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Multiple Digital beam forming for Active Phased Array RADARs

D.Subbarao, Tejavath Rama Krishna

***Abstract:** To overcome the issue of processing A/D channels in digital multiple beam forming technology where antennas hold large phased array radar are replaced by multiplexed signal processing unit on FPGA. Which is timed shared for different beam formers without any effect on performance. VHDL modeling of 16 element phased array antenna system and RTL implementation of complex NCO, digital mixer, low pass filter, multiplexers, demultiplexers, ROM for coefficient storage and Multiplier unit. By simulating the code in ModelSimfrom Mentor Graphics,FPGA synthesis in Xilinx ISE for timing and area. Hardware FPGA output is shown on Chipscope pro analyzer.*

***Index terms:** A/D channels, phased array antenna, Hardware FPGA, Chipscope pro analyzer.*

I. INTRODUCTION

Increasing use of antennas in densely populated areas introduces multipath effects and intersystem interference. Also, low cost technology is expected to result in proliferation of jamming systems, which is of concern to security and military organization around the world. The need to reduce such interference is driving include design of antennas, receivers and processing systems, particularly phased array antennas [1]. Phased array radaradvancement has let to unprecedented advances in aerospace platforms and to national defense capability. Phased array [2] for airborne platform is reviewed from historical and technology view point.

Digital Beam Forming (DBF) [3] is a combination between "the antenna technology" and "the digital technology" and based on changing of RF signal elements of every antenna into streams of binary baseband signals representingcos and sin channels which can regain amplitude and phase signals of the array.

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dr.D.Subbarao, Dr. tejavath Rama Krishna,[1]professor & Hod/Ecesiddhartha Institute Of Engineering&Technology[2]assistant Professor, Sri Chaitanya Technical Campus College Of Engineering & Technology Ramakrishnateja00@Gmail.Com,

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The main function is to get perfect conversion of the analog signal into the digital regime. Various antennas patterns can be arranged in similar time slot is achievable with digital receiver as these signals can be copies without losing any information as these signals are converted to Intermediate Frequency signals of75Mhz where A/D converter requires [4] a sampling frequency of 100 MHz.

Every single antenna has respective receiver channel followed by an analogue-to-digital converter and a digital down converter (DDC) [5]. Finite Impulsive Response Filter (FIR) is used for proper calculation for special transversal filer which equalizes frequency response and propagation delay [6]. For calibrating a RF Tests signal will be given to receiver channel which is either f known magnitude or is frequency modulated, this filter also check with side lobes suppression weights. In summation stage the inputs is from ADC of the receiver converted as a complex I & Q signal through a phase shifter the number of such stages can be assumed as 100.

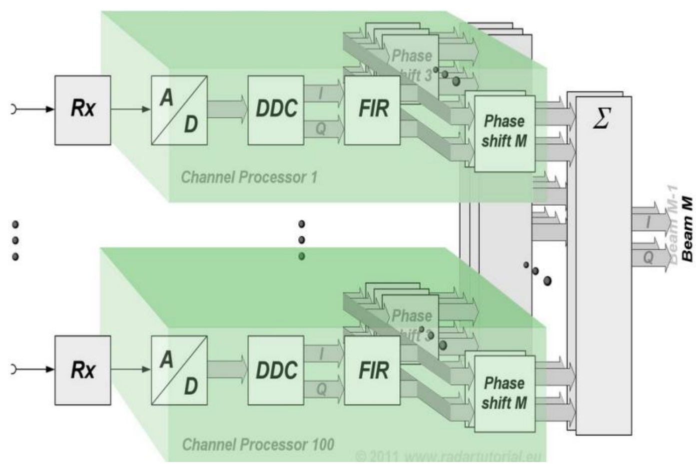

Figure 1: Block diagram of a beam forming processor

A. *Phased array Radar:*

Beams are formed by phase shifting [7] each radiating element to get constructive/destructive interference so as to steer the beams in the desired direction. In below figure (left) both radiating elements are fed with the same phase with signal constructive in main direction

