Digital Beam forming Algorithms for Radar Applications

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Abstract

Beam forming can be achieved by combining elements in an array in way that certain angles get constructive interference and some destructive interference, which can be utilized for both transmitter and receiver ends so that they can achieve spatial selectivity. Combination of antenna and digital technology as Digital Beam Forming (DBF) which was developed by workers in sonar and Radar systems which was enhanced by development of aperture synthesis methods leading to modern dipolar arrays improvement. Converting RF signals into cos and sin signals representing amplitude and phase values which are combined to get desired output this is done by converting analog signal into digital. Antenna is considered as a device which converts spatio signals into strictly temporal signals which makes it helpful for various signal processing techniques.

Keywords : Beam Forming (DBF), Radar systems, signal processing techniques

I.   Introduction

As digital signals can be copied with any data loss hence the ability to organize antenna patterns is possible .In general the received signal is digitized after converting it to intermediate frequency.
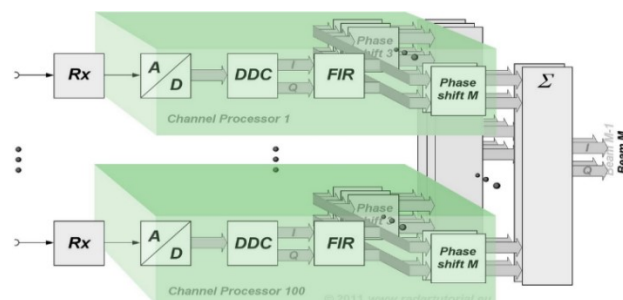

Figure 1: Block diagram of a beam forming processor

Every receiver has got respective ADC and DDC. For proper addition a transversal filter is used which tries to equalize the frequency and corrects the responses. This is a FIR filter which is tuned in automatic calibration routine. The output of ADC is fed to summation stages via I & Q signals. The number of summations depends in the received antenna beams. One can observe the radiating elements in the phased array antennas and they also have the phase shifters. Here the beams gets produced by shifting the phases from one place to the other and get constructive and destructive interference to have beam steering [XXIV] in desired direction. reference.The signals are ejected in the upper ward direction 2 degrees less than lower radiating element. If the emitter is electronic phase shifter then the beam direction can be managed,highest value is 120°.
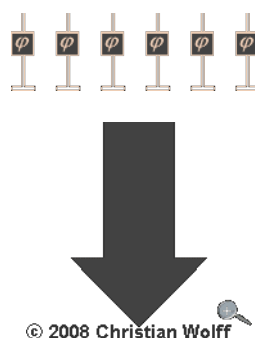

Figure 2: How the electronic beam-deflection gets Animated

II. Proposed Digital beam forming

The advantages seen above are make the DBF [XXV] more approachable but they do not have digital receivers for respective instead has small number of receivers serving many antennas leading to subarray level DBF but gives limited spatial or angular extent

A. Configuring the proposed DBF

DBF has got state of art technology used to synthesis multiple receiver beams in digital domain from digital videos to 480 digital channels of array group scalability and adaptability. This is specifically defined for high end FPGA and used in high end optical link and floating point representations are used to get dynamic range and by operating DBF at high frequencies reusing of beams is possible. It has also got in built radars which help in knowing virtual threats, health of system from front end antenna, TR modules AGRs and communicates information to maintain radar processor [XXVI], capable of configuring all AGRS and in a way to test and validate algorithms interfaces.

B. Software and Hard ware configurations:

The software tools and hardware platform used for implementing the proposed DBF is as follows.

i)   Software configuration
Programming languages -VHDL, MATLAB
Operating systems-windows 7
Simulation Tool-MODELSIM SE 6.6b

Synthesis Tool -Xilinx ISE design suite 13.2
On-chip Functional-chipscope pro core analyzer 13.2
    ii)   Hardware Configuration
FPGA board with JTAG Interface-Xilinx SPARTAN 6(XC6SLX45-3csg324)
    C. Specification of Design
The specification of each of the task of DBF implemented in this project are listed as under.

