

# Internal Technical Report

## 15mtr Backend @NCRA, PUNE.

*Irappa & Mekhala*  
*Ver. 1.0 , 12/12/2013.*

### Index

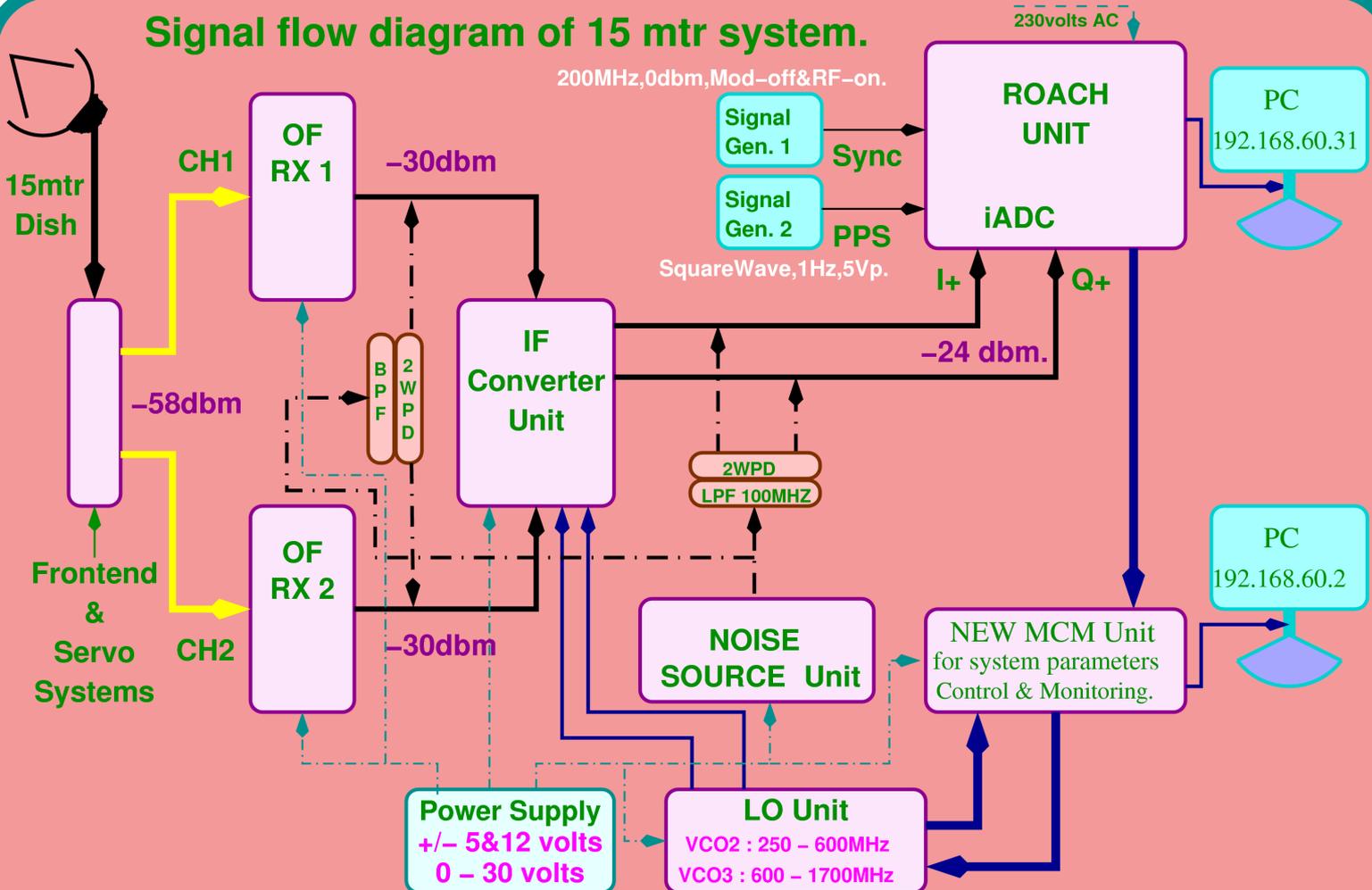
1. Introduction
2. Block diagram of 15mtr system
3. Digital backend and specifications
4. Design details
  - a. ADC
  - b. Delay
  - c. DDC
  - d. FFT
  - e. MAC
  - f. Clock and Sync signals
5. Calculations
6. Lab tests and Results
7. SOP
8. Conclusions



## 2. Block diagram of 15mtr system

The block diagram of 15mtr system.