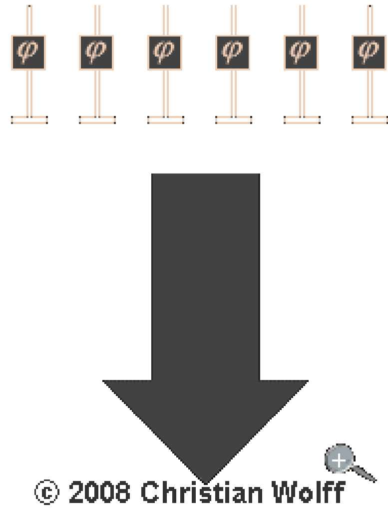

Figure 2: Animation of the electronic beam-deflection

Here right, the flag is discharged by the upper emanating component with a stage move of 22 degrees later than of the lower transmitting component as main direction emitted signal moves slightly up pointing the beam pointing direction in increasing phase.

II. DIGITAL BEAM FORMING

Proposed approach has Digital beamforming (DBF) in staged exhibit radars [8] is a developing pattern for numerous reasons, including advanced versatile techniques, for example, scratch-off of undesired signs, improvement in immediate powerful range, and various synchronous get shafts. In the glorified DBF framework with an advanced beneficiary at each component, it is conceivable to shape a self-assertively huge number and self-assertively directed arrangement of concurrent get bars, given adequate figuring and information taking care of assets. Numerous pragmatic DBF frameworks don't have a computerized collector at each component, but instead fewer advanced recipients with each serving various radio wire components consolidated as a subarray. In the subsequent subarray-level DBF [9], a discretionarily vast number of bars may in any case be framed carefully, however the conceivable rakish or spatial degree of the bars will be restricted by the directivity example of the joined subarray of reception apparatus components. In either case (component level or subarray-level DBF) it is conceivable to utilize the different concurrent get pillars

A. Configuring the proposed DBF

DBF digitally synthesis receive beams used in active phase array radars [10], it also wide range radar which has ability to steer nulls for rejection of unwanted noise, dwell time, scalability, improving performance, flexibility, high Doppler resolution. This system uses high end FPGA's and optical links, floating point representations for implementation. By using high frequency and reusing multiple beams number of FPGA's can be minimized. Using built in radar environment DBF capacity can be increased such as to know case of threat, Doppler Effect and others by using information fed by users. To estimate algorithms and interface Automatic Test Equipment is used to stimulate text and video information from array. DBF [11] along with sub systems of a medium-power active phased array radar and successfully calibrated.

B. Specification of Design

The specification of each of the task of DBF implemented in this project is listed as under.

Parameter	Value	Comments
Input signal type	Band pass signal	Coming from typical superhytrodyne receiver
Input signal frequency range	1.5-3.5 MHz	2 MHz BW and 2.5 Mhz IF frequency value
Sampling rate	10 MHz	
DDC filter size	16 taps	
DDC decimation	4	DDC output sampling rate 2.5 Msps
NCO values: COS	1 0 -1 0	As fo=fs/4
NCO value : - SIN	0 -1 0 1	As fo=fs/4
Number of array elements	16	Linear array as shown in below figure.
Element spacing	3 meters	d as shown in below figure

RF analog signal at every antenna element is converted to digital form using high speed samples from ADC [12] with single and quad phase signals as inputs.The multiple beams are formed depending on sampling rate of ADC's, processor capacity and operating frequency.The main block diagram for digital beam forming consists of

- Digital Down-Counter
- Multiplier & Adder

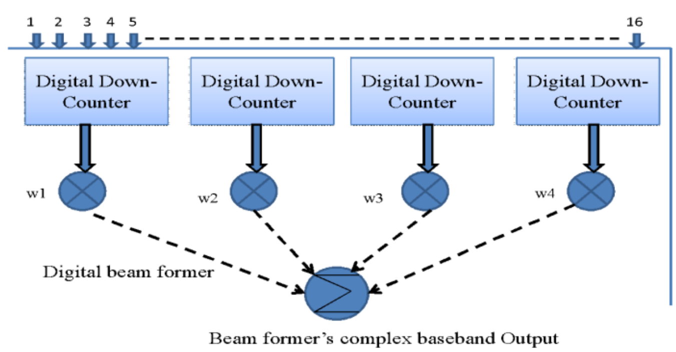

Figure 3. Digital Beam Forming (Block Diagram)

