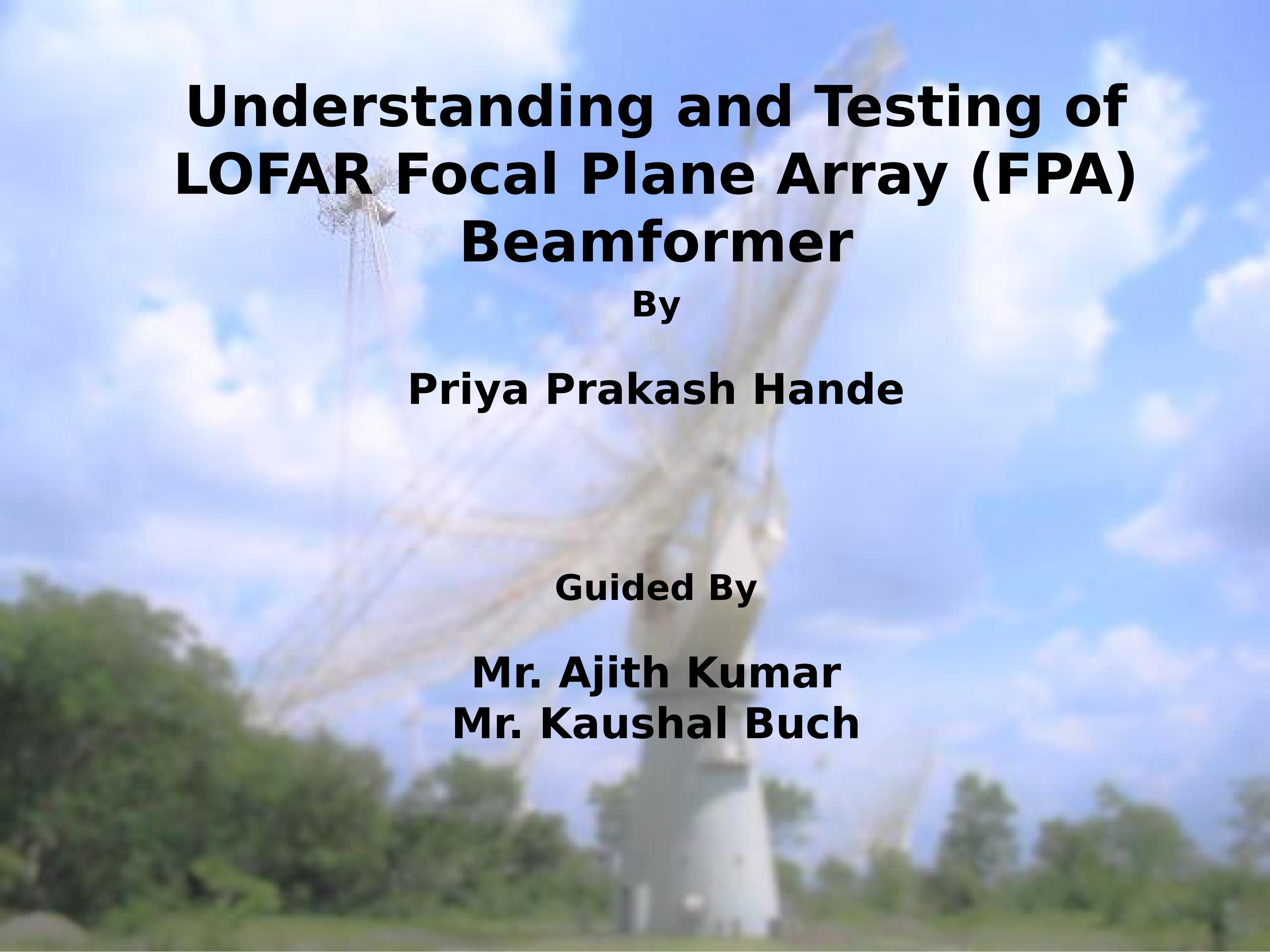

Understanding and Testing of LOFAR Focal Plane Array (FPA) Beamformer

By

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Guided By

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My Work

Understanding the Focal Plane Array Beamformer.
Carrying simple test using Beamformer modes.
Preparing Documentation for LOFAR FPA Beamformer.
Carrying out simulation for the beams.

Overview of the presentation

- Introduction to LOFAR FPA Beamformer
- Technical Specifications for the System.
- Basic Block Diagram
- Tracing the System
- Testing the System
- Baseband Conversion in Down Conversion Unit (DCU)
- Testing DCU
- Power levels for LO
- Testing DPB
- Signal Processing in Digital Processing Board (DPB).
- Debugging the Digital Section
- Testing System after Debugging
- Matlab Simulation Examples

Introduction to LOFAR FPA Beamformer

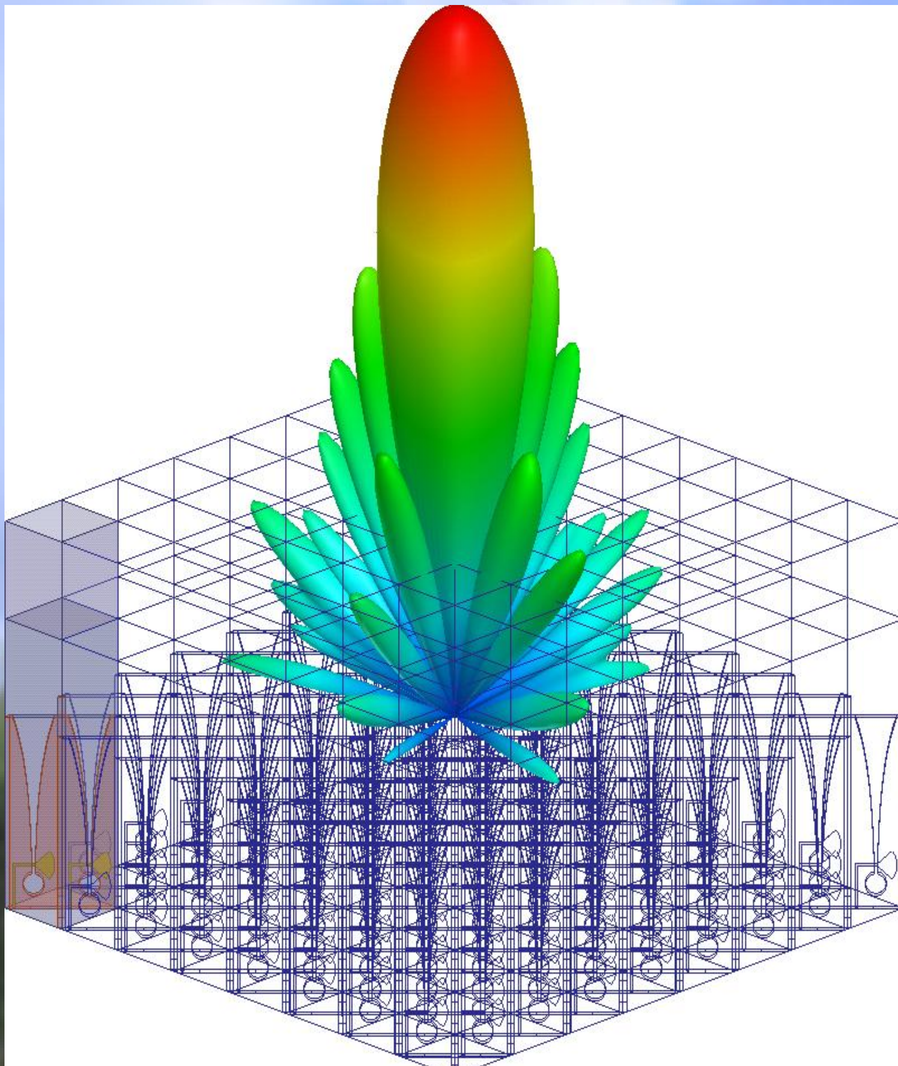


Image Courtesy : www.google.com

LOFAR, the Low Frequency Array, is a multi-purpose sensor array. Its main application is astronomy at low frequencies (10-240 MHz)

One such system of LOFAR is the FPA Beamformer consisting of 8*9*2 elements.

There are two distinct antennae types: the Low Band Antennae (LBA) operating between 10 and 90 MHz and the High Band Antennae (HBA) operating between 110 and 250 MHz

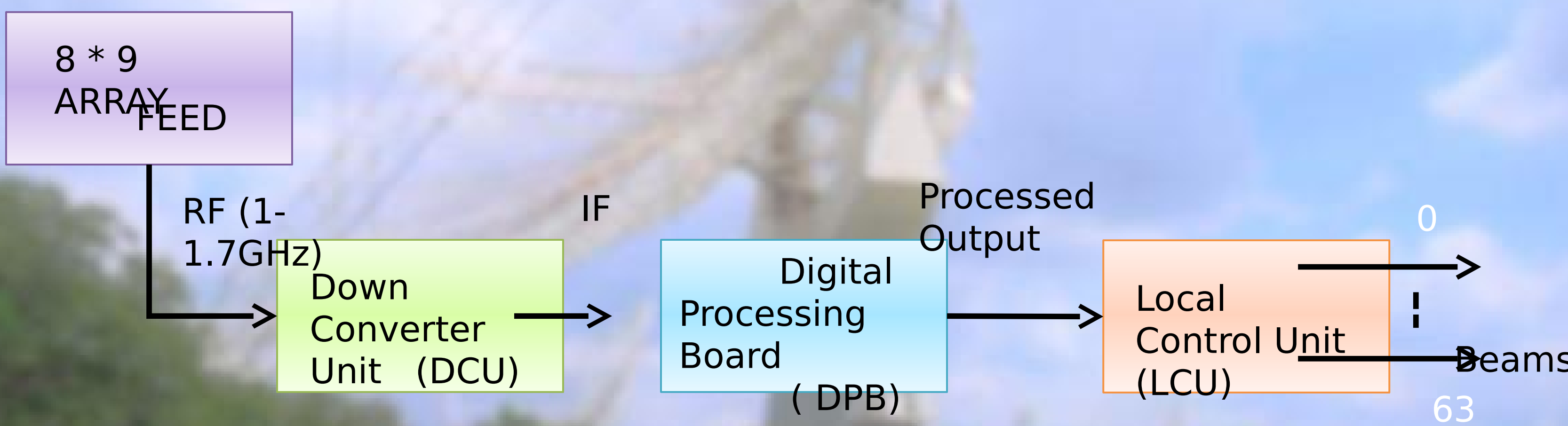
The frequencies in between low band and high band are not used due to RFI from FM radio transmitters.

Technical Specifications

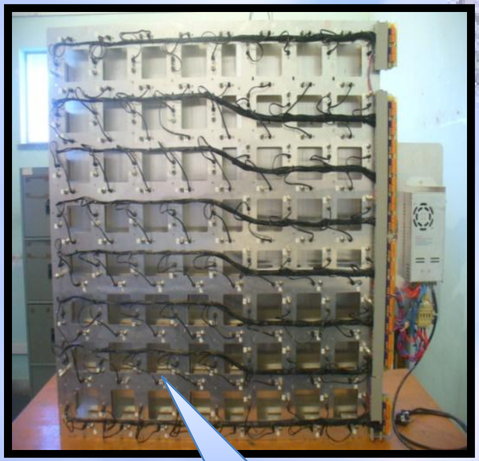
Number of Antennas inputs (DCU'S)	64
Polarization	Dual Polarization
Number of RCU's	64
Number of RSP's	8
Number of Antenna Processor	32
Number of Beamlet Processor	8
Network used	1 Gbps Ethernet link and 10Gbps Infiniband
Data rate from Switches to Digital Board	100 Mbps(control and data)
Clock Frequency	200 MHz/160 MHz (Depending on modes)
station output beam bandwidth	47.65 MHz(clock=200 MHz), 38.12 MHz(clock=160 MHz)
FFT Point	1024
Number of Subbands	512
Beamlets	244 (Depending on the

Basic Block Diagram

Focal Plane Array is a feed of 8*9 Vivaldi elements.
Signal frequency to DCU is 1.0 GHz to 1.7 GHz.
In DCU signal conversion to baseband level takes place.
Digital Processing Board (DPB) digitization and processing on the signal processed output in the form of data.
The processed Local Control Unit (LCU) 64 beams. Those 64 beams can be used for observing objects located in sky with increased field of view.



