# UNDERSTANDING AND TESTING OF LOFAR FOCAL PLANE ARRAY (FPA) BEAMFORMER

STUDENT PROJECT

By

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# Abstract

The purpose of the project was to understand and test the LOFAR Focal Plane Array (FPA) Beamformer, a system that is procured from ASTRON. In Focal Plane Array each element receives signals from the sky and looks in a slightly different direction while seeing a slightly different part of the sky. This means that by combining the signals of all elements a larger part of the sky can be observed with large field of view.

In LOFAR FPA System, the signal from the FPA feed is down converted to IF and then converted to digitized processed output using Digital Processing which then is carried to Local controller for performing beamforming process by adjusting appropriate phase and amplitude.

The system was analyzed by providing test inputs and the programming inputs. A systematic debugging of all the section of the beamforming unit was carried out. The architecture of each of the section was understood along with its software interface.

In parallel simulations were carried out on the MATLAB software which are relevant for the LOFAR FPA and eGMRT activity. The use of Phased Array toolbox, Antenna Toolbox and RF toolbox in Matlab 2015a software was made in the simulations.

# Acknowledgements

This project would not have attained this level without the kind support and help of many individuals and organizations. I would like to extend my sincere thanks to all of them.

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I would like to express my gratitude towards my parents & members of Analog and Digital backend group, Computer group (Mr.Mangesh Umbarje and Mr.Sumit Mirajkar) G.M.R.T for their kind co-operation and encouragement which helped me in completion of this project.

I would like to express my special gratitude and thanks to the non-technical staff as well for providing the necessary help and support.  My thanks and appreciation also goes to my colleagues and employees who have willingly helped me as and when needed.

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# 1 Understanding LOFAR FPA Beamformer

## 1.1 Introduction

LOFAR, the Low Frequency Array, is a multi-purpose sensor array. Its main application is astronomy at low radio frequencies (10-240 MHz). At station level the signals from individual elements are combined digitally into a phased array. Electronic beam-forming techniques make the system agile and allow for rapid repointing of the telescope as well as simultaneous observations of multiple, independent areas of the sky.

One such system of LOFAR is the FPA Beamformer consisting of 8*9*2 elements. (I.e. 8*9 is the array with dual polarization). There are two distinct antenna 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.

## 1.2 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 Beamforming mode) |

*Table 1: Technical Specifications for FPA Beamformer*

## 1.3  Basic block diagram of FPA System
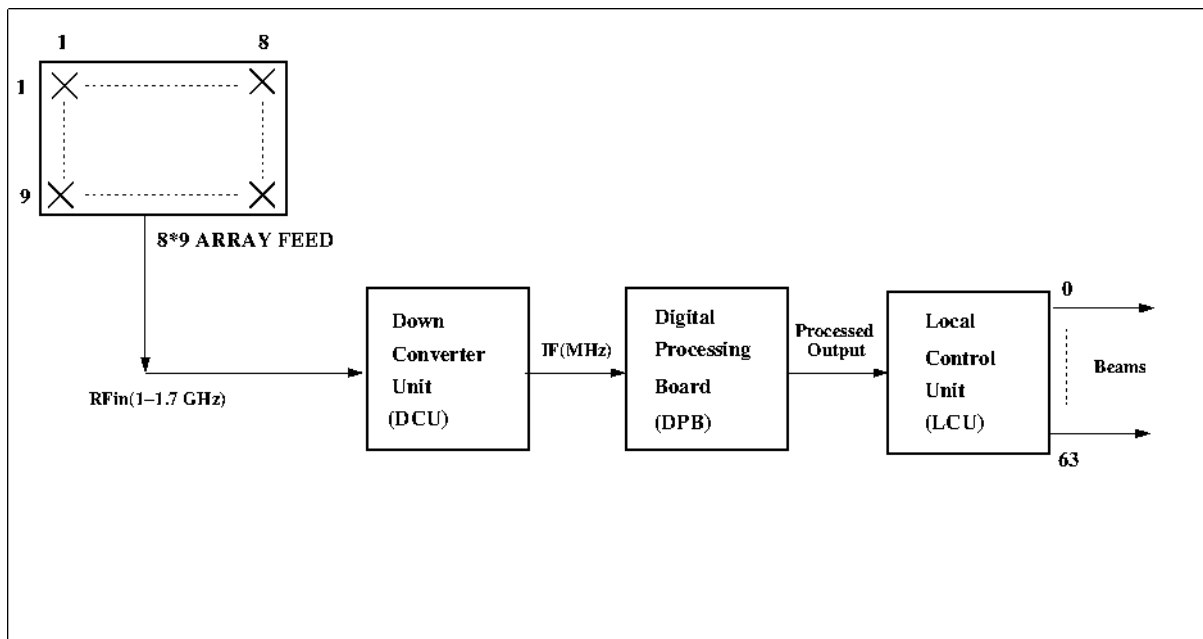


*Figure 1: Signal Processing in FPA System*

## 1.4  Description

Focal Plane Array is a feed of 8*9 Vivaldi elements. The signal frequency coming to the feed is in L-Band, ranging from 1.0 GHz to 1.7 GHz. This frequency is provided to the Downconverter Unit (DCU), where the signal gets converted to baseband level. The intermediate frequency is 150 MHz .This Intermediate frequency (IF) is followed by Digital Processing Board (DPB), where digitization and processing on the signal results in processed output. The processed output is handled by the Local Control Unit (LCU), which provides 64 beams at output. Those 64 beams can be used for observing objects located in sky with increased field of view.
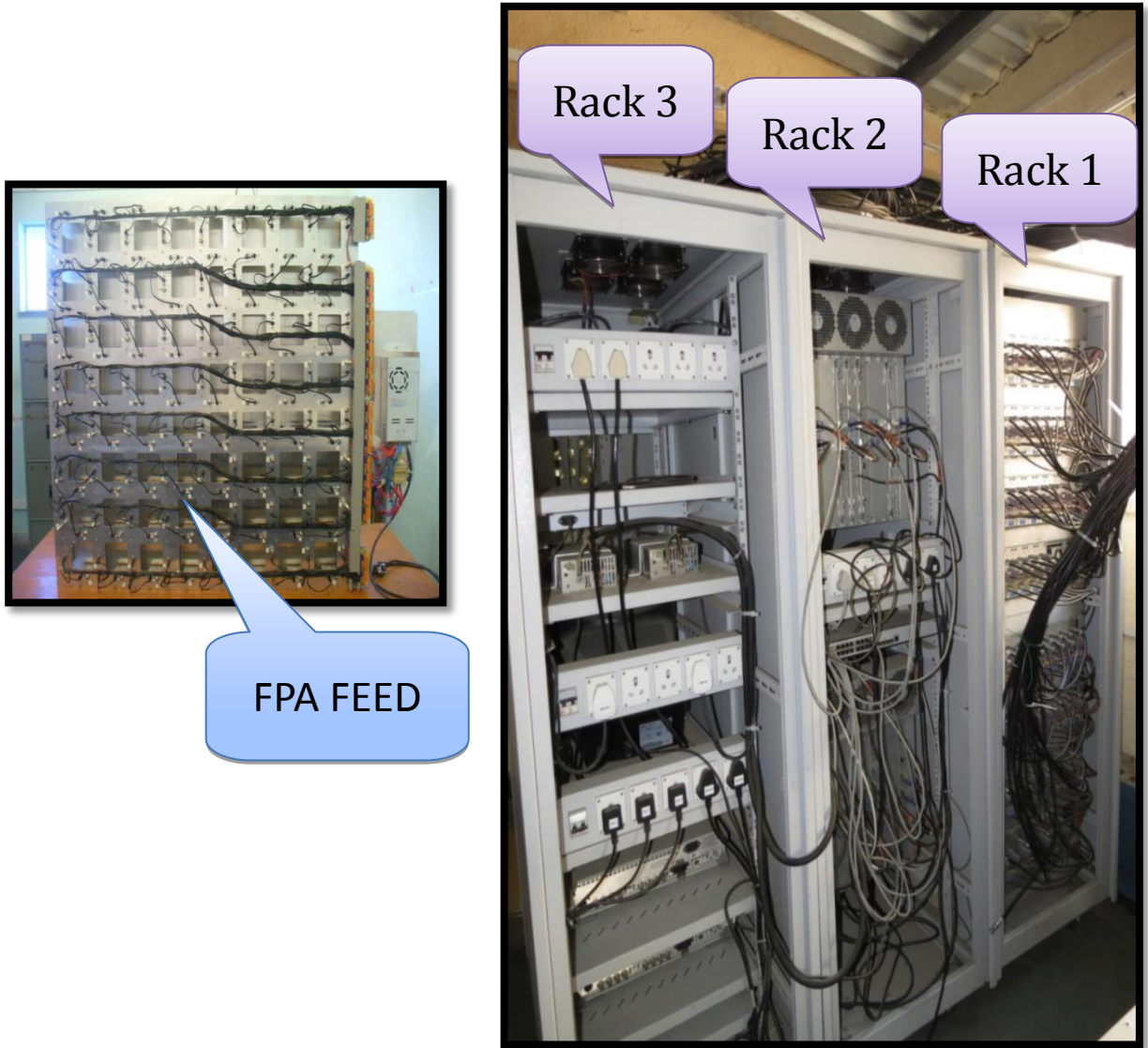
*Image 1: Photograph of Focal Plane Array Beamformer System Racks and feed*

## 1.5    Tracing the FPA Beamformer System

Tracing of the Focal Plane Array Beamformer System started from the Down Converter Unit (DCU). DCU is equipped with 4 ports along with 12 Volt power supply having 9 pin D-type connector, one as an input for RF frequency, other two ports are for the LOs and one for the output intermediate frequency (IF). The cables use for RFin port is RG6 cable with F type female connector (75 ohm). For the LO, the cables used are LMR 400 with N-type connector at the input side of the signal generator. For the IFout port, the cable type use is RG223 with SMA connector at the input side. The IF coming to the Digital Processing Board (DPB) are distributed in two subbracks. i.e. Subrack 1 consisting of IF1-IF32 inputs and Subrack 2 consisting of IF33-IF60 inputs. There are two power supplies each of 48 Volts provided to the two subbracks of DPB. Time Distribution system (TDS) provided 10 MHz and 1PPS clock signals to the boards and 1 PPS signal to the PC. RS232 cable is use between DPB and PC for exchange of data. There is one Ethernet switch through which data communication is carried out from DPB and PC.
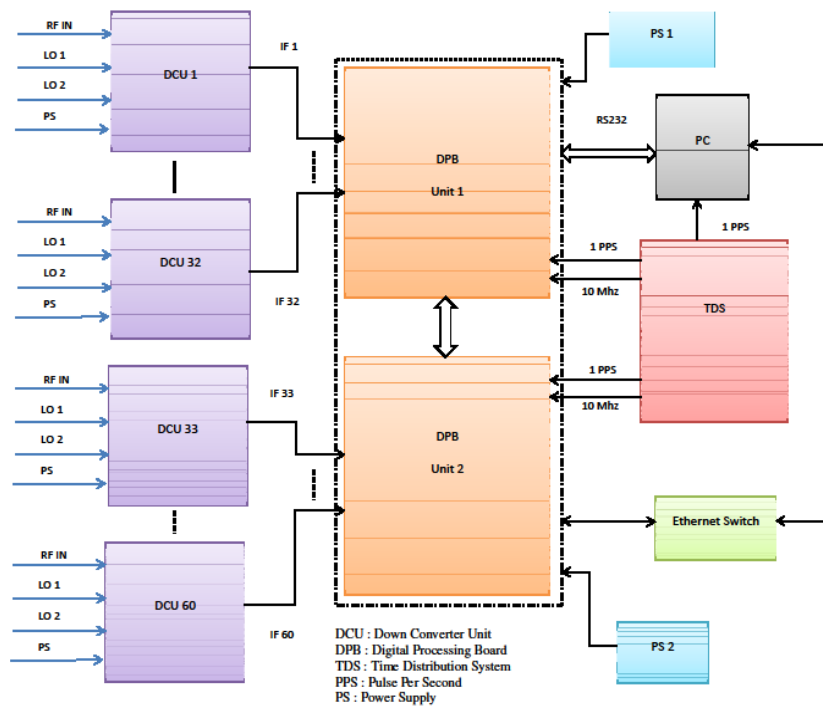


