NATIONAL CENTRE FOR RADIO ASTROPHYSICS

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**Internal Technical Report**

# Efficient Cooling Arrangement and Integration of 30 antenna GWB system for uGMRT Digital Backend

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## Document history :

| Revision | Date | Modification / Change |
|---|---|---|
| Ver. 1.0 | 14/05/2017 | Initial version (consolidated various reports on cooling & integration on GWB system. |
| | | |
| | | |

**Objective :**

To propose a suitable cooling arrangement for the new Digiatal Backend system GWB (GMRT Wideband Backend) for the uGMRT receiver, so that the system can co-exist with the GMRT Software Backend (GSB) in the correlator room at Central electronics building (CEB).

Also to propose a suitable rack with efficient cooling arrangements for the GWB system and to provide in-depth details about the integration of GWB system.

## Index

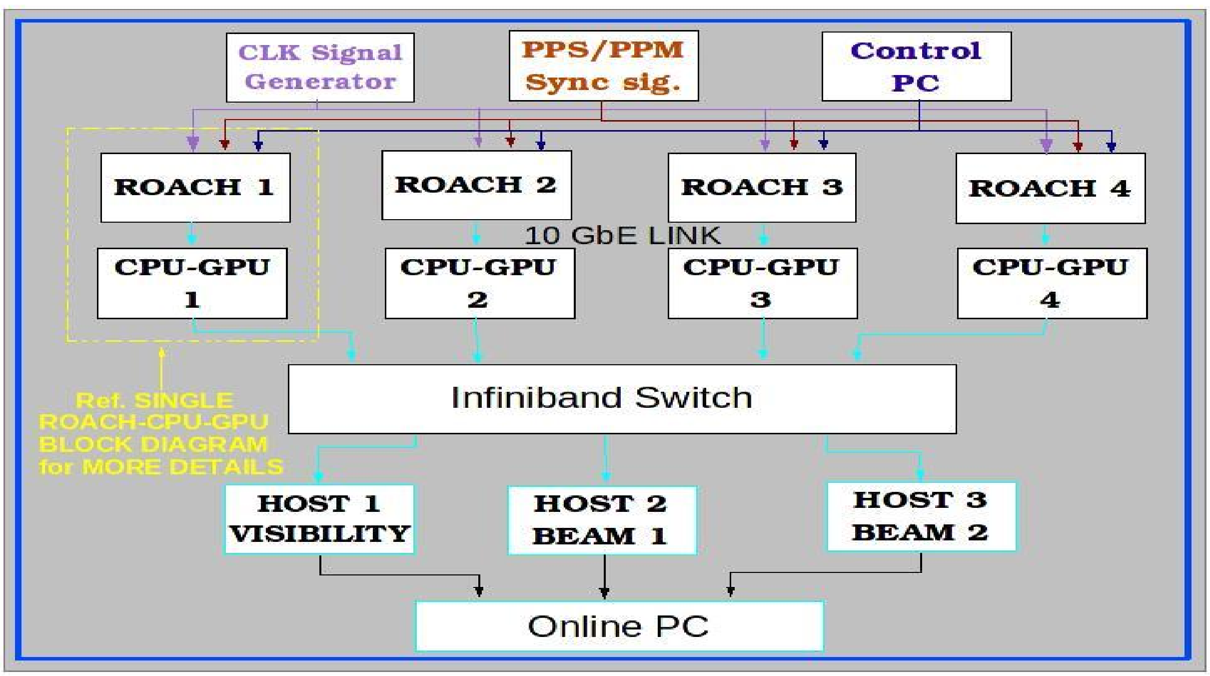
# A. Introduction.

