Design & Analysis of IIR Notch Filter using LabVIEW

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Abstract—**This paper presents the implementation of IIR notch filter using signal processing tool kit of LabVIEW software. User interface is designed using LabVIEW to obtain the simulation results of digital IIR notch filtering technique. Simulation results are presented in terms of magnitude squared value of notch frequency for different nature of noise signals. The results shows that the designed notch filter gives best performance by extracting notch peaks from different sources of noisy signals.**

Keywords— Digital signal processing; Elliptic bandpass filter; IIR notch filter; Lab VIEW.

I. INTRODUCTION

In transmission of information from the source to receiver, noise from the surroundings automatically gets added to the signal. The noisy signal will contains two components, one carries the information of interest i.e. the useful signal; the other consists of noise which is in the background of the useful signal [1].These errors are unwanted because they reduces the accuracy and perceived quality of signal. Therefore, the effective removal or reduction of noise in the field of signal processing is an active area of research. In order to keep tracking the frequencies changes in the input signal, the notch filters must be employed in the DSP system so as to update that system recursively [2][3]. This notch filter is able to extract the desired sinusoid component of a given signal provided that the signal frequency remains constant. The method of suppressing a sinusoid interference corrupting an information carrying signal is to use a fixed notch filter tuned to the frequency of interference [4].

A fixed notch filter may eliminate the noise when it is centered exactly at the frequency for which the filter was designed. This notch filter can be designed by employing a particular type of filter structure [5]. There are basically two classes of digital filter model i.e, Finite impulse response (FIR) filters & Infinite impulse response (IIR) filters. FIR filters are realized by a moving average model which consists of zeros only where as an IIR filter can be realized by an autoregressive moving average model which consists of poles & zeros. It is desired that IIR filters can be economically & effectively modeled as compared to FIR models [6]. Digital IIR notch filtering concept depends upon the external factors, when it comes to the elimination or retrieval of frequency components embedded in the background noise. This problem can be solved by either of the two ways depending upon the nature of the information signal. The first case is when the sinusoidal frequency is known & is time invariant. Under these circumstances, a tunable IIR notch filter can be designed such that it attains unity gain at all frequencies, except at the notch frequency (where the gain is zero), which means that filter only modifies a known part of the frequency spectrum leaving the remaining portion unchanged. The second type is when the sinusoidal frequency is not known and is time varying. The solution to this problem is by implementing an adaptive notch filter whose coefficients are determined by the observed time series [2]. The digital notch filter designed to reject a specific frequency rather than a whole spectrum, this kind of notch filter is known as single notch filter which rejects only a prescribed frequency. At times, when more than one interfering frequencies exists then multiple notch filter is required. The simplest way to get rid of this problem is to cascade single notch filters [6]. This IIR notch filter has a number of advantages over conventional analog filters in terms of stability, accuracy, reliability, flexibility and cost.

The paper is organized as follows: In section II, implementation of IIR notch filter is described by step by step simulation. Section III shows the simulation results of the designed filter in section section II. In section IV, the conclusion & future scope of designed filter is given.

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II. DESIGN OF IIR NOTCH FILTER

To design a digital notch filter, there are many methods for IIR filter design and they are as follows: (i) analog filter transformation (ii) all pass filter implementation (iii) pole-zero placement technique. Firstly, for an analog filter transformation, transformation of an analog notch filter into a digital notch filter is performed simply by taking bilinear transform, impulse invariance method or step invariance method. Secondly, the IIR notch filter can be implemented by equivalent realization of an all pass filter. Due to the mirror image symmetry relationship between the numerator & denominator polynomials of all pass filter, the notch can be realized easily [4]-[6]. Thirdly, pole-zero placement technique is one of the simplest & most efficient technique for IIR notch filtering which is being implemented in this paper. The transfer function of a notch filter is given as

$$H(z) = \frac{1}{2} \frac{(1+a_2)-2a_1 z^{-1}+(1+a_2)z^{-2}}{1-a_1 z^{-1}+a_2 z^{-2}} = \frac{Y(z)}{X(z)} \quad (1)$$