Fig : Generalize Block Diagram of Focal Plane Array

*Figure 2: Tracing diagram of the FPA System*

## 1.6 Testing the System
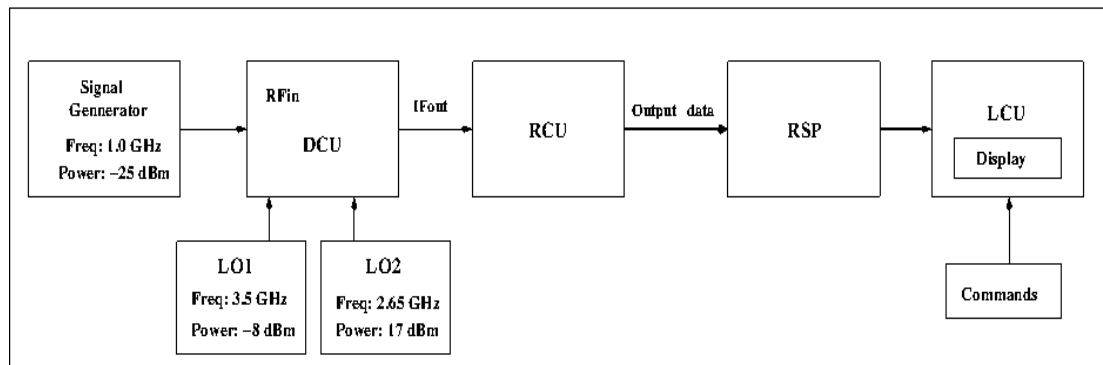


*Figure 3: Test setup for testing the system.*

Testing the system was done by providing 1.0 GHz, -25 dBm CW signal to the RFin port of the DCU Unit. LO1 frequency was set to 3.5 GHz with power level -8 dBm. LO2 frequency was set to 2.65 GHz with power level 17 dBm. The following commands were given to the system:

- **swlevel 2**
- **rspctl --clock=200**
- **rspctl --reg**
- **rspctl --rcumode=3**
- **rspctl --prsg=0**
- **rspctl --rcuenable=1**
- **rspctl --statistics --select=0:63**

In first several attempts, there was no data in the output spectrum. The GNU plot after running the last command was blank as shown in Image 2.
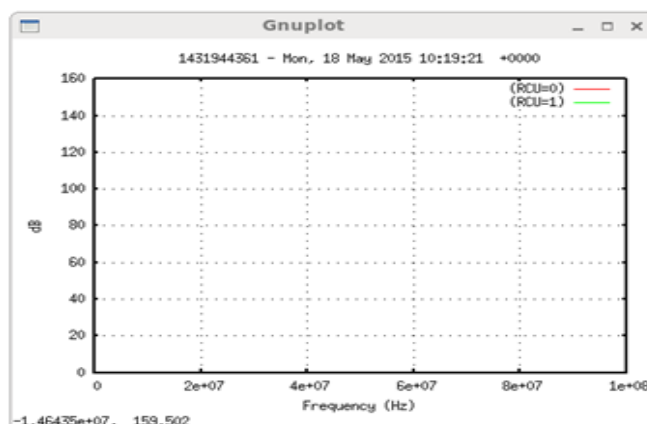


*Image 2: Output Spectrum of FPA System (Blank)*

This called for a more detailed debugging of the system which is covered in the later sections of this report.

# 2 Down Conversion Unit (DCU)

## 2.1 Down converter Unit
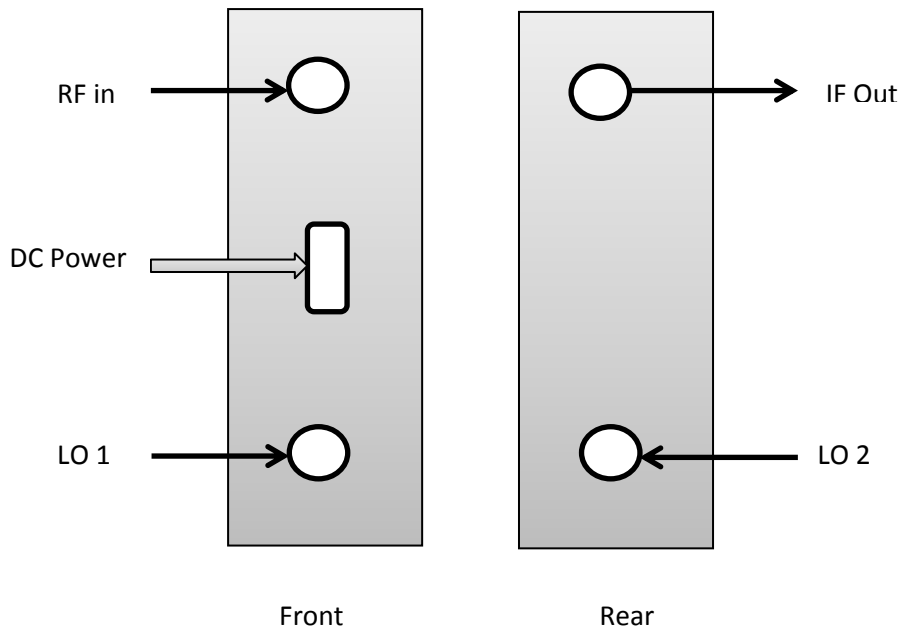


*Figure 4: Down Converter Unit front and Rear view*

## 2.2 Block Diagram of DCU
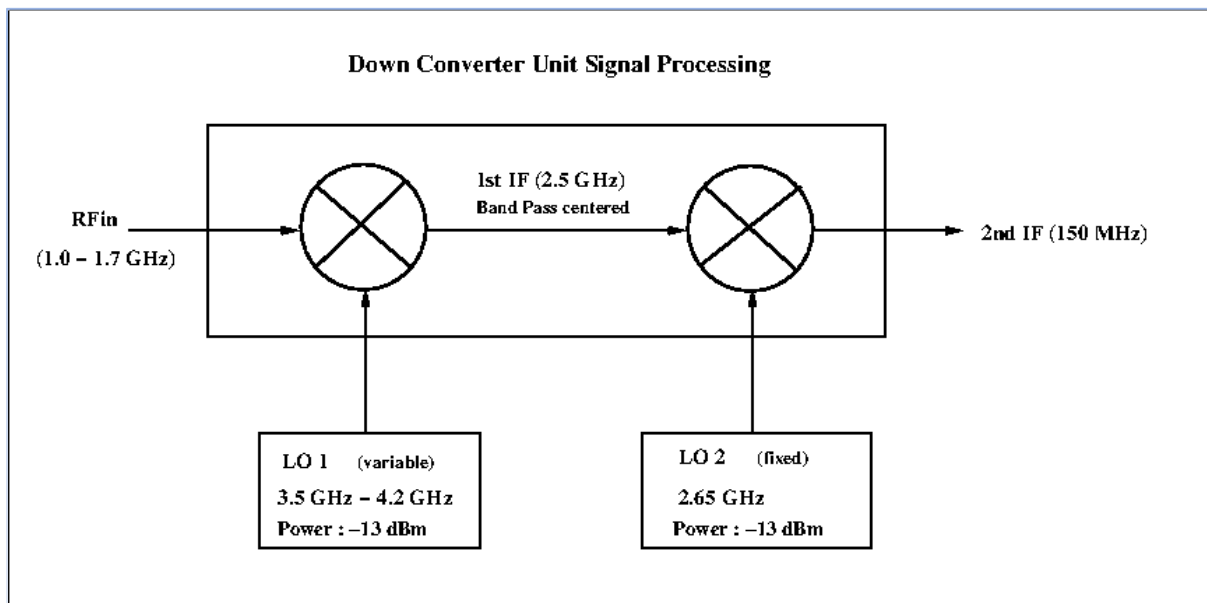


*Figure 5: Baseband Conversion of signal in DCU*

The L-band frequency signals coming in range between 1.0 GHz – 1.7 GHz are connected to the Downconverter Unit (DCU) with RG6 coaxial cable which is connectorized 75 ohm cable with F type connector. The cables are delay matched to within 100ps. They are low loss cables, (17dB for 60m). Down converter unit (DCU) has about 20 dB gain with 7 dB gain equalization across the band. There are two sets of LO's , LO1 moves the RF to an IF centered at 2.5 GHz after which then passes through the BPF centered at 2.5 GHz and 80MHz wide. The LO1 power has to be about -13 to -15 dBm. The DCU needs to be supplied 12V regulated power supply. LO2 is set to 2.65 GHz so that next IF is centered at 150 MHz, through SMA connector.

In order to debug the system the RFin frequency and the LO1 frequency should be matched in a way the first IF came out as 2.65 GHz. To get proper IF at the output, the following changes were made in the test setup (as shown in the figure 6)

## 2.3   Test setup for DCU
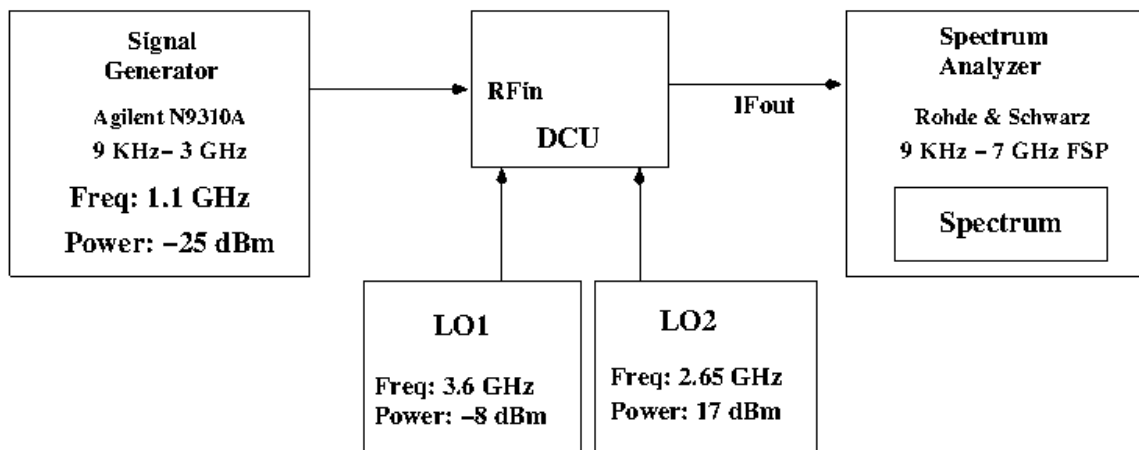


*Figure 6: Test setup for DCU*

The input settings done were:
- **RFin Freq =  1.1GHz**
- **Power= -25.0dBm**
- **Lo1 frequency  = 3.6 GHz**
- **Power = -8.00 dBm**
- **Lo2 Frequency = 2.65 GHz**
- **Power = 17.0dBm**

## 2.4 Observation

The power level for the IFout signal was very low. After setting the power levels for the LO, the power was distributed using two 1:8 way power splitters. Testing the power level at the LO port, the signal power was -14.9 and -10.21 dBm.