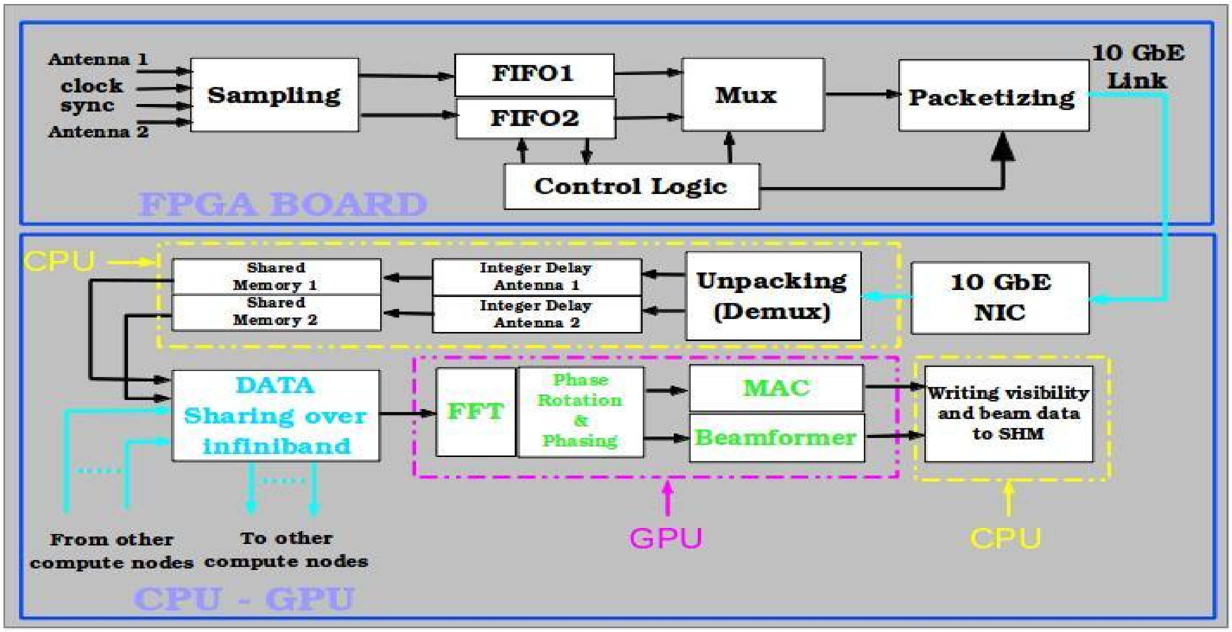
**GWB sytem.**

As part of GMRT upgradation (uGMRT), the back-end systems are undergoing major changes to achieve the specifications like increased bandwidth of 400MHz, direct processing of RF signals, increased dynamic range, improved channel resolution. The digital backend part of this upgrade named as GWB(GMRT WIDEBAND BACKEND). This is a 30-antenna dual polarization correlator.

The design is a hybrid one using FPGAs and CPU-GPUs for various processes in the digital back-end chain. FPGAs connected with ADCs perform the digitisation and packetising the data, while CPU-GPUs acquire the data, perform correlation and record the visibilities and beamformer output data onto a disk for post-processing and analysis. The implementation is a time-slicing model, where each compute node gets a slice of contiguous time series data from all the antennas, on which it performs spectral conversion, correlation and Incoherent Array (IA) and/or Phased Array (PA) beamformation operations. For narrowband mode observations, the data is digitally down-converted and decimated before the spectral conversion stage. Dedicated 10 Gigabit Ethernet links are used for transferring digitized data from the FPGAs to the compute nodes, while a 40 Gbps Infiniband network is used for both redistribution of data for time slicing, and gathering of results onto the host nodes for final recording. Figure 1 shows the top level design of the GWB.

**Block Diagrams :**






## Study of efficient cooling, electrical power consumption and integration of GWB system.

To accommodate the 30 antennae GPU based GWB system with the existing GSB system in the correlator room, it was necessary to do a detailed study of the power consumption, efficient cooling and specifications & placement of the racks in the correlator room.

This report is to document all the calculations, tests, measurements and analysis done before integrating, testing and releasing the GWB system for astronomical use. This report also documents about the units, cables etc.. used in the system. And also explains the factors considered in deciding the various things like placement of units in the racks, cables movement within & inter racks, provisions for future expansions, utilization of infrastructure etc.. to achieve the following things :

1. Use the infrastructure available with us to it's best, in such a way that, we will be able to meet our specific goals & expectations.
2. By doing simple modifications / additions to racks, bring down the cost of racks to be acquired.
3. Reduce the running cost of AC plant by utilizing the cool air efficiently. And
4. Reduce the failure of components by providing sufficient & regular cooling at all points in a rack and all the time.