Here, $a_1 = 1.3711242$, $a_2 = 0.93906244$

For the designing of an IIR filter, bandpass filter is considered with the following specifications: passband response=0.5dB, passband frequency=1200 to 2600 Hz, stopband attenuation = 20 dB, stopband frequency=1500 to 2500 Hz, sampling frequency=8000 Hz. The elliptic method is chosen to achieve a narrowband transmission. This design of an IIR filter is achieved by using DFD classical design express of signal processing tool kit of LabVIEW software. The virtual instrument (VI) is designed for IIR filter using elliptic bandpass filter in LabVIEW [8]-[10]. The virtual instrument (VI) is a graphical program obtained by selecting various icons from signal processing toolkits available in LabVIEW & joined together to make this notch filtering system. But firstly, the general IIR filter is designed using signal processing toolkit. The block diagram of design of IIR filter in LabVIEW is shown in Fig. 1.
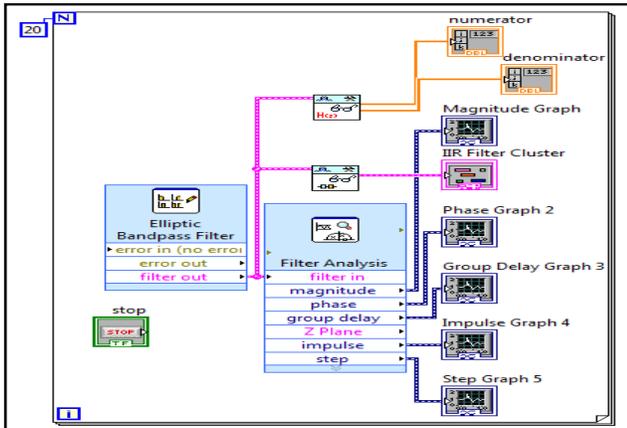

Fig. 1. Block diagram of design of IIR filter in LabVIEW

The filter coefficients corresponds to the IIR cascaded second order structure. The simulation results of this filter are shown in section IV. The filter analysis depicting the magnitude response, phase response and group delay graphs of the filter characteristics with respect to its step response and impulse response are done. Then the reverse & forward coefficients are obtained for a II order filter structure from depending upon the equation of transfer function.

This developed IIR filter is then used for designing an IIR filtering system in which five sinusoidal signals of different frequencies 500 Hz, 1000 Hz, 1500 Hz, 2000 Hz and 2500 Hz are used with a sampling frequency of 8000 Hz is used to be filtered from a second order IIR filter. The elliptic bandpass filtering method is used for filtering as it is provides the reduced order of the filter [6]. The reduced order makes this filter more economical as compared to other designing methods. The output results with respect to the FFT output are obtained by using spectral measurements block attached with a linear filtering block of LabVIEW. The below shown block diagram depicts the above explained IIR filtering system of second order. The simulation results of this filtering system are shown in section IV.
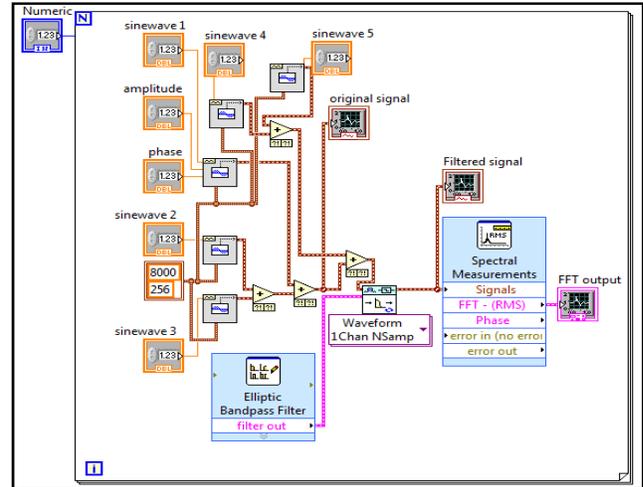