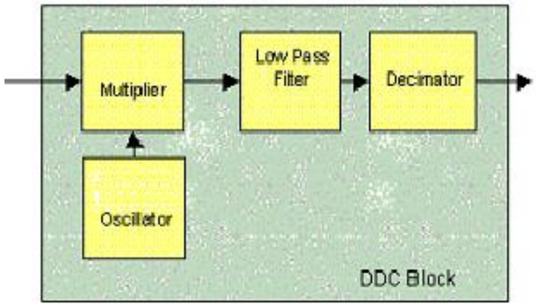

Figure 4. Digital down Counter

The input signals taken from DDS & extra distance,phase shift are calculated and their values are multiplied and given as input to DDC. The DDC (Digital Down-Counter) comprises of NCO (Numerically Controlled Oscillator), Multiplier, low pass channel and Decimator.

C. Oscillator (NCO)

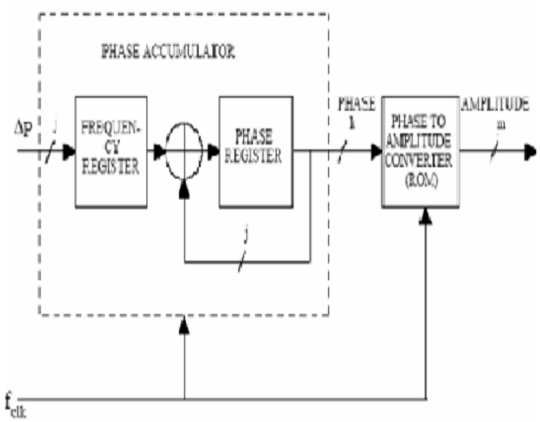

Figure 5. NCO (Oscillator)

The main function of NCO is to generate cosine signal which acts as carrier whereas ROM will give area optimization.

D. Low Pass Filter

A channel which passes low recurrence flags and decreases sufficiency to '0' of high recurrence. Weakening differs from channel to channel as high cut off, treble cut off .Low Pass channel [13] is inverse to High pass channel though band pass channel is a blend of both.

Using wideband signal the sampling rate is small and output range is high which should be checked as overall system design constraint. The best way to use is as a Multi-rate-FIR filter as it's a, effective method for actualizing substantial channels with demolition. Accepting channel is split,we can perform enough separating to permit some destruction while second channel reduces sampling rate by reducing usage of tap filters[14]. The response of the first filter can be improved by matching the DDC output with filter output with decimation of signal at 2. In case the decimation value is high, a third stage filter can be used by implementing taps as 4x more in first stage which will give best performance.

Filter coefficients are to be selected referring frequency response of the filter, various ways of check the specifications are:

1. Window design method
2. Weighted least squares design
3. Minimax design
4. In practice the equi-ripple design is often used

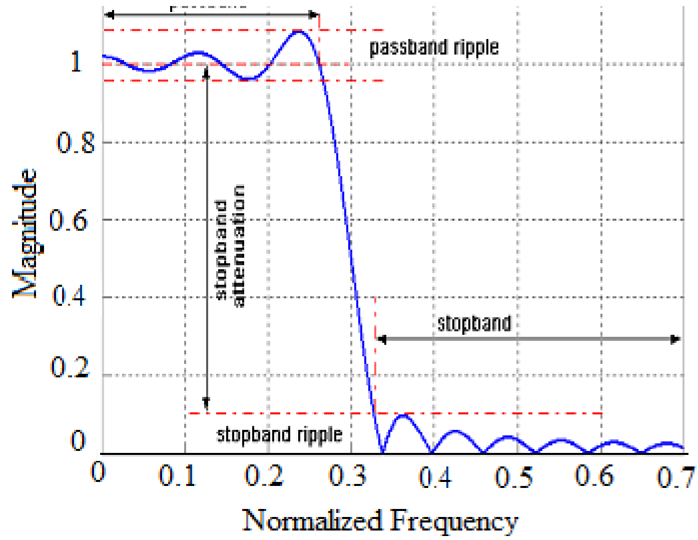

Figure 6. Low pass filter

E. Specifications

Table 1.Beamforming specifications:

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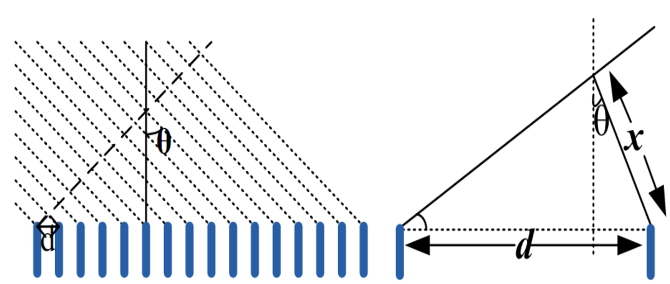
Element spacing	3 meters	d as shown in below figure

A linear array Input considered signal

Figure 7. Lline



ar array

$$\sin \theta = x/d$$
$$x = d \sin \theta$$
x is the additional distance travelled

III. PHASED ARRAY RADAR ANTENNA

The word "radar" was originally an acronym, RADAR, for "radio identification and extending." Phased exhibit Radar is a variety of reception apparatuses which have relative stages changing in a successful radiation way fortify toward a path and crushed in another direction.Phased cluster transmission was initially created in 1905 by Nobel Laureate Karl Ferdinand Braun who showed upgraded transmission of radio waves in a single heading. The staged cluster is utilized for example in optical correspondence as a wavelength-selective splitter which is composed of radiating elements with phase shifter respectively using which beams are formed to get constructive interference.Here main beams are pointed towards increasing phase shift and if the signal is through a electronic phase shift the direction of beam get adjusted electronically using benefits of a digital Beam forming architecture.

- High gain width loss side lobes
- Its ability to permit the beam to jump from one target to the next in a few microseconds
- Arbitrarily to provide an agile beam under computer control
- Multiplication operation by emitting several beams simultaneously

A. Types of phased radars (Types of Beam Forming):

There are two principle diverse sorts of staged clusters likewise called" pillar formers".

1. Time area pillar formers

2. Recurrence area shaft formers.

Time area beam former works by presenting time delays. The essential activity is designated "deferral and sum", where the incoming signal is delayed for certain time and later then adds together.

B. Frequency domain beam formers

Different frequency components in the received signal are separated into multiple frequency bins. Applied with different delays and sum beam formers every frequency binthe resultant is main lobe in different directions with different frequencies which is advantageous and is mostly used with SPS-48 radar.The second type uses Spatial Frequency where discrete Fourier Transform (DFT) is used where discrete samples of every individual elements are taken during processing,where output is evenly spaced beams.

The systems are utilized to make two sorts of stage exhibit:

- Dynamic - a variety of variable stage shifters are utilized to move the pillar
- Fixed - the pillar position is stationary as for the cluster face and the entire radio wire is moved

Further sub arranged into dynamic and fixed exhibit:

- Active - speakers or processors in each stage shifter component
- Passive - expansive focal speaker with constricting stage shifters

C. Dynamic Phased Array

This technique does not require physical development of the beam,instead it is moved electronically which delivers quick movement to follow targets while checking for new targets utilizing one radar set. Recieving wires positions can be anticipated and used to make electronic estimates that meddles with radar activity which enables bars to be gone for arbitrary areas that wipes out helplessness. This is additionally attractive for military applications.

D. Fixed Phase Array

Fixed stage cluster radio wires are ordinarily used to make a reception apparatus with a more attractive structure factor than the ordinary illustrative reflector or cassegrain reflector. Fixed staged cluster radar consolidate fixed stage shifters. This sort of stage cluster is physically moved amid the track and sweep process. There are two designs.