## B. Efficient Cooling Study :

To accommodate the 30 antennae GPU based GWB system with the existing GSB system in the correlator room, it was necessary to do a detailed study of the power consumption, efficient cooling and specifications & placement of the racks in the correlator room.

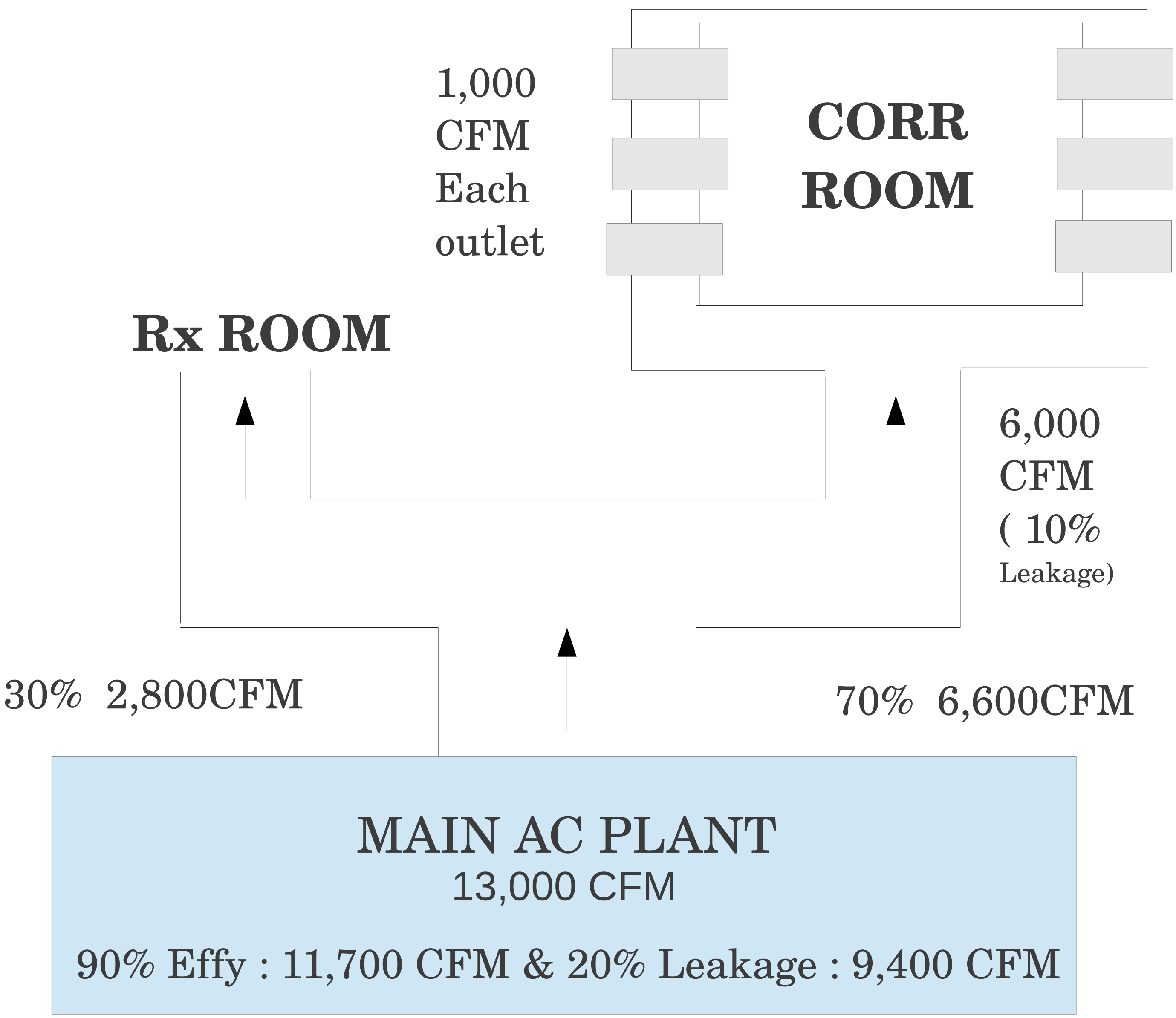
Started with the theoretical calculations of the cool air flow at each outlet. Capacity of AC plant is 1300 cfm (Cubic Feet per Minute). The cool air coming out from the AC plant is split between correlator and receiver rooms in the ratio of 70:30. By considering 90% efficiency of the AC plant and 20% leakages in the duct, the air reaching the correlator room is 6,000cfm. There are 6 ducts in the correlator room. So 1,000 cfm of cool air is expected from each outlet.

