Design Of Heterogeneous Spectrometers In Radio Astronomy Using FPGA Based Scale Down Implementation

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Abstract--- **Radio Astronomy is non commercial, passive user of radio frequency Spectrum. It is also a branch of Fundamentals scientific research that provides us with the most useful dataon the origins of our universe. The recent and planned growth in radio communication systems presents a real threat to the future of radio astronomy as a viable sceintific discipline.**

This work is about a heterogeneous design, allowing us to benefit from the strengths of FPGAs. A design called the Packetized Astronomy Signal Processor, or PASP, is run on the FPGA. PASP splits up the large band into smaller bands that can be processed using off the shelf servers. The sub-bands are put into packets on the FPGA and sent over a 10 gigabit Ethernet switch to a cluster of servers. The servers receive the data from the switch and process it using spectroscopy software provided in the software package or special purpose application software written by the user and linked into the provided packet processing infrastructure.In this project, we are using DDFS IP core, to generate required frequency components. These are used to model the limited band width signal. The poly phase FFT is performed on the input signal for scale downing & sub banding. After that the sub band signals are packetized, where a header and footer is provided to frame a packet.

MXE is used for simulation and functional verification. Xillinx ISE is used for synthesis, P&R and bit file generation. Xilinx FPGA board will be used for testing and demonstration of the implemented system. The final results in FPGA shall be verified with chipscope where the packetized spectrum data can be seen.

Keywords–- ***DDFS-Direct Digital Frequency Synthesizer, PASP- Packetized Astronomy Signal Processor, MXE-Model Sim Xilinx editor.***

I.INTRODUCTION

Spectrometer is the term that is applied to the instruments that operate over a wide range of wave lengths,From gamma rays to x-rays in to the far infrared. so the systems which are working at the nomal frequencies cannot handle these instruments. The instruments generated by this package use a heterogeneous design, allowing us to benefit from the strengths of FPGAs. The FPGA board is able to sample and process very high bandwidths that a single CPU or GPU would not be able to manage; once tha FPGA has split up the band then a platform that is easier than an FPGA to program but still provides high compute power.

This soft ware package includes an FPGA design and server software to do spectroscopy, as well as server bench marks used to determine an optimal instrument configuration. Both the FPGA and server software are parameterized, a design called the packetized Astronomy Signal Processor, or PASP, is run on the FPGA. PASP splits up large band into smaller bands that can be processed using off the shelf servers. The sub bands are put into into packets on the FPGA and sent over a gigabit Ethernet switch to a cluster of servers. The servers receive the data from the switch and process it using spectroscopy software provided in the soft ware package. There are four modules in this paper namely DDFS, PFB, FFT, and PACKETIZER.

II. DESIGN FLOW

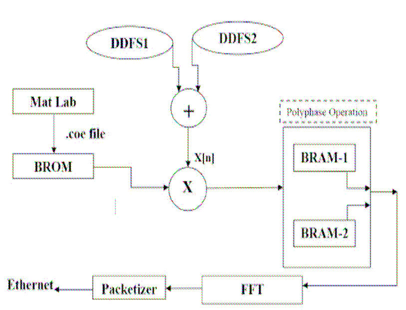

Fig.1 design flow

This Design which we have developed a software package to automatically generate spectrometers with minimal user input. Spectrometer design is often done by building the instrument from scratch. We have automated this design, creating a parameterized spectrometer that only requires a recompile to implement a change in specification. This spectrometer combines FPGAs and GPUs, doing coarse channelization on the FPGA and sending each sub band to the GPUs for further processing. The server software is designed for flexibility, allowing astronomers to easily modify the processing algorithm run on the GPU and customize the instrument to t their science goals

III. DESIGN IMPLIMENTATION

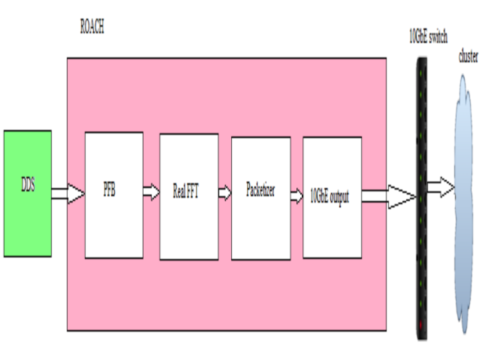

Fig.2 Block Diagram

A . DDFS

Direct digital frequency synthesizer (DDFS) is an electronic means of generating discrete samples from single or multiple sources for converting them to sine wave to different frequencies with the help of reference frequency. DDFS also known as Numerically Controlled Oscillator(NCO), is a technique which uses digital data and mixed signal processing blocks to generate signal waveforms that are repetitive in nature. A DDFS can provide fast switching and high frequency resolution, over a wide band of frequency.

