Implementation of zoom FFT in ultrasonic blood flow analysis using VLSI technology

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ABSTRACT

An adequate blood flow supply is necessary for all organs of the body. Analysis of the blood flow finds its importance in the diagnoses of diseases. There are many techniques for analyzing the blood flow. These techniques are not affordable by the poor people because of their high expense. So we have implemented a technique called Zoom-FFT. This technique is simple and affordable to detect the blood clots and other diseases. Here a specific application will be dealt i.e., ultrasonic blood flow analyzer using ZOOM FFT. The implementation must be achieved with a single VLSI chip in order for the system to be both cost-effective and power efficient and thus widely accepted.

Introduction

Blood flow analysis[1] is done by passing a high frequency ultrasonic wave in the blood vessels through a transducer (transmitter). The reflected signal from the receiver Transducer has a different frequency due to the Doppler principle. This signal is passed to a MATLAB Simulink input to find the frequency spectrum. Because of the high frequency of the ultrasonic wave, the resolution of the frequency spectrum output will not be good. Therefore we go for advanced Zoom FFT technique, wherein a very small frequency change due to the clot formation can be obtained with a good resolution. It can be used to locate the initial presence of a blood clot. All of these tasks must be achieved with a single VLSI chip for the system to be both cost-effective and power efficient.

This research paper proposes:

1. Study of Bio-medical signal processing[1],[2].
2. Mixing down the input signal to the base band frequency using Hilbert Transform[3],[4].
3. Finding the down sampling using the decimation process [3]
4. Obtaining the spectrum output using fast Fourier transform [3], [4]
5. Simulation is done by Matlab/C.[5]
6. XILINX FPGA trainer kit does real time implementation. [9]

Sound is a compressional wave. Sounds at frequencies above the audible range, to say above 20 KHz are Ultrasonic wave, in the megahertz range. These waves are widely used for the blood flow analysis.

Doppler Effect Phenomenon:

A shift in frequency (f) of the wave will be expected due to the source and observers motion relative to each other[1]. If the distance between them is reduced or increased. That shift in frequency depends on the velocity of sound which also depends on density of the medium, in which it propagates. When a small object (eg.Blood clot) is situated in the path of the sound wave, the wave will be resisted (scattered). A direct measurement of this velocity will provide useful information about the dynamic property of the medium. The Velocity of sound in Blood is 1570 m/s. Perceived velocity is $V'=V-V_0$

In terms of frequency (f), as a velocity dependent factor.

$$f_p = \frac{f_0\,(V+V_0)}{V-V_s} \qquad\qquad -(1)$$

for both objects moving towards.

$$f_p = \frac{f_0\,(V-V_0)}{V+V_s} \qquad\qquad -(2)$$

for both objects moving away from each other.

f_0 : Actual frequency.
f_p : Perceived frequency.
V : Velocity of wave.
V_s : Source velocity.
V_0 : Velocity of observer.

Thus we get the perceived frequency proportionately changed with respect to changes in measuring media. This process is explained using animation as below in fig.1

Fig.1.Perceived frequency change with respect to change in measuring media

The Doppler effect can be explained with respect to pitch or wavelength, since all are dependent to each other. We will illustrate the Doppler effect with an example. Say, A car passes you on the street blowing its horn at a frequency of 440Hz, the whole way, As the car approaches you, you will hear a pitch > 440Hz(in increasing order). After the car passes you and drives away from you, you will hear a pitch lower < 440Hz (in descending order). The Doppler effect is applied in ultrasound range for human blood flow analysis.

Steps involved:

- Sound generation: The ultrasonic sound is generated using the piezoelectric transducer[6]
- Number of transducer may vary from 1 to many.
- Narrow beam of wave is to be feed in.

- Continuous mode of operation with no timed switching is applied in real time to measure Frequency and Amplitude
- Doppler shift analysis for frequency content is to be done[7].
- Creation of image – to plot in 2 Dimension Display using color differentiation.

