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Design and Analysis of Band Pass FIR Filter using Different Window Techniques

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Abstract - Digital filtering is one of the main basic need of Digital signal processing; So Digital filters are widely used in many digital signal processing applications. In this paper band-pass FIR filter is implemented by using Signal processing toolbox FDAtool. The filter performance can be verified using MATLAB program and Simulink in MATLAB.

Digital FIR filter design can be done rapidly,experimental result showed that the band pass filter, filtered the unwanted frequency band from the compound input signal.

The performance analysis of a FIR filter with different window functions by using SimulinkModel, provide rapid, more convenient and reduce workload as compare to run MATLAB program.

Keyword:FIR filter, Window Function, MATLAB, Simulink

I. INTRODUCTION

Digital filters have an important role in digital signal processing applications. These are widely used in digital signal processing applications, such as digital signal filtering, noise reduction, frequency analysis, multimedia compression, biomedical signal processing and image enhancement etc. A digital filter is a system which passes some desired signals more than others to reduce or enhance certain aspects of that signal. It can be used to pass the signals according to the specified frequency pass-band and reject the frequency other than the pass-band specification. The basic filter types can be divided into four categories: low-pass, high-pass, band-pass, and band-stop. On the basis of impulse response, there are two fundamental types of digital Filters:

Infinite Impulse Response (IIR) filters, and Finite Impulse Response (FIR) filters [1]

Finite Impulse Response digital filter has strictly exact linear phase, relatively easy to design, highly stable, computationally intensive, less sensitive to finite word-length effects, arbitrary amplitude-frequency characteristic and real-time stable signal processing requirements etc. Thus, it is widely used in different digital signal processing applications [1, 2]

FIR filter is described by differential equation. The output signal is a convolution of an input signal and the impulse response of the filter.

x (n) is the input signal

h (n) is the impulse response of fir filter

o/py (n) =x(n)*h (n)

The transfer function of a causal FIR filter is obtained by taking the z-transform of impulse response of FIR filtersh (n). There are many straightforward techniques for designing FIR digital filters to meet required frequency and phase response specifications, such as window design method or frequency sampling techniques.

The Window method is the most popular and effective method because this method is simple, convenient, fast and easy to understand. The main advantage of this design technique is that the impulse response coefficient can be obtained in closed form without the need for solving complex optimization problems.

Window functions can be divided into two categories; Fixed and Adjustable window functions. Mostly used fixed window functions are; Rectangular window, Hann window, hamming window and Blackman window. On the other hand the Kaiser window is a kind of adjustable window function. These different widows are used for the Digital FIR filter designing and spectral performance analysis [3]

In the digital filter, Finite Impulse Response digital filter has strictly linear phase and arbitrary amplitude-frequency characteristic, and drift-free, high stability, etc. Thus, it was widely used in systems of carrying information by waveform, such as digital audio, signal processing.

MATLAB is created and developed by Math WorkCompany, and is used for the conceptual design, modeling and simulation, real time implementation. The design and simulation analysis of digital filter is quickly and efficiently achieved by using powerful computing capabilities of MATLAB, the users are not only familiar with the performance parameters of the digital filter, but also feel convenient in calculation as it provide simplification. As one of MATLAB signal processing boxes, Simulink has powerful features and friendly user interface, while the combination of Simulink and MATLAB make the users more easily and effectively build simulation [4].

II. FILTER INTRODUCTION

A. FIR filter

Suppose impulse response of filter is h (n) (n = 0, 1, 2, ⋯, N-1), input signal is x (n), so filter is to achieve differential equation

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

The transfer function

$$H(Z) = \sum_{k=0}^{k-1} h(k)\, z^{-k} \quad (2)$$

of FIR filter is obtained after finishing z-transform for the 1[st]type, it can be seen from the 2[nd]type that, the direct-type structure is most simple and practical, less the amount of multiplication in several realization structures of FIR digital filter. The realization structure is adopted in the text, and its block diagram is shown in Fig.1.

B. Design methods of FIR filter

There are several methods of FIR filter, for example: window function design method, optimization design method, frequency sampling design method. Window function design technique is one of the main FIR filter design methods, because of its simple operation and easy physical meaning, window function method has become a method for widely use in engineering practice.