### Signal flow diagram of 15 mtr system.



Note : Signal Powers mentioned in figure are Total Power over 100MHz Bandwidth.

Analog signals from the 15 meter dish base, come to 15mtr system in the lab through optical cable. After converted back to electrical, these signals reach the digital backend through IF system.

The digital backend has ADC with ROACH in a single unit/box. It needs clock and PPS signals with two inputs. Clock of 800MHz, 0dbm is provided using Signal generator and PPS(Pulse Per Second) from GPS unit. Two analog inputs get converted into digital by ADC card. Through ZDOK connector digitized signals go to ROACH unit.

In the ROACH unit data goes through Delay correction, DDC, FFT and MAC.

### 3. Digital backend and specifications

ADC :

ADC with 1x [Atmel/e2V AT84AD001B](#) 8-bit Dual 1Gsps. It needs

- Inputs
  - Clock: 10MHz-1GHz 50Ohm 0dBm
  - Signal: 2 analog inputs.
  - Sync: LVTTTL (5V tolerant, ([SN65LVDS1](#)))
- Outputs
  - 1x [Tyco Z-DOK+](#) 40 differential pair connector
    - 8x (1x8 or 2x4) 8-bit offset binary data
    - 2x digital clocks to CASPER standard Z-DOK clock pins

ROACH :

ROACH (Reconfigurable Open Architecture Computing Hardware) is Vertex 5 FPGA based reconfigurable hardware. The centrepiece of ROACH is a Xilinx Virtex 5 FPGA (either LX110T for logic-intensive applications, or SX95T for DSP-slice-intensive applications). A separate PowerPC runs Linux and is used to control the board (program the FPGA and allow interfacing between the FPGA "software registers/BRAMs/FIFOs" and external devices using Ethernet).

Two quad data rate (QDR) SRAMs provide high-speed, medium-capacity memory (specifically for doing corner-turns), and one DDR2 DIMM provides slower-speed, high-capacity buffer memory for the FPGA. The PowerPC has an independent DDR2 DIMM in order to boot Linux/BORPH.

The two Z-DOK connectors allow ADC, DAC and other interface cards to be attached to the FPGA, in the same manner as the [IBOB](#) allowed (with backwards compatibility for the ADC boards used with the IBOB).

Four CX4 connectors provide a total of 40Gbits/sec bandwidth for connecting ROACH boards together, or connecting them to other XAUI/10GbE-capable devices.

100Mbps ethernet port is used for both control and acquisition of the data.

Specifications :

Correlated output for real time analysis with i. Normal & ii. Zoom and Raw ADC data for offline analysis.

Processing Bandwidth : 100MHz for normal mode. For zoom modes with Decimation Factors(DF) 2,4,8,16,32,64&128 is 100MHz/DF