Snap of FPA Racks and Feed



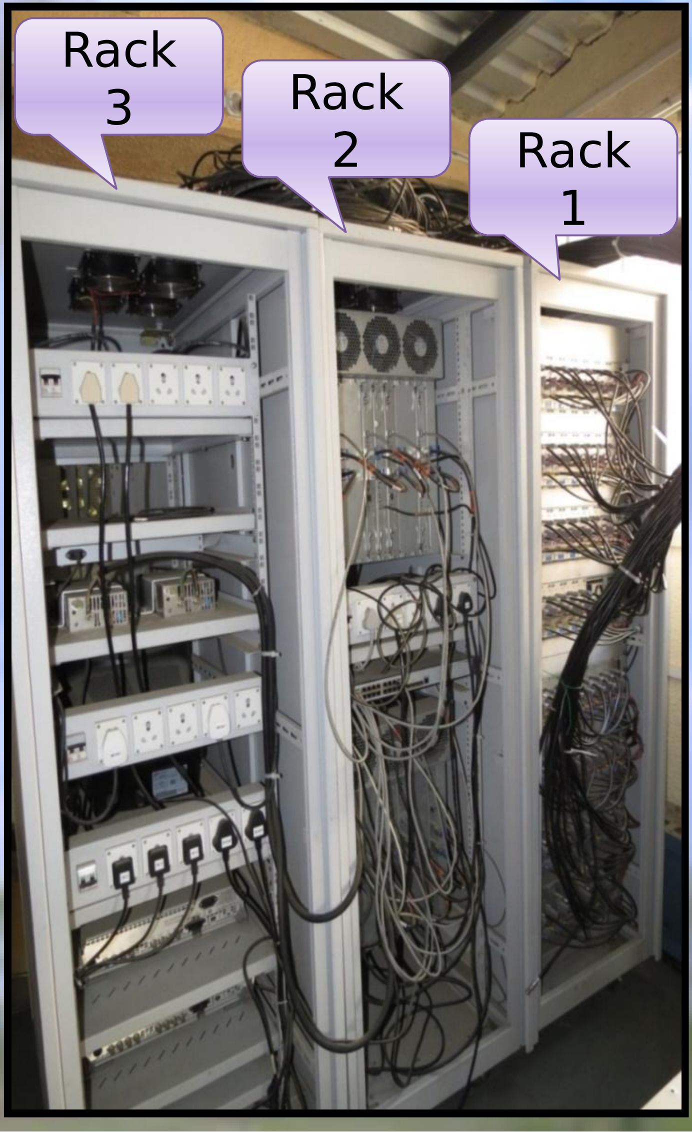
- **Rack 1** : 64 Down

  Converter Units

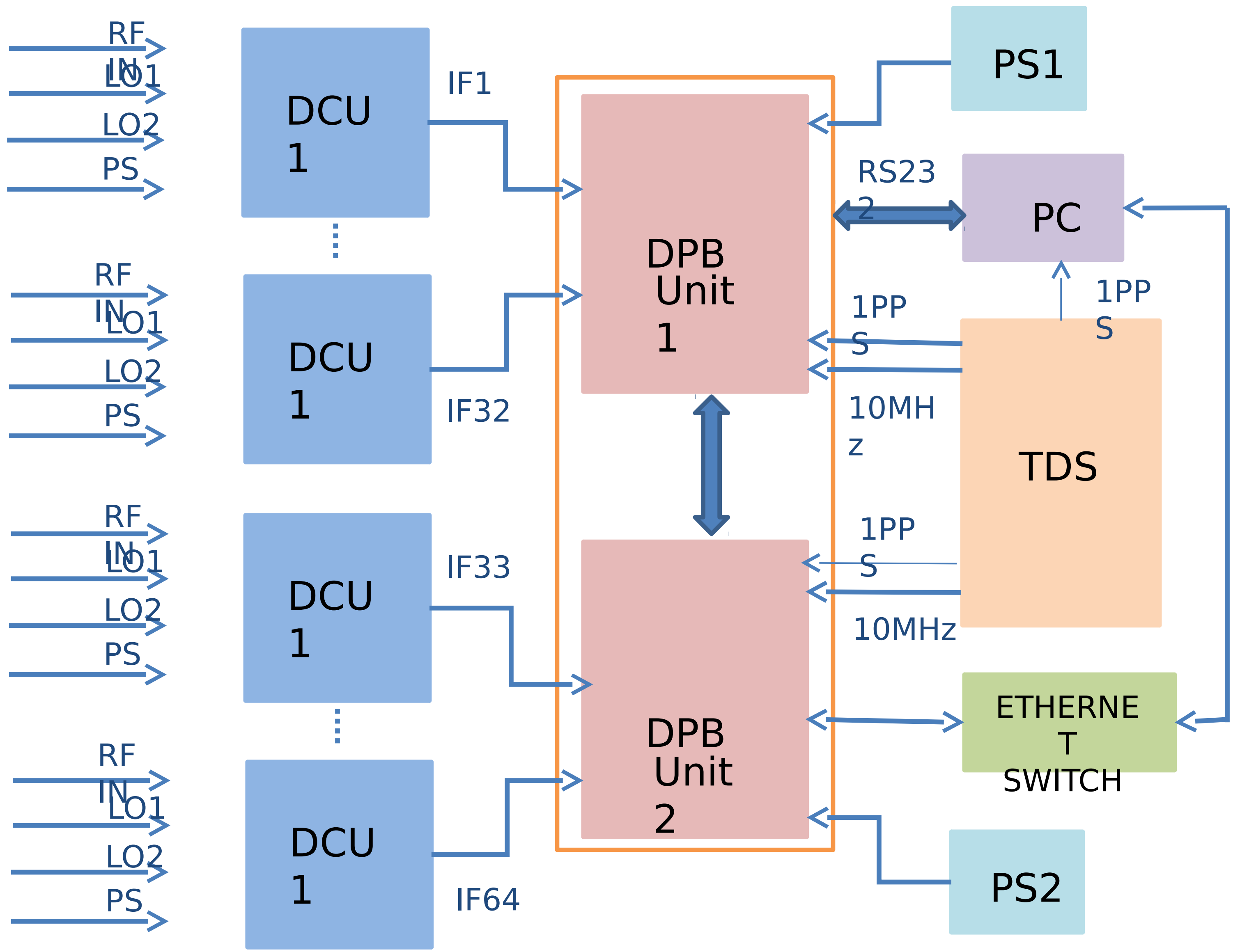
- **Rack 2** : Two subbracks of Digital Processing Board.

- **Rack 3** : Local Control Unit PC with Redhat Linux Operating System.

- **Feed** : 64 Vivaldi elements.



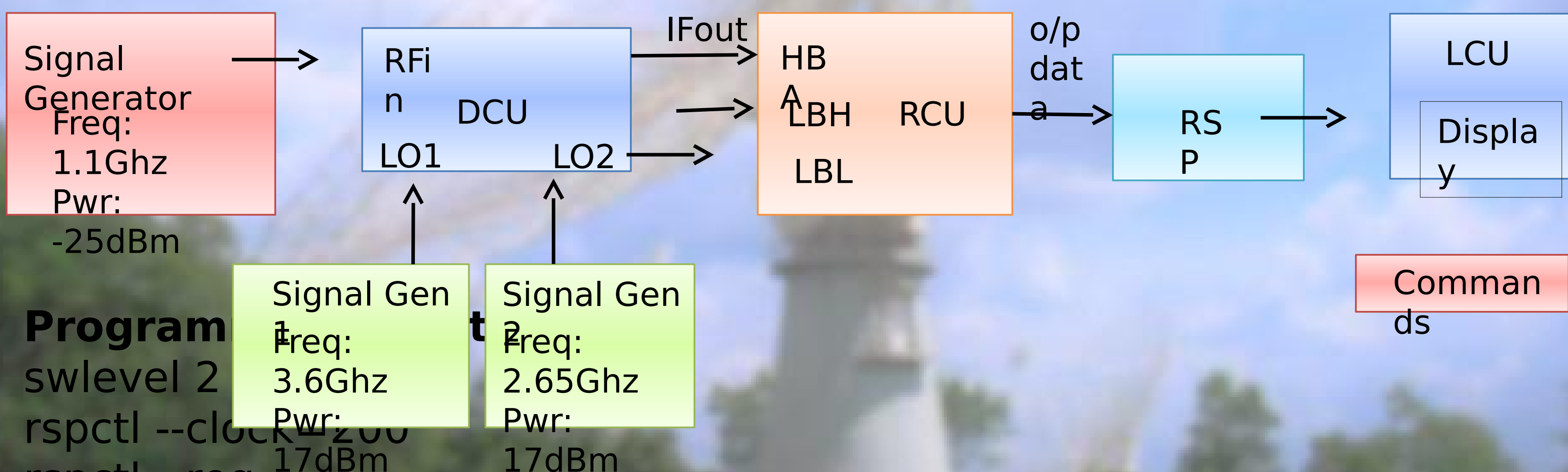
Block Diagram



Prepared after tracing the interconnections doing reverse engineering

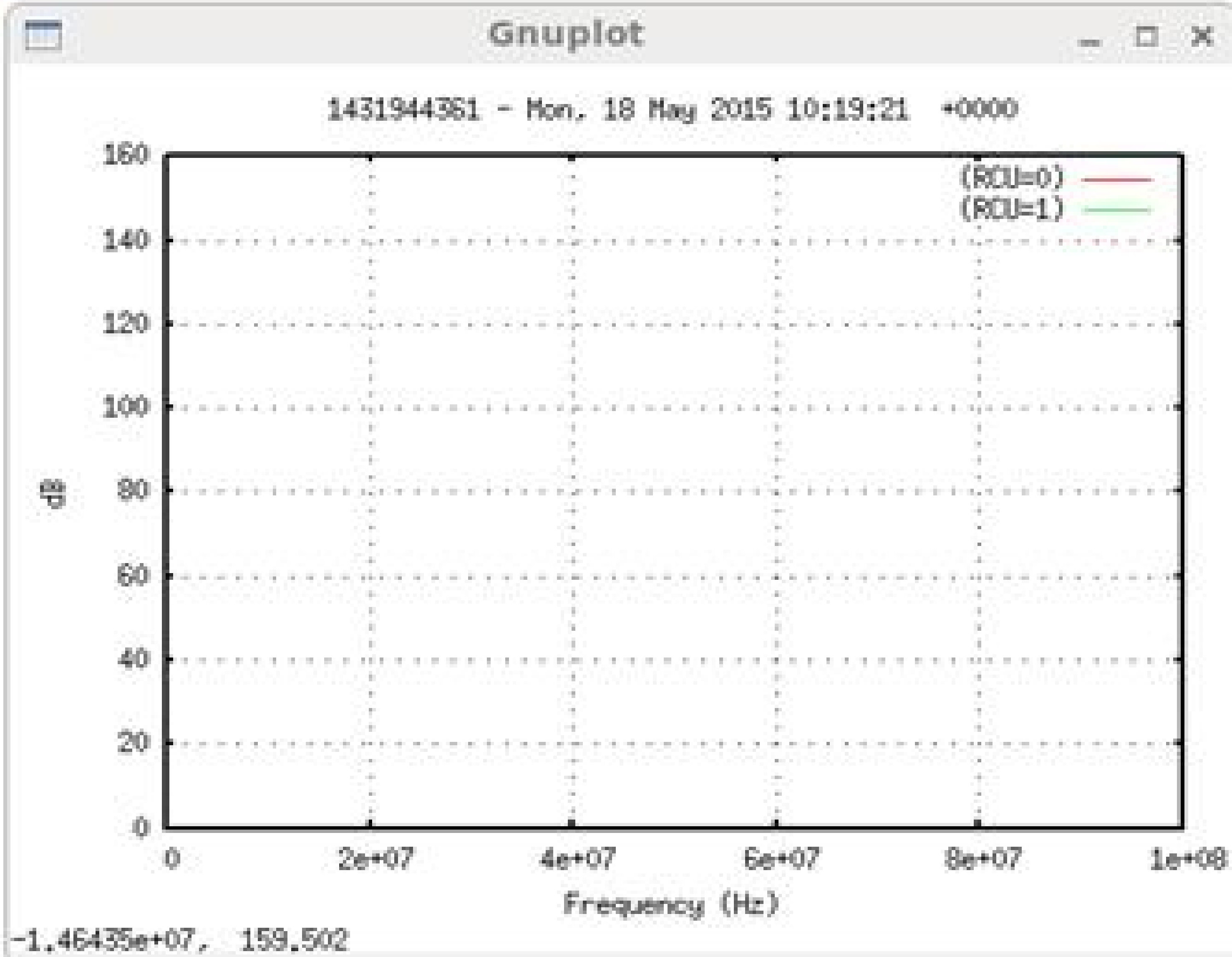
Test Setup for the System

Test Inputs :
RFin Freq : 1.1 GHz, -25 dBm
LO1 Freq : 3.6 GHz, 17 dBm
LO2 Freq : 2.65 GHz, 17 dBm



Program [illegible]
swlevel 2
rspctl --clock=200
rspctl --reg
rspctl --rcumode=5
rspctl --prsg=0

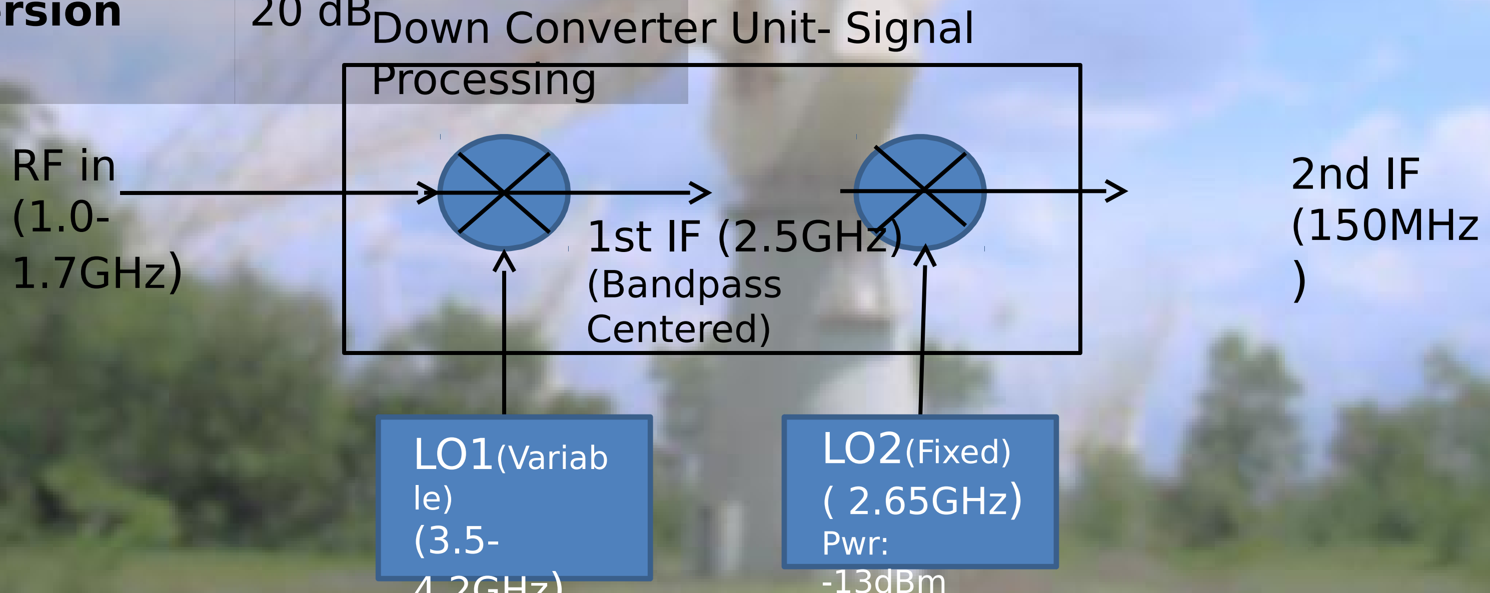
Output Spectrum



Baseband Conversion in Down Converter Unit(DCU)

