnitude specifications are used in the design but with different orders for each filter type. Table 1 shows the main frequency specifications used in all types while the main magnitude specification for all types are shown in table 2. The orders used at each type are specified in table 3.

TABLE 1
THE MAIN FREQUENCY SPECIFICATIONS

Parameter	Value
Normalized cutoff frequency ω_c	0.2
Normalized pass-band frequency ω_p	0.24
Normalized stop-band frequency ω_s	0.16

TABLE 2
THE MAIN MAGNITUDE SPECIFICATIONS

Parameter	Value
deviation from zero in stop-band d_s	80 dB
Deviation from one in pass-band d_p	1 dB

TABLE 3
THE ORDER AT FIR AND IIR TYPES

Design Method	Type	order
FIR	Generalized Equiripple	4, 6, 8, 10, 16, 20
	Equiripple	1,3,5,7,10,15,20
	Constrained Least squares	1,3,5,7,10,15,20
	Constrained Equiripple	1,3,5,7,10,15,20
	Least Pth-norm	1,3,5,7,10,15,20
	Least-square	1,3,5,7,10,15,20
IIR	Butterworth	1,3,5,7,10,15,20
	ChebyshevI	1,3,5,7,10,15,20
	ChebyshevII	1,3,5,7,10,15,20
	Elliptic	3, 5, 7, 10, 15, 20
	Least P_{th}-norm	1,3,5,7,10,15,20

Since the window type of FIR include many types (e.g. Hamming , Kaiser, rectangular,..etc) so all types are designed using the fdatool at the same main frequency and magnitude specifications and at order (15) and compare their magnitude response to select best window type. Then a comparison between magnitude responses of different filter types of FIR including the best window type is done at the same main frequency and magnitude specifications and at the two orders (15) and (100). In addition, a comparison between magnitude responses of different filter types of IIR is also done at the same order (15)

The magnitude response of the different designed filters is plotted using the Fdatool to select the best filter design with the minimum order that reject clutter signals. The assessment is based on the magnitude response specifications, e.g. transition band, stop-band attenuation, and ripples in pass-band….etc. The best filter should have a fast roll-off to separate closely spaced frequencies (the pass-band cut-off frequency ω_p should be as close as possible to the stop-band cut-off frequency ω_s i.e. transition band should be narrow. There must be no pass band ripple, for the pass-band frequencies to move through the filter unaltered. To adequately block the stop-band frequencies, it is necessary to have good stop-band attenuation

III. RESULTS

Fig. 2 shows magnitude response of Hilbert obtained by shifting the sinc function. Fig 3 shows Hilbert frequency response obtained by window method.

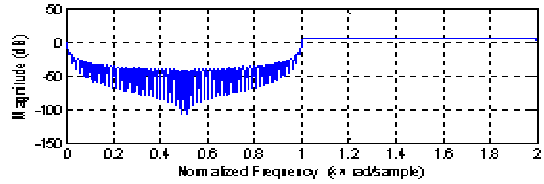

Fig.2. Hilbert magnitude response obtained by shifting the sinc function.

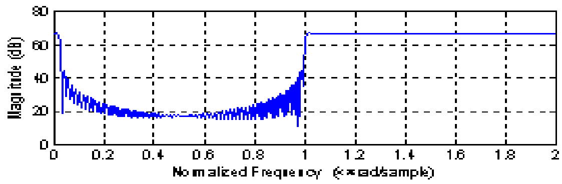

Fig.3. Hilbert magnitude response obtained by window method

Figs 4-9 show the magnitude response of different filters types using FIR method by applying different orders . the figures presents the magnitude of frequency response vs. normalized frequency. Fig. 10 shows the magnitude response of different types of window filter type. Fig. 11. shows the magnitude response of different types of FIR at the same order (15) . Fig. 12. shows the magnitude response of different types of FIR at the same order (100)

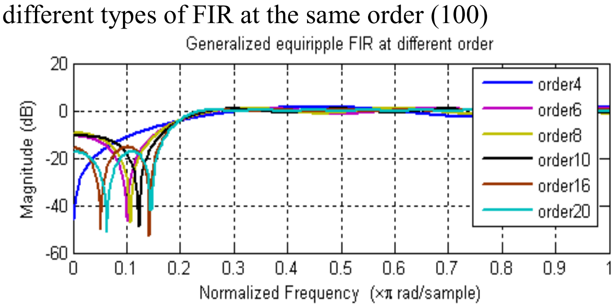

Fig. 4. Magnitude Response of Generalized Equirippple FIR at orders (4, 6, 8, 10, 16, 20)