A standard DDFS architecture consists of a phase accumulator, a ROM/lookup table, a DAC and some reconstruction filters. There are different methods of sine/cosine wave generation have reported with different merit and their limitations. These are with memory, reduced memory and memory less architecture.Few are DDFS with Look-Up-Table (LUT), DDFS with sine and cosine function. Direct Digital Frequency Synthesizer with Look-Up- Table is the method in which phase value of sine wave is stored in an Erasable Programmable Read Only Memory (EPROM) and phase angle is called for to form sine wave. The address to the LUT is generated through a phase accumulator. The resolution of the DDFS depends on the memory size, if the memory locations are more, the frequency resolution is more. The phase accumulator size is greatly depends on the memory. The phase accumulator works on the principle of arithmetic over flow. The value of the phase accumulator keeps on increasing in steps in each cycle of the reference clock till the accumulator overflows and repeat the same sequence.

The phase accumulator size is greater than the address bits of memory locations and accumulator bits are truncated. If M is the tuning ratio, then

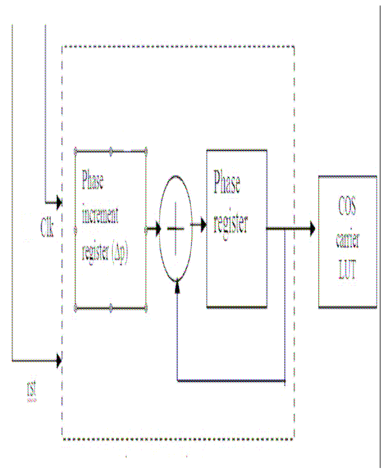

Fig.3 Basic Block diagram of Direct Digital Frequency Synthesizer

The output frequency:

$$f_{oot}= \frac{M^* f_{olk}}{2^n}$$

And resolution:

$F_{olk/2}{}^{n}$

B . Polyphase Filter Banks (PFB)

This filters is used to down converting the high frequency signals into low frequency signals, because down systems cannot handle the high frequency signals, so we are down converting by using polyphase filters. The Fourier transform is perhaps the most widely used and generally applicable component of the signal processing toolbox.

It allows us to frequency domain representation of a time domain signal. Unfortunately using FT in DSP systems, we face a problem due to the dicreate nature of the digital systems. The abrupt nature of the time domain signal translates into frequency domain. This result in what is called spectral leakage; where some of the energy in the bin "leaks" into adjusent bins. This gives an inaccurate spectral foot print, especially when adjusent bins have vastly differing amplitudes, as illustrated in fig.4(a)S This inaccurate representation can underestimate available spectrum for a cognitive ratio.This can be overcome by windowing in time-domain.

Poly phase filter banks are an efficient way of accomplishing this. Filter banks are an established structure used in multirate signal processing and have applications in compression and image processing and have applications in compression and image processing.

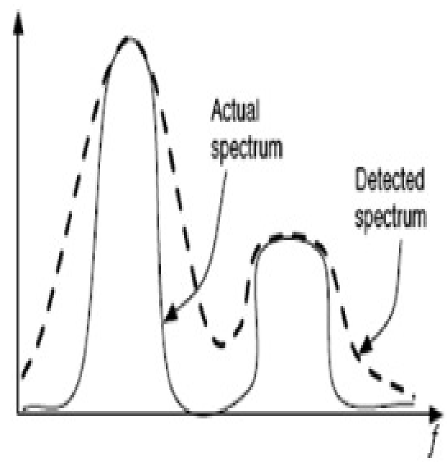

Fig .4(a) Spectral leakage using PSD estimation

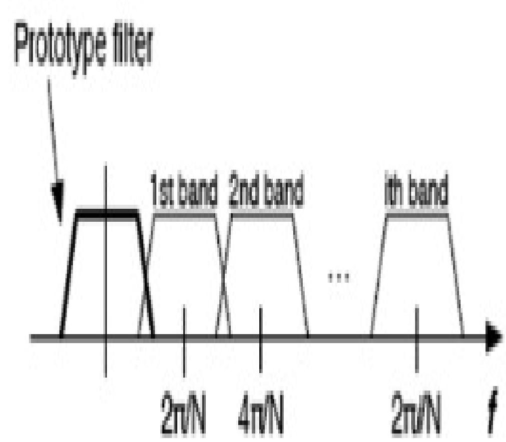

Fig .4(b) Frequency representation of a filter bank

Polyphase filter banks enable us to do this more efficiently, by decomposing a single prototype filter, into sub filters and effectively modulating these using an FFT. These filters can then be run at a fraction of original sampling rate depending upon filter banks used.