There are six kinds of basic window function; they are Rectangular window, Triangular window, Han window, Hamming window, Blackman window and Kaiser Window. The basic idea of all window function design method is to select the filter on the basis of suitable and ideal frequency characteristics, and then its impulse response was truncated to obtain a FIR filter of linear-phase and cause and effect. Therefore the focus of this method is to select an appropriate window function and a suitable ideal filter [5]. Suppose the ideal response of desired filter is

$$h_d(e^{j\omega}) = \sum_{n=-\infty}^{\infty} h_d(n)e^{-jn\omega} \quad (3)$$

The design of FIR filter lies in finding a transfer function

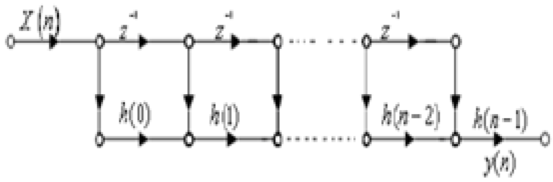

Figure: 1

$$H(e^{j\omega}) = \sum_{n=0}^{N-1} h(n)e^{-jn\omega} \quad (4)$$

To approximate $H_{ad}(e^{j\omega})$, suppose

$$h_d(n) = \frac{1}{2\pi}\int_{-x}^{x} H_d\,(e^{j\omega})e^{jn\omega}\ d_\omega \quad (5)$$

The rectangular frequency characteristics of $H_d(e^{j\omega})$so $h_d(n)$ must be an infinite sequence and non-causal. The h(n) of FIR filter to be designed is inevitable finite; infinite $h_d(n)$was approximated by using finite h(n). The most effective way is to cut off $h_d(n)$, or $h_d(n)$ was intercepted by using finite window function sequence w(n), i.e.

$$h(n) = h_d\,(n)\omega\,(n) \quad (6)$$

So the shape and length of Window function sequence were very critical. In the design process, window function w(n) was selected according to requirements of transition bandwidth and stop-band attenuation of FIR filter.

C. Introduction to window functions [8]

Rectangular window

The rectangular window (sometimes known as the **boxcar** or **Dirichlet window**) is the simplest window, equivalent to replacing all but *N* values of a data sequence by zeros, making it appear as though the waveform suddenly turns on and off:

w(n) = 1.

Blackman windows

Blackman windows are defined as:

$$w(n) = 0.42 + 0.5\cos\left(\frac{2\pi n}{N-1}\right) + 0.08\, cos\left(\frac{4\pi n}{N-1}\right)$$

Hamming window.

$$w(n) = 0.54 + 0.46\cos\left(\frac{2\pi n}{N}\right)$$

Hann (Hanning) window

$$w(n) = 0.5 + 0.5\cos\left(\frac{2\pi n}{N}\right)$$

Triangular window

Triangular windows are given by:

$$w(n) = 1 - \left|\frac{n - \frac{N-1}{2}}{\frac{L}{2}}\right|$$

where **L** can be N, N+1 or N-1 the latter is also known as **Bartlett window**. All three definitions converge at large *N*.

D. Window function design steps of FIR filter

1) The unit impulse response $h_d(n)$ of ideal filter was obtained by applying inverse Fourier transform to the ideal characteristics $H_d(e^{j\omega})$of digital filter. Suppose the cut-off frequency of ideal low-pass filter was wc, the amplitude frequency characteristics were: the$H_d(e^{j\omega}) = 1$, when $0 \le w \le w_0$ the $H_d(e^{j\omega}) = 0$, when $w_0 \le w \le \pi$, or

$$h_d(n) = \frac{1}{2\pi}\int_{\omega_c}^{\omega} e^{jn\omega}\, d_\omega = \frac{\sin[\omega_c(n-\alpha)]}{\pi(n-\alpha)} \quad (7)$$

2) The window function w(n) and window length N were identified according to performance indicators, window length was obtained according to the transition zone that was similar to the main lobe width of the window function.

3) Unit impulse response of the filter was acquired, as given in (6).