To study the cool air flow, specifications and design of the racks to be procured, one rack of 42U ( HxWxD - 2065mm x 600mm x 1000mm ) has been modified to carry out the heat load test. And also to decide the placement of units in the rack and placement of racks in the correlator room. 4 hellogen lamps of 1KW each have been used for this test.

Aim was to findout the cool air available at various locations & it's heat absorption capacity, which depends on the humidity and temperature of the cool air. And thereby deciding whether this is sufficient to dissipate the heat, which will be generated by 30 antennae GWB system. If cool air is not sufficient, ways to achieve it. Also to decide the placement of racks in the correlator room by considering various factors like cool air inlets, hot air exhausts, cables movement mainly inter racks and space for man-meterial movements.

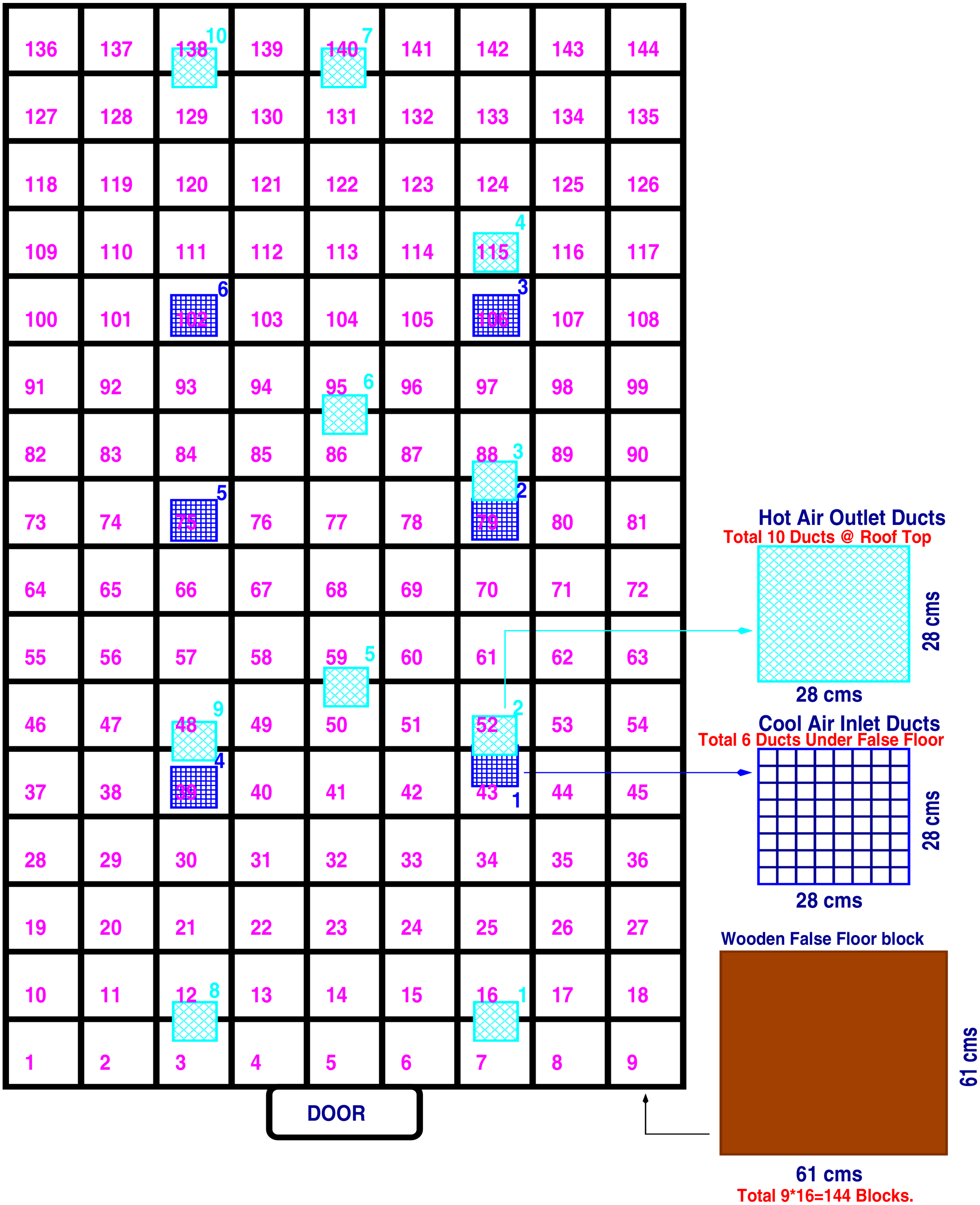
These theoretical and practical calculations were re-evaluated using the air flow meter. Finally all the calculations, exprriment results and measured values are matching.