Parameter	Value	Comments
Type of the input signal	Band pass signal	This signal will be received from super heterodyne receiver
Range of the frequency for the input signal	1.5-3.5 MHz	2 MHz BW and 2.5 Mhz IF is the value of the frequency
Sampling rate	10 MHz	
Size of the DDC filter	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
Quantity of the array elements available	16	Linear array as shown in below figure.
Element spacing	3 meters	d as shown in below figure

III.   Principle of digital beam forming

      The operations are carried out digitally where the RF signal is converted to digital form using ADC, whose output is fed to DDC [V] to obtain 2 down converted signals, one in phase and the other quadrature phase. These I & Q signals are feed to multiplexer and the final outputs are are summed to get a beam. The main block diagram for digital beam forming consists of

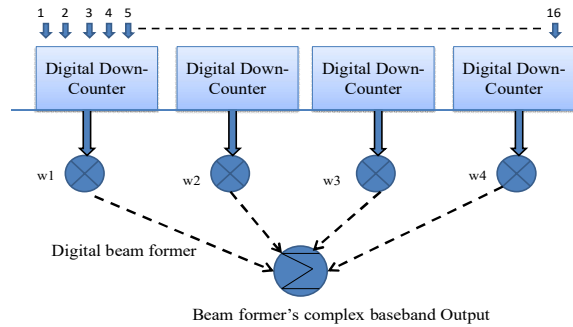   1.   Digital Down-Counter
      2.   Multiplier & Adder

Beam former's complex baseband Output

Figure 3.block diagram of the Digital Beam which is producing

A. Digital down-counter

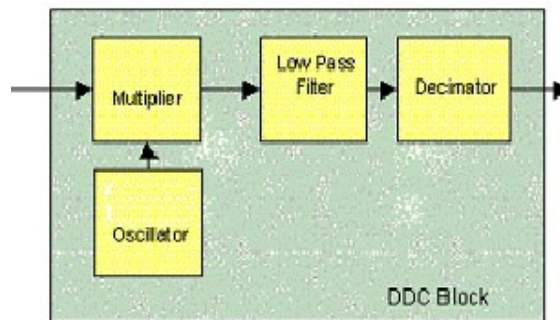The below is the DDC structure which consists of Oscillator (NCO), Multiplier, Low Pass Filter, Decimator.

Figure 4. Digital down Counter

B. Oscillator (NCO)

Carrier signals are generated based on ROM techniques for reducing area consumption.
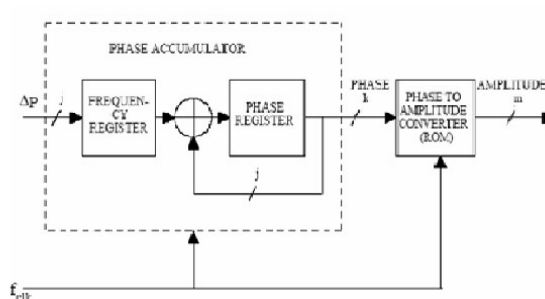

Figure 5. NCO (Oscillator)

C. *Phase Accumulator Module*

This block consists of various types of registers which are helpful for storing the phase increment values and is fed to 8 bit adder as an input and the remaining input values are taken from the phase register output. The names of the registers which are utilized are phase increment register, adder and phase register. The output is four values added to the previous phase value, initial value is 0 so the next clock pulses are 4,8,12,16 and so on. This output is added to multiplier and given to NCO block. This block has a common clock and reset signals. Frequency modulating value is added for the delta phase [IV]. This adding of delta phase helps in enhancement of the phase for every clock and also the frequency signal. Modulator being digital affect the resultant frequency and if modulating signal is analog then ADC is utilized to change it to digital.