Using filter banks for spectrum sensing offers a number of advantages. Firstly, we can scan wide portions of the spectrum (high input sampling rate), efficiently (using fewer resources at a lower sampling rate).secondly, the results of spectrum sensing using filter banks are far more accurate than basic energy detection using averaged FFT. Finally, the use of filter banks for transmission and reception of signals is an area that has gained renewed interest at present. It is envisaged that such techniques could supersede current multicarrier transmission methods. It would then be possible to use the same computational structure for sending and receiving; an attractive proposition for resource limited applications.

C. Fast Fourier Transform

We are using FFT for calculating the frequency spectrum that at a particular point the maximum signal energy will be calculated, that cannot done by DFT. The FFT is a faster version of the Discrete Fourier Transform (DFT). He FFT utilizes some clever algorithms to do the same thing as the DFT, but in much less time.

A FFT is an efficient algorithm to compute the DFT and it's inverse. There are many distinct algorithms involving a wide range of mathematics, from a simple complex –number arithmetic to group theory and number theory. A DFT decomposes a sequence of values into components of different frequencies. This operation is useful in many fields but computing it directly from definition is often too slow to be practical. An FFT is a way to compute the same result more quickly.

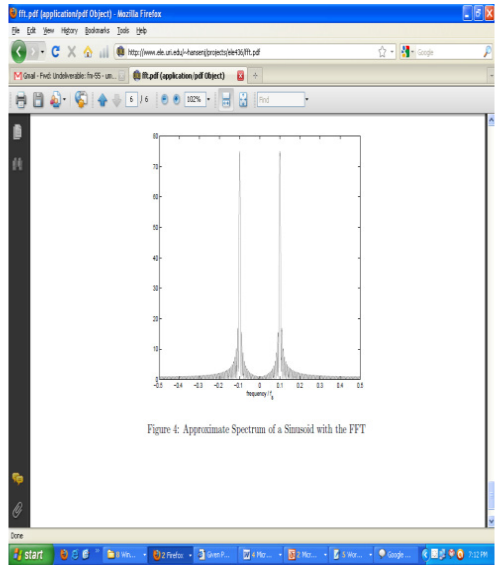

Fig.5 Two peaks in FFT computation

Computing a DFT of N points in the definition, takes $O(N^2)$ arithmetical operations, while an FFt can compute the same result in only O(N log N) operations. The .difference in speed can be substantial, especially for long data sets where N may be in the thousands or millions in practice, the computation time can be reduced by several orders of magnitude in such cases, and the improvement is roughly proportional to N/log (N).

D. Packetizer

In order to dynamically balance the work distribution, the packetizer uses pull architecture: when workers are ready for further processing they ask the packetizer for a next packet. FFT outputs are given to the packetizer block. We are using 64-point FFT, so that we can get 64 sub-band values (complex) as result of fft operation.

These FFT outputs are given to magnitude calculator block to get the magnitudes of corresponding bands. Magnitude calculator takes the complex term (real imaginary) and calculates the maximum value from given real, imaginary values. It gives the output max+min/2 as magnitude of corresponding band.

The outputs of Magnitude calculator are given to Packetizer module, where adding of header and footer for payload (message) are done to form packet. It adds header(24bit) at the starting of payload, payload consist of 64 sub-band magnitudes each of 23 bit from Magnitude calculator followed by footer(24bit).In our implementation we are using “AABBCC” as header information to indicate starting of packet and “DDEEFF” as footer information to indicate the end of packet. Before adding header and footer information it will add footer first to indicate unwanted information.