RF Frequency	**1000 – 1750 MHz**
LO1 Frequency	3.5 – 4.2 GHz (variable)
LO1 Power	-13 dBm
LO2 Frequency	2.65 GHz (fixed)
LO2 Power	13 dBm
IF output Frequency	150 MHz (IF2)
IF Band width	80 MHz
Conversion Gain	20 dB

RFin connector	**F type (75 Ohm, female)**
LO1 connector	SMA (female)
LO2 connector	SMA (female)
IF out connector	SMA (female)
Power supply connectors	9 pin D type



Power levels for LO

Frequency (GHz)	Power (dBm)				
	A	B	C	D	E
3.6	17.00	15.27	3.30	-8.0	-14.9

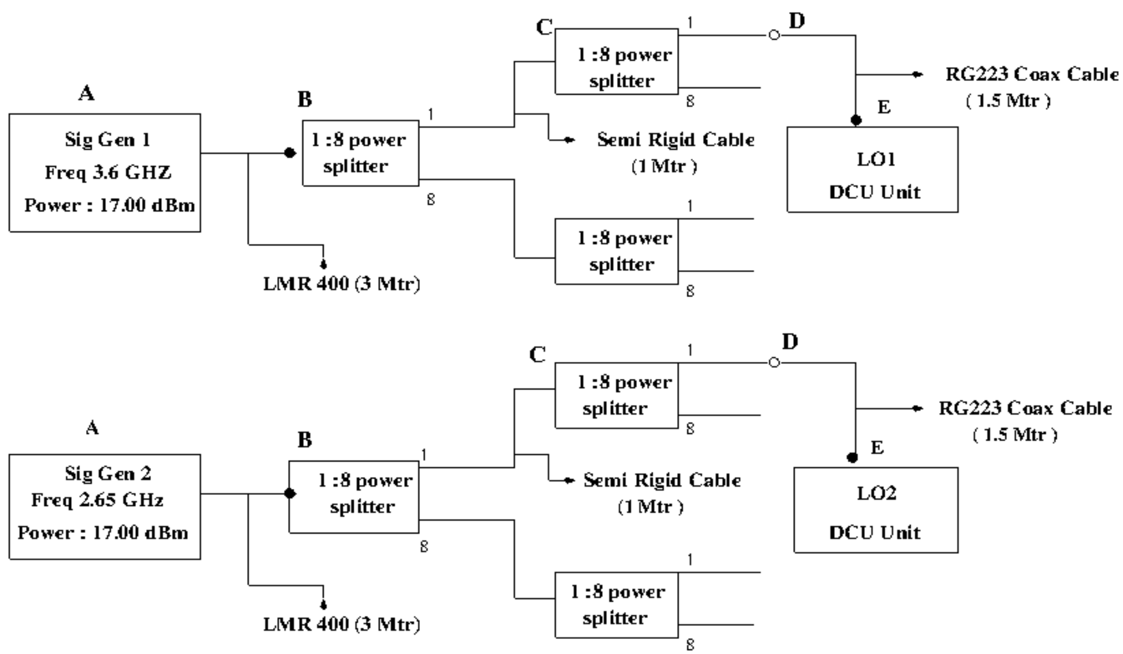


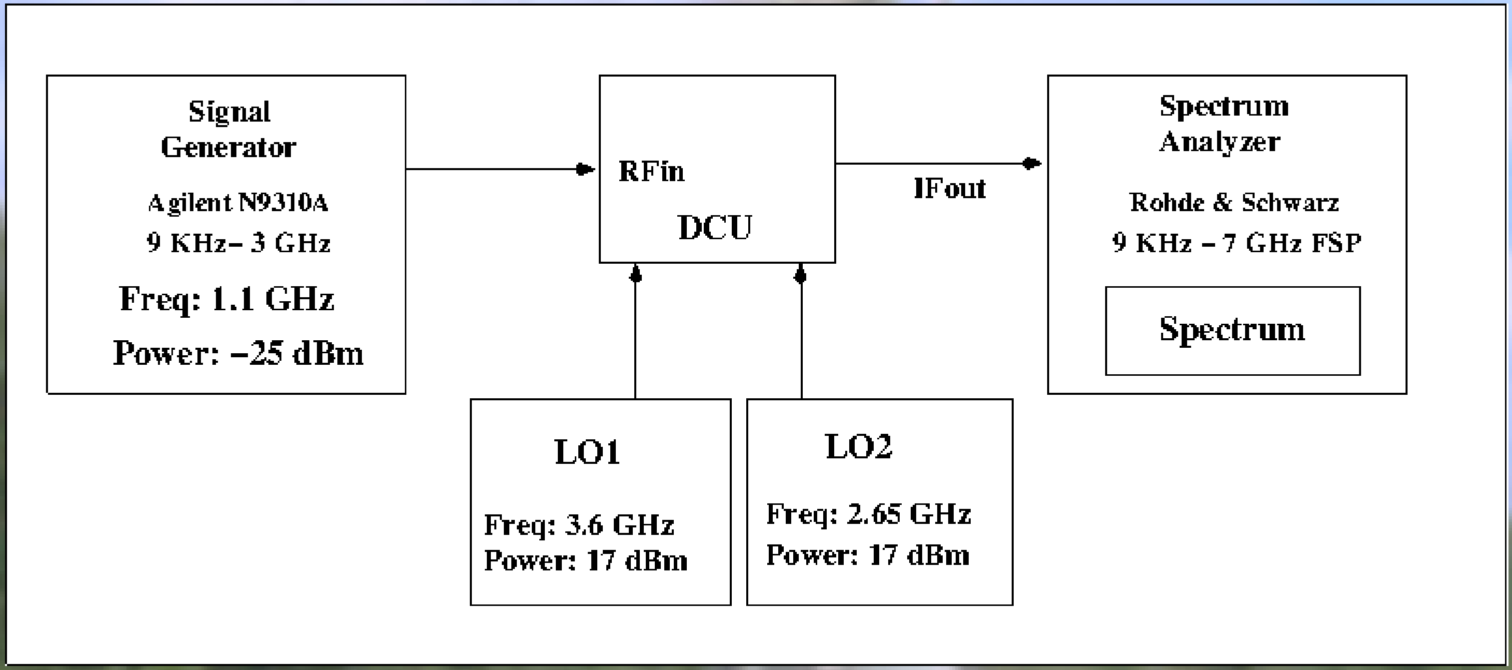
Fig : Test Points for the LO's

- The power limit for the LO Signal Gen is 17 dBm.
- Considering the loss for cable, 2 8-way power divider 17 dBm power from LO Signal Gen resulted in -14 dBm and -10 dBm power levels at LO ports of DCU.
- Actual power level at the LO port should be around -13 to -15 dBm.

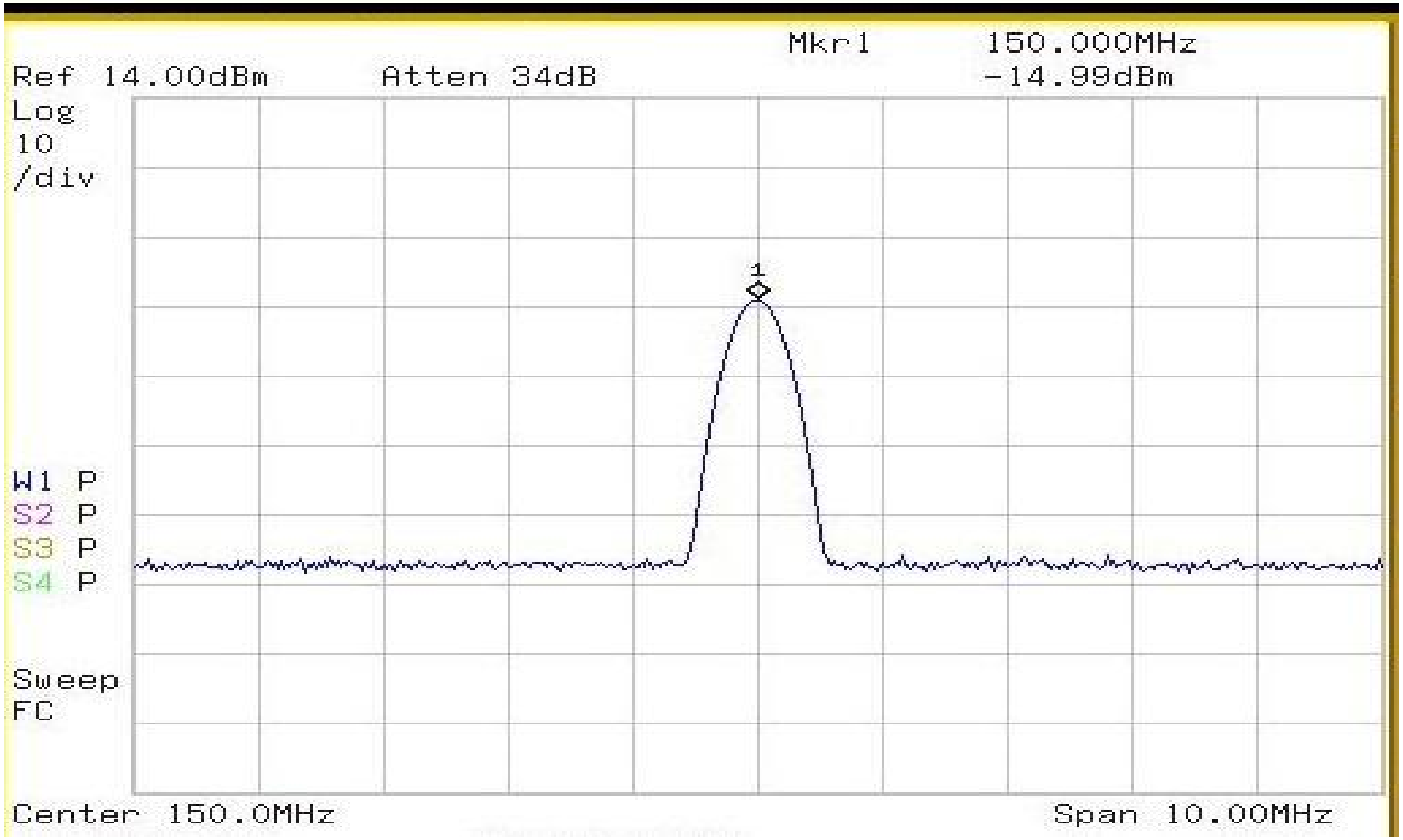
Test Setup for DCU

After taking information to DCU, following test setup was made to test the IF Signal with the appropriate power level.