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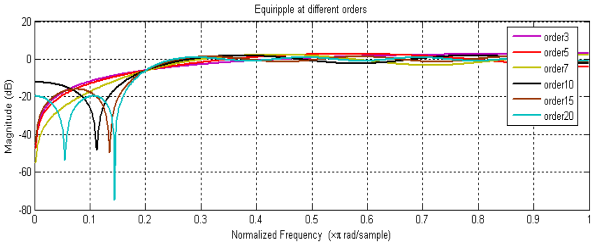

Fig. 5. Magnitude Response of Equiripple FIR at orders (1,3,5,7,10,15,20)

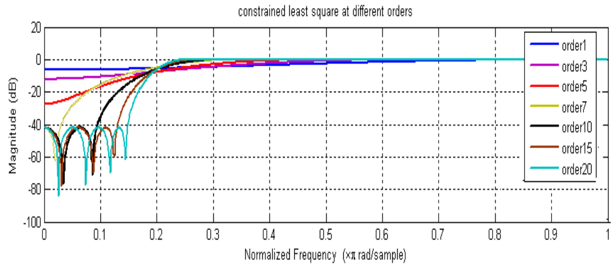

Fig. 6. Magnitude Response of constrined least squares FIR at orders (1,3,5,7,10,15,20)

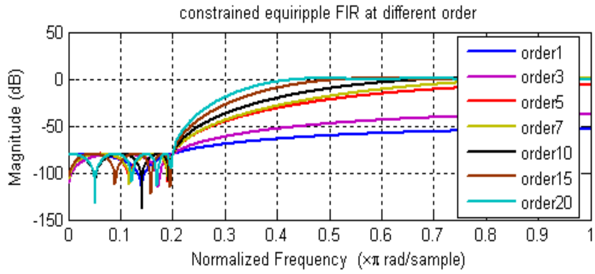

Fig.7. Magnitude Response of constrined Equiripple FIR at orders (1,3,5,7,10,15,20)

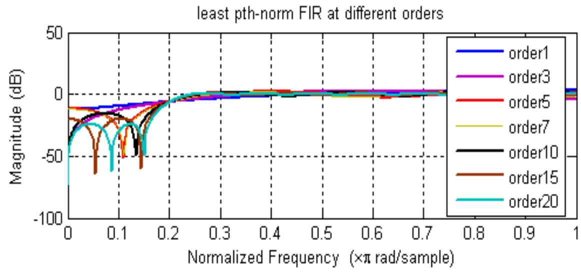

Fig. 8. Magnitude Response of least pth-norm FIR at orders (1,3,5,7,10,15,20)

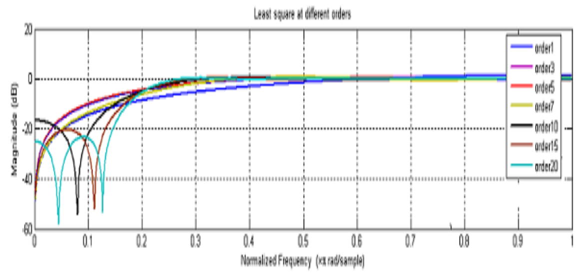

Fig. 9. Magnitude Response of least squares FIR at orders (1,3,5,7,10,15,20)