Real Blood Flow Analysis:

In an Ultrasonic blood flow analysis, a beam of ultrasonic energy is directed through a blood vessel at a shallow angle and its transit time is then measured[1]. Morecommon are the ultrasonic analyzers based on the Doppler principle. An oscillator, operating at a frequency of several Mega Hertz, excites a piezoelectric transducer[6]. This transducer is coupled to the wall of an exposed blood vessel and sends an ultrasonic beam with a frequency F into the flowing blood. A small part of the transmitted energy is scattered back and is received by a second transducer arranged opposite the first one as shown in Fig.2. Because the scattering occurs mainly as a result of the moving blood cells. The reflected signal has a different frequency due to a Doppler effect.

Purpose of Zooming:

Minute variations in blood flow can be seen. For example when the blood vessel has got a blood clot. There will be variations in the blood flow depending on the size of the blood clot[2]. When the blood clot is in its initial stage. There will be a very slight variations in the blood flow, which can be easily monitored by this technique.Fig.3.shows the blood flow in a normal blood vessel and the blood vessel with clot formation. Due to the normal blood flow the frequency $F_1 = f + df$, where f is the frequency of the transmitted signal and df is the Doppler frequency of the reflected signal. Due to the blood flow in the blood vessel with clot the frequency $F_2 = f + df + Df$, where Df is an extra frequency component , the Doppler frequency due to the clot formation.
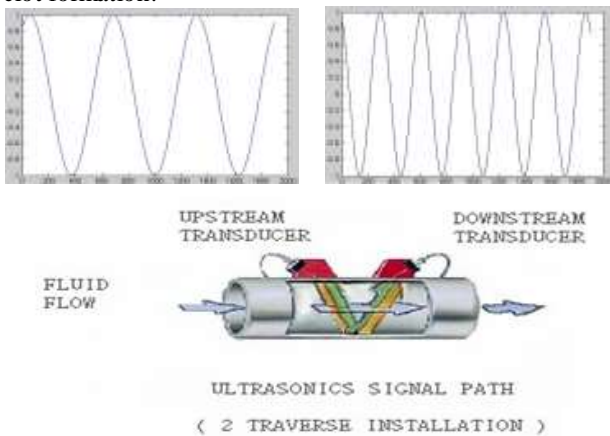

Fig.2.Internal view of the Transducer, Transmitter signal and receiver signal
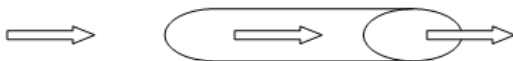
Normal blood vessel
$F_1 = f + df$

Fig.3.Shows the frequency variation of blood flow with and without the clot

Blood vessel with clot formation
$F_2 = f + df + Df$

Zoom Fast Fourier Transform:

The Zoom-FFT[8] is a process where an input signal is mixed down to baseband and then decimated, prior to passing it into a standard FFT. The advantage is for example that if you have a sample rate of 10 MHz and require at least 10Hz resolution over a small frequency band (say 1 KHz) then you do not need a 1 Mega point FFT, just decimate by a factor of 4096 and use a 256 point FFT which is obviously quicker.In contrast, the zoom-FFT uses digital down conversion techniques to localize the standard FFT to a narrow band of frequencies that are centered on a higher frequency. The zoom-FFT is used to reduce the sample rate required when analyzing narrowband signals - E.G. in HF communications. Fig.4 shows the Digital Mix Representation.
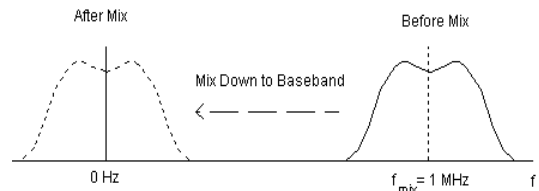

Fig.4.Digital Mix Representation

Zoom FFT analysis is simply an efficient computation of a subset of the FFT. You use this kind of tool when you are mainly interested in a certain frequency band of 10 kHz to 11 kHz. Rather than computing the FFT for the entire frequency range, you only perform computations on a subset of frequencies. Thus, you can save significant amount of processing power and time using this method. Fig.5.shows the Zoom-FFT Architecture.
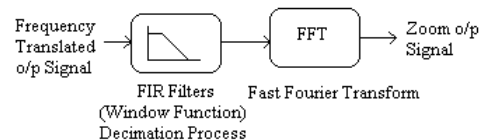

Fig.5.Zoom-FFT Architecture

Spectrum analyzers originally provided the zoom FFT to offer higher frequency resolution over a specific bandwidth, given the limitation of a small amount of on-board memory. With the zoom FFT, you can obtain a very fine frequency resolution (narrow band analysis) without computing the entire spectrum. The ability to increase the frequency resolution of a Spectral measurement in part of frequency range. Zoom can also apply to time domain (oscilloscope measurement).