The frequencies for the RF and the LO1 were set so the difference resulted in 2.5 GHz IF. And LO2 was set to 2.65 GHz so that the second IF centered at the 150 MHz



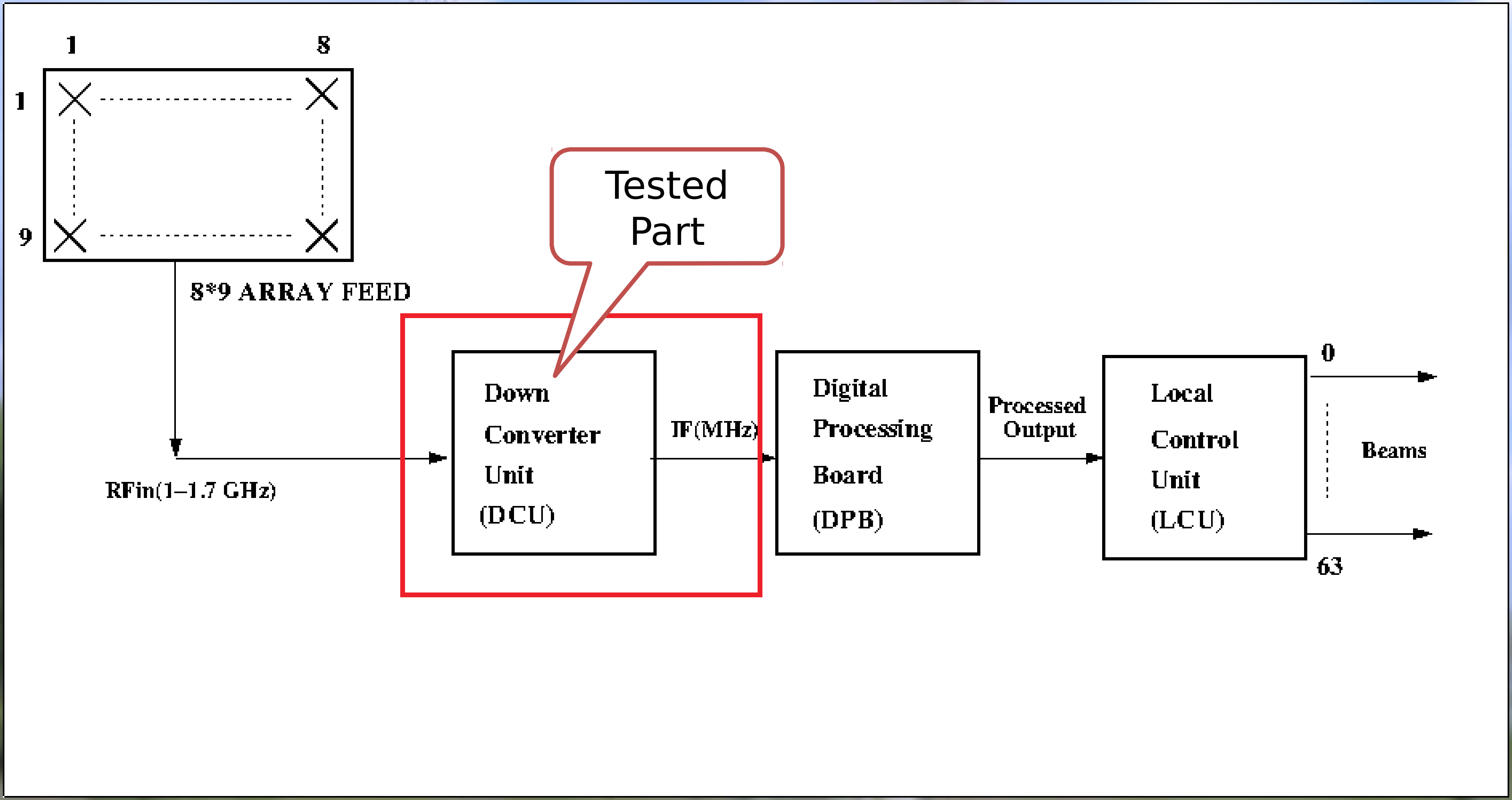
Output IF Plot



Input Freq to DCU: 1.1 GHz
Power : -25 dBm

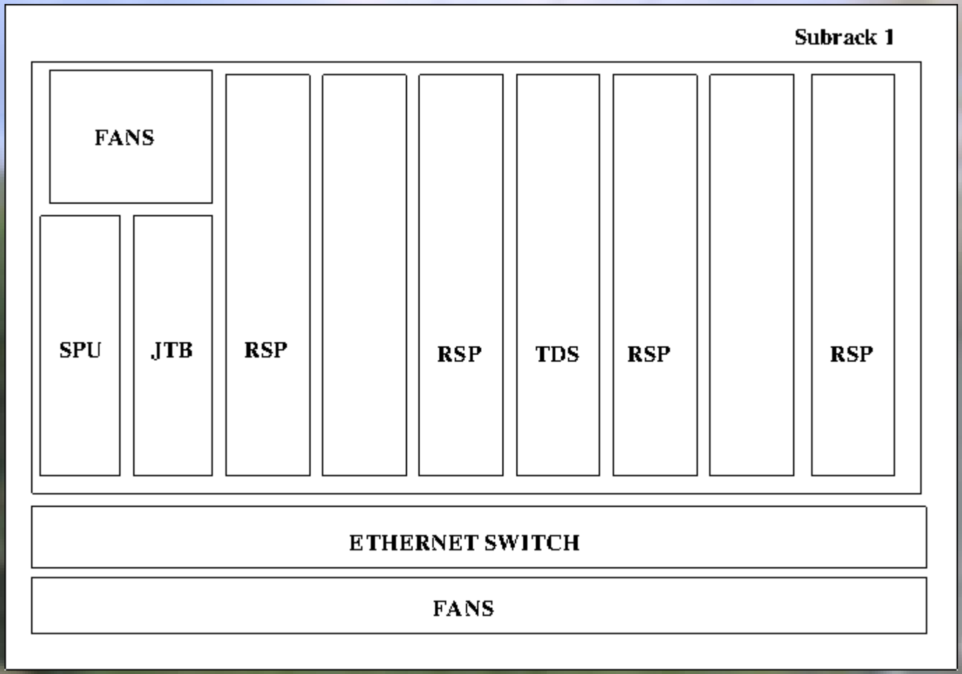
Spectrum Analyzer Settings : Centre Freq= 150 MHz
RBW= 300 KHz, VBW= 3KHz, Span= 10 MHz

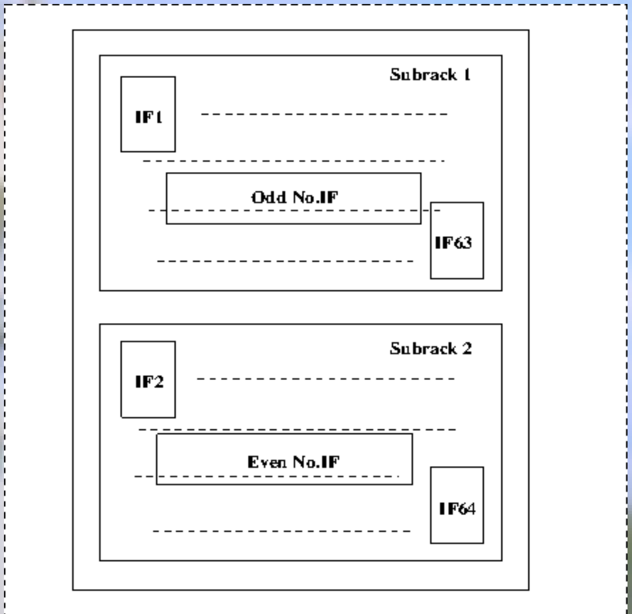
Block Diagram



Digital Processing Board

- Front View:
- There are different units in DPB (SPU, JTB, RSP, TDS)
- Each board has different function.
- There is Ethernet switch for exchange of data
- Rear view:
- 32 Receiver units in Subrack 1, another receiver units in Subrack 2
- LBL, LBH, HBA input frequency connectors.



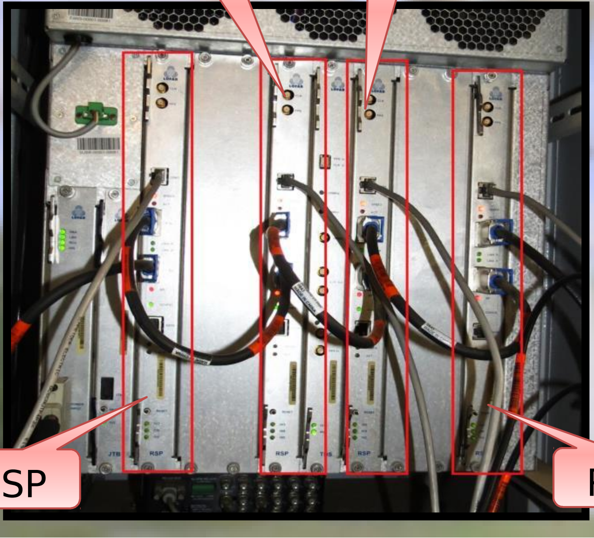


Rear view of DPB (Receiver Unit)

Some Snaps of DPB

32 Receiver Units

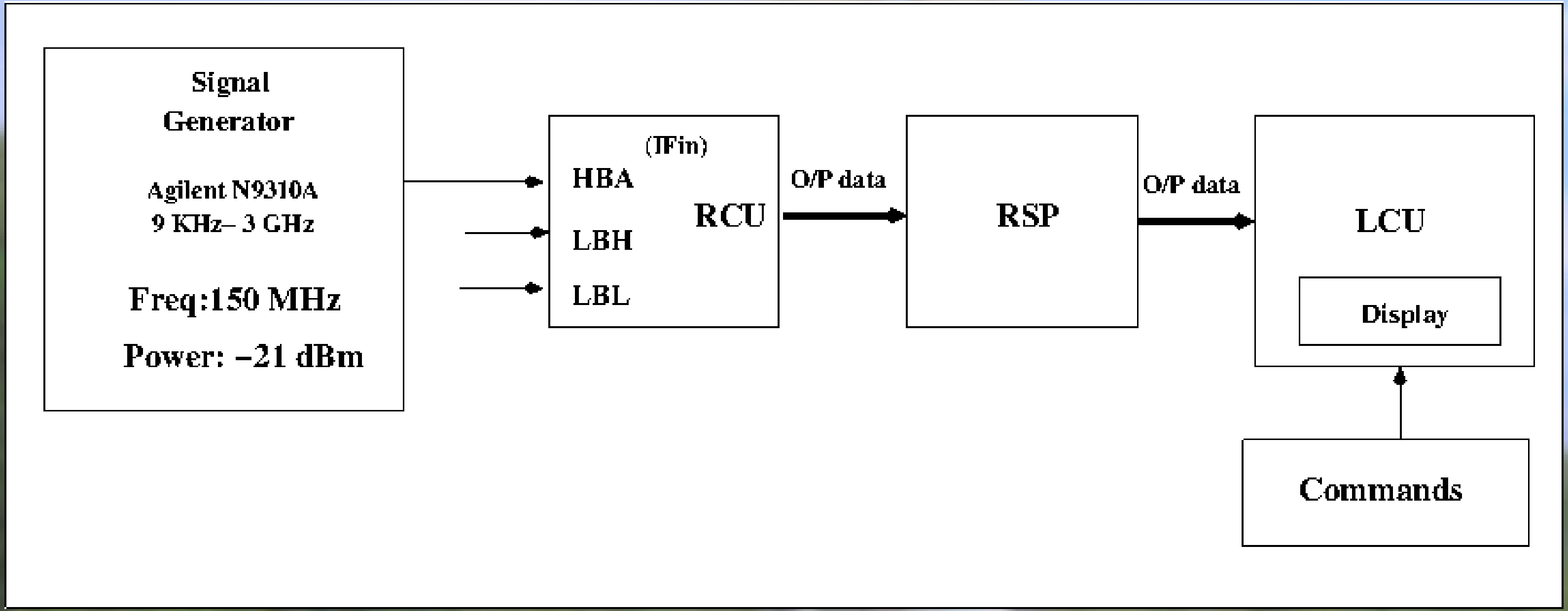
4 RSP Boards



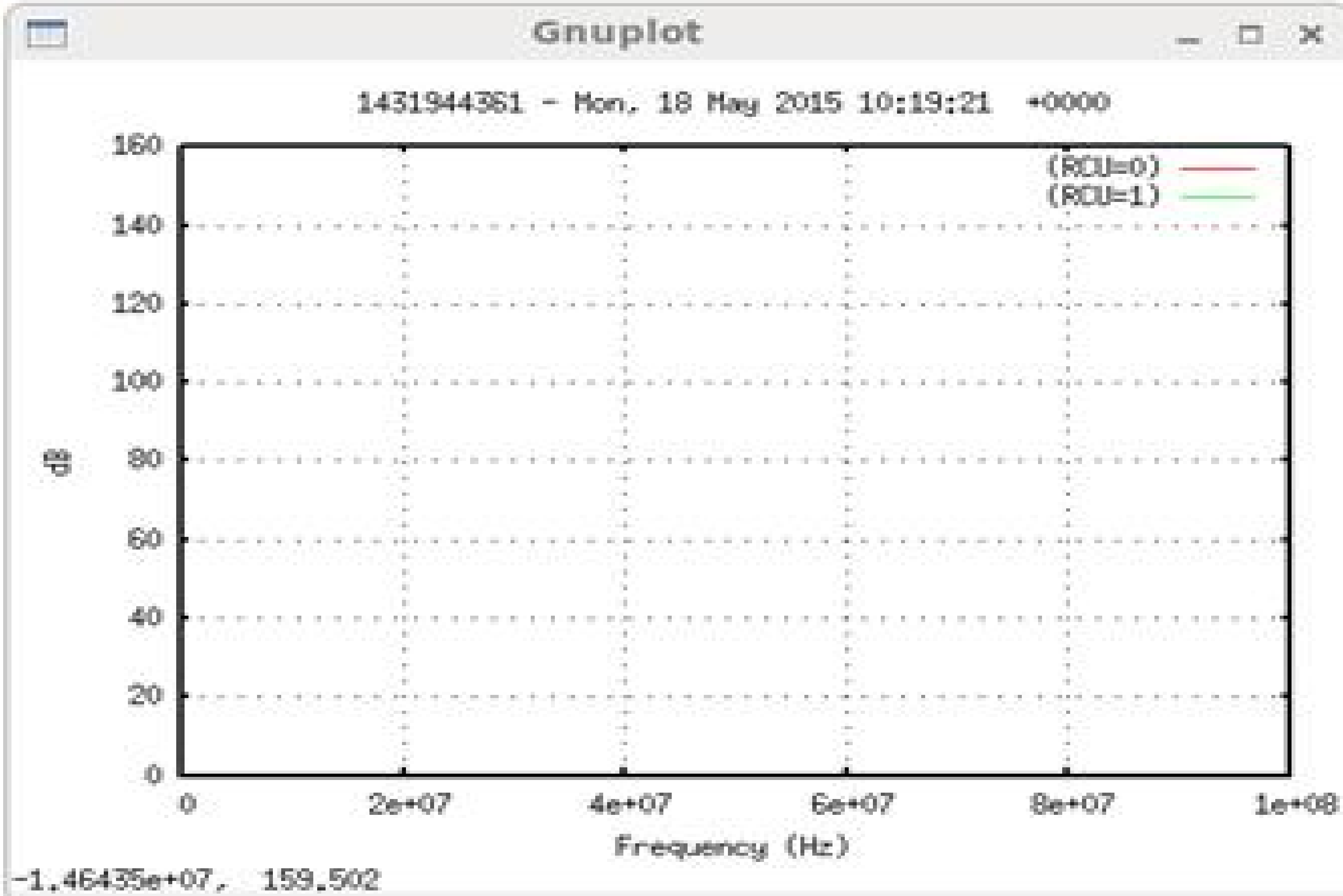
LCU with Red Hat Linux machine

Test Setup for Digital Processing Board

To check the digital section I tested the Digital Processing Board by directly providing the 150 MHz IF to the Receiver Unit along with providing the programming input to the Local Control Unit (LCU).