4) Performance indicators of the filter were tested. [6]

III. SIMULINK SIMULATION OF FIR BAND-PASS FILTER

As one of the MATLAB toolboxes, Simulink is a software package to model, simulative and analyze the dynamic system, interactive graphical environment is provided, it only need to move the module of library, to window of simulation files by using the mouse [7], model of system block diagram is rapidly built without compiling code.

The Simulink Library Browser dialog box were opened when you input Simulink in the MATLABcommand window, in the dialog box, Digital Filter Design, Sine Wave, Vector Scope and Spectrum Scope module of Signal Processing Block set library and Add module of Math Operations library were transferred to new simulation file (.mdl), each module was connected to constitute the simulation model of band-pass filter, as shown in Fig.2

The article took mixed input signal e.g.

s (t) = sin 2π tf1 + sin 2π tf2 + sin 2π tf3.... (8)

where f1=100Hz, f2=250Hz, f3=400Hz.A filter was designed to filter high-frequency signal components.

Parameter settings of each module are as follows:

1) Digital Filter Design module: Fs=1000; F-pass=150; F-stop=350;

2) Add module: List of signs set +++;

3) Sine Wave 1, Sine Wave 2 and Sine Wave 3 module: Frequency (HZ) set respectively: 100, 250 and 400, Sample time set 1/1000. The rest used the systemdefault.

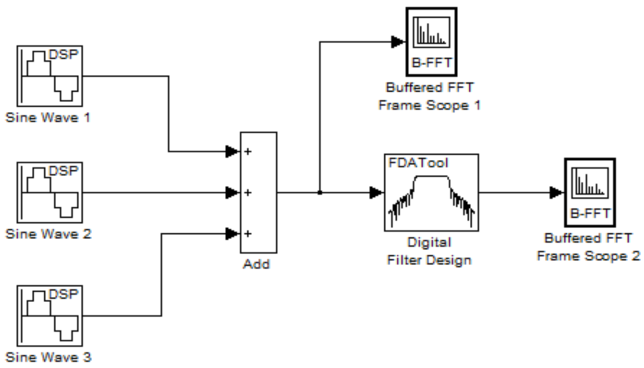

Figure 2: Simulink Simulation Model

The frequencyspectrum of the mixed unfilteredsignal in figure 3

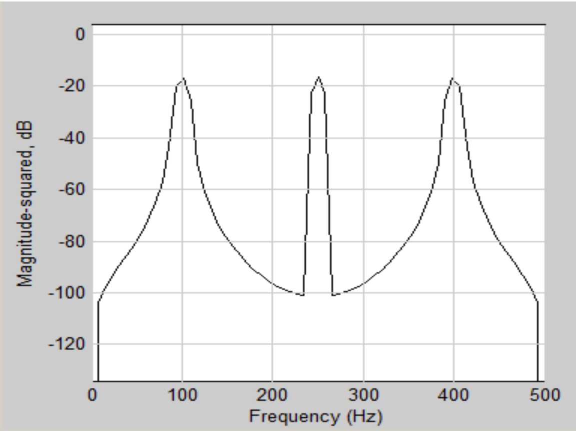

Figure 3 frequency spectrum of mixed signal at input

By using FDAtool the magnitude response of designed band- pass filter based on different window function and the filtered output frequency spectrum of mixed signal when it passes through filters are given as follows

Rectangular Window based Filter:

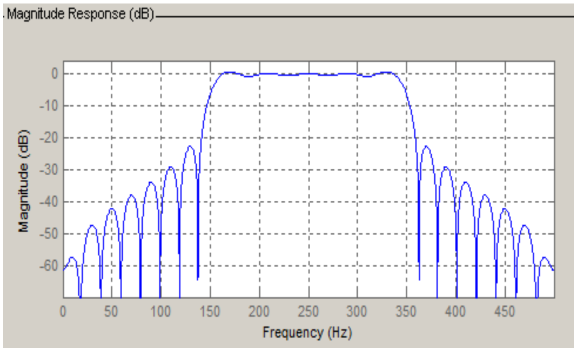

Figure 4: Magnitude response of Rectangular window based filter

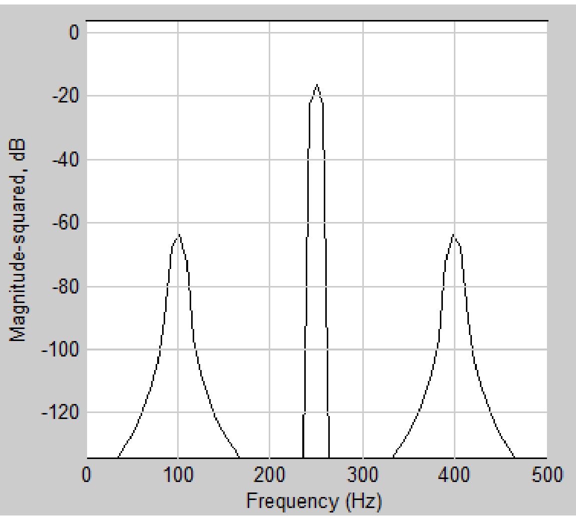

Figure 5: Frequency spectrum of output of Rectangular window based filter

Bartlett Window based filter:

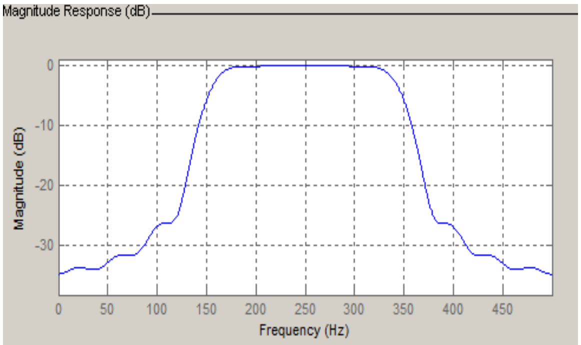

Figure 6: Magnitude response of Bartlett window based filter

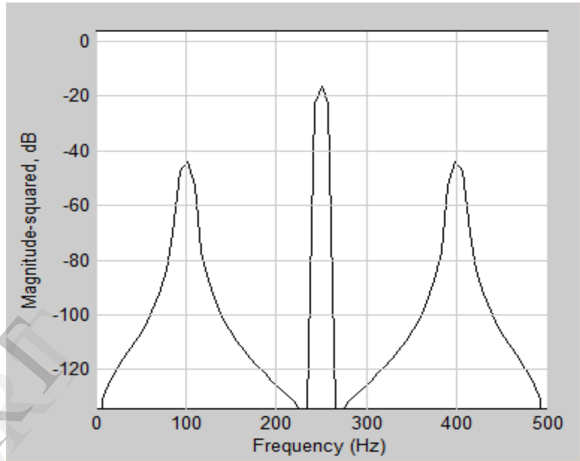

Figure 7:Frequency spectrum of output of Bartlett window based filter

Hann Window based Filter:

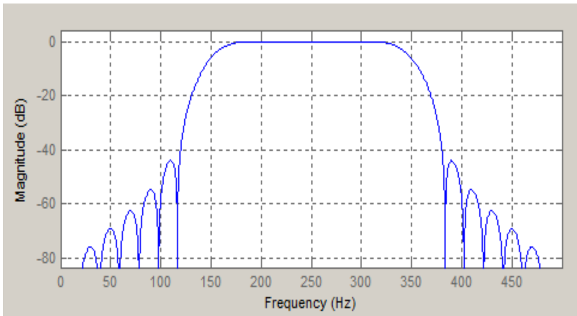

Figure 8: Magnitude response of Hann window based filter

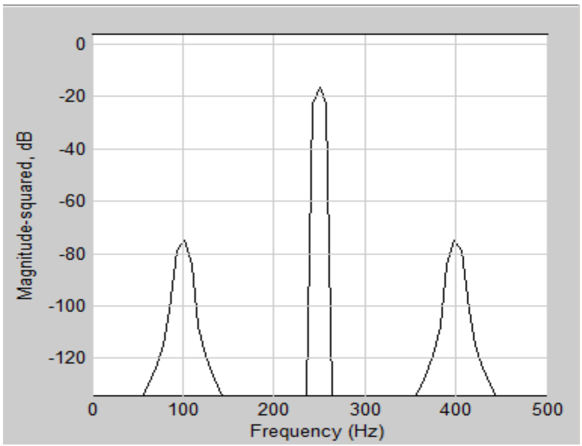

Figure 9: Frequency spectrum of output of Hann window based filter

Hamming Window based Filter:

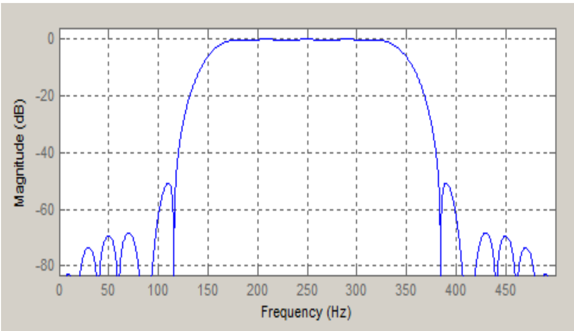

Figure 10:Magnitude response of Hamming window based filter

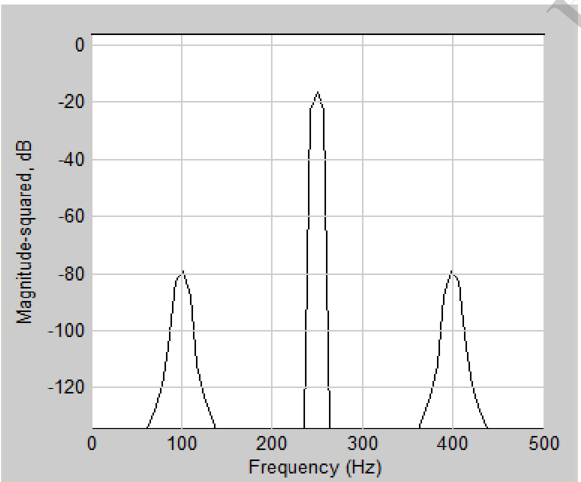

Figure 11:Frequency spectrum of output of Hamming window based filter

Blackman Window based Filter:

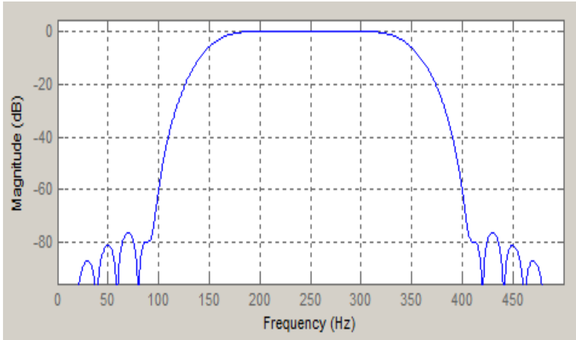

Figure 12: Magnitude response of Blackman window based filter

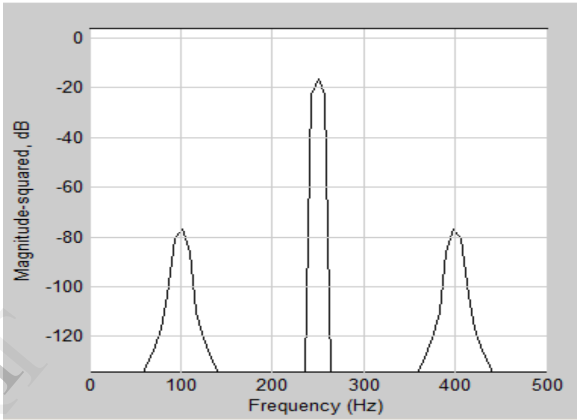

Figure 13: Frequency spectrum of output of Blackman window based filter

Conclusion: The spectral analysis of the mixed signal based of different window function by using Simulink simulation method is a rapid, convenient and reduced workload way as compared to MATLAB programming method. The FDAtool and Simulink provide a strong practical base for design and analysis of different filterson the specify parameters which fulfill desired requirement. Concurrently, on the basing of the actual filter characteristics, parameters can be changed to meet the engineering requirements in the design process.

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