## 2.5 Local Oscillator (LO) Testing

Following is the test setup for the total path loss and LO power levels through the distribution network.
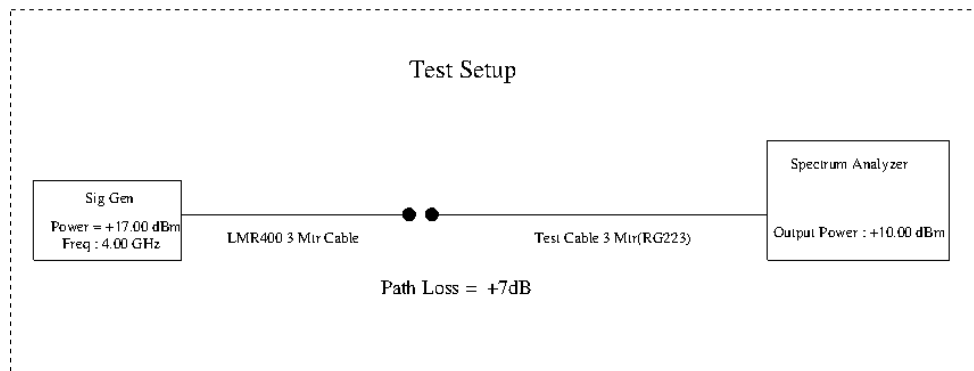


*Figure 7: Path loss for LMR400 cable with test cable.*

Test setup for checking power levels at different points of LO distribution network
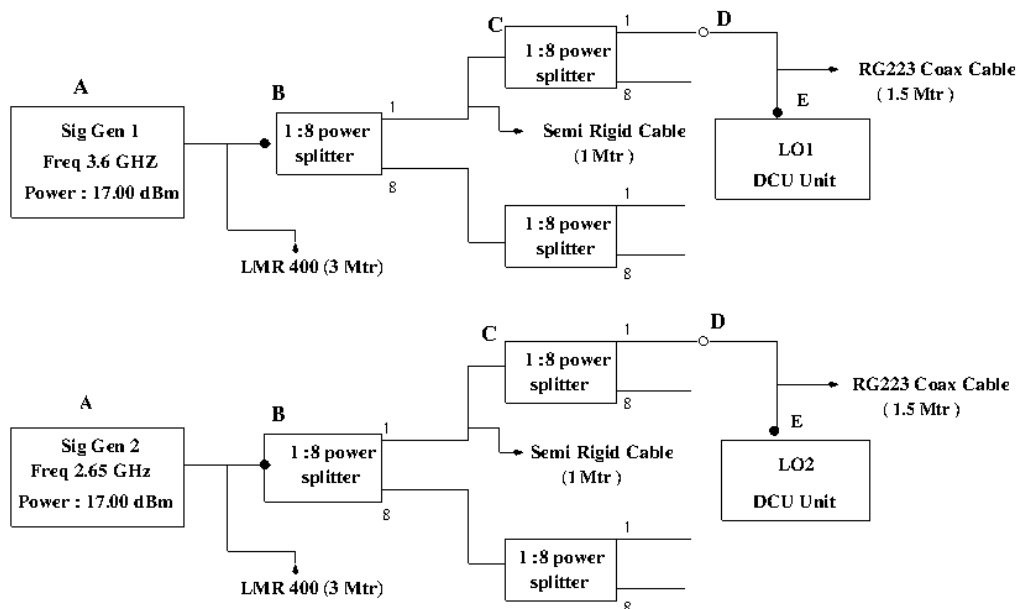


*Figure 8: Power levels throughout the distribution network of LO*

Table 2 shows the Power levels at different points. The Input Power from LO Signal Generators (i.e.LO1 Power: 17.00 dBm & Lo2 Power: 17.00 dBm) is kept constant for all the readings.

| Frequency | A | B | C | D | E |
|---|---|---|---|---|---|
| 3.6 GHz | 17.00 dBm | 15.27 dBm | 3.30 dBm | -8.0 dBm | -14.9 dBm |
| 2.65 GHz | 17.00 dBm | 14.92 dBm | 4.92 dBm | -4.92 dBm | -10.21 dBm |

*Table 2: power levels at different points of distribution for LO's*

## 2.6   DCU Test Results

After providing correct frequency to the LO and overcoming the LO power bug, the test results concluded with proper functioning of the DCU. The IFout frequency with test setting:

- **RFin Freq: 1.1 GHz.  -25dBm**
- **LO1 Freq: 3.6 GHz, 17 dBm**
- **LO2 Freq: 2.65 GHz, 17 dBm**

**Result:  Measured Freq: 150 MHz,  -14.99dBm**
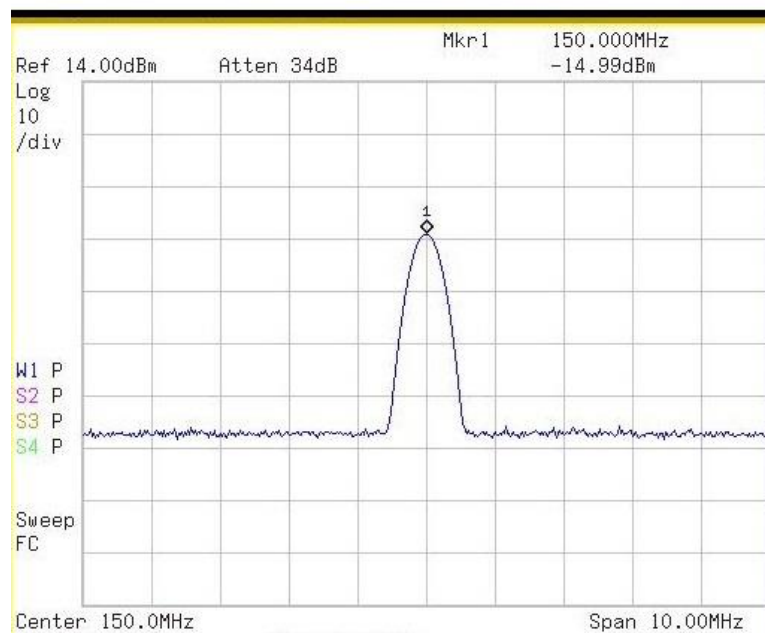


*Image 3 : Plot of IF (150 MHz)*

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

# 3  Digital Processing Board

## 3.1  Front view of Digital Processing Board

A full LOFAR station contains two sub racks for Digital Processing. One half of the rack is populated with 32 receiver units (RCU's).The other half of the rack is populated with 4 RSP boards, 2 TBB boards, 1 TDS board, 1 JTAG board and 1 SPU board.
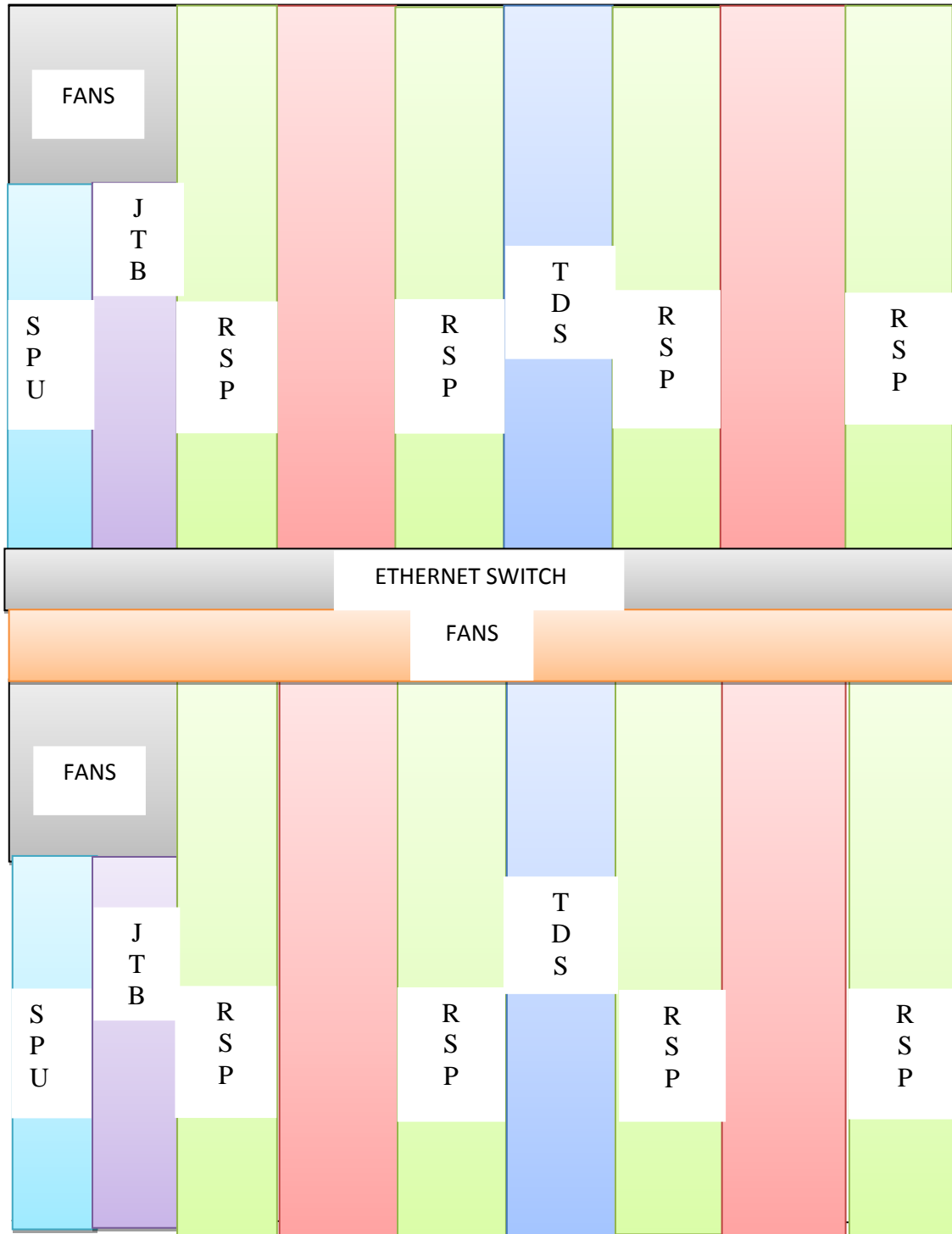


SPU: Station Power Unit or Sub Rack Power Unit    TDS: Time Distribution System
JTB: JTAG Test Board                              RSP: Remote Station Processing