Digital zoom (frequency domain) is usually implemented by multiplying the input signal with a sine and cosine at a new desired center frequency, and then low-pass filtering the data, followed by sampling rate reduction (decimation). In contrast, a "visual zoom" simply increases the size of the plot of data without adding any new information.

In traditional FFT Spectrum Analyzers, zoom was implemented in hardware to get around the memory limitations of the processors, which made it impossible to economically perform large Fourier Transforms. However, as memory size and processor speed has increased, large FFT's are now economically possible. When you need to have high frequency resolution this can be achieved in a number of different ways:

1.Large FFT: Has the advantage that it gives the keeps all spectral lines over the entire frequency range, whereas zoom only picks a sub-set of a given frequency range. Thus with zoom, multiple computations must be made to cover a broader frequency range.

2. Destructive zoom: The traditional zoom method implemented with digital filters, which throw away frequency information outside the selected range.

3. Non-destructive zoom: A zoom technique, which keeps the entire original time function. Thus zoom can be performed in different frequency ranges on the same data without requiring the acquisition of new data.

The input signal for the frequency under design can be a cosine wave or a sine wave this periodic is only for the implementation of the work. For real time implementation any non-periodic signal can also be considered.

Frequency Translation:

The signal, which is of high frequency, should be translated to a low frequency to get the proper response of the input signal. This is implemented by frequency translation[4].

If cos (1900) is considered as an input signal it can be translated to cos(100) by the procedure as depicted in the figure(6).

The output arrived is as follows,

$\cos(A-B) = \cos(A)\cos(B)+\sin(A)\sin(B)$. —(1)

i.e, $\cos(2000-1900) = \cos(2000)\cos(1900) + \sin(2000)\sin(1900)$. $= \cos(100)$.
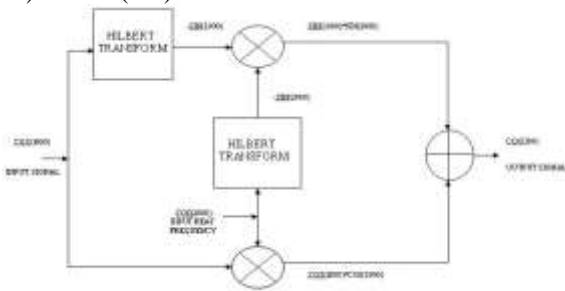

Fig.6.Block Diagram of Frequency Translation

Thus the input wave, which has frequency 1900Hz is translated into 100Hz.

Discrete Hilbert Transform

The Hilbert transform[1],[4] is related to the actual data by a 90° phase shift; sines become cosines and vice versa. Equation-(2) gives the frequency translating function.

$$f(n) = (1/N) \sum_{m=0}^{N-1} [1-(-1)^{m-n}]f(m)\cot(m-n)(\pi/N) \quad -(2)$$

Decimation:

Resampling at discrete instances the already sampled wave we get equation-(3).

$$Y(m)=\sum_{k=0}^{N-1} h(k)x(Mm-k), M=\text{decimation factor.} \quad -(3)$$

FFT:

The Fast Fourier Transform (FFT) is an algorithm that efficiently contains the frequency domain .Eq.4 gives the FFT Equation.

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nk/N} \quad 0\leq k\leq N-1 \quad -(4)$$

Advantages:

The following are the advantages of Zoom FFT Technique.

1. Increased frequency domain resolution
2.Reduced hardware cost and complexity

3.Wider spectral range.In places where the frequency content has to be analyzed, this zooming FFT can be utilized, mainly for the hidden glitches during signal frequency transition.

Applications:

The following are the applications of Zoom FFT technique.