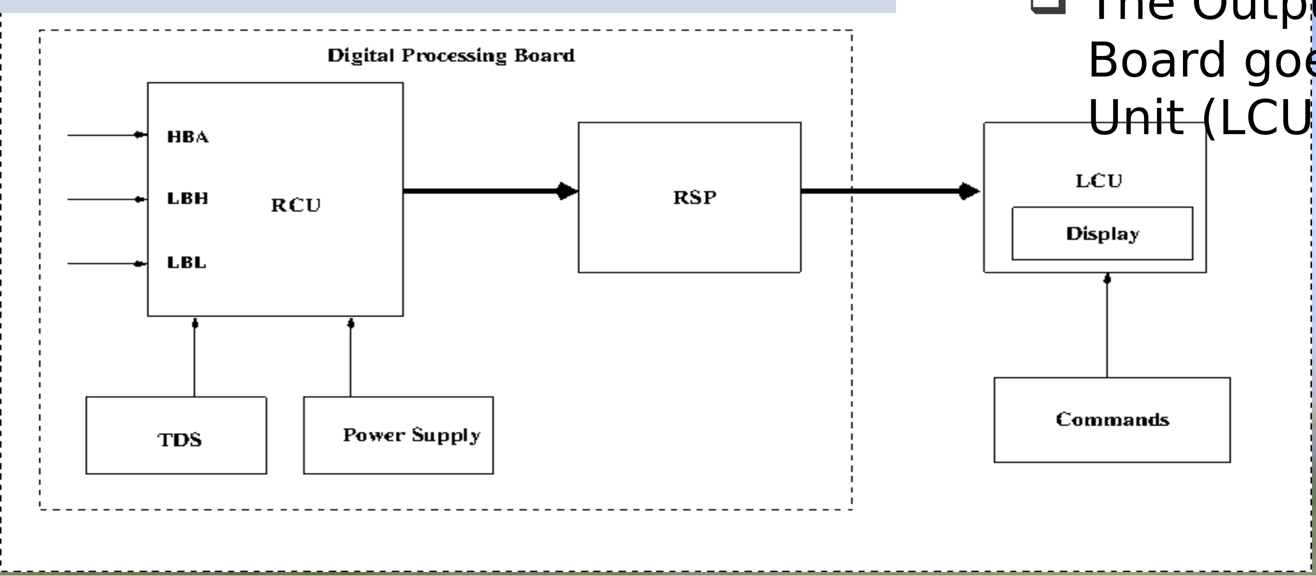
Output Spectrum



Block Diagram of Digital Processing Board

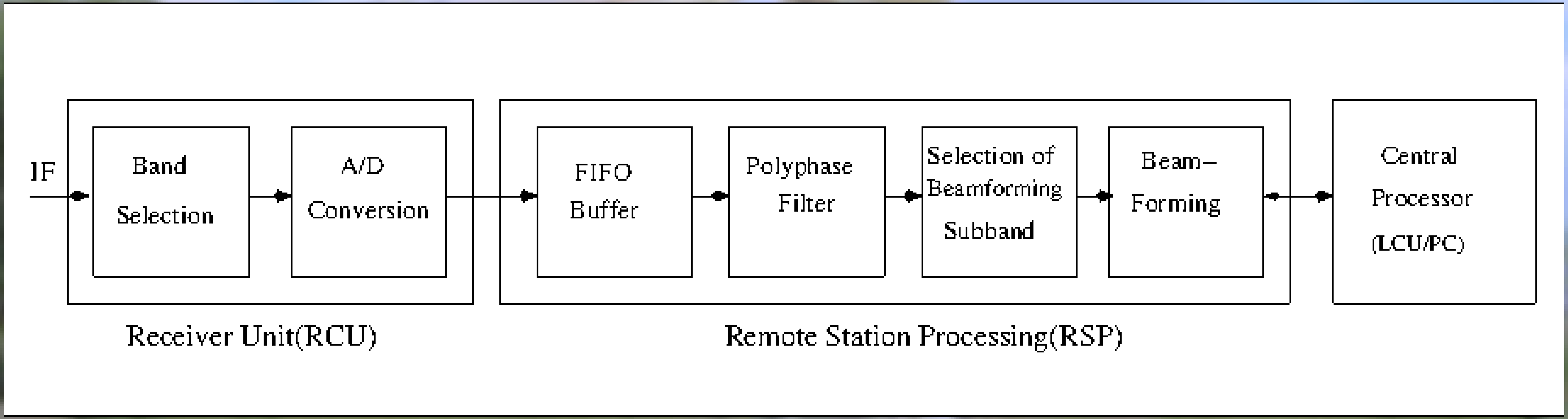
RCU Modes	Input Mode	Sampling Clock
1	LBL input 10-90 MHz	200 MHz
2	LBL input 30-90 MHz	200 MHz
3	LBH input 10-90 MHz	200 MHz
4	LBH input 30-90 MHz	200 MHz
5	HB input 110-190 MHz	200 MHz
6	HB input 170-230 MHz	160 MHz
7	HB input 210-270 MHz	200 MHz

- The Digital Processing Board (DPB) consists of the 64 Receiver Units (RCU's)
- RCU contains inbuilt Frequency band selector block along with ADC block.
- Output from the RCU is provided to the Remote Station Processing (RSP) Unit where the INFINIBAND connections are provided.
- The Output data from the RSP Board goes to the Local Control Unit (LCU).



gnal Processing in Digital Processing Boa

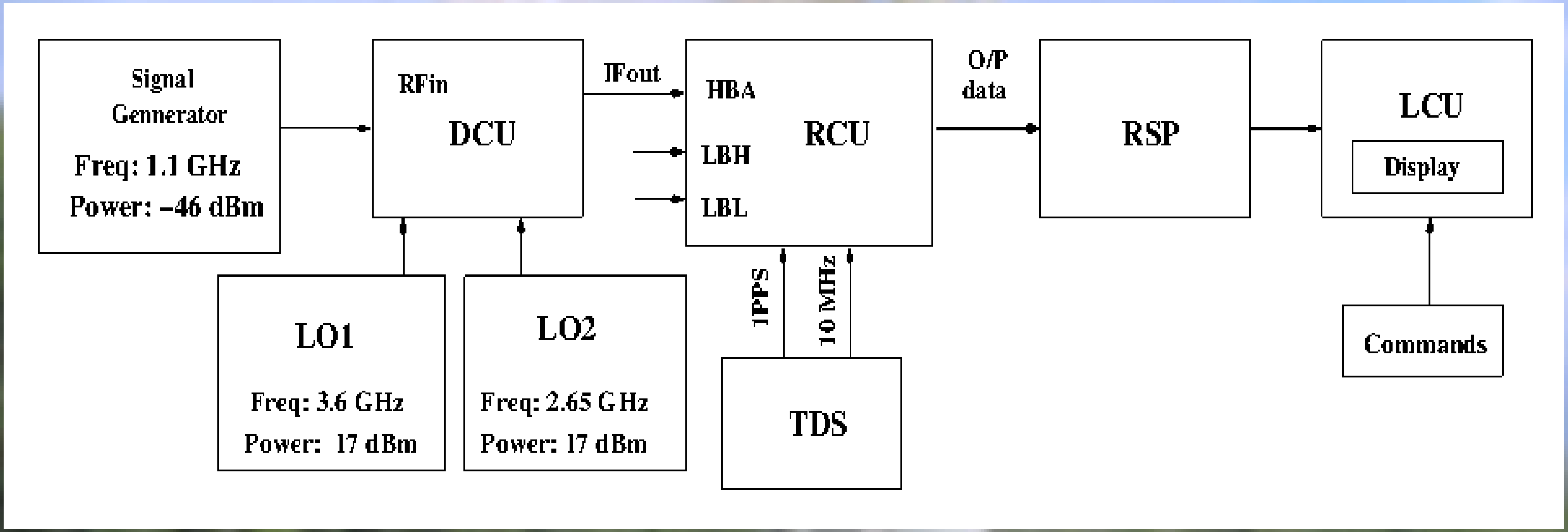
- The IF comes to the Band Selection Block.
- There are three different bands (considering the HBA mode) i.e. 110-190 MHz, 170-230 MHz, 210-270 MHz
- ADC converts the continuous time varying signal to discrete signal
- FIFO Buffer compensates for differences in signal delays in the coaxial cables.
- Polyphase Filter divides the wide band input signal into so-called subbands.
- Then Selection and Beamforming takes place. Beamformed data is sent to Central Processor (LCU).