*Figure 9: Front view of Digital Processing Board (DPB)*

## 3.2 Rear view of Digital Processing Board
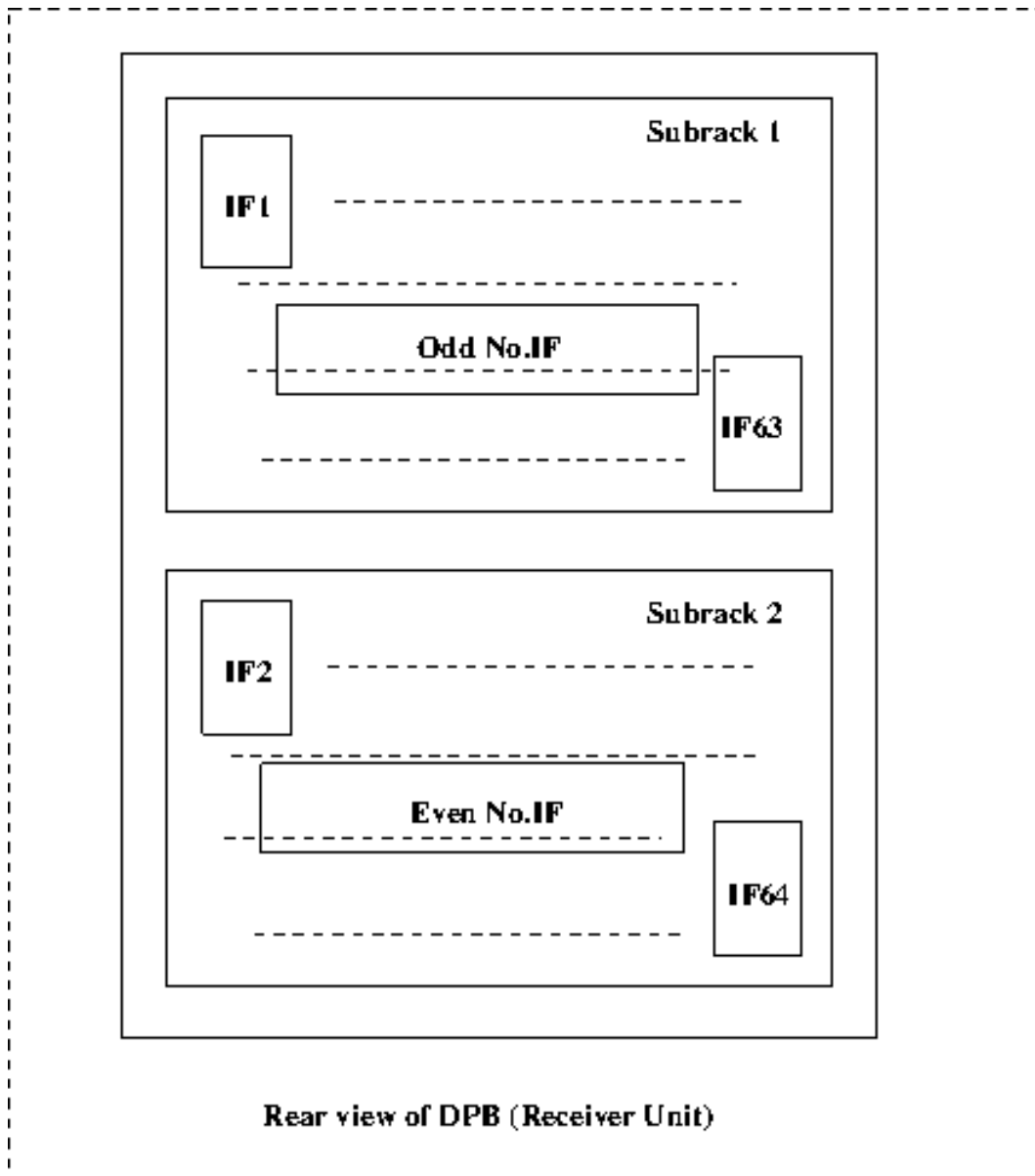


*Figure 10: Distribution of receiver units in DPB Subracks*

## 3.3   Testing Digital Processing Board
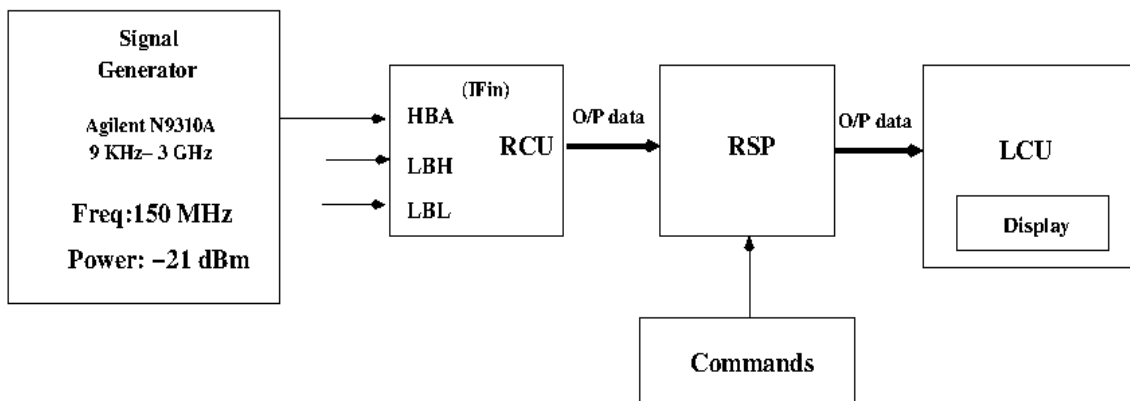


*Figure 11: Test setup for testing Digital Processing Board*

Testing the Digital Processing Board initiated by providing 150 MHz, -21dBm CW signal from signal generator as shown in the figure 11 to the RCU in port of the DPB and run the following commands,

- **swlevel 2**
- **rspctl --clock=200**
- **rspctl --reg**
- **rspctl --rcumode=3**
- **rspctl --prsg=0**
- **rspctl --rcuenable=1**
- **rspctl --statistics --select=0:63**

The resultant spectrum was blank which required a more closer look at the system for debugging the cause.
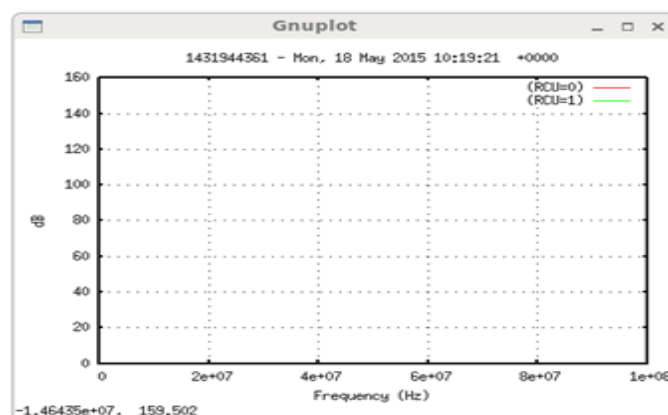


*Image 4: Output Spectrum of FPA system (Blank)*

## 3.4 Digital Processing Board : Block Diagram
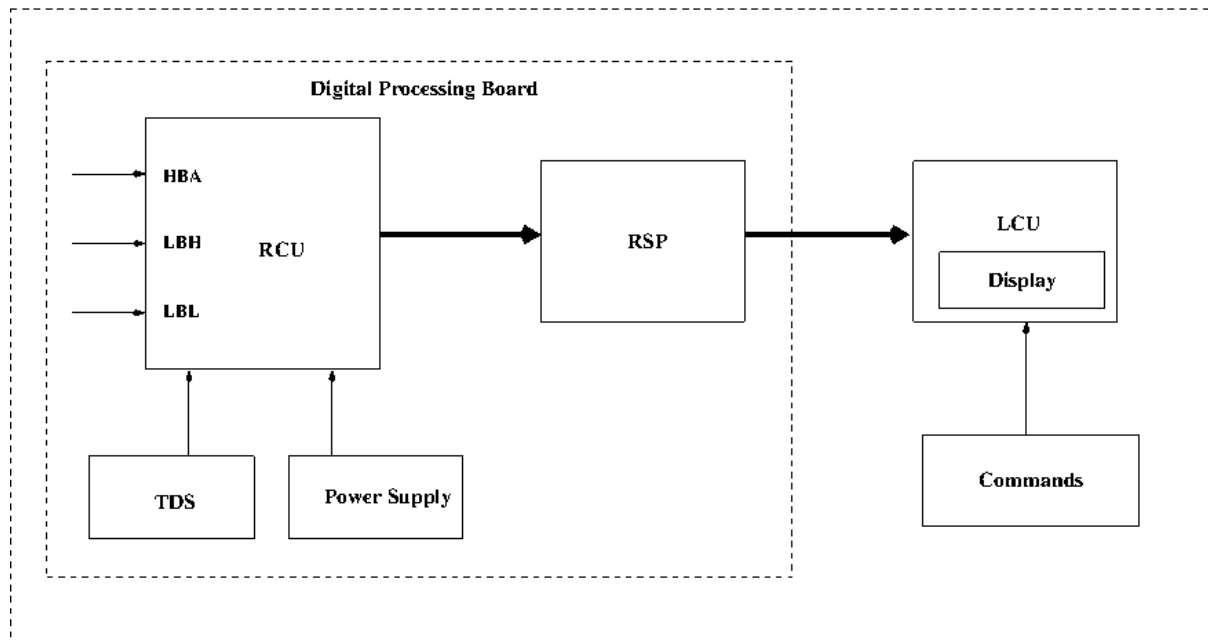


*Figure 12: Block Diagram of DPB*

The Digital Processing Board (DPB) consists of the 64 Receiver Units (RCUs and the inputs connected to the input connectors (In this case, HBA). RCU contains inbuilt frequency band selector block along with the ADC. Output from the RCU is provided to the Remote Station Processing (RSP) Unit where the INFINIBAND connections are provided in a ring topology with the TX of one board connected to the Rx of the next and the TX of the last board connected to the Rx of the first. The final output data from the RSP Board goes to the Local Control Unit (LCU).

## 3.5   Information to Receiver Unit (RCU)
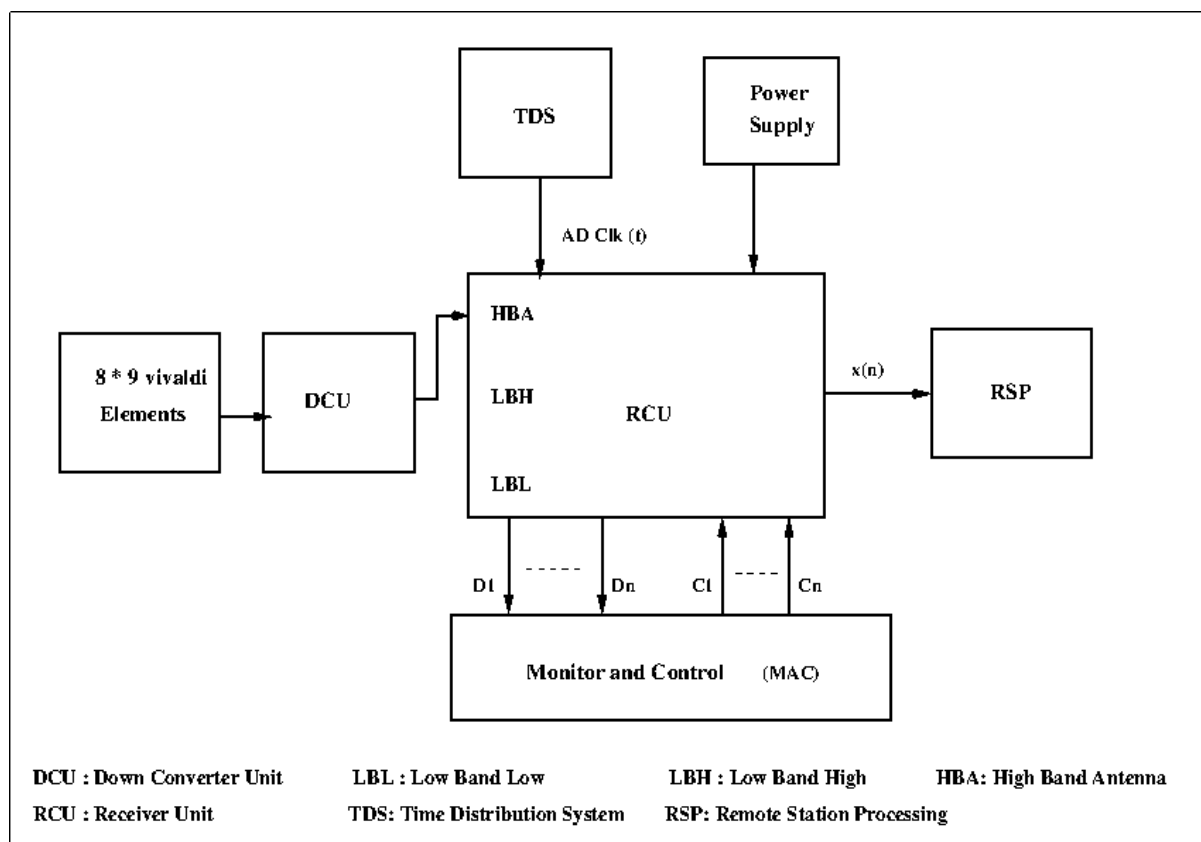


*Figure 13: Block Diagram of RCU*

There are 32 receiver units (RCUs).  Every antenna is connected with two receivers. The X-polarity of an antenna is connected with the even receiver number unit and the Y-polarity with the odd receiver number unit (ANT 0-X = RCU 0, ANT 0-Y = RCU 1). The receiver unit has three input connectors. The upper connector is the HB input, the middle LBH and the lower connector is the LBL input. The LED indicates which input is selected. In Figure 13, the HBA input is selected. The IF Signal is then fed to the HBA port of the receiver, where it gets bandpass sampled with a 200 MHz clock. The HBA band is 110-190 MHz The High Band chain undergoes 75-50 units conversion, along with selection of the different frequency bands ranging from 110 -270 MHz Conversion of analog signal into digital domain is carried out with 12- bit ADC. The Time Distribution System (TDS) provides 10 MHz and 1PPS clock signals. In order to have proper functioning MAC (monitor and control) and power supply are provided. Output of the receiver comes in the form of data to the Remote Station Processing (RSP) Board where output side of the receiver is backplane. The antenna bias voltage at the center pin of the connector is +8V for LBL/LBH input and +48V for the HB input.