1.) Ultrasonic blood flow analysis.
2.) RF communications.
3.) Mechanical stress analysis.
4.) Doppler radar.
5.) Bio-medical fields.
6.) Side band analysis, and modulation analysis

Xilinx &Matlab(6.5):

The Xilinx System Generator for DSP is a plug-in to Simulink that enables designers to develop high-performance DSP systems for Xilinx FPGAs. Designers can design and simulate a system using MATLAB, Simulink, and Xilinx library of bit/cycle-true models. The tool will then automatically generate synthesizable Hardware Description Language (HDL) code mapped to Xilinx pre-optimized algorithms. This HDL design can then be synthesized for implementation in Virtex-II Pro Platform FPGAs and Spartan-IIE FPGAs. As a result, designers can define an abstract representation of a system-level design and easily transform this single source code into a gate-level representation. Additionally, it provides automatic generation of a HDL testbench, which enables design verification upon implementation. Whilst DSP processors still represent the mainstream, FPGAs are increasingly being used for applications with sample rates above 1MSPS where DSP processors typically start to run out of steam. Xilinx's FPGAs can support real-time processing rates up to 300 MSPS.[9]
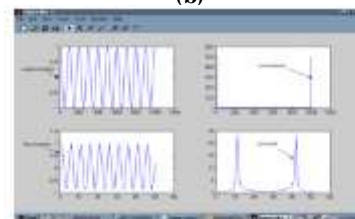
Conclusion:

Currently the paper has been tested on the simulation basis, the output of the simulations are satisfactory Fig.8.(a),(b). Real time experimentation is being done, using the Piezo electric ultrasonic transducer for verification purpose. Our plan is to implement in to a single VLSI chip.
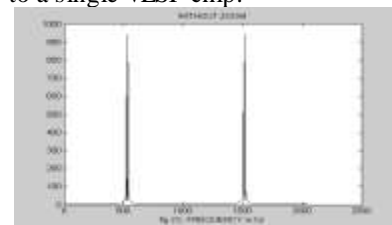
(a)
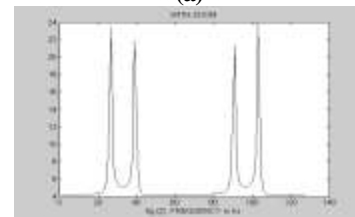
(b)

(c)

Fig.8. (a) Simulation results without zoom, (b) Simulation results with zoom,

(c)Simulation results with zoom/without zoom and input signals

References:

[1] Leslie Cromwell, Erich A.Pfeiffer, Fred J.Wiebell, "Biomedical Instrumentation and Measurements", Prentice Hall,1980.

[2] Willis J.Tompkins, "Biomedical Digital Signal processing", Prentice Hall of India Pvt Ltd, 2001.

[3] John G.Proakis and Dimitris G.Manolak-is, "Digital signal Processing", Prentice Hall of India Pvt Ltd, 2000.

[4] N.Sarkar, "Elements of Digital Signal P-processing", Khanna Publishers, 2000.

[5] Vinay K.Ingle, John G.Proakis, "Digital Signal Processing Using Matlab", Thomson Asia Pvt Ltd.,Singapore, 2001.

[6] Tatsuo Togawa, Toshiyo Tamusa, "Bio- medical Transducers and Instruments", CRC Press LLC, 1997.

[7] Edited by Lawrence R.Rabiner, Charles M.Rader, "Digital Signal processing", IEEE Press.

[8] Oran E.Brigham, "FFT and its Applicati-ons", Prentice Hall, 1988.

[9]www.mathworks.com & www.xilinx.com

Authors Biography

N.J.R.Muniraj is presently working as a Principal of Tejaa Shakthi Institute of Technology, Coimbatore. He has more than 22 years of teaching and five years of industrial experience. He has presented more than 40 National and International papers and published fifteen international journal papers. His research area includes VLSI Signal Processing, Neural Networks, Image Processing and MEMS. He is also heading the Tejaa Shakthi Innovation centre. He expresses his sincere thanks to his chairman Mr.T.N.P.Muthu Natarajan and the secretary Ms.A.Tharalakshmi for their support and encouragement.