IV.   Phased array radar antenna

RADAR's are utilized in police traffic, knowing weather conditions and many more. Radars are used fordetecting and tracking purpose [III]. RADARS [Radio Detection and Ranging] are categorized as seen in below figure.
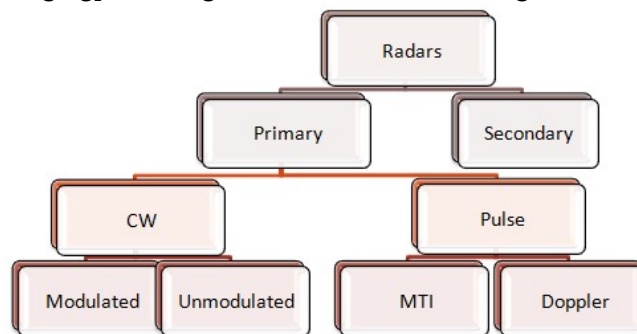

Figure 6: Classification based on specific function

Primary Radar: The high frequency signals are being transmitted to the target area by taking the help of the primary radar. Later these pulses gets reflected through that target and then received by the similar radar back which are extracted to get target information.

Secondary Radar: By taking the help of the transponder these secondary radar functions on the active answer signals. This transponder will be on the airborne target/object.

Pulsed Radar: This broadcasts the high power and frequency pulses to the area of target and waits for the echo of the broadcasted signal prior to transmission of next pulse.The resolution of the RADAR depends on the repeated pulse frequency.

MTI (Moving Target Indicator) Radar: This helps in separating the echoes of the moving targets from the stable objects. This is purposely done for rejecting the clutters.

Pulse Doppler Radar: The kind of pulse radar which utilizes doppler frequency shift for determining the echo signals and to reject clutters.

Continuous Wave Radar: it transmits high frequency signals and reflects energy is also received back and processed continuously. It's of two different types

1. **Un-modulated**: These are used by police as the signal which is being transmitted will have the constant amplitude and frequency.
2. **Modulated:**It cannot measure range as it's not possible at run time whereas un modulated can measure range.

Phased array Radar : Here the relative phases of respective antennas vary in a way to give effective radiation in desired direction. It has group of antennas connected to common source. This type of transmission started in 1905 by Nobel laureate Karl Ferdinand Braun who given a clear explanation about the upgraded broadcasting of radio waves in one direction.

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

The two different types of phased arrays present here are:
1. Time domain beam formers: works on time delays with basic operation as delay and sum where incoming signal is delayed from each array by some amount of time.
2. Frequency domain beam formers : this domain is again subcategorized into two types:
   a) First one will splits the frequency components which are available in the received signal area into various frequency bins by applying delay and sum, output is the main lobe.
   b) The second type uses spatial frequency where discrete samples of individual elements are taken into consideration

One can produce two types of phase arrays by utilizing these techniques. They are Dynamic array and fixed array. Their functions are as below:
- Dynamic –beam moving from one location to another using shifters.
- Fixed –fixed position of the beam.

Further divide as:
- Active –consists of active elements like amplifiers
- Passive –consists of passive elements only.

Dynamic Phased Array : It has a manageable phase shifter which is utilized for moving the beam in track with array phase beam [VI].The movement of this beam happens electronically which produces antenna fast motion to get small pencil like beam and mostly used in military applications.

Fixed Phase Array : These are utilized for producing an antenna with desired form factor when compared to existing parabolic reflector.

Active Phase Array : It uses transmit amplifications with phase shift in every antenna, it receives pre amplification. Transmitter and receiver share similar phase shifter configuration [8]. Phase reset is not required in the end.

Passive Phase Array: These use large amplifiers producing microwave signals consisting of waveguide elements which have phase shift.

V.   Implementation of digital beam forming on FPGA

A.   RTL schematic
i)   Design Summary

The below figure shows the specifications as project file name, module name, target device, product version, device utilized, summary, performance summery like final timing score, routing results, timing constraints, clock data, errors and warnings etc. Window appears when the following commands are given