The HB input can also deliver the modem control signal for the HBA tile. The convention is that the X-polarity is used to bias a single tile. The Y-polarity has a modem to control the delay lines in the tile. Every receiver unit has a built-in modem. To select the modem functionality on the receiver places the jumper close to the input in the lowest position. When the jumper is in the highest position the input of the HB contains the bias voltage.



*Image 5: 32 Receiver Units of Subrack 1 of DPB*

## 3.6 Remote Station Processing (RSP) Board
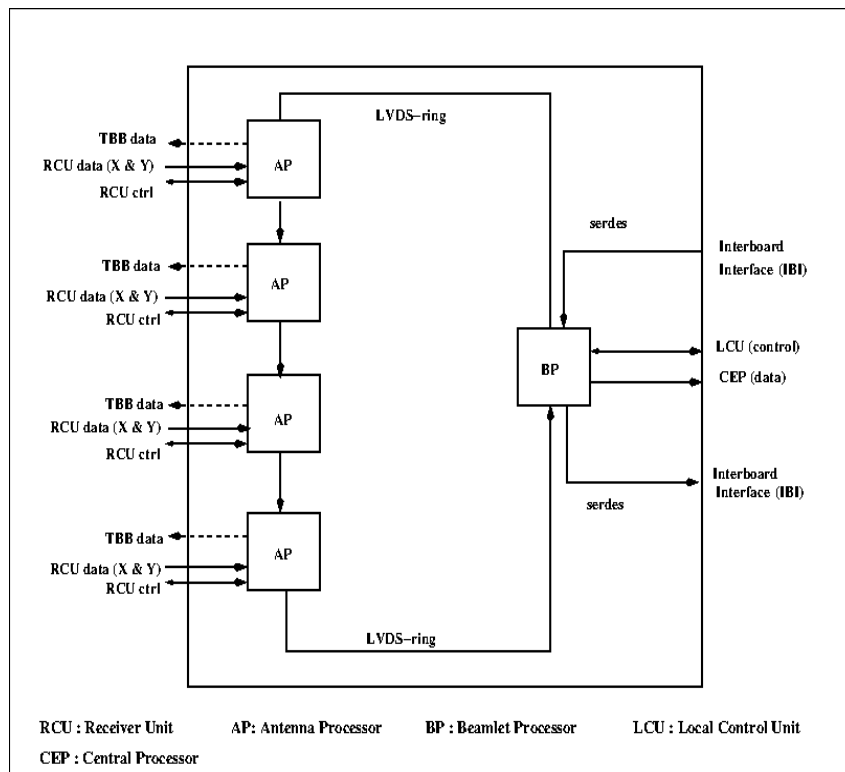


*Figure 14: Internal Functioning of RSP Board*

The embedded processing of an RSP board filters the digital antenna data, transforms the data into the frequency domain, selects frequency ranges and beamforms them. There is also functionality available to take subband statistics data and to perform station cross correlation. The raw digital time samples from the receiver boards can also be sent to Transient Buffer Boards (TBB) to capture and trigger on transient events. An RSP board consists of five FPGAs. Four antenna processor (AP in Fig. 9) FPGAs which processes the antenna data, and one board processor (BP) FPGA which handles board control, data output and external interfaces. The FPGAs are connected to each other by the internal ring, a high speed LVDS (low voltage differential signaling) parallel interface. RSP boards are connected to each other using the inter-board interface which is a high-speed connection using SERDES (serializer-deserializer) components. Two Ethernet interfaces for LCU (control) and for CEP (data) are present. Each antenna processor is connected with two receivers giving the full 100MHz baseband input signal from two antenna polarizations.
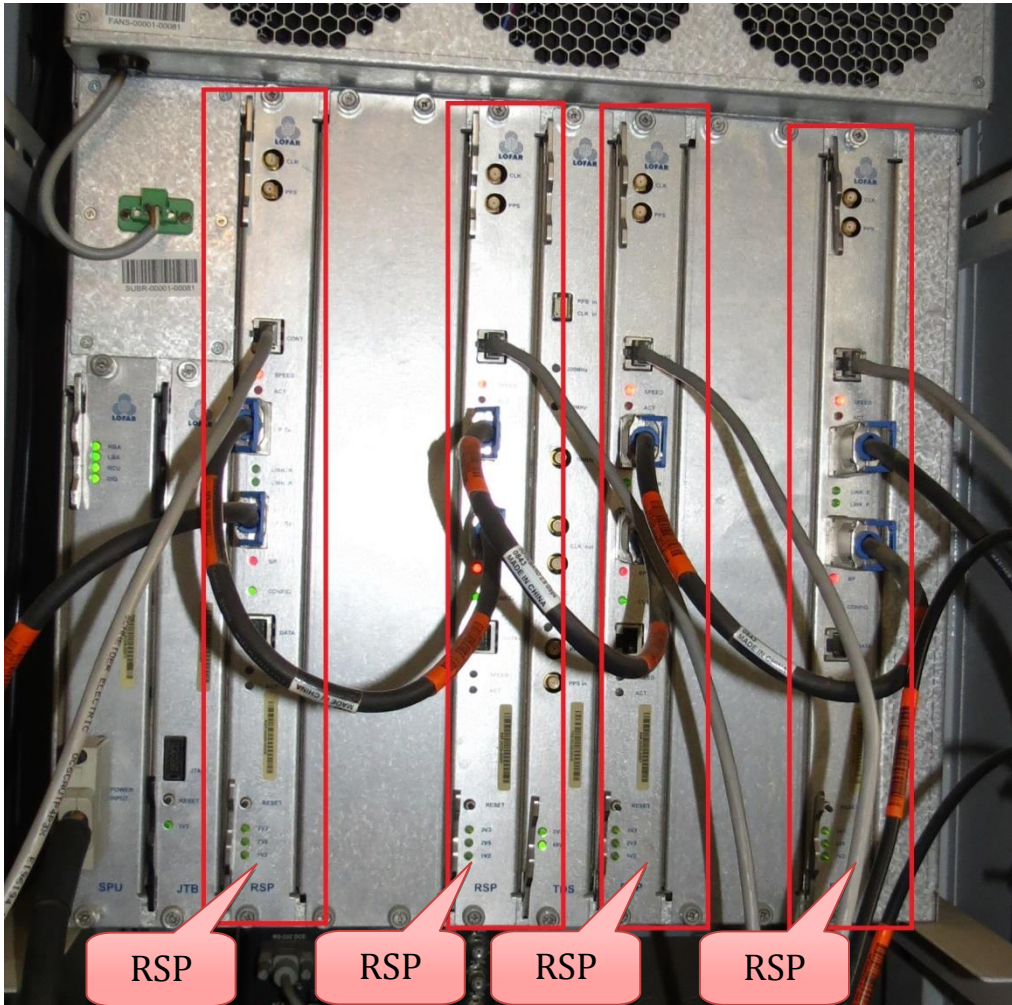
*Image 6: Subrack 1 of DPB showing 4 RSP Boards*

### 3.7   Local Control Unit

The local control unit (LCU) is a 19 inch rack PC with Redhat Linux operating system. This system is locally mountable or can be accessed remotely. The connection goes via the switch. The LCU controls all the boards in the sub racks, it receives the 1 PPS timing signal from the time distribution system, and can also be used to monitor the temperature inside the station or read alarm contacts.



*Image 7: Snap of LCU*

## 3.8   Program settings and data

First a directory called data is created. The name of this directory contains the date and the name of the creator.
• Example:  mkdir /data/20071116mn

Before the measurement can start the status of the software need to be checked. This can be done with

• **swlevel**

Current level is 2
Status of all software level:
1: ServiceBroker: 7593
1: CTStartDaemon:  7608
---
2: RSPDriver:  19104
---
3: TBBDriver: 20006
---
4: PVSS00pmon:  DOWN
4: PropertyAgent: DOWN
4: CodeLoggingProcessor:  DOWN
---
5: amcserver:  DOWN
5: CalServer:  DOWN
5: BeamServer:  DOWN
---
6: StationControl:  DOWN
6: DigitalBoardControl: DOWN
6: CalibrationControl:  DOWN
6: BeamControl:  DOWN

The level can be set by entering a number appended to swlevel (example: swlevel 5). The maximum level is 5 for manual setting. Use swlevel 0 to stop all the processes.

To set the RCUs and the TDS in the correct mode, take reference of Table 3. If one wants to measure HBA antenna in the 110…190 MHz mode. This means that the settings must be clock at 200MHz and RCUMODE=5.

Table 3 shows the different receiver modes for different frequency bands.

| 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 |

*Table 3: Receiver modes with different frequency band*

- **rspctl - -clock = 200**

It takes about 40 seconds for the TDS to stabilize the clock and for the RSP board to read and verify all registers. This process can be monitored with the following command.
- **rspctl - -regstat**

When the RSPDriver is ready (only **** and ....) send the following command to select the correct mode
- **rspctl - -rcumode=3**

The autocorrelation spectrum of the selected antennas can be displayed with.
- **rspctl - -statistics - -select=0:63**

## 3.9 Debugging Digital section
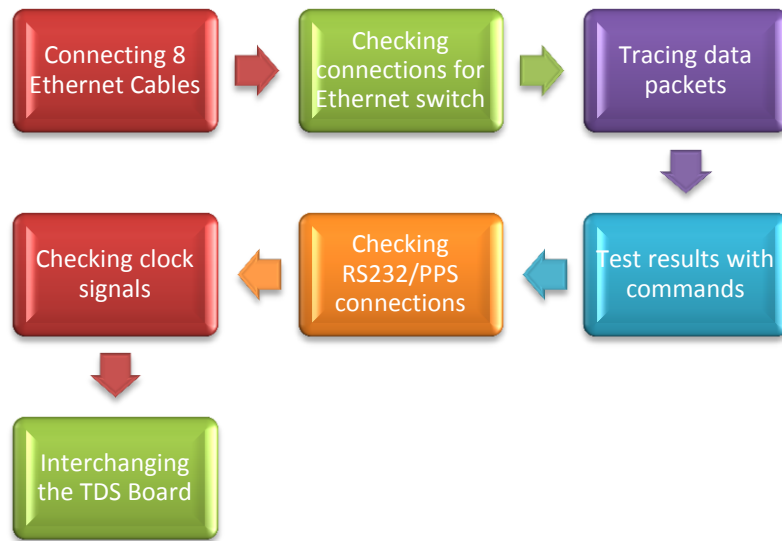


*Figure 15: Steps carried out for debugging the error*

a. **Connecting 8 Ethernet cables to the DPB**

Transmission of the data didn't take place as the data port was left open. As there are two ports CONTROL and DATA for the transmission. Tried insertion of 8 Ethernet cables each with 1 meter in length to the data port of the Digital processing Board.

b. **Checking the connections for Ethernet switch(100 Mbps full duplex)**

After putting back those 8 Ethernet cables, connections for the switch were tested out. As of lose connections between the cables or the interchange between the cables may have resulted in the output failure.

c. **Tracing out the data packets through the Wireshark software (Failure of RSP Board Communication).**

It was clear that communication between the boards was not happening. Capturing of packets for network analysis at microscopic level using Wireshark software was carried out. This confirmed the absence of communication between the RSP Boards.

d. **Checking 10 MHz and 1 PPS clock signals**

No communication between the boards led to a clue of improper clock signals. So testing the 10 MHz and 1 PPS signals on the Digital Oscilloscope was carried out.