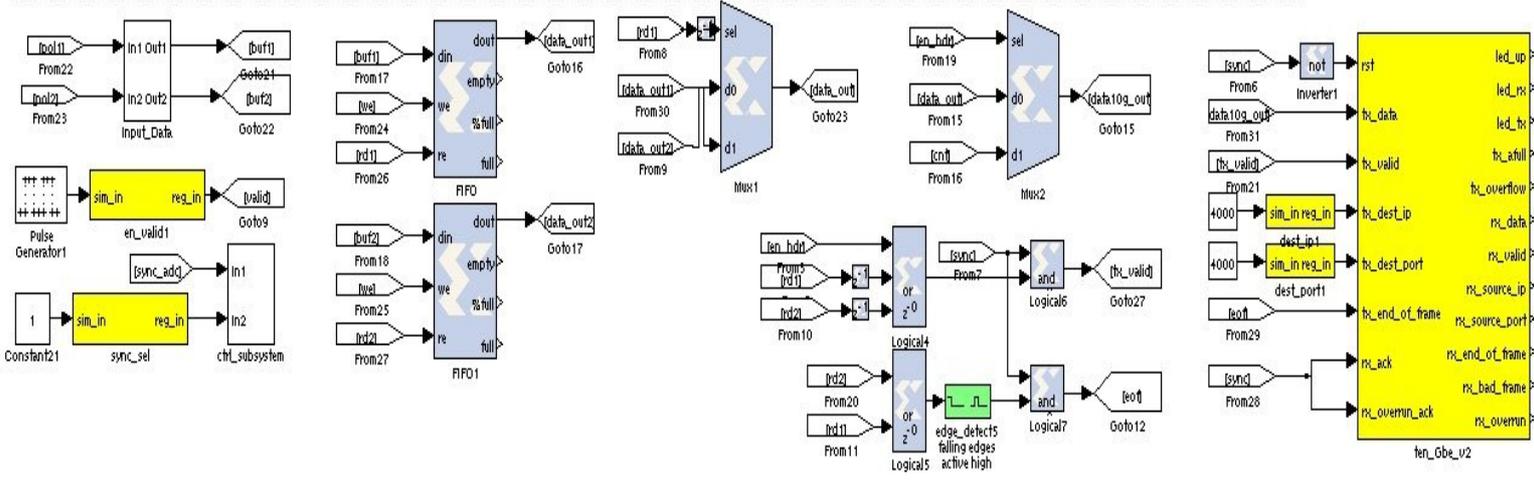
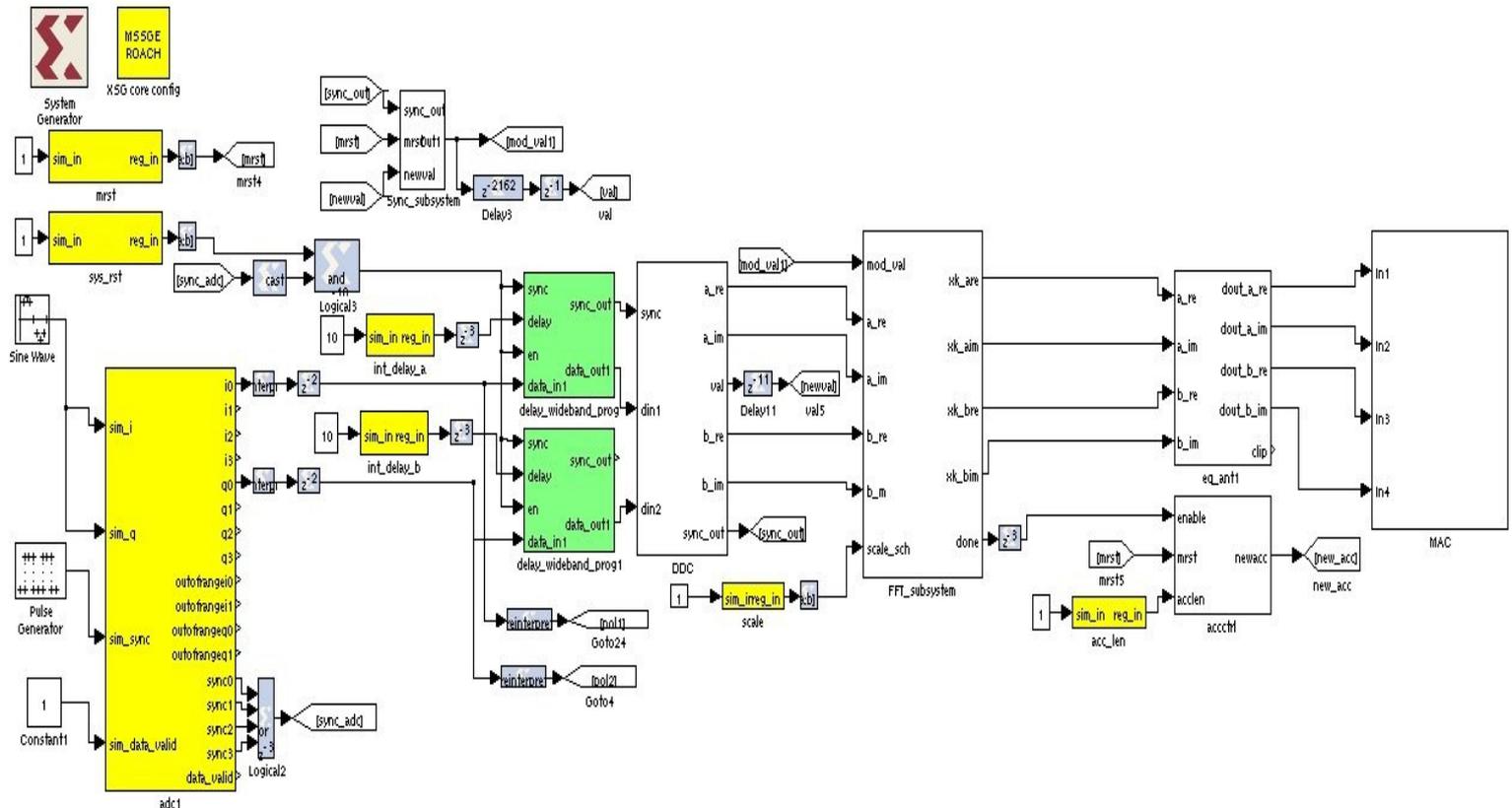
Delay correction of max 256 clock cycles ie  $5\text{ns} * 256 = 1280 \text{ nsec}$ .