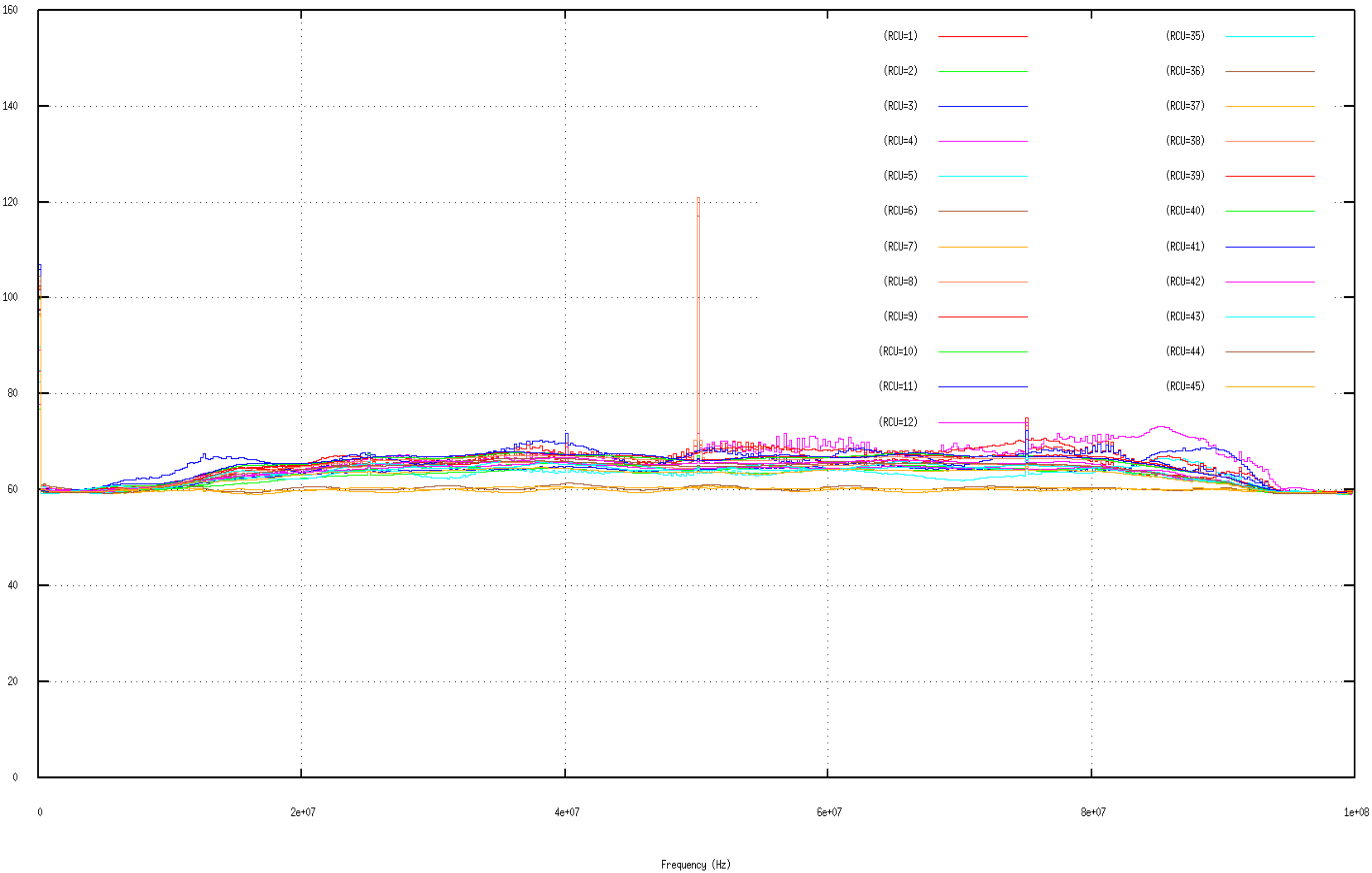
Debugging the Digital Section

Test Setup after debugging

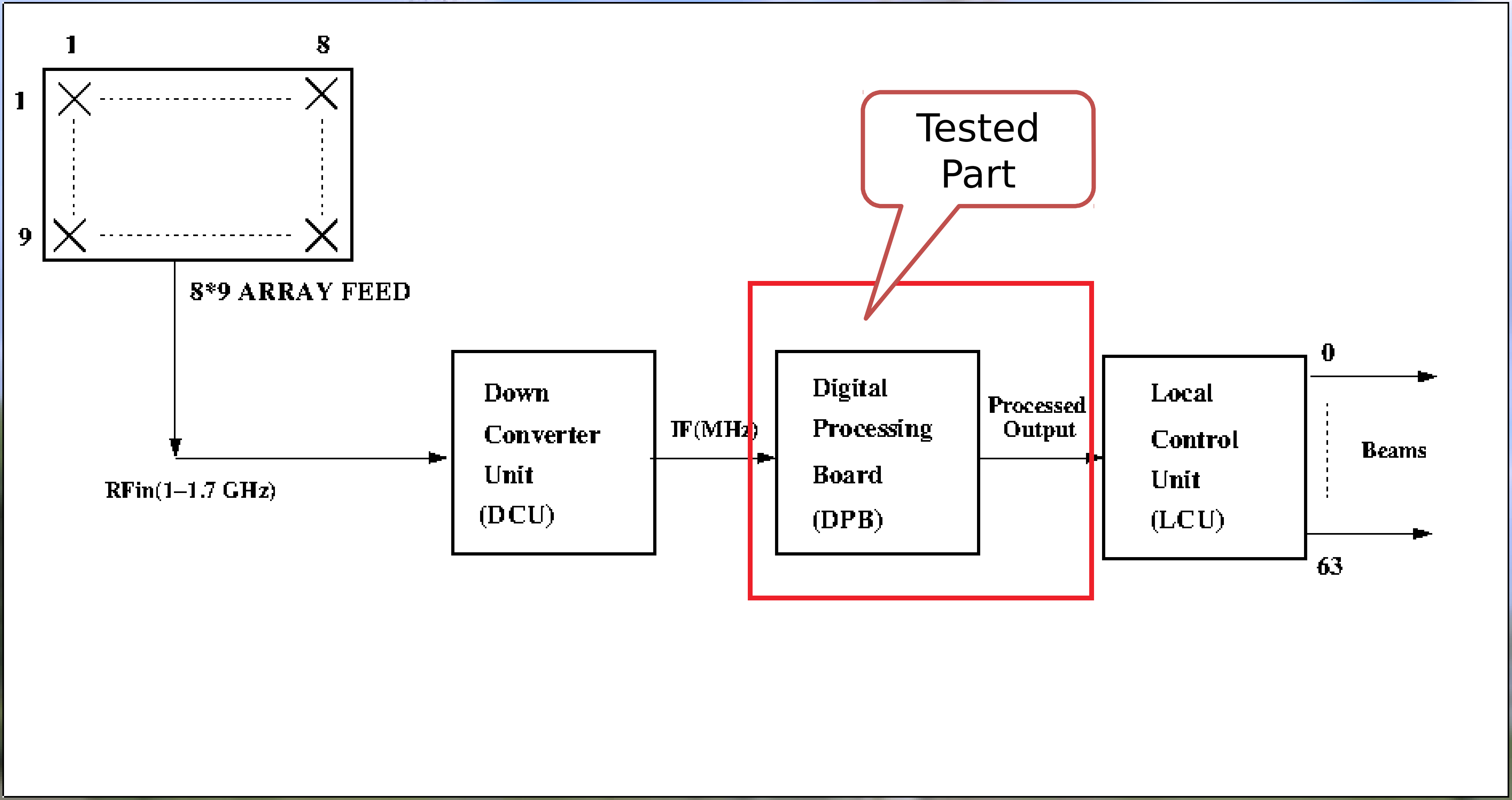
Final Test setup for the FPA system including analog and digital section.
Provided test inputs and the Programming inputs to the system.
Following is the setup made for testing the FPA System



Output Spectrum

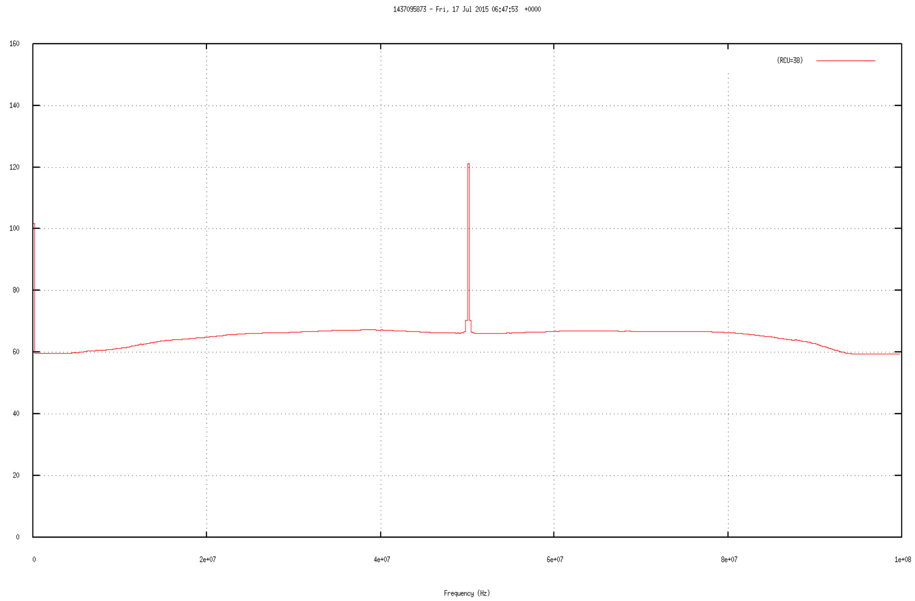


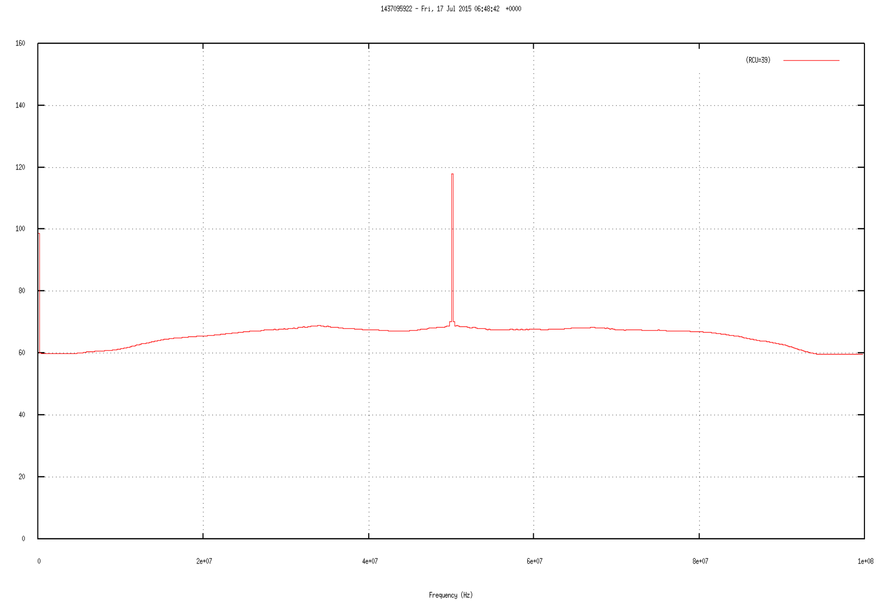
Block Diagram

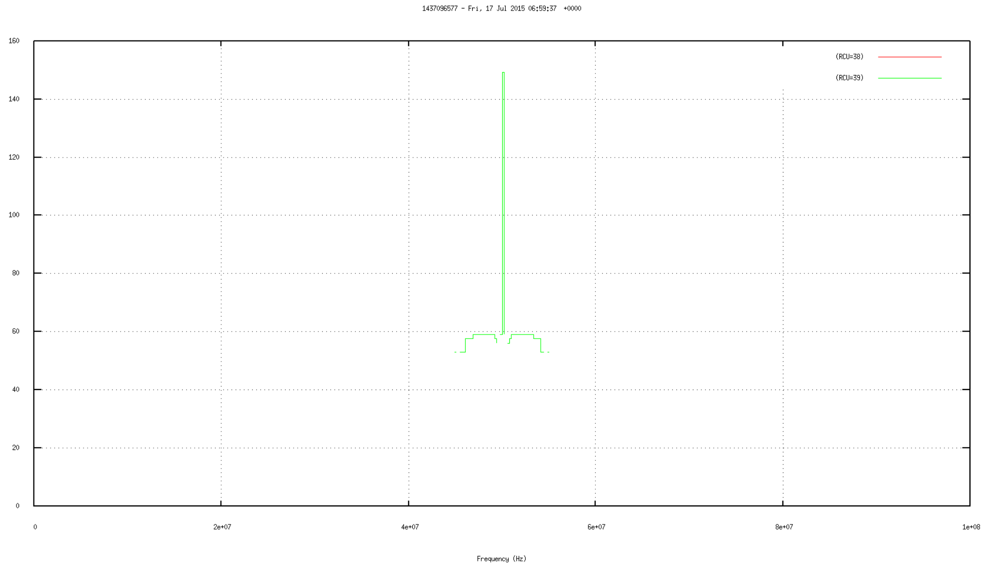


Tried But Failed !

1. Providing the phase to the specific channel.







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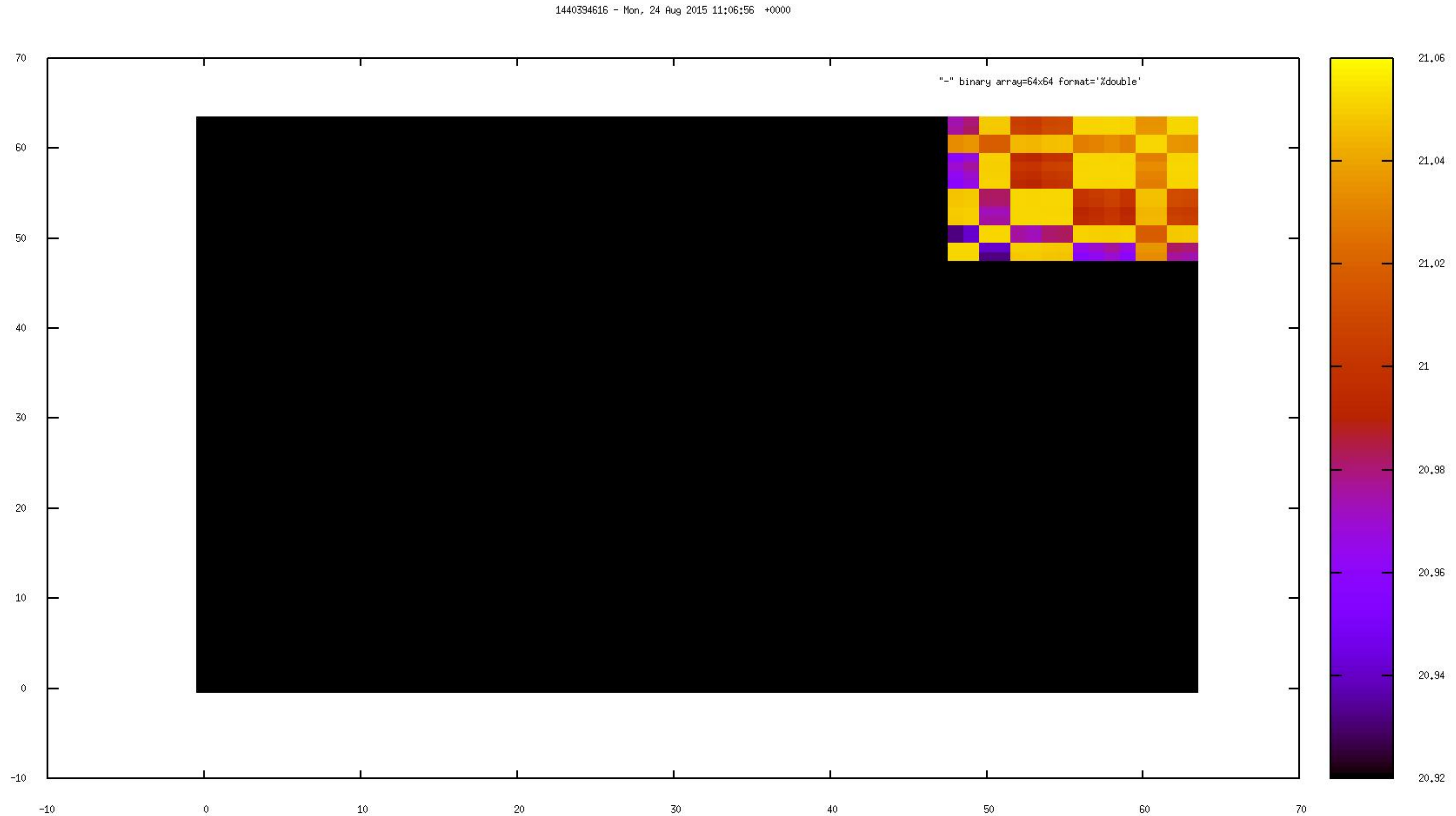
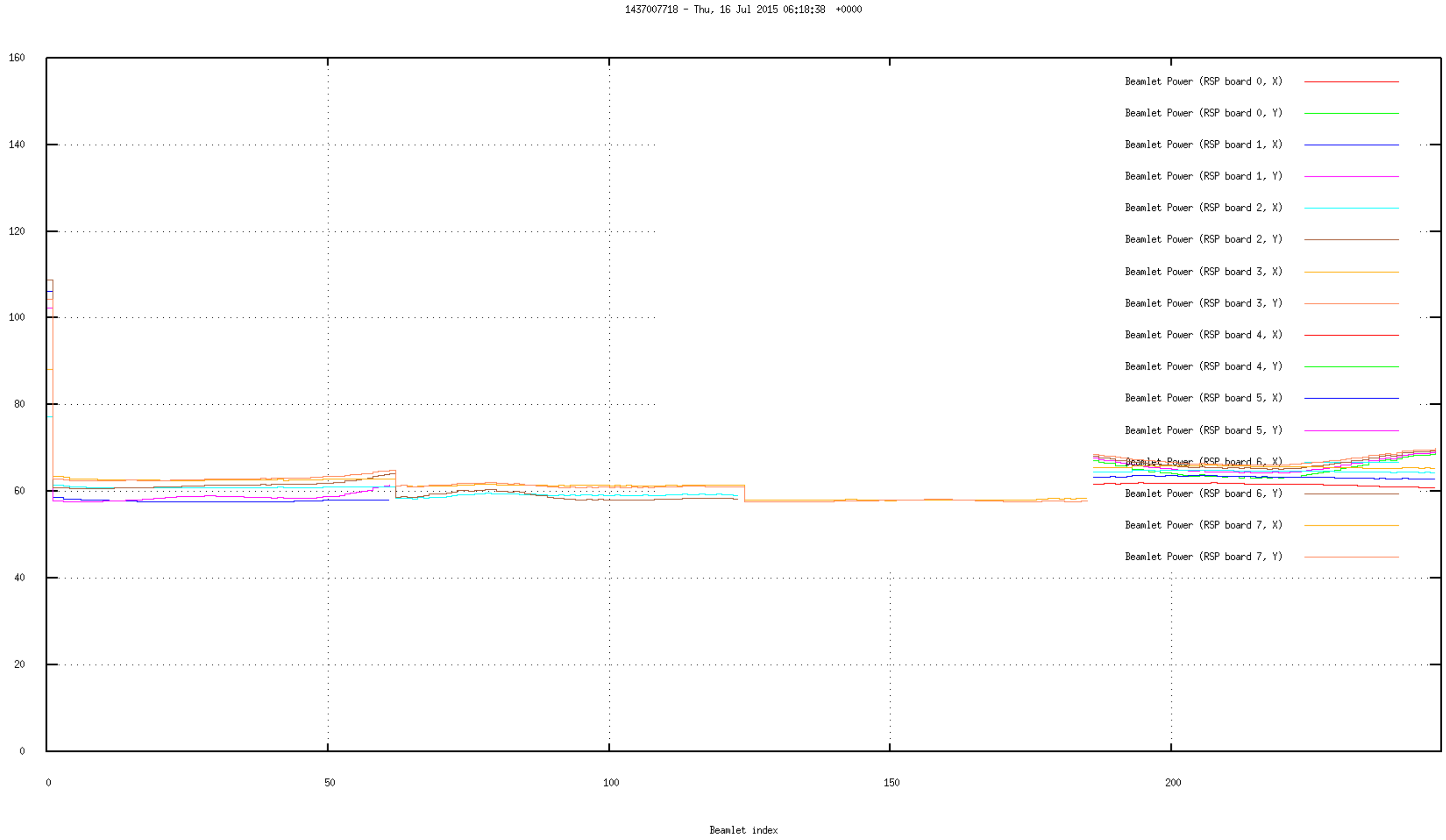
2. To initiate with basic beamforming tried plotting the Phase Spectrum of beamformed output.
Command:
rspctl --xcstatistics --xcangle