- First double click on the Xilinx 13.2i
- Then open project (name project as ise_prj_FM_52_beam_forming.xise.ise.
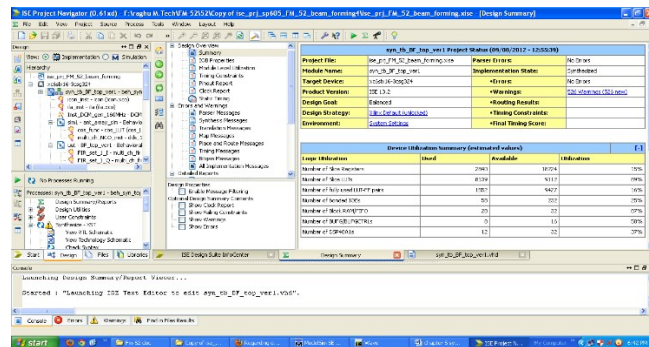
Figure 7: Summary of the designed program

ii)   Top module (syn_tb_BF_top_ver1)
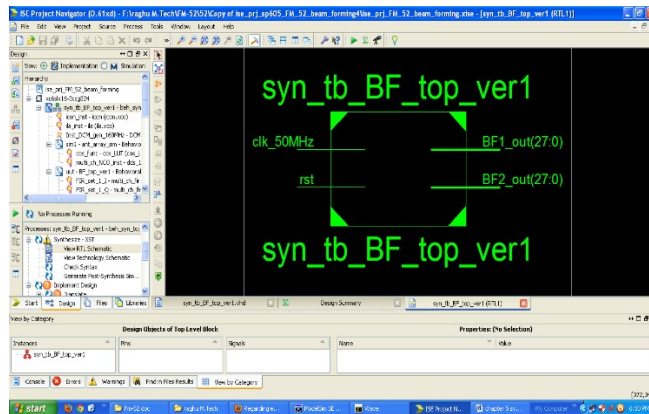
Figure 8: Top module

The above figure shows the virtual image of commands given by user in VHDL language as 50 MHz clock signal as input and reset pin BF1,BF2 as beam forming output 1 & 2.
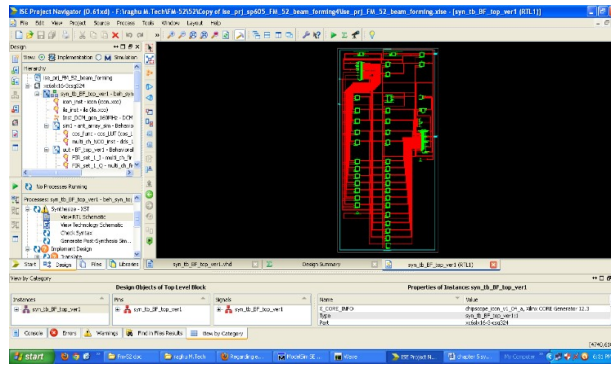
Figure 9: sub modules in top module

Left hand side top shows antenna receiver connections for input and antenna devices are shown in green colored components blocks and red color line shows connection among devices. Beam forming outputs are shown on right hand side.

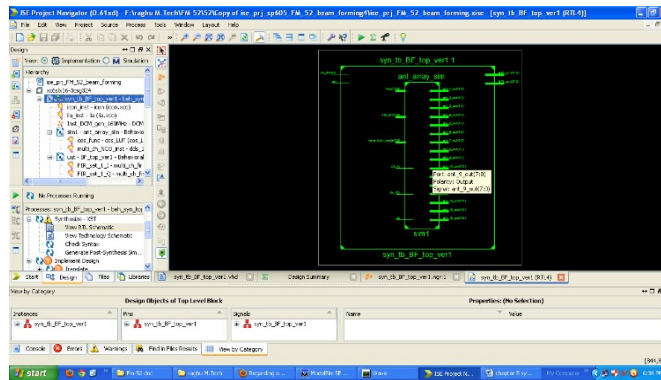iii)   Antenna Array Module (ant_arr_sim) :

Figure 10: antenna array module

The above figure gives information about ports handling input, output and reset connections which can be seen in white box by mouse movement.