FFT of 1024 points. So 512 FFT channels.

Integration time of 1 sec.

Raw data output rate is 400Mbytes/sec (2bytes\*200MHz) for offline analysis.

# 4. Design details



### a. ADC

This works with 800MHz clock. The digitized output is 4 parallel streams corresponds to 4 consecutive samples. So the data rate becomes  $1/4^{\text{th}}$  ie 200MHz.

The data goes to ROACH unit through ZDOK connectors. Only one digitized channel out of 4 is further processed in order to get 100MHz bandwidth.

### b. Delay

Max delay correction of 256 clock cycles ie 1280nsec is provided for instrumental delay.

### c. DDC

This block is for zoom modes. The sub-system of DDC includes dds for generating  $f_0$ , low pass filters of the order of 51, decimation unit. The bandwidth of low pass filter changes with decimation factor.  $BW = 100\text{MHz}/DF$ .

### d. FFT

1K FFT is done on the digitized data. Scaling factor is provided to this block for avoiding overflow in subsequent stages of FFT.

### e. MAC

The power is calculated for both channels and integrated for 1sec. The final integrated data is stored in the 4 BRAMs (for 2 selfs and cross real and cross img.) . Presently integration time of 1sec. is fixed in the acq script. Appropriate changes in the script can be made to accept the user input.

### f. Clock and Sync signals

Clock of 800MHz, 0dbm and 1 PPS for synchronization.

## 5. Calculations

ADC clock = 800MHz,      FPGA clock/channel = 200MHz (5nano sec.),  
Operable Bandwidth = 100MHz, FFT points / FFT = 1024 (512 FFT channels).

Normal modes :

Time required for 1 FFT =  $1024 \times 5 \text{ nsec} = 5120 \times 10^{-9} \text{ sec.}$

No. of FFT's for 1 sec integration =  $1 \text{ sec} / (5120 \times 10^{-9}) \text{ sec} = 195312.5$

Zoom modes :

Decimation Factor(DF) = 2

Operable Bandwidth =  $100 \text{ MHz} / 2 = 50 \text{ MHz}$

Time required for 1 FFT =  $1024 \times 5 \text{ nsec} \times 2 = 10240 \times 10^{-9} \text{ sec.}$

No. of FFT's for 1 sec integration =  $1 \text{ sec} / (10240 \times 10^{-9}) \text{ sec} = 97656$

Decimation Factor(DF) = 4

Operable Bandwidth =  $100 \text{ MHz} / 4 = 25 \text{ MHz}$

Time required for 1 FFT =  $1024 \times 5 \text{ nsec} \times 4 = 20480 \times 10^{-9} \text{ sec.}$

No. of FFT's for 1 sec integration =  $1 \text{ sec} / (20480 \times 10^{-9}) \text{ sec} = 48828.$

Decimation Factor(DF) = 8

Operable Bandwidth =  $100 \text{ MHz} / 8 = 12.5 \text{ MHz}$

Time required for 1 FFT =  $1024 \times 5 \text{ nsec} \times 8 = 40960 \times 10^{-9} \text{ sec.}$

No. of FFT's for 1 sec integration =  $1 \text{ sec} / (40960 \times 10^{-9}) \text{ sec} = 24414$

Decimation Factor(DF) = 16

Operable Bandwidth =  $100 \text{ MHz} / 16 = 6.25 \text{ MHz}$

Time required for 1 FFT =  $1024 \times 5 \text{ nsec} \times 16 = 81920 \times 10^{-9} \text{ sec.}$

No. of FFT's for 1 sec integration =  $1 \text{ sec} / (81920 \times 10^{-9}) \text{ sec} = 12207.$

Decimation Factor(DF) = 32

Operable Bandwidth =  $100 \text{ MHz} / 32 = 3.125 \text{ MHz}$

Time required for 1 FFT =  $1024 \times 5 \text{ nsec} \times 32 = 163840 \times 10^{-9} \text{ sec.}$

No. of FFT's for 1 sec integration =  $1 \text{ sec} / (163840 \times 10^{-9}) \text{ sec} = 6103.5$

Decimation Factor(DF) = 64

Operable Bandwidth = 100MHz / 64 = 1.5625MHz

Time required for 1 FFT = 1024 x 5 nsec x 64 = 327680x10<sup>-9</sup> sec.