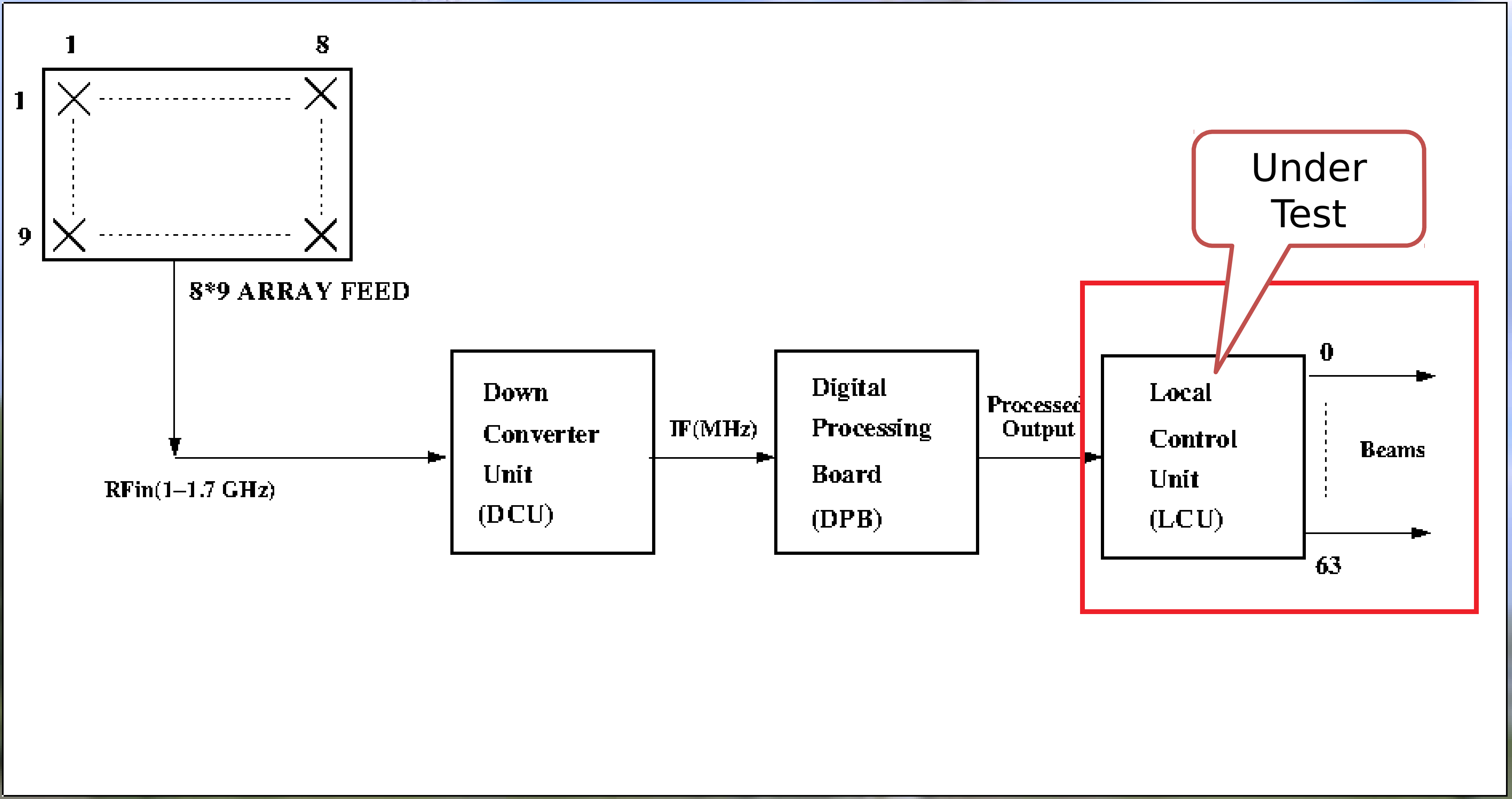


Contd…

3. To see spectrum of beamformed output.
Command:
rspctl –statistics=beamlet



Block Diagram



Simulation in MATLAB

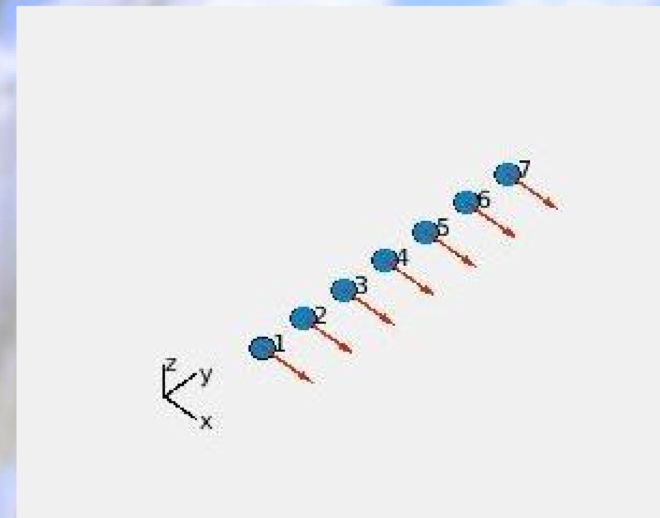
Uniform Linear Array

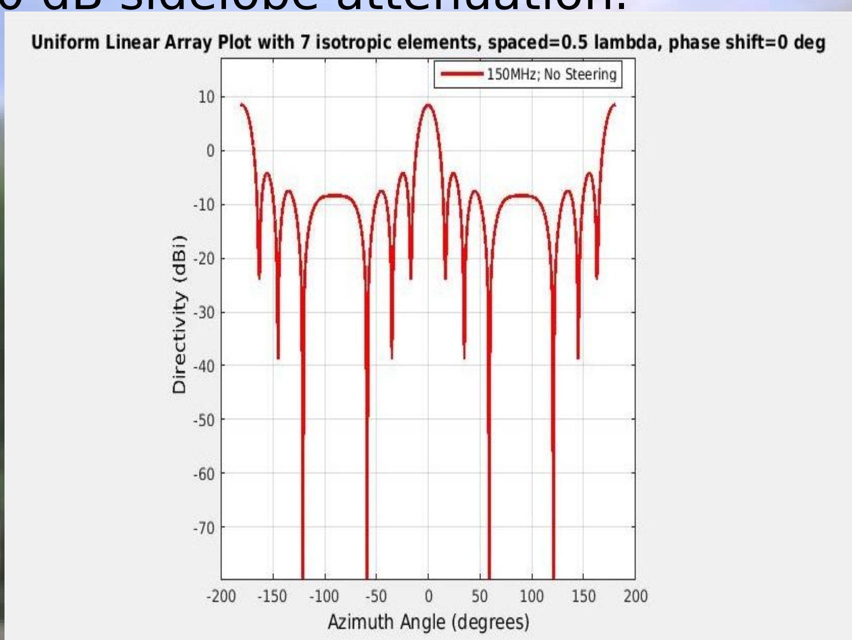
- **Uniform Linear Array (ULA)** :

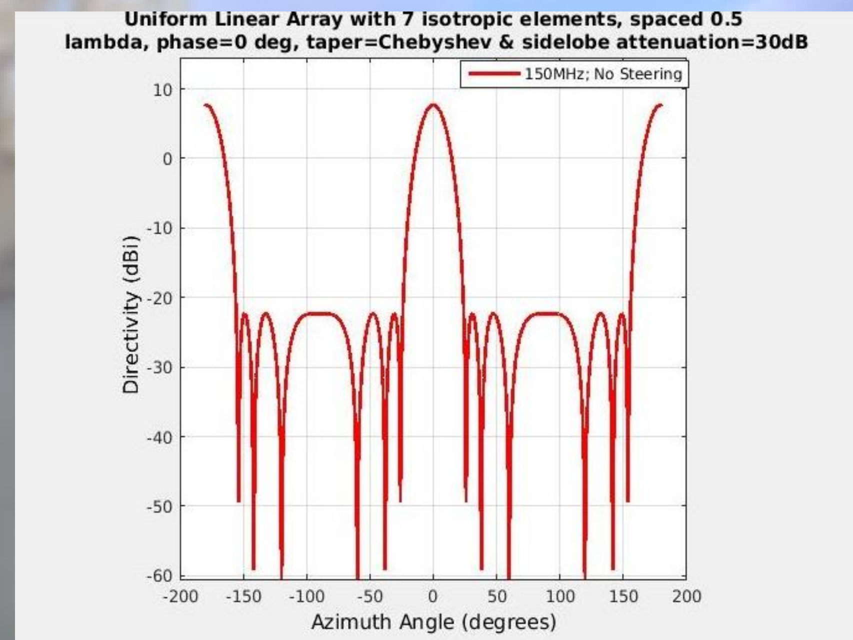
An array of identical elements with identical magnitudes and with progressive phase is called uniform array.

Figure 1 is of Uniform Linear Array for 7 Isotropic elements spaced 0.5 Lambda and phase shift is 0 degree.