**1. AC distribution layout.**




**AC Plant : Air Handling Unit (AHU) capacity 13,000 Cubic Feet per Minute (CFM).**

## 2. Correlator Room Floor diagram.




Note : outlet rooftop duct number 2 has been moved at above the floor tile number 75 in the month of October 2016 to facilitate the outlet hot air from GWB racks 1 & 2 to go out through hot air duct.

## 3. Theoratical Calculations.

For this theoratical calculations, we have considered the following as inputs :
1. Maximum heat energy from GWB system is 21,500 watts.
2. Cool air entering the correlator room is 6000 CFM (Cubic Feet per Minute).
3. Difference in temperature of air in the corr room = 15 DegCel from inlet to outlet.
4. Constants :
   a. 1 Joule = 0.238902957619 calories.
   b. 1 ft^3 = 0.02832 mtr^3
   c. average Air density is 1.128666667 kg/mtr^3 for average temperature of 17.5 DegCel.
   d. Specific Heat of air @ 20 DegCel & 1 pascal is 240 calories/kg degree celsius.

**A. Maximum Total Heat Energy in calories/min. from the GWB system.**

Total Heat Energy in Joules/min. = Total Power consumption * 1 minute
= 21,500 watts * 60 sec. = 12,90,000 Joules/min.

1 Joule = 0.238902957619 calories , 1 calorie = 4.186 joules .

Total Heat Energy in calories/min. = 12,90,000 * 0.238902957619 = 3,08,185 calories/min.

**B. Heat Absorption of the cool air in calories/min. from the AHU(AC Plant).**

| Heat Absorption of the cool air = | mass kg/min. | * | Specific Heat of air Calories/kg degree celsius | * | Diff. in temp. degree cel. |
|---|---|---|---|---|---|

a. “mass”
   mass = Air Density kg/mtr^3 * Volume mtr^3/min. = kg/min.

i. Air Density in kg/mtr^3 :

http://www.weatheronline.in/weather/maps/city & http://www.denysschen.com/catalogue/density.aspx

Air Density @ Pune (above sea level of 1837 feet or 560 mtrs and relative humidity varies between 24 to 94 % in the year 2014) for average relative humidity of 59%) is ....

| Temperature in DegCel | Air Density in kg/mtr^3 @ pressure of 1 pascal |
|---|---|
| 10 | 1.16 |
| 17 | 1.13 |
| 25 | 1.096 |

So average Air density is 1.128666667 kg/mtr^3 for average temperature of 17.5 DegCel.

ii. Air Volume in mtr^3/min :

   1 ft^3 = 0.02832 mtr^3 & 1 mtr^3 = 35.31467 ft^3
So volume of cool air reaching corr. Room = 6,000 ft^3/min. = 169.92 mtr^3/min.

So mass of cool air = 1.128666667 * 169.92
reaching corr. Room kg/mtr^3 mtr^3/min.

= 191.783040057 kg/min.

b. “Specific Heat of air = 240 calories/kg degree celsius.
@ temp. of 20degree cel. &
pressure of 1 pascal
*www.usc.edu/org/.../Heat%20Capacity%20and%20Specific%20Heat.pdf* , *http://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html*

c. “Diff. in temperature = 25 – 10 = 15 degree celsius
of corr. Room

So,

Heat Absorption = 191.783040057 * 240 * 15
of the cool air kg/min. Calories/kg per DegCel. DegCel.

= 6,90,419 calories/min.