No. of FFT's for 1 sec integration = 1sec / (327680 x 10<sup>-9</sup>) sec = 3051.75

Decimation Factor(DF) = 128

Operable Bandwidth = 100MHz / 128 = 0.78125MHz

Time required for 1 FFT = 1024 x 5 nsec x 128 = 655360x10<sup>-9</sup> sec.

No. of FFT's for 1 sec integration = 1sec / (655360 x 10<sup>-9</sup>) sec = 1525.875

The following table gives the LO for each steps and Decimation Factors.

LO in Hz							
DF	2	4	8	16	32	64	128
Step No							
0	0,000,000	0,000,000	0,000,000	0,000,000	0,000,000	0,000,000	0,000,000
1	50,000,000	25,000,000	12,500,000	6,250,000	3,125,000	1,562,500	0,781,250
2	100,000,000	50,000,000	25,000,000	12,500,000	6,250,000	3,125,000	1,562,500
3		75,000,000	37,500,000	18,750,000	9,375,000	4,687,500	2,343,750
4		100,000,000	50,000,000	25,000,000	12,500,000	6,250,000	3,125,000
5			62,500,000	31,250,000	15,625,000	7,812,500	3,906,250
6			75,000,000	37,500,000	18,750,000	9,375,000	4,687,500
7			87,500,000	43,750,000	21,875,000	10,937,500	5,468,750
8			100,000,000	50,000,000	25,000,000	12,500,000	6,250,000
....							
15				93,750,000			
16				100,000,000			
31					96,875,000		
32					100,000,000		
63						98,437,500	
64						100,000,000	
127							99,218,750
128							100,000,000

Note : If you are using default -U 1 (Upper Side Band) , then steps are from 0 to (DF -1) and for -U 0 (Lower Side Band) , 1 to DF.

## 6. Lab tests and Results

### a. Inputs

Carried-out the tests using CW and 32MHz Noise signals. As you seen in the block diagram , Clock of 800MHz,0dbm from signal generator and 1 pps from GPS unit or signal generator ( 1Hz ) to Clk\_i and Sync inputs at ADC. Then feed the input signals either CW & Noise to both (I+ & Q+) channels or one channel each of ADC.

### b. Modes

- I. Correlated output for real time analysis with i. Normal & ii. Zoom and
- II. Raw ADC data for offline analysis.

Programs used in the Real time modes.

`./init_roach.py` This script is used for programming and initialization of the ROACH board.

`./acq_roach.py` This script is used for acquiring the data.

#### I. Real time

**i.Normal mode** : In this mode the output is 100MHz over 512 FFT channels.

eg. `./init_roach.py` or `./init_roach.py -M n -U 1`

for normal mode with Upper side band. These two parameters are default in the script.

**ii. Zoom mode** : In this mode the output depends upon the Decimation Factor selected from 2,4,8,16,32,64 & 128. Which slice of 100MHz depends upon the LO step size.

eg. `./init_roach.py -M z2 -L 1` for zoom mode with DF 2 and LO step/slice 1. So Bandwidth is of 50MHz. And the slice selected is from 50MHz to 100MHz. `-L 0` for 0 to 50MHz band. Add `-U 0` for LSB.

`./acq_roach.py <ROACH IP> -f <output file>`

This is the script for acquiring the data and dumping in the output file for all modes.

eg. `./acq_roach.py 192.168.100.40 -f d2_lo1_rf98.dat`

For analysing the data the following script with options may be used.

`./xtrgsb32 -v <output data file> -c <channel numbers> -t <time samples>`

eg `./xtrgsb32 -v /home/cms15m/testing_scripts/d2_lo1_rf98.dat -c 1,511 -t 1,10000`

**Stability Checks :**

## 7. SOP

### SOP for testing 15mtr Backend using ROACH @ NCRA, PUNE.

*Irappa, Mekhala, Jitendra, Navnath & Ajith  
Ver. 2.0, 12/12/2013.*

The Correlator for 15 meter is a single FPGA based ( ROACH unit with one iADC ) correlator. This design accepts signals from both polarization of single antenna through iADC. The ADC samples at 200 Mhz clock giving 8bits of digitized data per pol. Two modes are supported by this design viz. Correlated output for real time analysis and raw ADC data for offline analysis.

**Real Time mode :** In real time mode 1024 point FFT is done on the digitized data. The data is intergrated for **1 sec**. The final output goes to control PC through 100Mbps ethernet.

**Offline mode :** The digitized ADC data is acquired via 10Gbe, hence giving flexibility for the user to do offline correlation/analysis. The data is sent in form of 8K bytes per packet. Each packet comprises of 64 bits of header followed by data . Each 64 bit data consist of 32 bit from Pol1 and 32 bits from Pol2.