Fig. 2. Block diagram of design of IIR filtering system

Finally the IIR notch filter is designed using notch peak design block of signal processing toolkit. The filter is designed by bandwidth method i.e, filter type will remain the same however the values of center frequency f_o=600 Hz, Q factor=20, Bandwidth=80 Hz, sampling frequency of 8000 Hz. These four parameters plays a very important role in designing of any type of notch filter. Here, f_o is the center frequency corresponding to the peak value of the amplitude response of a filter. For the bandpass or bandstop filter, it is equal to the geometric mean of the -3 dB frequencies. Bandwidth is a frequency band which is calculated by the higher -3 dB frequency (roll-off point) minus the lower -3 dB frequency (roll-off point). Then comes the quality factor, the quantity that is widely used in different applications [5]. In physics & engineering, the Q-factor is a dimensionless parameter that

describes how underdamped an oscillator or resonator is. For a filter, this factor defines the sharpness of the amplitude response. so the output of the above designed filter is shown below in which the magnitude squared of highest notch peak is observed at a bandwidth of 80 Hz, center frequency f_o at 600 Hz and sampling frequency at 8000 Hz [6]-[11]. The filter coefficients are updated according to the value of numerator and denominator are given by the transfer function in eq(1).
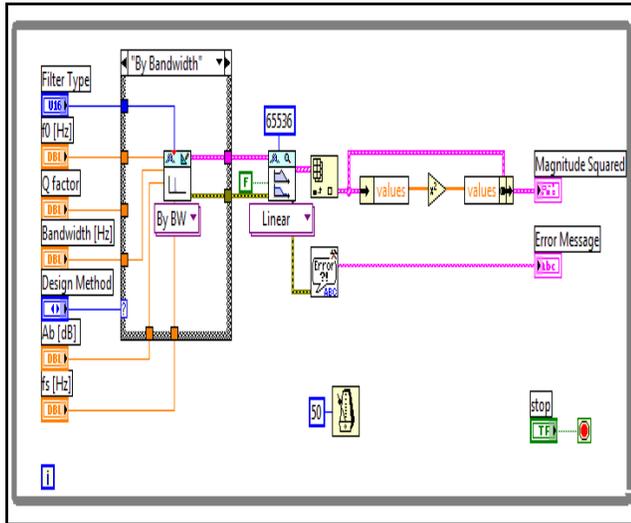

Fig. 3. Block diagram of IIR notch filter using LabVIEW

The IIR notch filter is designed by using sine waveform with uniform noise and the filter is able to extract the notch frequency of 600 Hz from it. This way it is possible to extract the immersed sinusoid by simply assigning the value of notch frequency f_o from given signal. The block diagram of this filtering system is shown below.
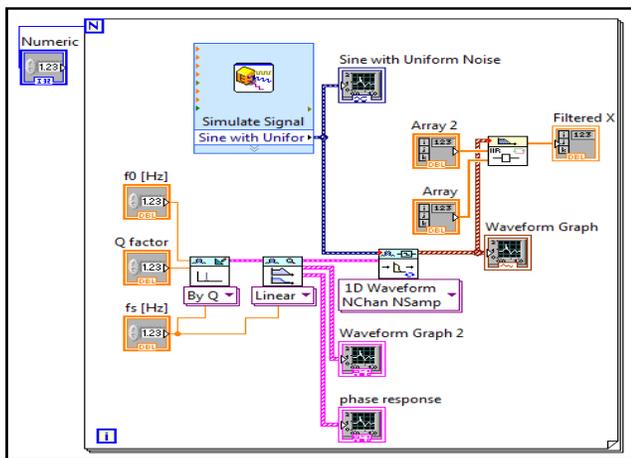

Fig. 4. Block diagram of IIR notch filtering system using sinewave with uniform noise.

Similarly, the same technique is applied to extract an unknown notch frequency from tones & noise waveforms as shown in the below given block diagram. The IIR notch filter is extracting the notch frequency at 600 Hz and the simulation results of the same are given in section III.
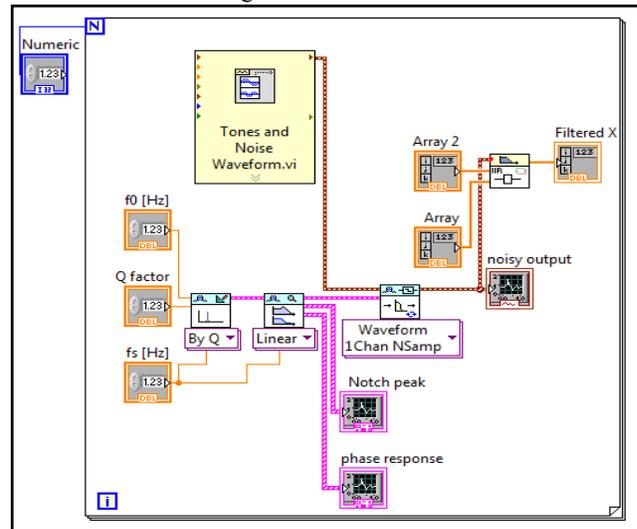