- Multiple frequencies with a deferral line
- Multiple adjoining bars

IV. IMPLEMENTATION OF DIGITAL BEAM FORMING ON FPGA

A. Design Summary:

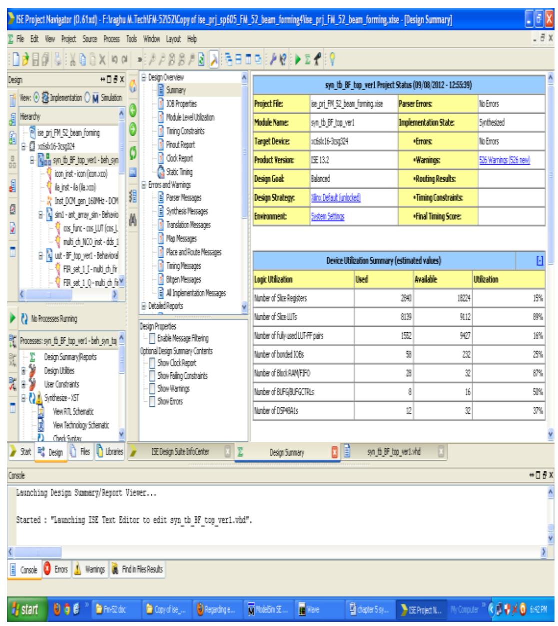


Figure 8: Summary of the designed program

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These windows opens by double click on the Xilinx 13.2i→open project and name it as ise_prj_FM_52_beam_forming.xise.ise

B. Top module (syn_tb_BF_top_ver1):

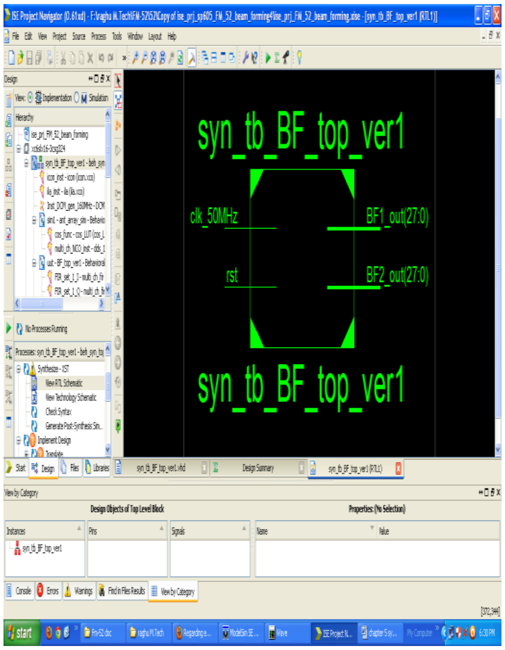

Figure9: Top view of gate

The above shows 50Mhz clock signal as input and Reset pin and BF1 BF2 are the beam forming output 1&2

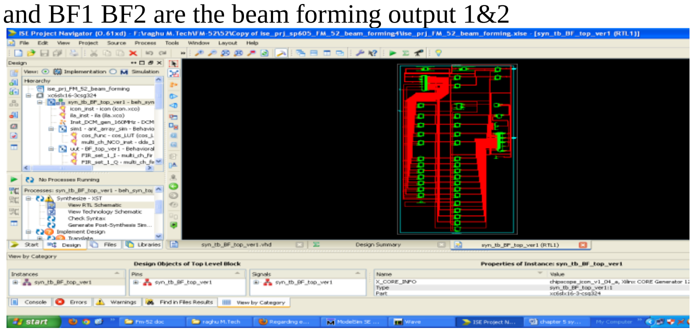

Figure 10: sub modules in top module

Antenna receiver for input as shown on left hand side top while the green colored component block is the antenna and other devices whereas the red colored line are the connection among the devices. Right hand side middle component act as beam forming outputs.

C. Antenna Array Module (ant_arr_sim):

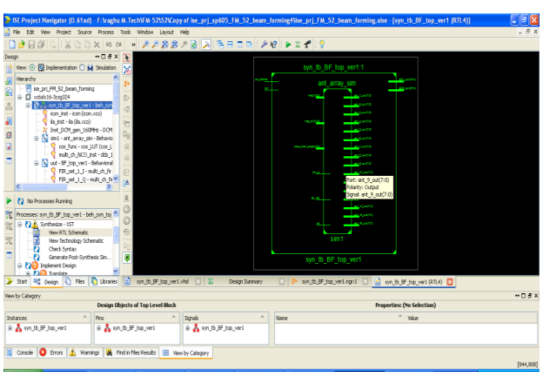

Figure 11: antenna array module

The above shows the different ports and their respective connections, when we move the mouse on a port then its assignment can be seen. It also shows16 antenna receiver connection for beam forming