#### I : Power ON and instrument settings.

- (a) Power on wall socket , AC distribution board in the RACK and power supply (*verify : PC ,Optical Fibre Rx units ,Analog bin & ROACH Unit are powered ON*)
- (b) Now Switch ON the instruments and do the following settings -
- (c) Signal generator settings as CLOCK to ROACH : Freq = 800MHz , Power = 0dbm, Set "Mod to OFF and RF to ON"
- (d) 1 pps trigger for ADC : *from the PPS unit.*
- (e) Power "ON" the ROACH unit by press the switch at front panel 'ON'. To Power OFF hold down the same switch for few seconds.

#### II : Interconnections.

##### (A) Only for testing the Digital part.

- a. Inputs I+ & Q+ : Connect the ouput from Analog Noise source PIU to LPF of 100MHz or less. Then LPF output to 2 Way Power Divider (2WPD). Connect these two signals as inputs to I+ & Q+ ports of ROACH unit.
- b. PPS : Connect the PPS unit's output of 1Hz,Square waveform & 5Vp to Sync input of ROACH unit.
- c. Clk : Connect the 800MHz , 0dbm to clk\_i input of ROACH unit.

##### (B) For testing the 15mtr Analog & Digital backends.

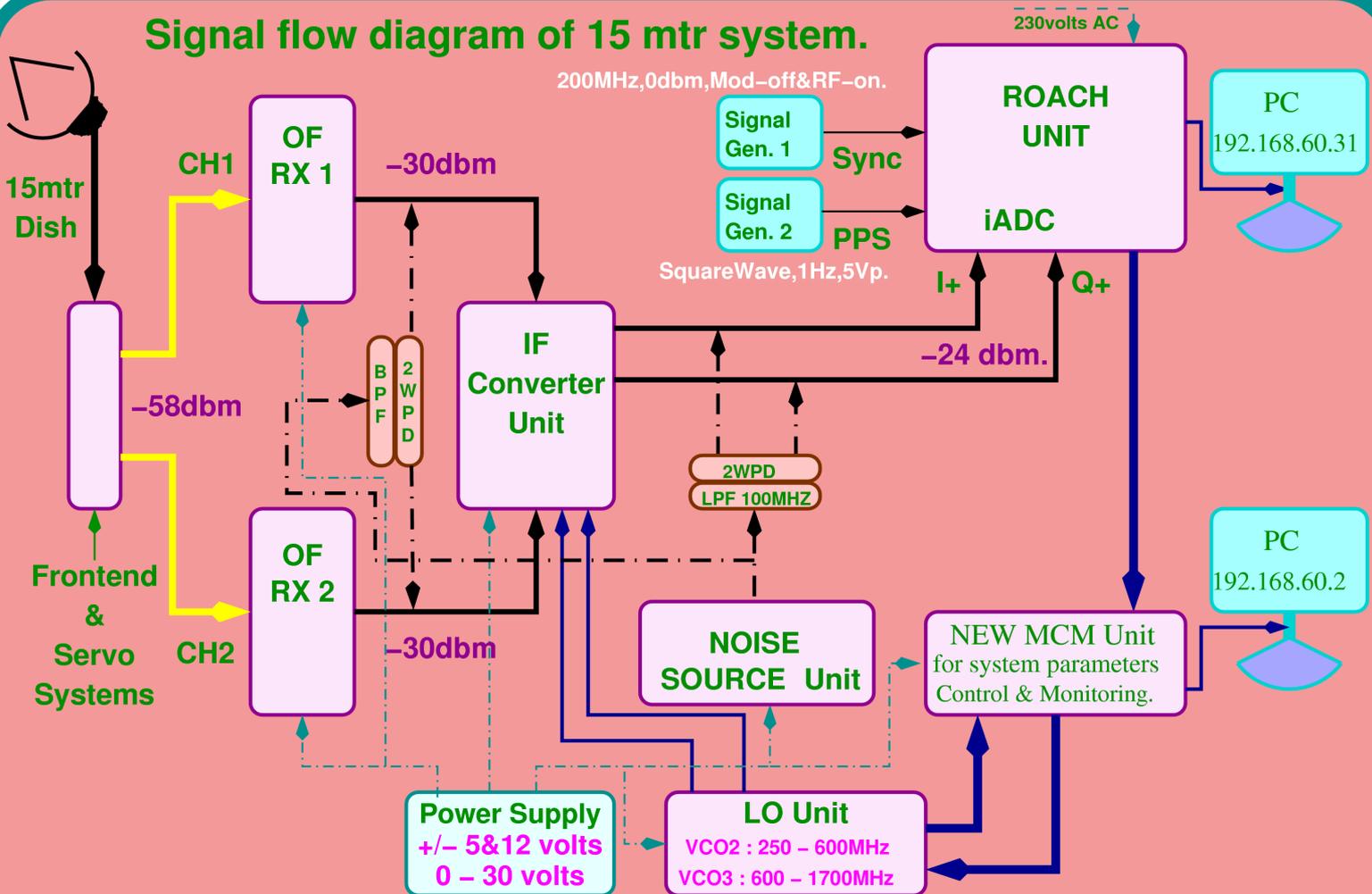
This test can be done either using antenna signals or Noise Source through BPF of 100MHz or less bandwidth & 2WPD.