IV.EXPERIMENTAL RESULTS

A. SIMULATION RESULTS

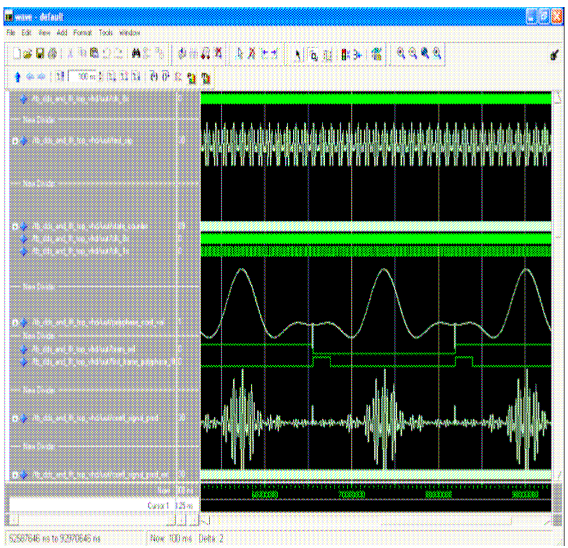

Fig.6 Filtered output

- It consists clock signal indicated by clk_8x which is 10 MHz as shown in figure .6
- The clock signal clk_1x represents decimated clock which is (10/8)MHz
- The state counter is common counter for all operations
- The test_sig is combination of two frequency signals at 6th bin and 8th bin.
- The polyphase_coeff_val signal is filter coefficient 512 each of 10 bit.

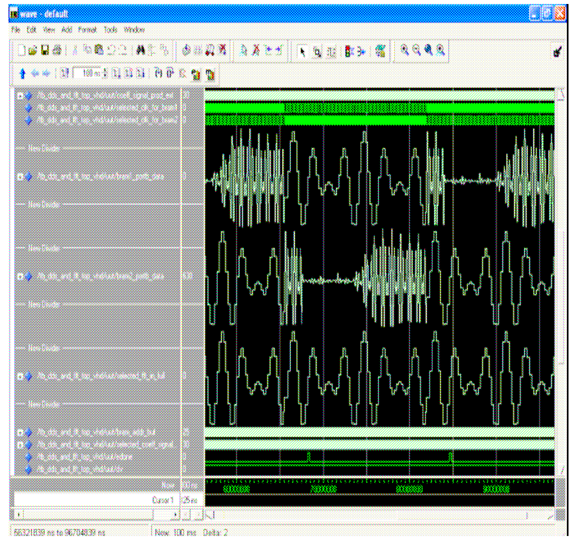

Fig. 7 BRAM outputs and FFT inputs

- There are two clock signals for bram1 and bram2 when the clock is low one the bram sends the signal.
- Bram1_portb_data and bram2_portb_data signals send data to fft.
- Selected_fft_in_full is combined signal of bram1 and bram2 at low clock.

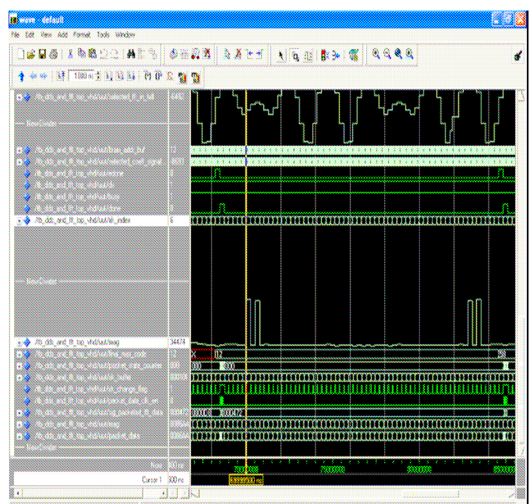

Fig.8 Spectrum Analysis

- The mag- signal gives the magnitude of 64 sub bands where peaks appear at 6th, 8th bin and (64-6) Th, (64-8) Th bins due to symmetry as shown in fig .8
- Since the input frequencies are given at that subbands.

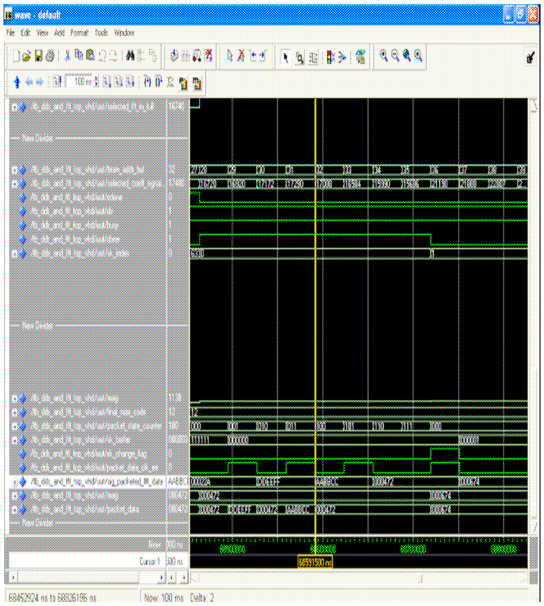

Fig.9 Packet Formation

- The signal sig_packeted_fft_data is the packet formatted output data as shown in fig .9
- With header (AABBCC) and footer (DDEEFF) information appended.
- The information bits are located in the each of 23 bit in the 64 bins.