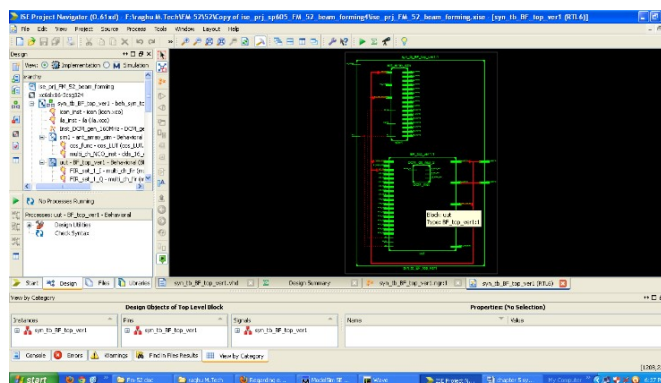iv)   Beam Forming Module (BF_top_ver1)

Figure 11: Beam Forming module

The window shown above depicts the 16 antenna input receivers's and their connection to ADC on left top block and beam forming output is shown on right hand side.

B. Simulation and chipscope results

Using VHDL coding, digital blocks of phased radar are simulated in 6.6b software.
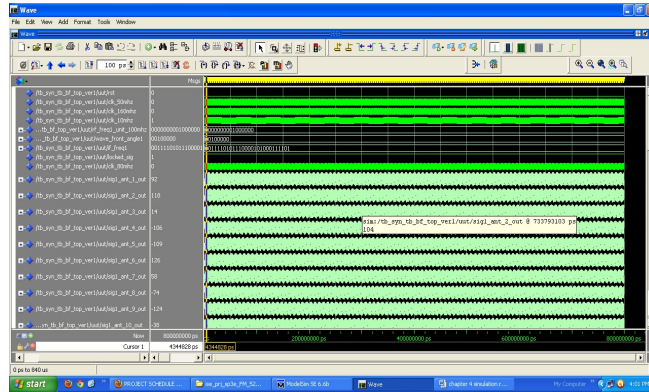
i)   Simulation results of syn_tb_BF_top_ver1

Figure 12: Antenna outputs

Left side shows the signal user utilizes with different colors for different frequencies. Binary values are given frequency and phase and the rest 16 signals are the outputs.
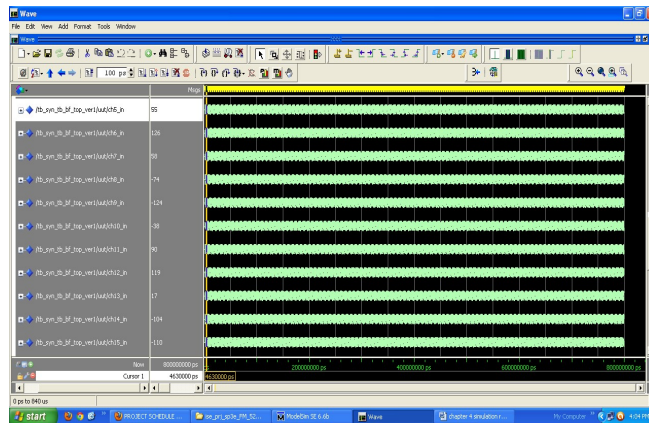

Figure 13: Beam forming inputs

The 16 channel generated from FSM outputs of MAC filter operating as channel to obtain multiple samples od DC and AMTLAB filter coefficient. The values are rounded to integers.
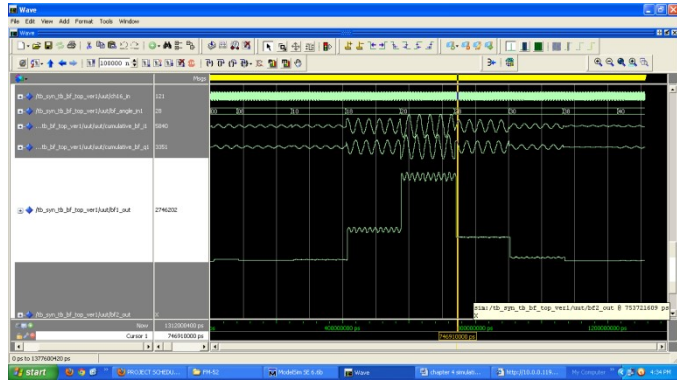
Figure 14: Single Digital Beam