- a. 10MHz LO Ref : connect 10MHz REF OUT from signal generator instrument's rear side to "ref in port" of the LO synth PIU in the Analog bin.

*(verify : will be usually connected)*

Please refer the following "[Signal flow diagram of 15mtr.](#)" and do the interconnections using appropriate cables.

## Signal flow diagram of 15 mtr system.



Note : Signal Powers mentioned in figure are Total Power over 100MHz Bandwidth.

### III : Testing through “CONTROL PC”.

#### (A) cms15m PC Login and Settings.

- LOGIN in to ctrl PC as user : cms15m passwd : cms15m
- Open two Xterm windows (*one for Backend control & another for Offline plotting*)
- Backend control terminal [cms15m@localhost ~]\$ cd  
~/roach\_scripts/roach\_scripts\_15m/IRU/15mtr/  
Dump data in the directory [cms15m@localhost ~]\$ cd /Data/
- Offline plotting terminal [cms15m@localhost ~]\$ cd  
/home/cms15m/roach\_scripts/zoom\_15m/TAX/

**NOTE : Final directory structure to be decided and modified here.**

#### (B) Initialization.

In the Backend control terminal

##### (a) help.

```
[cms15m@localhost 15mtr]$ ./init_roach.py -h
```

#####

Usage: `init_roach.py` <ROACH\_HOSTNAME\_or\_IP> [Options]

Options:

- h, --help        show this help message and exit
- M MODE, --mode=MODE        Modes:"n" for normal & "z\*" for zoom where  
                              \*=2/4/8/16/32/64/128 decimation factor
- b BOFFILE, --bof=BOFFILE  
                              Specify the bof file to load
- A ANTA, --anta=ANTA        Antenna "a" Integer Delay
- B ANTB, --antb=ANTB        Antenna "b" Integer Delay
- S SCALE, --antab=SCALE  
                              Scaling factor
- L LO, --lo=LO                LO frequency in Hz
- U BAND                        Select the band (1 for USB 2 for LSB)

**(b) usage :**

**# -m n for NORMAL(default) mode & z\* for zoom mode with DecimationFactor\*=2/4/8/16/32/64/128.**

**# use `./init_roach.py -M n/z* -A int -B int -S 74/63 -L int-Hz -U 0/1`**

**#**

<b># Spec.</b>	<b>option</b>	<b>Default</b>	<b>Remarks</b>
<b># Mode</b>	<b>-M</b>	<b>normal</b>	
<b># Delay</b>	<b>-A &amp; -B</b>	<b>0</b>	<b>for channel 1 &amp; 2 resp.</b>
<b># Scaling factor range for noise (63 for sine)</b>	<b>-S</b>	<b>74</b>	<b>This gives max. linear</b>
<b># LO</b>	<b>-L</b>	<b>50000000</b>	<b>In Hz for zoom mode</b>
<b># No. of FFTs for 1 sec. Integration.</b>	<b>-I</b>	<b>normal:195312.5</b>	<b>This option has been</b>
		<b>Zoom 2:97656.25, 4:48828.125, 8:24414.0625</b>	

only

hardcoded.

```
# 16:12207.03125, 32:6103.515625,
64:3051.7578125, 128:1525.87890625

# Upper/Lower Band -U 1 1 for Upper and 0 for
Lower
```

```
# eg1. ./init_roach.py
```

*# The above command sets all the default values mentioned above i.e. the design runs in normal mode with 1 sec integration time and 0 delay on both the channels.*

```
# eg2. ./init_roach.py -M z128 -L 781250 -U 0
```

*# The above command selects the zoom mode with decimation of 128, LO frequency of 0.78125MHz and lower band selected i.e. LO>RF*