Fig. 5. Block diagram of design of IIR notch filtering system using tones and noise waveform generator.

In the shown figure another IIR notch filter is designed for extracting notch frequency from uniform white noise waveform. The results given in section III shows that this filter is functioning properly in extracting the immersed noise sinusoid of frequency 600 Hz [7].
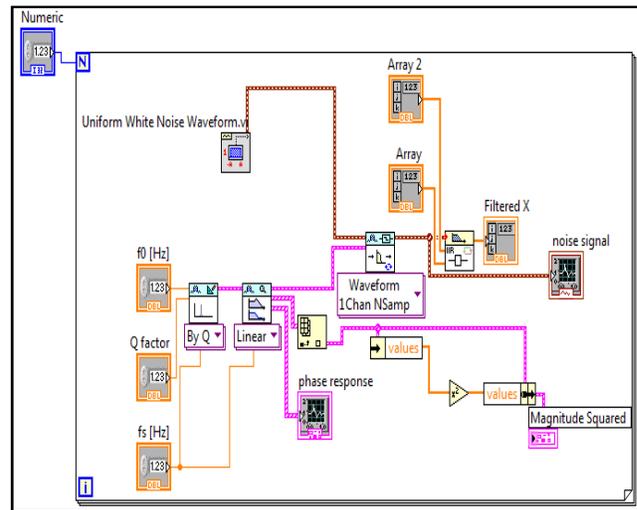

Fig. 6. Block diagram of design of IIR notch filtering system using white noise waveform.

III. SIMULATION RESULTS

The below shown figures are obtained on front panel window of LabVIEW. The fig. 7. shows the magnitude response, phase response, group delay ,Step response & impulse response of an elliptic bandpass IIR filter. Even the filter coefficients are updating in every iteration by using for loop. The filter structure used as per the transfer function is a second order IIR filter.
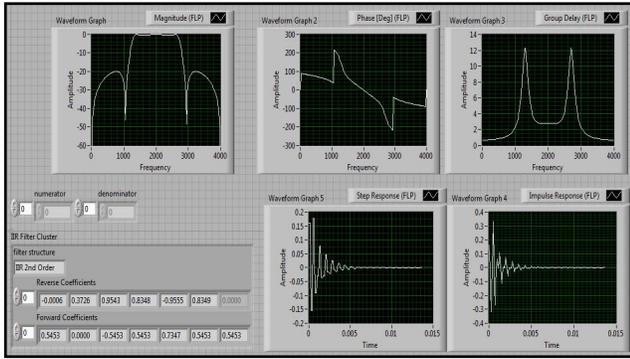
Fig. 7. Front panel of design of IIR filter using LabVIEW

Then by using this IIR filter structure a new IIR filtering system is designed and the simulation results shown in fig. 9 shows an original signal which is a mixture of five different frequency components. Then the second waveform shows the signals having the frequencies 1000 Hz and 3000 Hz are filtered out, & only the signal with 2000 Hz frequency should remain and be seen as the output signal. From the FFT graph, it can be seen that the desired stopband attenuation of 20 dB is obtained and also the FFT graphs shows the level of frequencies at respective given values. Now, this IIR filtering system is then used to extract notch frequency.