D. Beam Forming Module (BF_top_ver1):

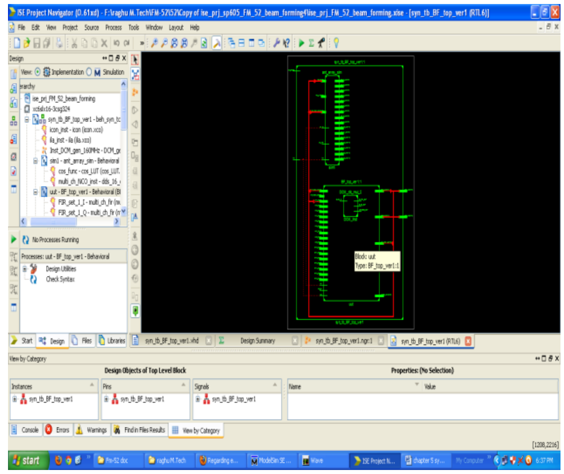

Figure12: Hardware-Beam Forming module

Top left box shows 16 antenna input receiver and their input to each of ADC block are shown on bottom left and beam forming outputs are shown on right side two lines.

Using modelsim 6.6b software digital block of DBF are stimulated and below are the results

E. Simulation results of syn_tb_BF_top_ver1:

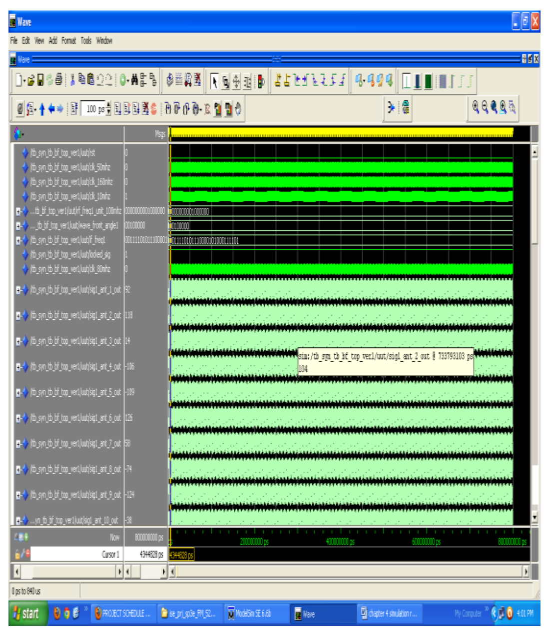

Figure 13: Antenna outputs

The above shows signals used as clock and inputs used for beam former output.

Clock signals of 50Mhz, 160Mhz and 10Mhz are the top green thick lines respectively. Frequency and phase of signals are shown by binary values the remaining are the 16 antenna outputs.

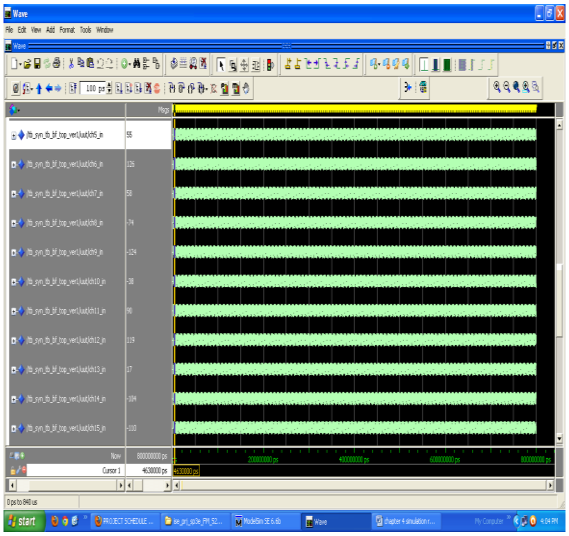

Figure 14: Beam forming inputs

The figure show the MAC filter outputs which generate DC output which are finite impulse and MATLAB coefficient which are floating points to be rounded to integers.