B. CHIPSCOPE RESULTS

Input signal subplot

- Input signal busplot for spectrum analysis as shown in fig .10The signal is a cosine signal which is a
- combination of two input frequency signals with desired peaks at 6th and 8th bins respectively.
- Due to symmetry of cosine signal the peaks will also appear at 58th and 56th bins.

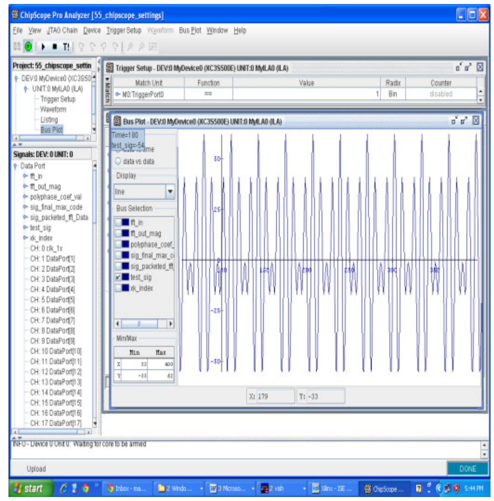

Fig.10 Input signal subplot

FFT subplot

- The signal test signal indicates the input subplot which is marked. FFT bus plot
- The combined signal of two dual port BRAM IP cores at low clock signal.
- The signal is indicated by fft_in in the subplot as shown in fig 11

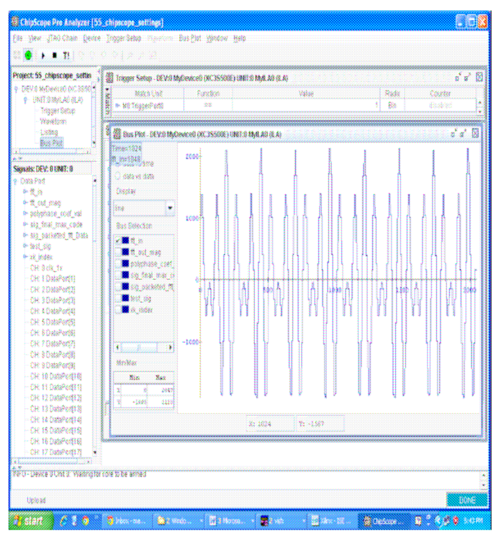

Fig.11 FFT subplot

Spectrum analysis subplot

- The output signal which has two peaks at given input frequencies 6th and 8th bin appear at the output.

- Due to symmetry the peaks also appear at 56th and 58th bin respectively.
- The signal is indicated by fft_out_mag in the subplot.

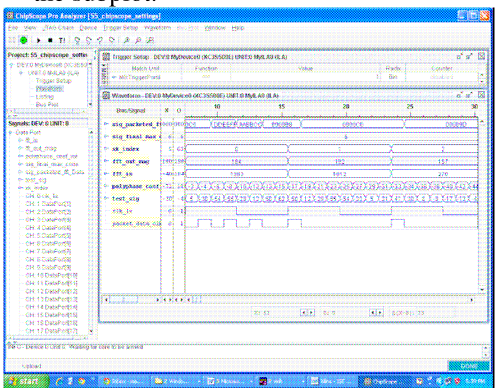

Fig.12 Packet data

V.CONCLUSION AND FUTURE SCOPE

In this paper we describe a radio astronomy instrument that is esily reconfigured to suit a verity of applications. This style of instrument can be extended to design a heterogeneous cluster running multiple processing algorithms at the same time. Many algorithms requires data to be broken into sub bands before it can be processed by the server which can be done on the same FPGA. Using multicast packets , multiple servers can be subscribe to the same sub bands generated on the PASP and process them in different ways.

This style of instrument design greatly accelerates time to science for many projects. Separating the implementation of the instrument from the hardware specifications has created a design that works well for a verity of computational resources and applications. As resources improve,the instrument can improve along with them, providing opportunity to do new science that wasn't possible before.

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