### **(C) Data dumping and offline analysis of real time data.**

#### **(a) Data dumping for offline analysis with tax**

```
[cms15m@localhost 15mtr]$ ./acq_normal_try.py 192.168.100.40 -f
/Data/<file_name>
eg. [cms15m@localhost 15mtr]$ ./acq_normal_try.py 192.168.100.40 -f
/Data/normal_NS13dbm32MHz.dat
```

```
[cms15m@localhost 15mtr]$ ./acq_zoom_try.py 192.168.100.40 -f
/Data/128d_LO11987793Hz_U1_shm_NS26dbm781250Hz.dat
```

#### **(b) Offline Analysis using tax**

```
[cms15m@localhost TAX]$ ./xtrgsb32 -h
```

```
USAGE: ./xtrgsb32 -v visibility file -o outfile -r refant -b baselines -c chansel -t timesel -n
0/1
```

e.g. below

```
USAGE: ./xtrgsb32 -v raw.dat -o raw.out -r C00 -b C01,C02,W01,W05,S01,E05 -c
45,1100,1,5 -t 1,110,2,5 -n 1
```

: Chan selection format is start\_chan,stop\_chan,chan\_incr,chan\_integ

: Time selection format is start\_time,stop\_time,time\_incr,time\_integ

In the Offline Plotting terminal

(a) Plot self spectrum for Ch 1 – 1000

```
[cms15m@localhost TAX]$ ./xtrgsb32 -v /Data/<file_name> -c 1,1000 -t 1,10000
```

(b) Plot cross spectrum for Ch 10 – 1000  
 [cms15m@localhost TAX]\$ ./xtrgsb32 -v /Data/<file\_name> -c 10,1000,1 -t 1,5,1,5  
 -n 1 -r C00

(c) Plot cross Ch – 300 over time  
 [cms15m@localhost TAX]\$ ./xtrgsb32 -v /Data/<file\_name> -c 300 -t 1,100000000  
 -n 1 -r C00

(d) Plot required records  
 [cms15m@localhost TAX]\$ ./xtrgsb32 -v /Data/<file\_name> -c 10,1000,1 -t  
 1,57,1,57 -n 1 -r C00  
 (keep this xterm open for Offline plotting)

### **(D) Checking the 10 Gbe link for raw data dumping mode.**

Connect the ROACH board to the data acquiring PC using 10GbE cable. Connect one end of 10GbE cable's CX4 connector to the CX-4 port 0 of ROACH unit and the other end to the 10GbE card on the data acquiring PC

1. Start the wireshark program : sudo wireshark
2. Go to “Capture” / “Interfaces”
3. Now observe the large numbers against the ethernet port corresponding to 10Gbe NIC.
4. Select “Options” against the same ethernet port. and check the box after XXX packets in “stop capture” to stop capture after XXX packets.
5. Then press start to capture XXX packets for analysis.
6. Then save the packets if required.

## **IV : “CONTROL & MONITORING GUI”.**

Make sure signals - @OFC Rx units OUTPUT : -30dbm Total power over 100MHz  
 Band.

@ROACH unit INPUT : -24dbm Total power over 100MHz  
 Band.\_

- a. start control and monitoring GUI by the following way :
- i. web-browser - <http://192.168.60.2:8080/cms-web/> user : sigcon passwd :
- sigcon

The GUI has the following menu bar :

HOME DASH BOARD MESSAGE CONSOLE ALARM ENGINEERING  
 INTERFACE SETTINGS INFORMATION LINKS

ENGINEERING INTERFACE has the following submenus :

dataserver backend servo sigcon frontend sentinal  
 each of these displays the following informations :  
 Status Monitoring Parameters Raw Parameters Basic Commands  
 Detailed Commands Trend Plot

- b. Select Engineering Interface / frontend.
- Basic commands / RFBAND : to set the RF band. Bands are (MHz) : 1170 ,  
 1280 , 1390 & 1660\*
- Basic commands / RFATTN : to set the RF attenuation By default “0”.

c. Select Engineering Interface / sigcon.

Basic commands / set lo : to set the LO. Always set the LO  
60MHz less than RF band selected.

Basic commands / set attn : to set the Attenuation. Default  
attenuation 4 dbm for both the channels.

d. Select Engineering Interface / backend.

Basic commands / INIT : to Initialize the ROACH Unit.

Feed the following information.

adclock fftlen acqinteg fftshift stainteg sampgain channelstart channelstop  
channelincr sampgainctrl stokes chanavg  
submit default values.

Home / CMS control / Date monitor / Plot : Spectral line display --> start  
: refresh time for plot is 30 seconds.

\* to set the 1660 RF band enter value as 1060.

## 8. Conclusions