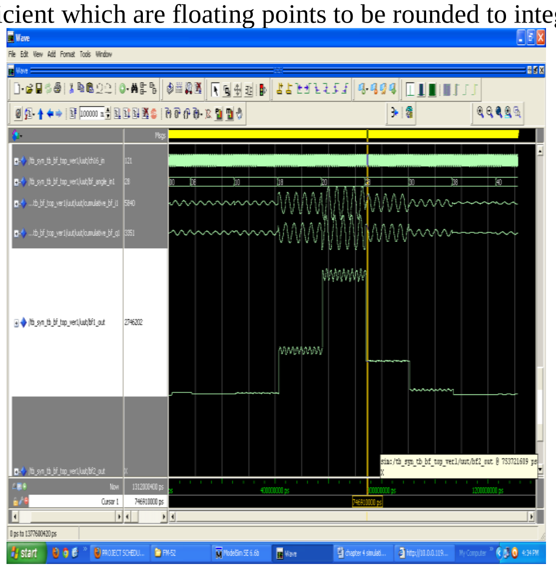

Figure 15. Single Digital Beam

Steering angle and signal formed from maximum information is shown above. Steering angle is taken from Magnitude of amplitudes –real components and imaginary components are the digital down converter.

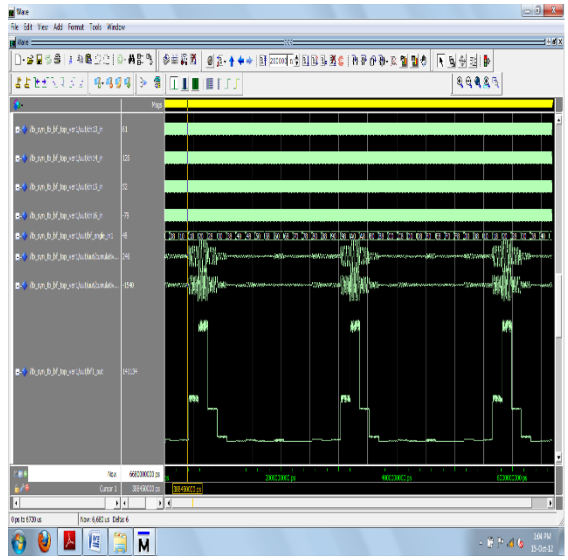

Figure 16. Multiple Digital Beams

Air traffic control and applications of radar are shown where digital line is the quad phase angles output and the next 2 are in phase component values. Thick line is the multiple beam formed signal.

F. Simulation results of antenna array module*:*

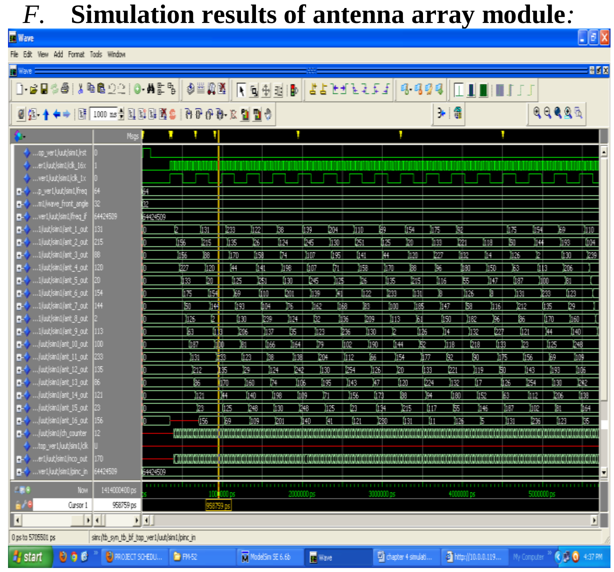

Figure 17: Antenna Array Digital outputs

16 antenna output are shown in digital format,1st is reset signal, first column shows reset as '0' which means its high of the values of the amplitude becomes zero where as2nd column reset is disabled and 160 Mhz and 10Mhz signals are applied later wave front angles are shown followed by 16 channels as 16 antenna outputs the last isthe NCOs output which is of high frequency.