The above shows the angle obtained from the magnitude value of amplitude of real and imaginary components produced by digital down converter which shows the array with maximum in formation 1st sine signal is the quadrature component and the 2nd is in phase component of signal.
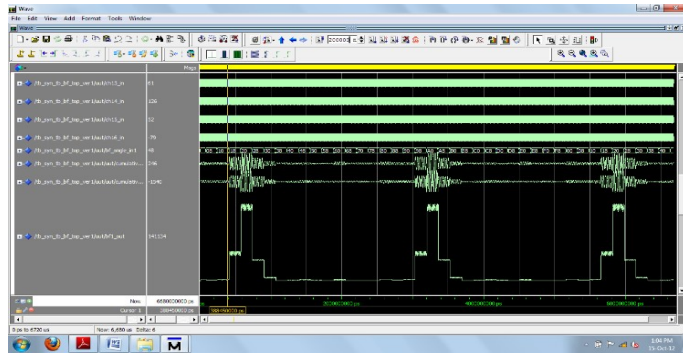

Figure 15: Multiple Digital Beams

The signals seen in the above figure are from weather forecasting and air traffic control where the digital line is the quadrature phase angled output and the other 2 signals are in phase signals. The thick line is the multiple beams which has maximum value at regular intervals of angles.
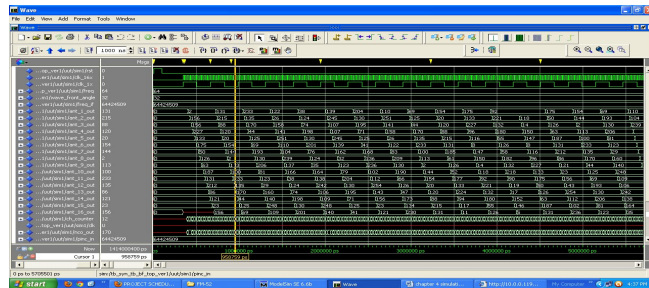
C. *Simulation results of antenna array module*

Figure 16: Antenna Array Digital outputs

Signals values are tehamplitudes1st signal is reset,1st column is drawn when reset is zero and 2nd column is when reset is 1.When the clock are applied at 160 MHz and 10 MHz the next waves are graphed later which 16 channel outputs are taken. The last graph is NCO output at high frequency.
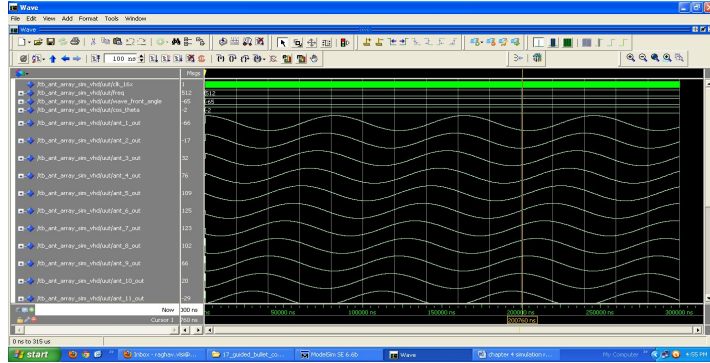

Figure 17: antenna array outputs with phase shifts

The above is the analog form where only 9 antenna outputs are seen which are repeated at regular intervals describing amplitudes.
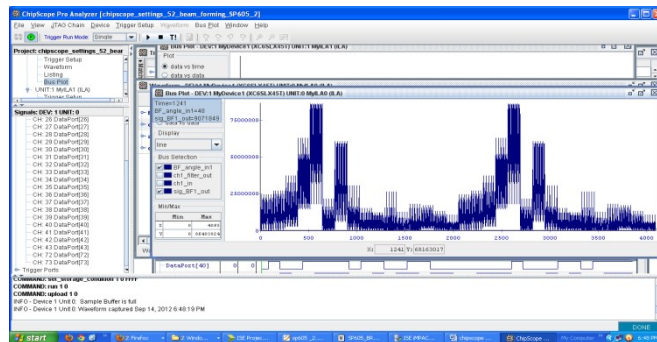
D. Chipscope results