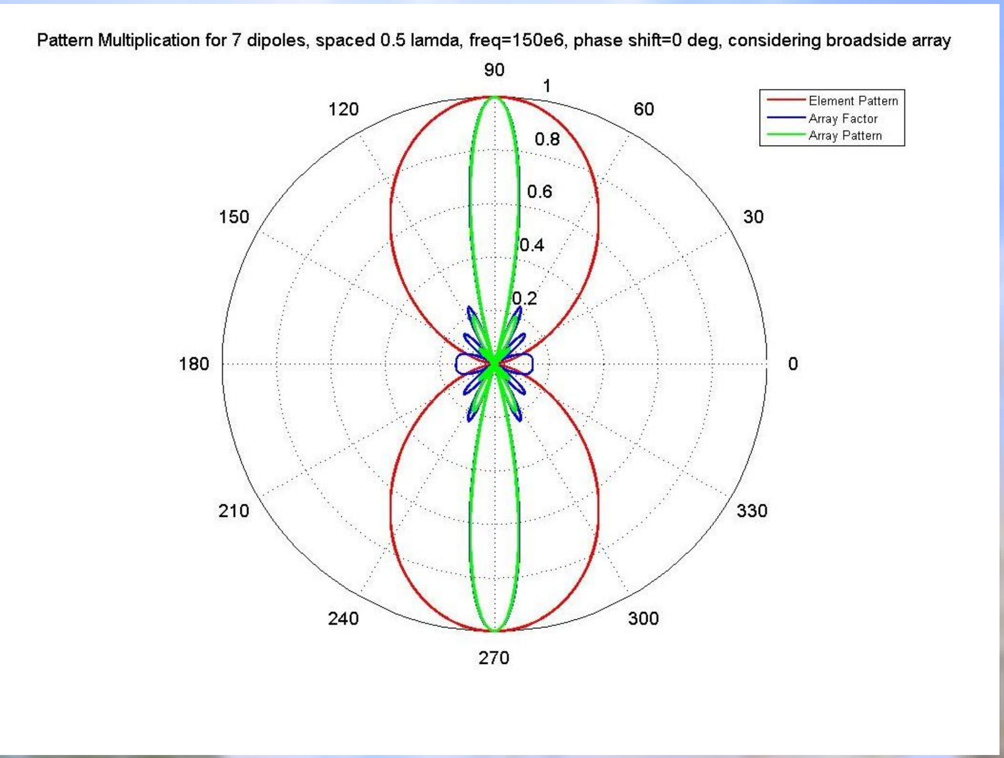
Figure 2 shows the same ULA with Chebyshev Window function providing 30 dB sidelobe attenuation.

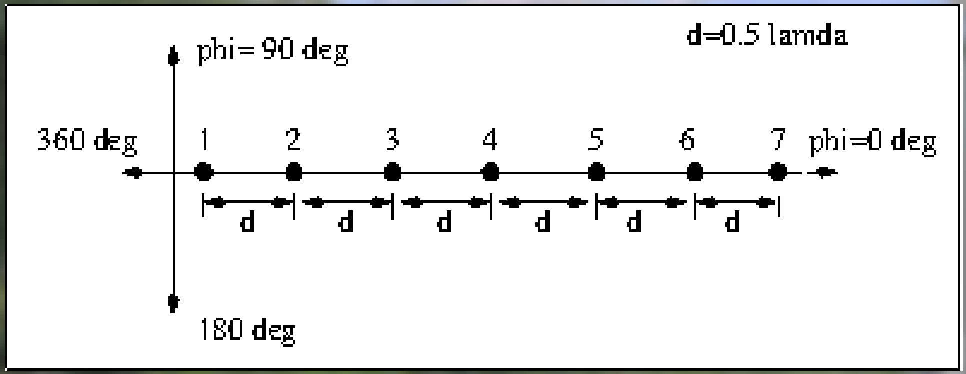






Broadside Array





- **Broadside Array :**

- In this is the case where $\delta = 0$ such that all element currents are in phase.

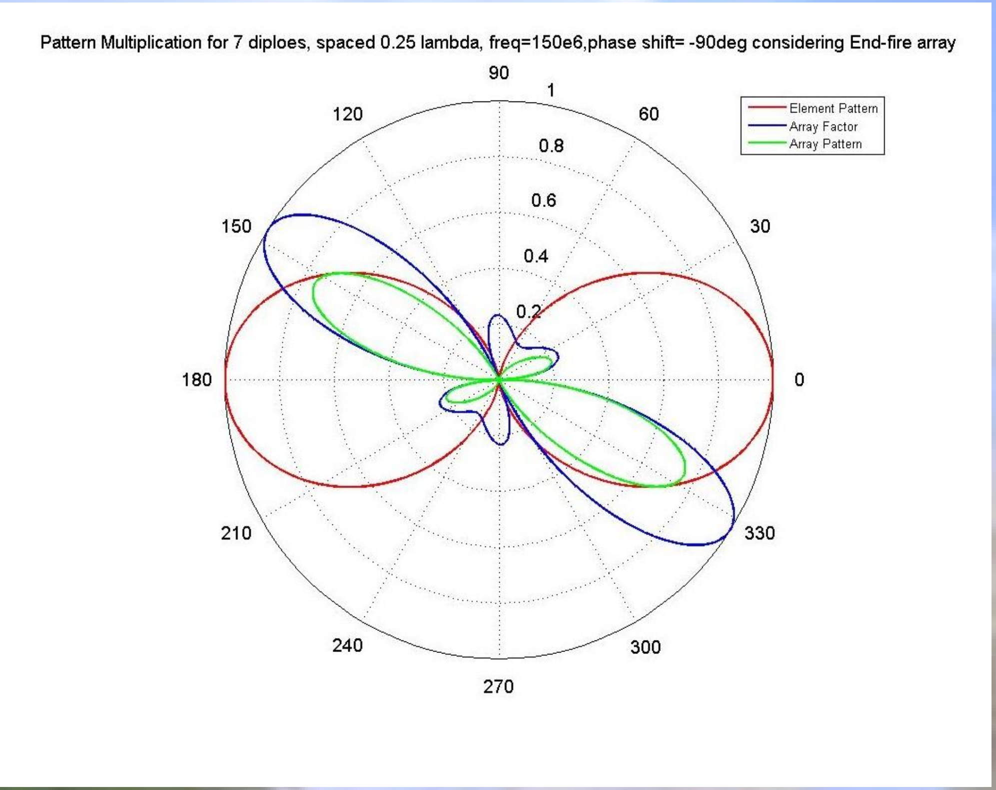
- broadside array because the maximum radiation is broadside to the array geometry.

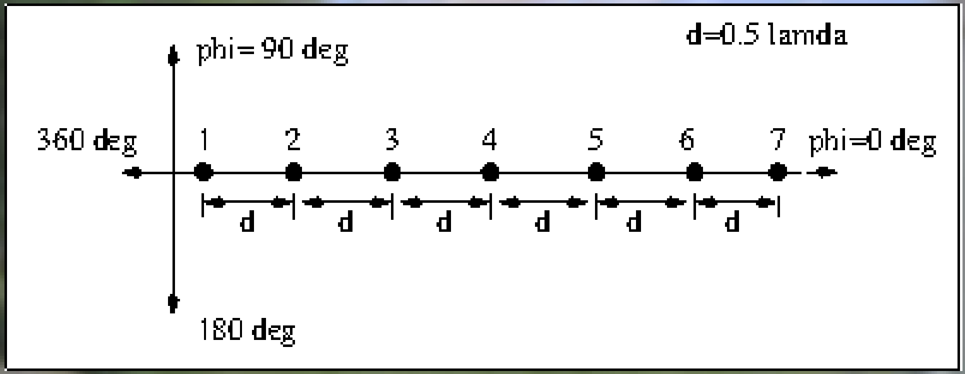
- Two major lobes are seen.($\theta = \pm\pi/2$)

- As the array element spacing increases, decreases the main lobe width.

The general rule for array radiation is that the main lobe width is inversely proportional to the array length.

End-fire Array





- **End-fire Array :**

- *end-fire* indicates that this array's maximum radiation is along the axis containing the array elements. (out the end)

  This case is achieved when $\delta = -kd$.

- main lobe width for the ordinary end-fire case is much greater than the main lobe width for the broadside case.

- Thus, beamwidth efficiency is not that good as the broadside array.

- Mr. Hansen- Woodyard developed directivity of end-fire array where the phase shift is modified such that $\delta = -(kd + \pi/N)$.

Phase Shift Beamformer

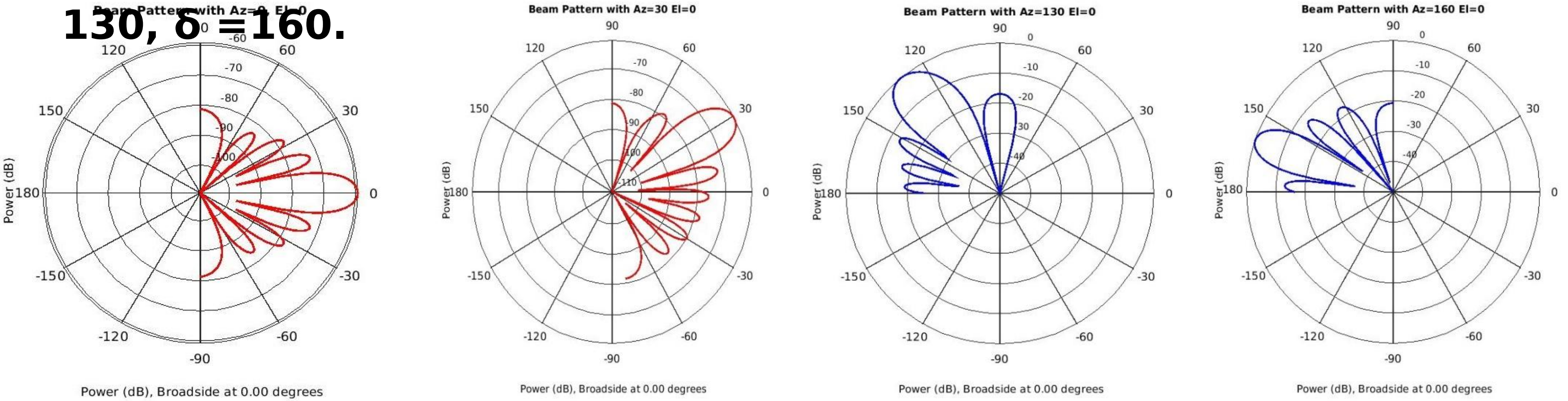
- A phase shift linear array is an array where the phase shift δ is a variable.

- It allowing the main lobe to be directed toward any direction of interest.

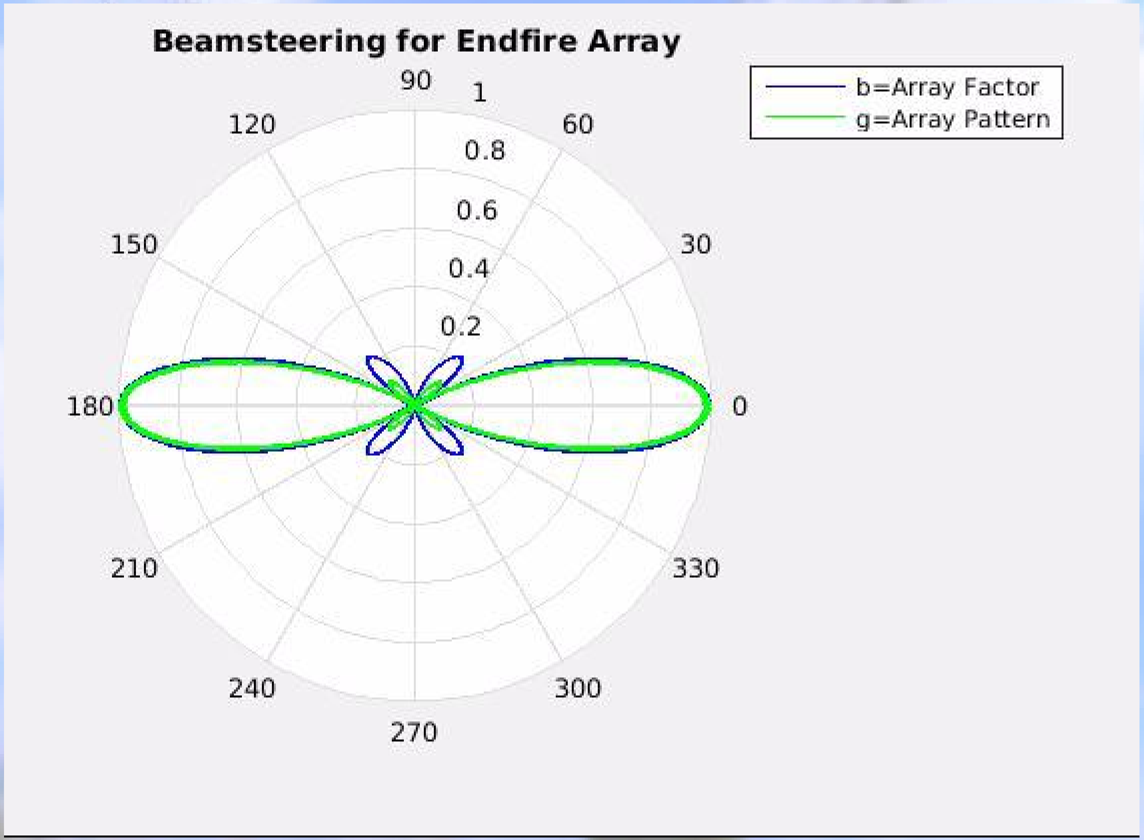
- The broadside and end-fire conditions are special cases of the more generalized phase shift array.

- The beam steering conditions can be satisfied by defining the phase shift
  $\delta = -kd\sin\theta 0$.

Figure shows the Phase shift beamformer with δ=0, δ=30, δ= 130, δ =160.



Beam steering for End-fire Array



Phi varied from 0 – 360 degree
Beam steering for end-fire array with 16 dipole elements spaced 0.25 lambda at 150 MHz

Future Scope

1. Testing FPA System in different beamforming modes.
2. Allocating the FPA Beamformer Racks and the feed to the proposed location.
3. Connecting FPA to the System and carrying out beamforming process.
4. Testing FPA on 15 Meter dish.

Deliverables

1. Documentation for LOFAR FPA Beamformer.
2. Debugging Report.
3. Proposal for shifting the FPA Beamformer Racks and feed to appropriate location.
4. Evaluation Report for the Matlab toolboxes- Phased Array toolbox, Antenna toolbox, RF toolbox.


Thank you