Following are the plots for the 10 MHz and 1 PPS clock signals.
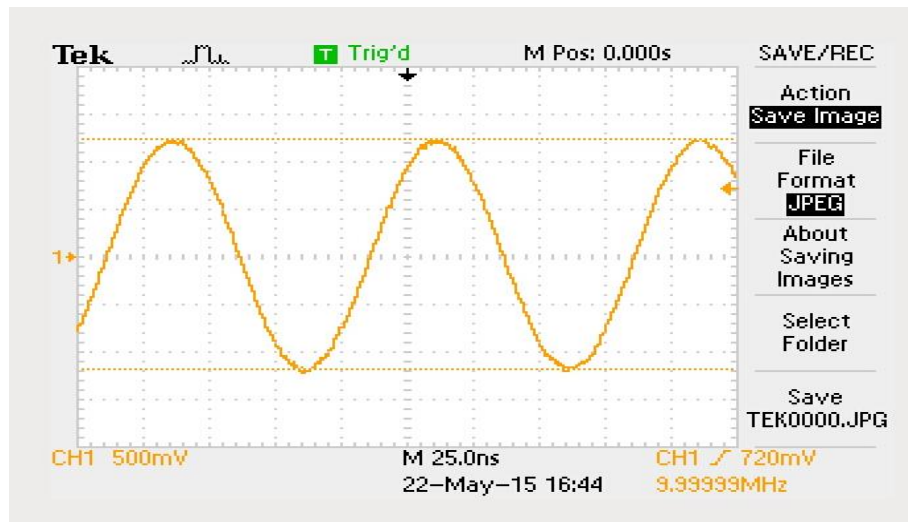


*Figure 16: Frequency Plot for 10 MHz signal from Rubidium standard (subrack1 of Digital Processing Board).*



*Figure17: Plot for 1 PPS signal from Rubidium (Digital Processing Board subrack1).*

e. **Checking RS232/PPS cable connection with PC and metal box (along with rubidium).**
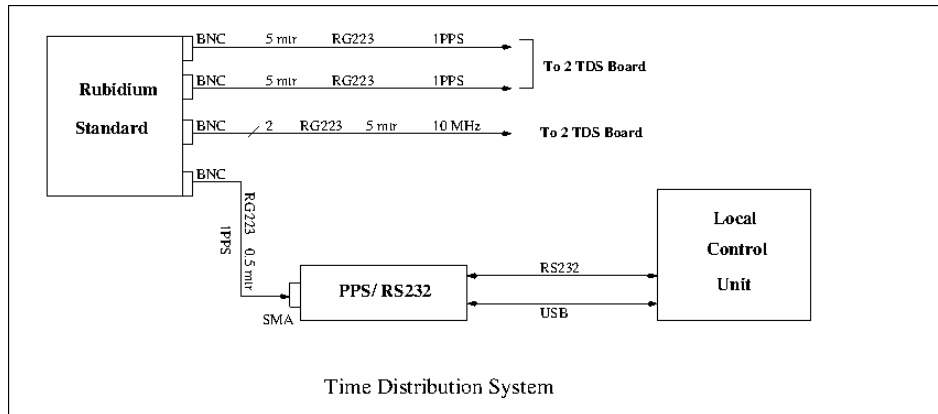


*Figure 18: Connections for Time Distribution System*

There are two 1PPS and 10 MHz clock signal going through RG223 with 5 meter length cable to the Time Distribution System (TDS), and 1PPS clock signal goes through RG223 cable with 0.5 meter length to the metal box. Output of the metal box is connected to Local Control Unit (LCU) through RS232 and USB cable. The connection of the RS232 cable from the metal box is done at the last RS232 port (right most port) while the RS232 cable coming from the rubidium standard is connected to the second right most RS232 port of the LCU. These connections were actually swapped which resulted in restoring them back in proper positions.

f. **Test results with ./ntpd.sh and ./pps.sh**

To know the reason for lack of communication between the boards log into the boards remotely using their respective IP addresses was done. This led to the fact that the clock to the board and sync between the boards was OK. Then for further debugging, the commands ntpd.sh and gps.sh which provided system delay, offset and jitter information were executed.

Following are the snaps of output taken after running the commands (./ntpd.sh and ./gps.sh)

```
[lofarsys@IN001C ~]$ cd /opt/stationtest/test/timing
[lofarsys@IN001C timing]$ ./pps.sh
check 1 puls per second
. Now running Linux 2.6.18-nano)
PPS API capabilities are 0x10f3
PPS API v1 set up (handle 3, mode 0x1001)
assert 1 time 1433307814.349605516 delta 1433307814.349605516 jitter -132543860
assert 2 time 1433307815.349486516 delta 0.999881000 jitter 1132424860
assert 3 time 1433307816.349370516 delta 0.999884000 jitter 3000
assert 4 time 1433307817.349249516 delta 0.999879000 jitter -5000
assert 5 time 1433307818.349131517 delta 0.999882001 jitter 3001
assert 6 time 1433307819.349015516 delta 0.999883999 jitter 1998
assert 7 time 1433307820.348893516 delta 0.999878000 jitter -5999
assert 8 time 1433307821.348774516 delta 0.999881000 jitter 3000
assert 9 time 1433307822.348659517 delta 0.999885001 jitter 4001
assert 10 time 1433307823.348537516 delta 0.999877999 jitter -7002
assert 11 time 1433307824.348419516 delta 0.999882000 jitter 4001

[lofarsys@IN001C timing]$ ./ntpd.sh
check ntpd server
     remote          refid      st t when poll reach   delay   offset  jitter
==============================================================================
 LOCAL(0)        .LOCL.         10 l    7   64  377   0.000    0.000   0.001
*gps1.gmrt.ncra. 77.67.82.0      3 u   62   64  377   2.283   40.193  23.728
[lofarsys@IN001C timing]$
```

Image 8: Snap of Commands

g. **Interchanging the TDS Boards:**

There was a problem with the first clock board. It does not get LOCKED as TDS1 does (see below).

[lofarsys@IN001C                etc]$                rspctl             --tdstat
150701  155240,126 [26151] TRACE  TRC [:] - TRACE  module activated
RSP |  10MHz input | output clock | PPS input | PLL 160MHZ | PLL 200MHz |
V3.3          |          V5.0          |          Temperature

| 0 | SMA | 200 | SMA | not locked | **not locked** | 3.2 | 4.3 | 35 |
| 1 | | Not | controlling | the | TD | board |
| 2 | | Not | controlling | the | TD | board |
| 3 | | Not | controlling | the | TD | board |
| 4 | SMA | 200 | SMA | not locked | **LOCKED** | 3.2 | 4.3 | 36 |
| 5 | | Not | controlling | the | TD | board |
| 6 | | Not | controlling | the | TD | board |

7 | Not controlling the TD board

**'This actually sorted out the problem and the system was put back into the running mode'.**

## 3.10 Test setup and results after debugging the Error
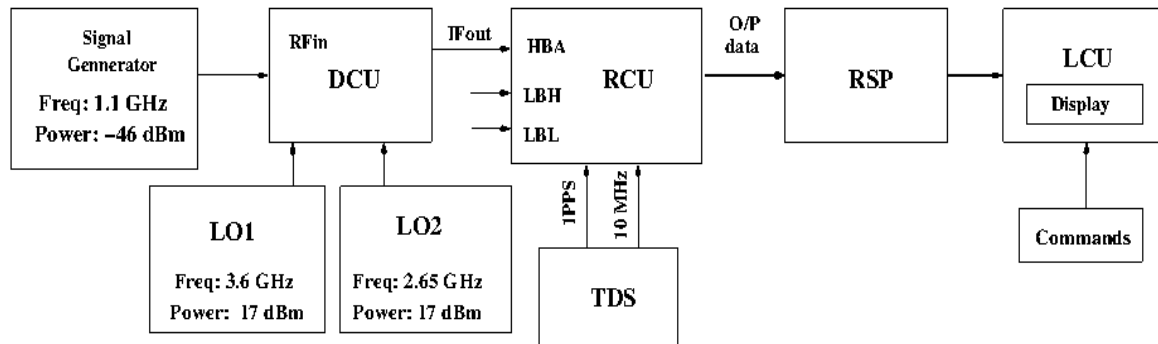


*Figure 19: Test setup and results after debugging the Error*

Following were the inputs provided to the DCU unit.

Test inputs:

- RFin frequency: 1.1 GHz, -46dBm
- LO1frequency: 3.6 GHz, 17 dBm
- LO2 frequency: 2.65 GHz, 17 dBm

Commands given to the LCU Unit:

- swlevel

```
---
[lofarsys@IN001C ~]$ swlevel 2
Going to level 2

Status of all software level:
1 : ServiceBroker            8541
---
2 : RSPDriver                8650
---
3 : AMCServer                DOWN
3 : CalServer                DOWN
3 : BeamServer               DOWN
---
4 : SoftwareMonitor          DOWN
4 : HardwareMonitor          DOWN
---
5 : SHMInfoServer            DOWN
---
6 : StationControl           DOWN
6 : ClockControl             DOWN
6 : CalibrationControl       DOWN
6 : BeamControl              DOWN
6 : TBBControl               DOWN
---                                _
```

*Image 9; Snap of Command 1*

- **rspctl –reg**

```
System Status      * * * * * * * * $
BF                 * * * * * * * * * * * * * * * * * * * *
 * * * * * * * * * * * * * * * * * * * * * * * * * * *
Subband Selection  * * * * * * * * * * * * * * * * * * * *
RCUSettings        . . . . . . . . . . . . . . . . . . . .
RCUProtocol        . . . . . . . . . . . . . . . . . . . .
RCU Read           . . . . . . . . . . . . . . . . . . . .
HBAProtocol        . . . . . . . . . . . . . . . . . . . .
RSUClear           . . . . . . . . $
DIAGWGSettings     . . . . . . . . . . . . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . . . . .
SubbandStats       * * * * * * * * * * * * * * * * * * * *
 * * * * * * * * * * * * * * * * * * * * * * * * * * *
BeamletStats       * * * * * * * * $
XCorrelationStats  * * * * * * * * * * * * * * * * * * * *
 * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * * * * * * * * * * * * * * * * * * * * * * * *
CDO                . . . . . . . . . . . . . . . . $
BS                 . . . . . . . . . . . . . . . . . . . .
TDSClear           . . . . . . . . $
TDSWrite           . . . . . . . . $
TDSRead            . . . . . . . . $
RAD                . . . . . . . . $
Timestamp          * * * * * * * * $
TDS Status (write) * * * * * * * * $
TDS Status (read)  * * * * * * * * $
TBBSettings        . . . . . . . . . . . . . . . . . . . .
TBBBandsel         . . . . . . . . . . . . . . . . . . . .
DIAGBypassSettings . . . . . . . . . . . . . . . . . . . .
RawDataBlock(write) . . . . . . . . $
RawDataBlock(read)  . . . . . . . . $
SerdesWrite        . . . . . . . . $
SerdesRead         . . . . . . . . $
```

*Image 10: Snap of command 2*

- **rspctl –ver**

```
[lofarsys@IN001C ~]$ rspctl --ver
150808 155637,912 [9168] TRACE  TRC [:] - TRACE module activated
RSP[ 0] RSP version = 5, BP version = 6.0, AP version = 6.0
RSP[ 1] RSP version = 5, BP version = 6.0, AP version = 6.0
RSP[ 2] RSP version = 5, BP version = 6.0, AP version = 6.0
RSP[ 3] RSP version = 5, BP version = 6.0, AP version = 6.0
RSP[ 4] RSP version = 5, BP version = 6.0, AP version = 6.0
RSP[ 5] RSP version = 5, BP version = 6.0, AP version = 6.0
RSP[ 6] RSP version = 5, BP version = 6.0, AP version = 6.0
RSP[ 7] RSP version = 5, BP version = 6.0, AP version = 6.0
[lofarsys@IN001C ~]$
```