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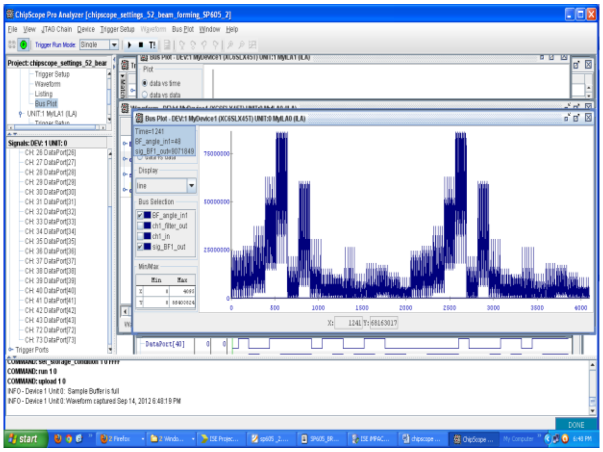

Figure 18: Beam forming input Vs output

The high value denotes the processed beam form signal with maximum signal information while antenna are at phase angle considering one inphase component and one quadrature component of the signal.Exponential representation of sine signal taken by a process carried by DDC and complex mode output called as quadrature component is shown in above figure.

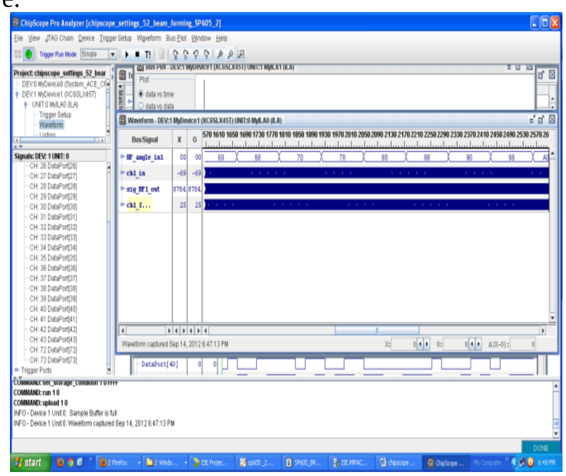

Figure 19: Beam forming digital output

By interfacing SPARTAN 6 (FPGA) and chip scope software the above digital representation is formed where the first signal wave front angle followed by the channel output signal and then signal beam formed signal.

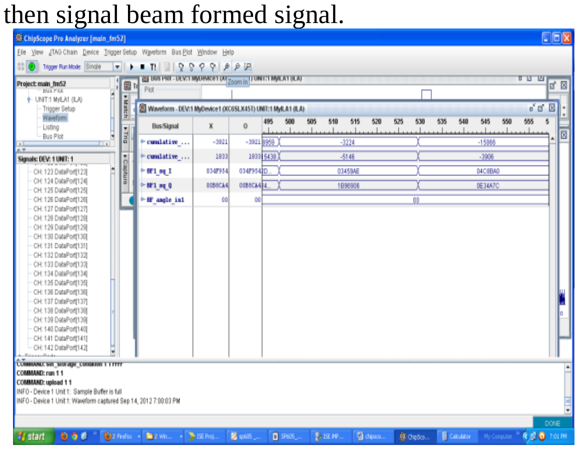

Figure 20: Beam forming digital I & q square signals

The digital notations formed when 1st signal is inphase.1st and 2nd signals are the two mode of information and called as cumulative component of signals whereas 3rd signal is quadrature component.

V.CONCLUSION AND FUTURE SCOPE

Computerized bar framing depends on the change of the RF motion at every reception apparatus components into two floods of parallel baseband signals speaking to I and Q channels. The computerized baseband flags at that point speak to the amplitudes and periods of flag got at every component of the cluster. The procedure of pillar shaping suggests weighting these computerized signs, accordingly modifying their amplitudes and stages with the end goal that when included they structure the ideal beam Using design and implementation, digital beam forming platform, the board and FPGA circuits, multiplexed signal processing, this method provides beams without taking effect on functionality with low cost making its use easy for phased array radar systems. The results of simulation and chip scope confirm maximum gain in desired direction and minimum in unwanted direction.

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