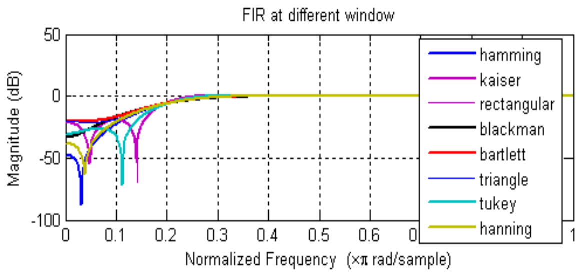

Fig. 10. Magnitude Response of different types of window at order 15

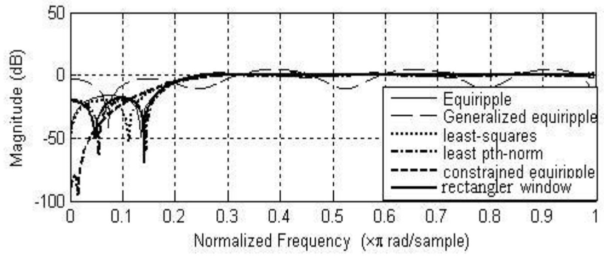

Fig. 11. comparison between different types of FIR at the same order 15

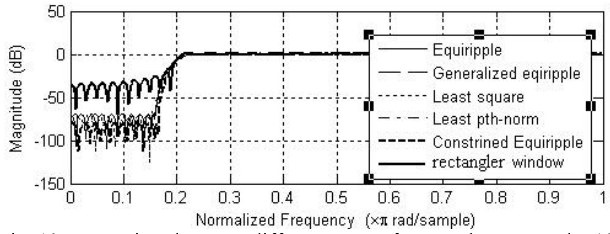

Fig. 12. comparison between different types of FIR at the same order 100

Figs 13-17 show the magnitude response of different filters types using IIR method by applying different orders . the figures presents the magnitude of frequency response vs. normalized frequency. Fig. 17. Show the magnitude response of different types of IIR at the same order (15) .

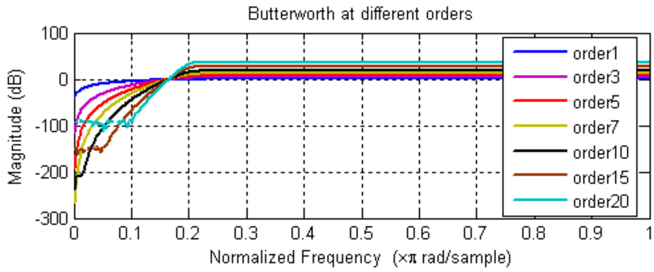

Fig.13.frequency response of Butterworth at orders (1,3,5,7,10,15,20)

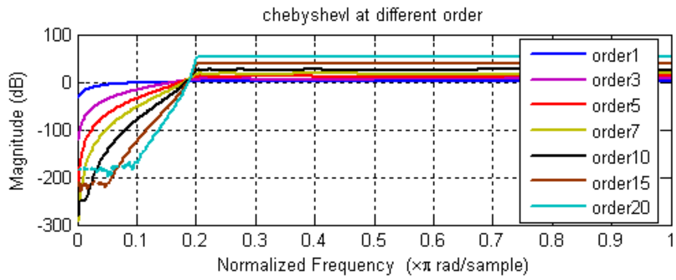

Fig.14. frequency response of chebyshevI at orders (1,3,5,7,10,15,20) order

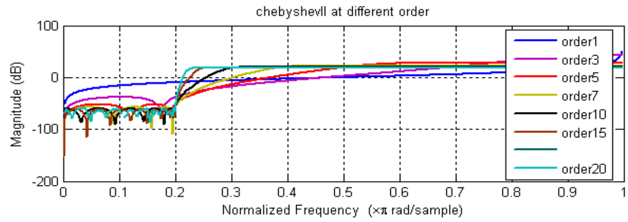

Fig.15. frequency response of chebyshevII at orders (1,3,5,7,10,15,20)

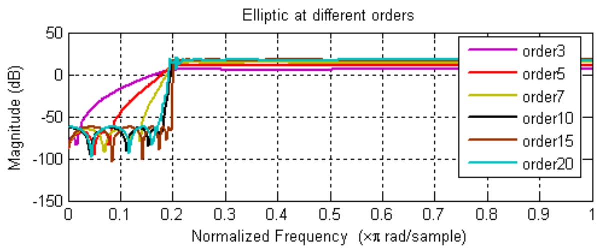

Fig.16. frequency response of Elliptic at (3, 5, 7, 10, 15, 20) order

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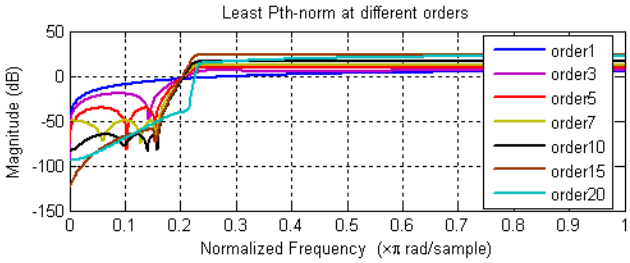