*Image 11: Snap of command 3*

- **rspctl --rcumode=5**

```
[lofarsys@IN001C ~]$ rspctl --rcumode=5
150808 155710,296 [9170] TRACE  TRC [:] - TRACE module activated
control(0) =0x0007a400
modified(0)=0x0007ff00
```

*Image 12: Snap of command 4*

- **rspctl --rcuenable=1**



```
[lofarsys@IN001C ~]$ rspctl --rcuenable=1
150808 155804,409 [9171] TRACE  TRC [:] - TRACE module activated
control(0) =0x00000080
modified(0)=0x00000080
```
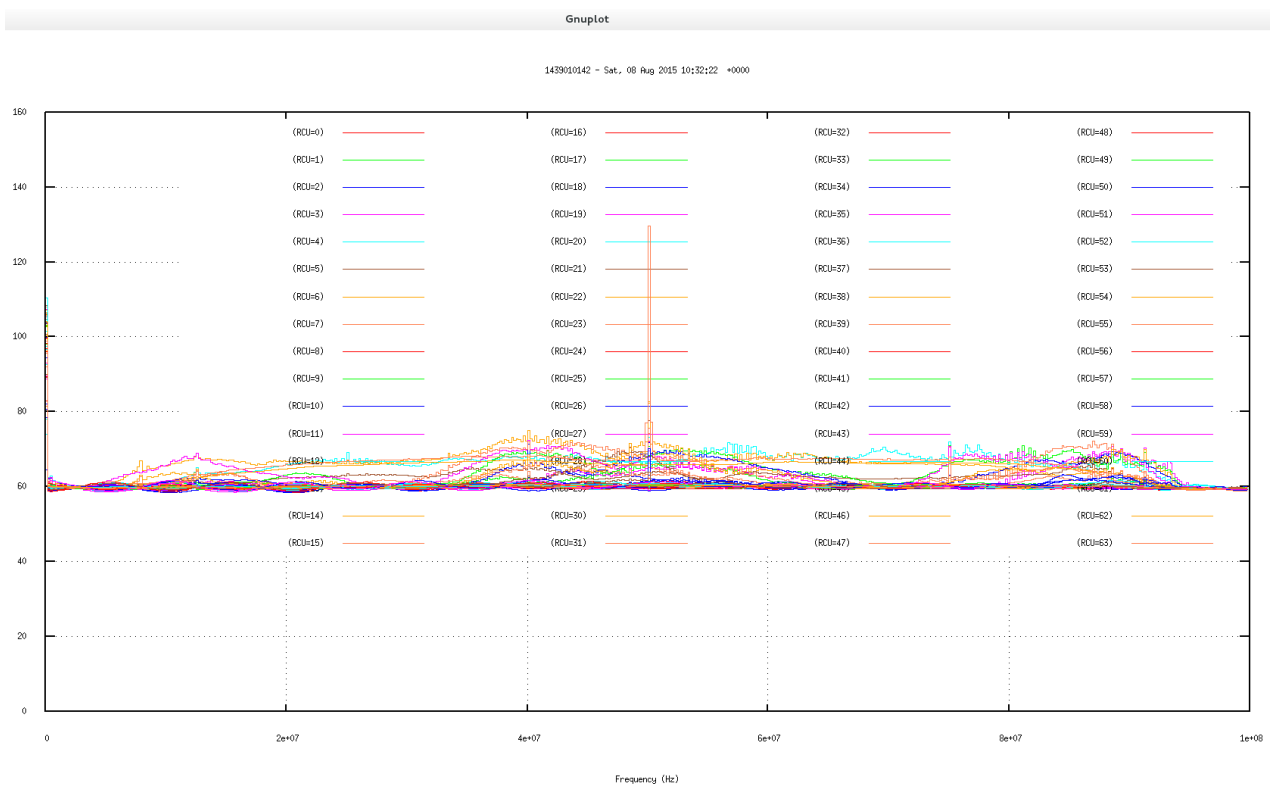
*Image 13: Snap of command 5*

- **rspctl --stati --sel=0:63**



```
[lofarsys@IN001C ~]$ rspctl --statistics --select=0:63
150808 160119,545 [9186] TRACE  TRC [:] - TRACE module activated
Taking subscription on the clockvalue
Current clockvalue is 200 Mhz
Dumping statistics in /localhome/lofarsys
```

*Image 14: Snap of command 6*

Output Plot



*Image 15: Output Spectrum of FPA system*

---

# 4   MATLAB SIMULATIONS

## 4.1   Broadside array

The most common mode of operation for a linear array is the broadside mode. This is the case where $\delta = 0$ such that all element currents are in phase. Figure 20 shows polar plot for a 7-element array for element distances $d/\lambda = .5$ and frequency=150e6 with element pattern, Array factor and array Pattern. This array is called a *broadside array* because the maximum radiation is broadside to the array geometry. Two major lobes are seen because the broadside array is symmetric about the $\theta = \pm\pi/2$ line. As the array element spacing increases, the array physically is longer thereby decreasing the main lobe width. The general rule for array radiation is that the main lobe width is inversely proportional to the array length.
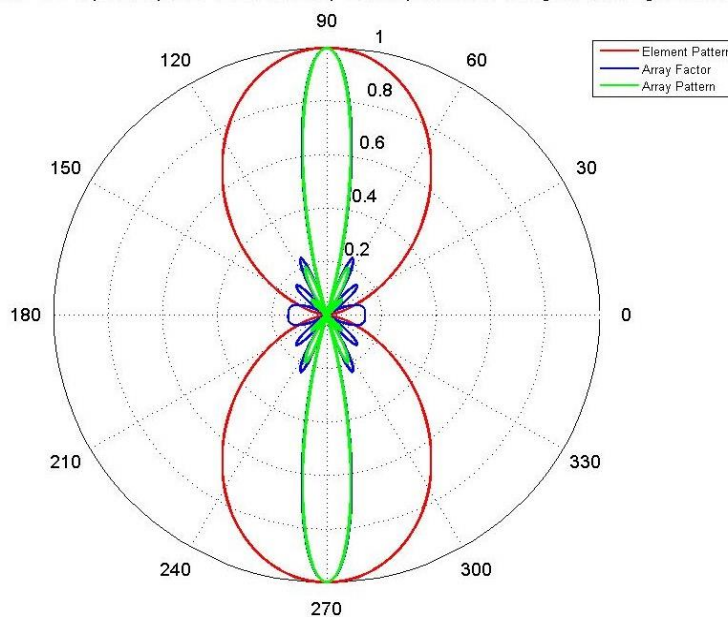
**Simulation**



*Figure 20: Simulation for Broadside Array*

## 4.2 End-Fire Array

The name *end-fire* indicates that this array's maximum radiation is along the axis containing the array elements. Thus, maximum radiation is "out the end" of the array. This case is achieved when $\delta = -kd$. Figure shows polar plot for the end-fire 7-element array for the distances $d/\lambda = .25$, frequency=150e6, and phase shift=90 deg with element pattern, array factor and array pattern. It should be noted that the main lobe width for the ordinary end-fire case is much greater than the main lobe width for the broadside case. Thus, ordinary end-fire arrays do not afford the same beamwidth efficiency as the broadside array. The beamwidth efficiency in this context is the beamwidth available relative to the overall array length.

An increased directivity end-fire array has been developed by Hansen- Woodyard where the phase shift is modified such that $\delta=-(kd+ \pi N)$.This provides a dramatic improvement in the beamwidth and directivity.
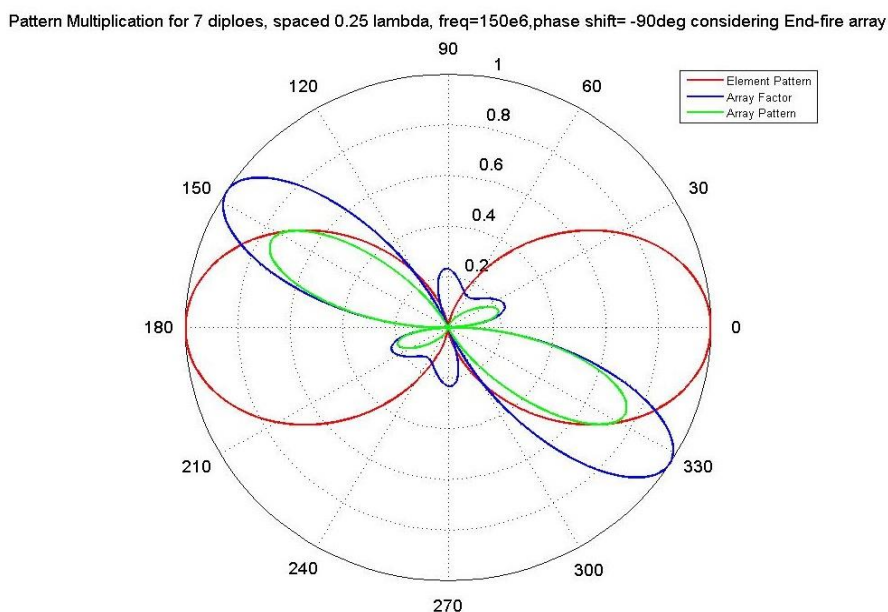
**Simulation**



*Figure 21: Simulation for End-fire Array*

## 4.3 Phase shift Beamformer

A phase shift linear array is an array where the phase shift $\delta$ is a variable thus 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 22 shows the Phase shift beamformer with δ=0, δ=30, δ= 130, δ =160.
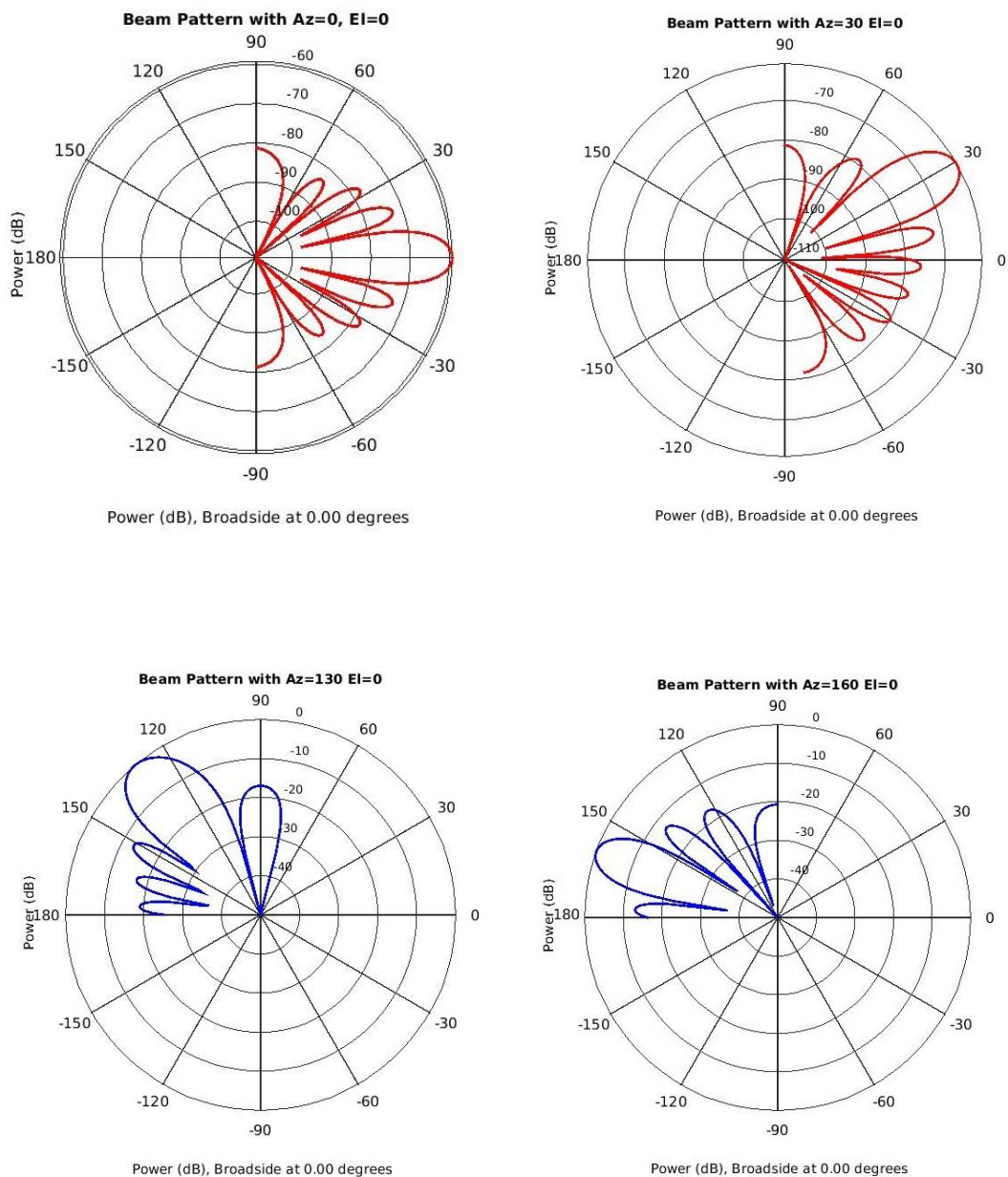


Figure 22: Simulation for Phase shift Beamformer

# Conclusion

This project was aimed at understanding the LOFAR Focal Plane Array Beamformer. The work carried out in this project was debugging of the system which served way for understanding the FPA Beamformer and the signal processing in it .Many things like Down conversion of RF signal to baseband level, Digital processing of the signal, beamforming basics,  Linux basics, handling RF instruments, and  information to RF cables and connectors were understood in detail.