Fig. 8. Front panel of design of IIR filtering system in LabVIEW

The fig. 9 shows the notch frequency extracted from a sinusoidal waveform at frequency f_o of 60 Hz, at sampling frequency f_s of 300 Hz. The Q-factor plays a very important role in this notch filtering system as it depicts the sharpness of the notch peak. The higher the value of Q-factor the more will be the sharpness of the peak.
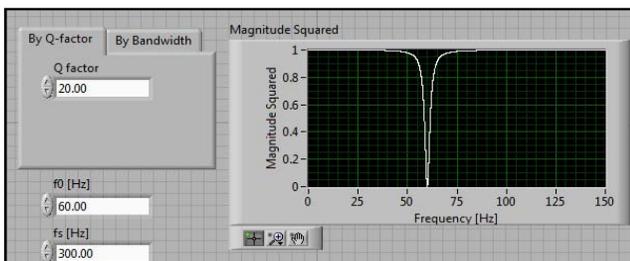

Fig. 9. Front panel showing the IIR notch filter output.

The results in fig. 10 shows the output of IIR notch filtering system using a simple sine wave with uniform noise signal and the achieved output in terms of magnitude squared value is shown as an extracted notch frequency.
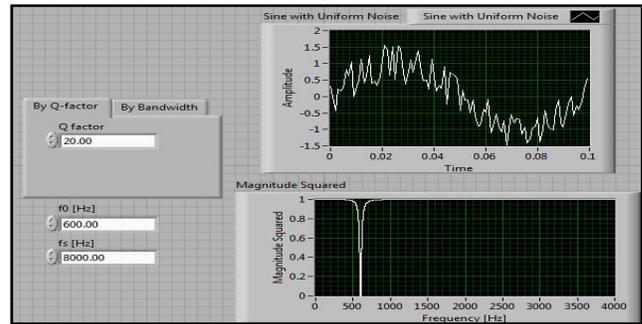

Fig. 10. Front panel of IIR notch filter on uniform noise sinewave signal

The simulation results in fig.11 shows the extracted notch frequency in terms of mean squared error, when replaced by a tone & noise signal at the input channel. Again this filter extracts the notch frequency at 600 Hz.
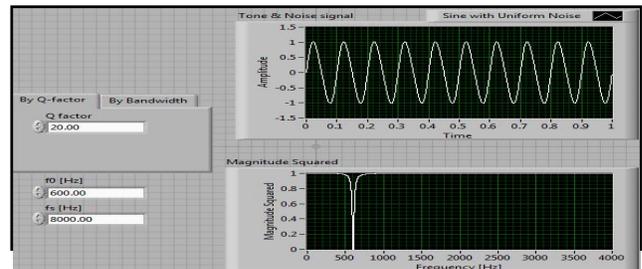

Fig. 11. Front panel of IIR notch filter on tones & noise waveforms

Another experiment with the same IIR notch filter is performed by replacing the tone & noise signal at the input with a uniform white noise signal. The simulation results in fig.12 depicts the extracted notch at frequency 600 Hz.
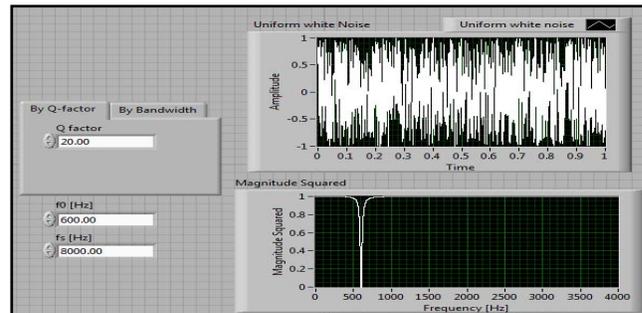

Fig. 12. Front panel of IIR notch filter on uniform white noise signal

These multiple simulations are performed with three different types of noise signals in order to check the performance and analysis of the designed IIR notch filter in LabVIEW for the purpose of extraction of the immersed notch frequency from a noisy input signal.

IV. CONCLUSION

The IIR notch filter is designed using signal processing toolkit of LabVIEW. Simulation results are obtained for extracting fixed values of frequencies from different sources of noise signals. These results are obtained for extracting fixed values of frequency at 60 Hz. So, in future it can also be designed as an adaptive notch filter for the varying values of notch frequencies. The future scope of this paper is that, that this filter can also be used for tracking multiple notches immersed in the background noise by simply cascading 'n' number of single notch filters.

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