Figure 18: Beam forming input Vs output

The above shows the beam forming signals where the peak is the high information signal where antennas are tuned to value of phase angle. Using one in phase component and the other quadrature component of signal, beam form signal is generated.
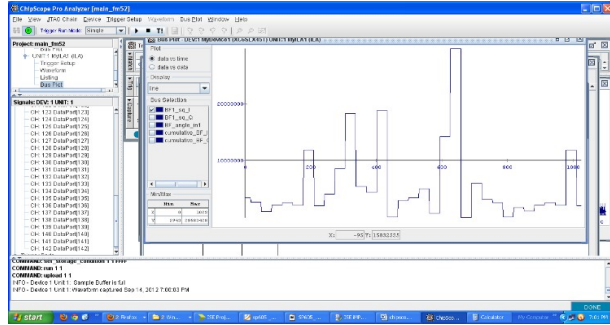
Figure 19:Beam forming I square signal

The above shows sine signals with real and imaginary values where real values are amplitudes of in phase components for 16 antenna outputs.
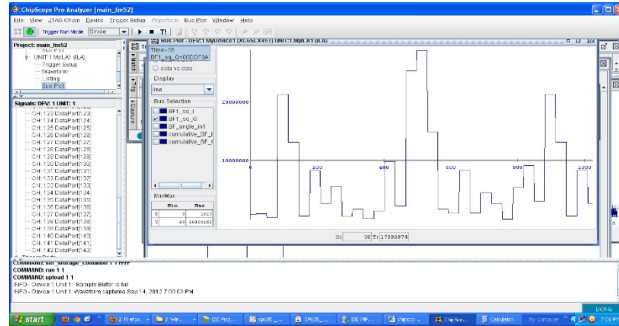
Figure 20: Beam forming q square signal

The above shows the mapping of imaginary values of sine signals taken from digital down converter as quadrature components of 16 antenna outputs.
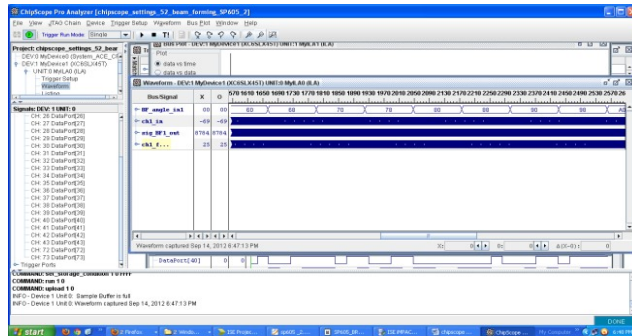

Figure 21: Beam forming digital output

The device above is the digital representation of single beam forming output signal produced by the SPARTAN 6 (FPGA) by interfacing chipscope software. The first signal is the front angle and the second is the channel output.
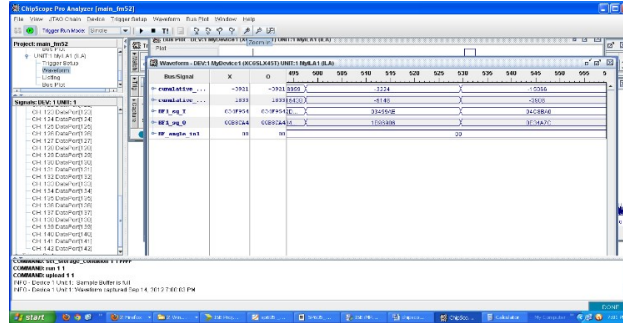
Figure 22: Beam forming digital I & q square signals

The above is the digital notation of components 1st one is the inphase component 2nd one is the cumulative component and 3rd one is the quadrature component.

VI. Conclusion

RF signal in two streams of binary data denoted as I and Q channels is the basis of Digital beam Forming where amplitudes and phases of signal received are adjusted to get the desired beam. Using FPGA makes the system low cost without compromising on functionality thus showing maximum gain in desired direction and minimum in unwanted direction.Multi beam array based technique is used where real time beam processing is not efficient hence a multiplexed signal which is time shared can be implemented without compromising on functionality. Implementing the same system with parallel array processing, more than 16 antennas input signals can be implemented.

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