During the process of troubleshooting, simulations related to beamforming and antenna array concept were carried out in Matlab using the Phased Array toolbox, Antenna Toolbox and RF Toolbox.

# Future Scope

1. Testing FPA System in different beamforming modes.

2. Relocating 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.

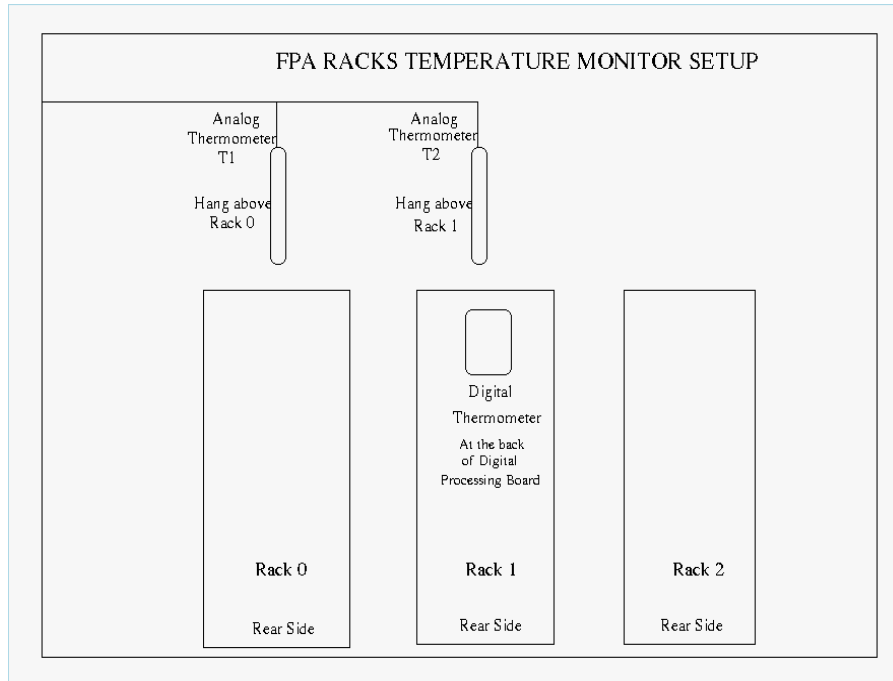# Appendix - A

## Monitoring FPA System Temperature

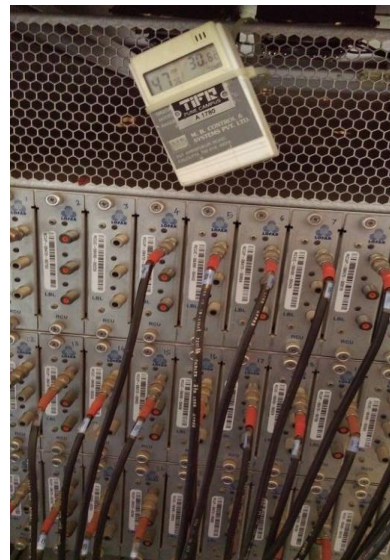

Figure 23: Setup for monitoring FPA Racks temperature



Image 15: Snaps of Thermometers mounted on FPA Racks

*Note: (One Pedestal Fan and One Ceiling Fan is Kept ON while measuring the temperature. DCU1 to DCU8 are powered with D type Connectors.
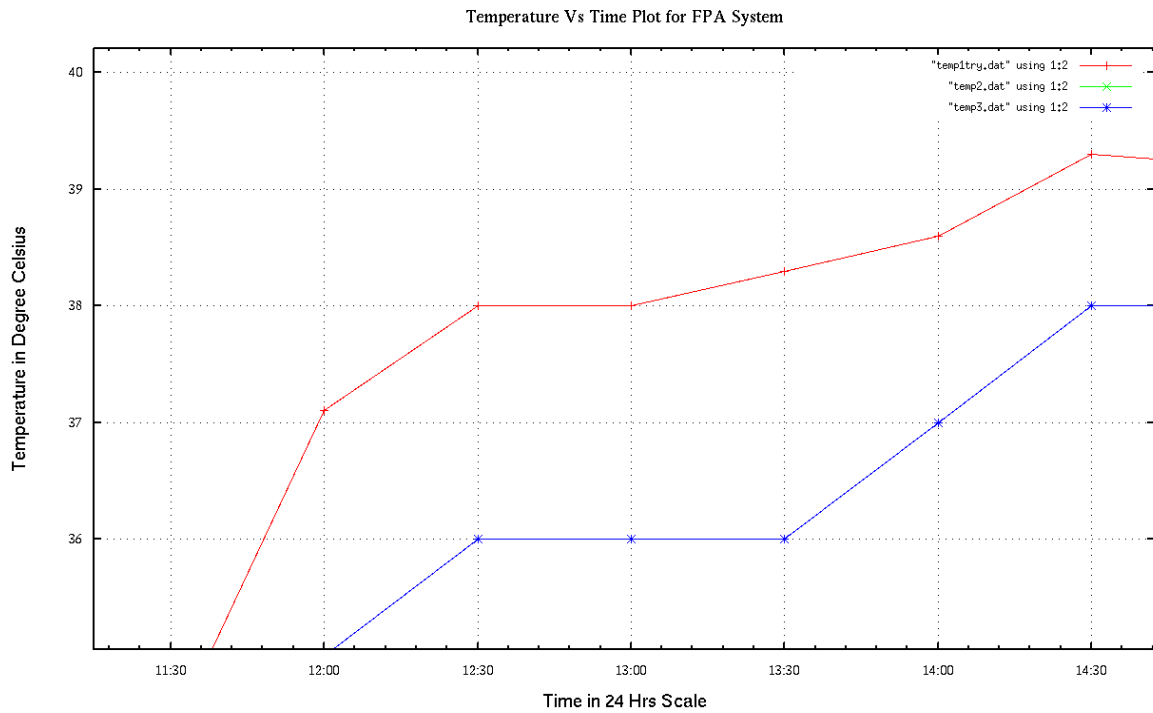
Figure 24: Plot for FPA System Temperature

The red line shows the Digital Thermometer readings while the blue and green line shows temperature reading for Analog Thermometer (which has overlapped due to same readings).

# Appendix - B

## FPA System Mapping

Table 4 shows the current mapping for the FPA system for HBA mode. This was done probably when input provided to the specific receiver unit which resulted output at different units.

| Input IF Signal to Receiver Unit | Output Receiver Peak in GNU Plot |
|---|---|
| 1 | 39 |
| 2 | 7 |
| 3 | 38 |
| 4 | 6 |
| 5 | 37 |
| 6 | 5 |
| 7 | 36 |
| 8 | 4 |
| 9 | 47 |
| 10 | 15 |
| 11 | 46 |
| 12 | 14 |
| 13 | 55 |
| 14 | 23 |
| 15 | 54 |
| 16 | 22 |
| 17 | 63 |
| 18 | 31 |
| 19 | 62 |
| 20 | 30 |
| 21 | 61 |
| 22 | 29 |
| 23 | 35 |
| 24 | 3 |
| 25 | 34 |
| 26 | 2 |
| 27 | 43 |

| Input IF Signal to Receiver Unit | Output Receiver Peak in GNU Plot |
|---|---|
| 28 | 11 |
| 29 | 42 |
| 30 | 10 |
| 31 | 45 |
| 32 | 13 |
| 33 | 44 |
| 34 | 12 |
| 35 | 53 |
| 36 | 21 |
| 37 | 52 |
| 38 | 20 |
| 39 | 59 |
| 40 | 27 |
| 41 | 58 |
| 42 | 26 |
| 43 | 60 |
| 44 | 28 |
| 45 | 33 |
| 46 | 1 |
| 47 | 32 |
| 48 | 0 |
| 49 | 41 |
| 50 | 9 |
| 51 | 40 |
| 52 | 8 |
| 53 | 49 |
| 54 | 17 |
| 55 | 48 |
| 56 | 16 |
| 57 | 51 |
| 58 | 19 |
| 59 | 50 |
| 60 | 18 |

Table 4: FPA System Mapping (Receiver peak)

# Appendix - C

## Shifting FPA Racks (Glass room layout):

For shifting the FPA racks, Glass room at the top of the Central Electronics Building (CEB) was considered as a suitable place. Many things were examined before proposing the re-allocation for the FPA racks e.g. the area for the racks, cabling between the racks and the feed, room ventilation, supply for UPS power etc.

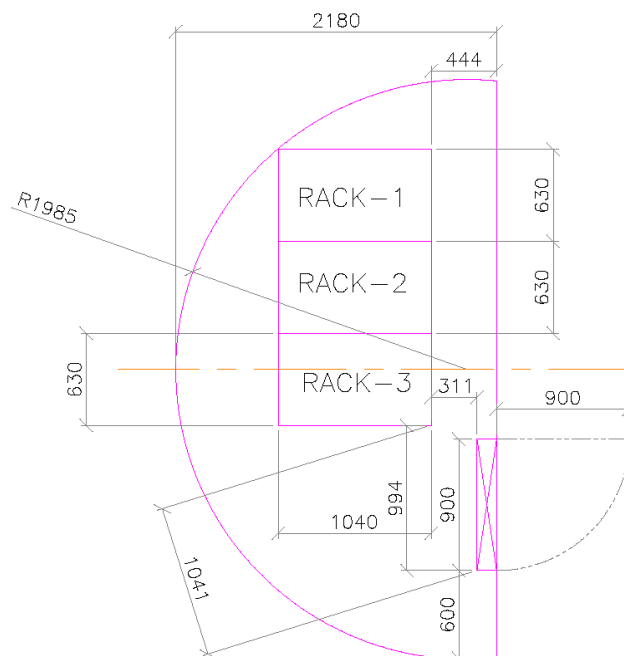Figure 25 shows the glass room layout for FPA Racks



Figure 25: Glass Room Layout for FPA System

The feed will be kept on the roof above the Glass room. Length of the cable coming from feed to the racks is approximately 10 metres. Thus, the routing of the cables can be done easily.

# REFERENCES

## For FPA

1. LOFAR Station User Manual
   Revision 1.0 Copyright by ASTRON in 2007

2. LOFAR station data Cookbook
   Revision 1.1 Copyright by ASRON in 2012

## For Matlab

1. Smart Antennas for wireless Communications - Frank Gross
   Published by- The McGraw-Hill Companies in 2005