Fig.17. frequency response of least Pth-norm at (1,3,5,7,10,15,20) order

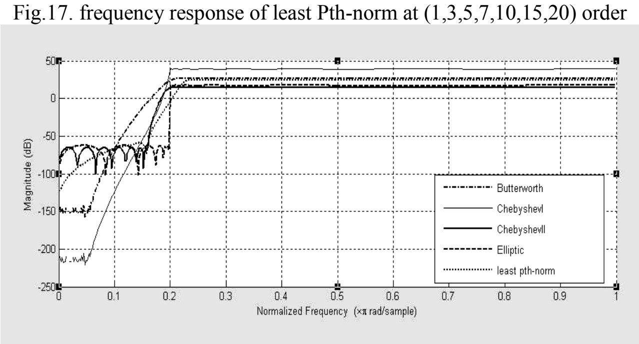

Fig .18 Comparison between different types of IIR design method at same order (15)

IV. DISCUSSION

The frequency response results of the two Hilbert filters implemented by two different methods showed that the method based on sifting sinc function by phase $-\pi/2$ gives better attenuation at the negative part of spectrum than the other method.

The magnitude response results of different types of HPF at different orders showed that the effect of changing the filter order on the magnitude response. From FIR results; The generalized Equiripple FIR and Equiripple FIR have approximately the same magnitude response but the difference in implementation is that the Generalized Equiripple deal with even order only; the magnitude response for both of them has wider transition band (slow roll-off) at low orders and as order increase the transition band decrease but still has poor stop band attenuation which doesn't meet our requirement to filter the clutter signal. Magnitude response of constrained least squares show that at low order it has very bad response and as order increase it gives better stop band attenuation than Equiripple and Generalized Equiripple . The performance of the constrained equiripple FIR has very good stopband attenuation at low orders but not sharp transition .the performance of the Least Pth-norm has bad stopband attenuation and as order increase;the transition band become narrower. The response of least square FIR give approximately the same response as Generalized Equiripple at order 10,15,20. the performance of window FIR showed that

a) Hamming window greatly reduce ringing. This improvement is at expense of transition width (longer ramp from stop-band to pass-band).
b) Rectangular window is simple window and its frequency response coincides on Kaiser Window which gives the best narrower transition band between pass-band and stop-band
c) Tukey window give good transition band after rectangular and Kaiser Window
d) Blackman window: Have slightly wider central lobes and less sideband than equivalent length hamming and hanning window.
e) Bartlett window: very similar to triangular window, it always ends with zeros while triangular window not.
f) Triangle widow frequency response coincides on Bartlett.

The Kaiser and rectangular window type of FIR design method give the best performance at low order as shown in fig.11.

All these results are consistent with the previous literature [4]; that the FIR is inadequate for most CFI applications. This is because of its poor stop-band attenuation and poor roll-off, wide transition band between pass-band and stop-band, at low orders. The transition band should be narrow otherwise blood flow signals over a considerable portion of the lower part of the available frequency band will be significantly attenuated and leave only Doppler signals corresponding to high flow rates [4]. To produce adequately narrow transition bands much higher order filters which require a large number of data samples is required. Unfortunately, large numbers of data samples are luxury, which cannot be afforded in CFI systems in order to maintain acceptable frame rates [4].

The results of different types of IIR showed that the IIR filters can be designed to produce more nearly ideal frequency response than FIR filters using relatively small number of orders. From the results of IIR; the magnitude response of the Butterworth show that as order increase, the transition width becomes narrower but it has slow rate in transition and poor attenuation for order10 or less. The magnitude response of ChebyshevI show that at low orders it has bad transition band and bad stop band attenuation as order increase, the transition width between pass band and stop band become narrower (better roll-off) and get better stop band attenuation than Butterworth. The magnitude response of ChebyshevII unlike type I, has a monotonic pass band and Equiripple stop band As order increase, it has Sharp cutoff rate in transition from stop-band to pass-band ;stop band ripple increase but get better stop band attenuation. The magnitude response of Elliptic filter has the very good stop band attenuation , smallest transition band ,sharpest cutoff rate among all other types of filters at order 10,15,20.the magnitude response Least P_{th}-norm response show that as N increase, the transition band decrease but still bad; it also not stable at order 15, 20.

ChebyshevII and elliptic IIR filters give the best sharpest cutoff rate (narrow transition band and best stop band attenuation) among all other types of filters and at low orders as shown in Fig.19 and increasing order not change shape of filter i.e. the required response can be achieved by small number of orders.

V. CONCLUSION

We conclude that the Hilbert filter can be designed using two different design method, the first method give better attenuation at the negative part of the magnitude response than other method.. also for clutter filter; increasing the order improve the performance of IIR and FIR frequency response but at the same order the IIR give better performance than FIR as FIR require higher order to achieve the required magnitude response which means more memory and more computation time.

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