So,
Heat Absorption of the cool air from each outlet = 6,90,419 / 6
in the correlator room = 1,15,070 Calories/min.

**Conclusion :**
a. Heat absorption of cool air from each inlet of 1000 CFM and inlet to outlet temperature difference of 15 DegCel is 1,15,070 Calories/minute.

b. So to absorb 3,08,185 calories/min. of heat generated by GWB system, we need 2.68 (308185÷115070) cool air inlets. Each inlet of 1000 CFM cool air.

## 4. Practical Measurements.

For this practical measurements, we have used the Heat load of 4000 Watts. Maximum GWB power consumption is 21,500 watts or 3,08,185 calories/minute(refer "GWB rackwise power consumption").

**A. Using 3 fans of 100cfm each to suck the cool air in the aluminium cage in the rack.**

We got the temperature difference of 15.5 degreeCel. So
Volume of cool air per inlet in the correlator room is 482 Cubic Feet/Minute instead of 1000CFM !!!

Total Heat Energy --> 3,08,185 calories/minute
Heat Absorption by 482cfm Cool Air --> 57,312 calories/minute
So 5.38 inlets with cool air of 482 CFM are required !!!

**B. Using 2 fans of 600cfm each to suck the cool air in the aluminium cage in the rack.**

If these fans are at 2' height of the al. cage, then the temperature difference is 5.4 degCel.
If moved these fans at the bottom of the rack and kept this 2' height slot in the al. cage open, then the temperature difference is 9.21degCel. This temperature increases by around 1 degCel, if we put 3 fans of 100cfm each at the open slot in the al. cage!

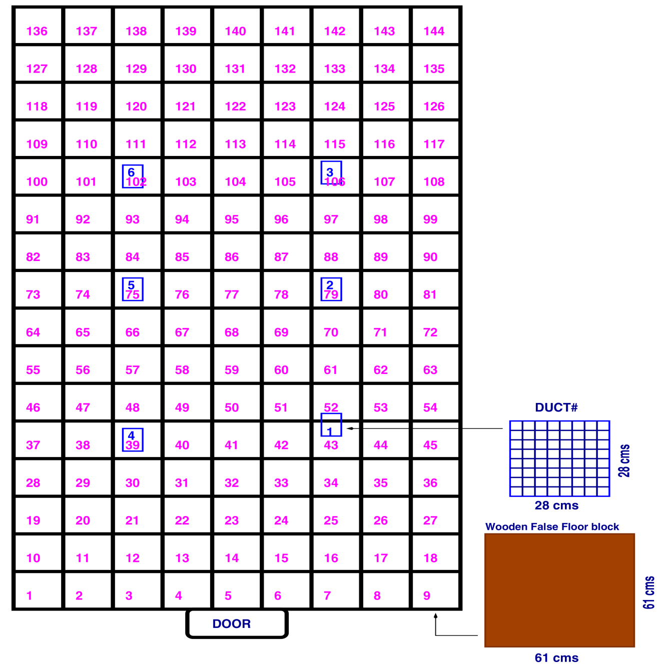
If we take 5.4 degCel., then

a. Volume of cool air per inlet in the correlator room is 1384 CFM.
b. Heat Absorption by 1384 CFM Cool Air is 1,64,565 calories/minute.
c. So 1.87 inlets with cool air of 1384 CFM are required.

If we take 9.21 degCel., then

a. Volume of cool air per inlet in the correlator room is 812 CFM.
b. Heat Absorption by 812 CFM Cool Air is 96,551 calories/minute.
c. So 3.19 inlets with cool air of 812 CFM are required.

## 5. Air flow measurement using anemometer.




For air flow measurement in the correlator room, we have used “ Pitot Tube Anemometer + Differential Manometer HD350” from Extech Instruments. Measured the air flow volume over the duct number 1 and 3. Using this meter, we measured air flow at 5 points in the duct (4 corners and at the centre about half a foot height) and took average of those readings. It was around 1600cfm & 1200cfm from duct number 1 & 3 respectively.

Detailed measurement of air flow from AC plant to end points in Correlator & Receiver rooms needs to be done at various possible locations. This will give the complete and exact know how about the cool air volume at different locations and leakages.

The air flow measurement procedure is explained in apendix “VI Air Flow Meter User Manual”

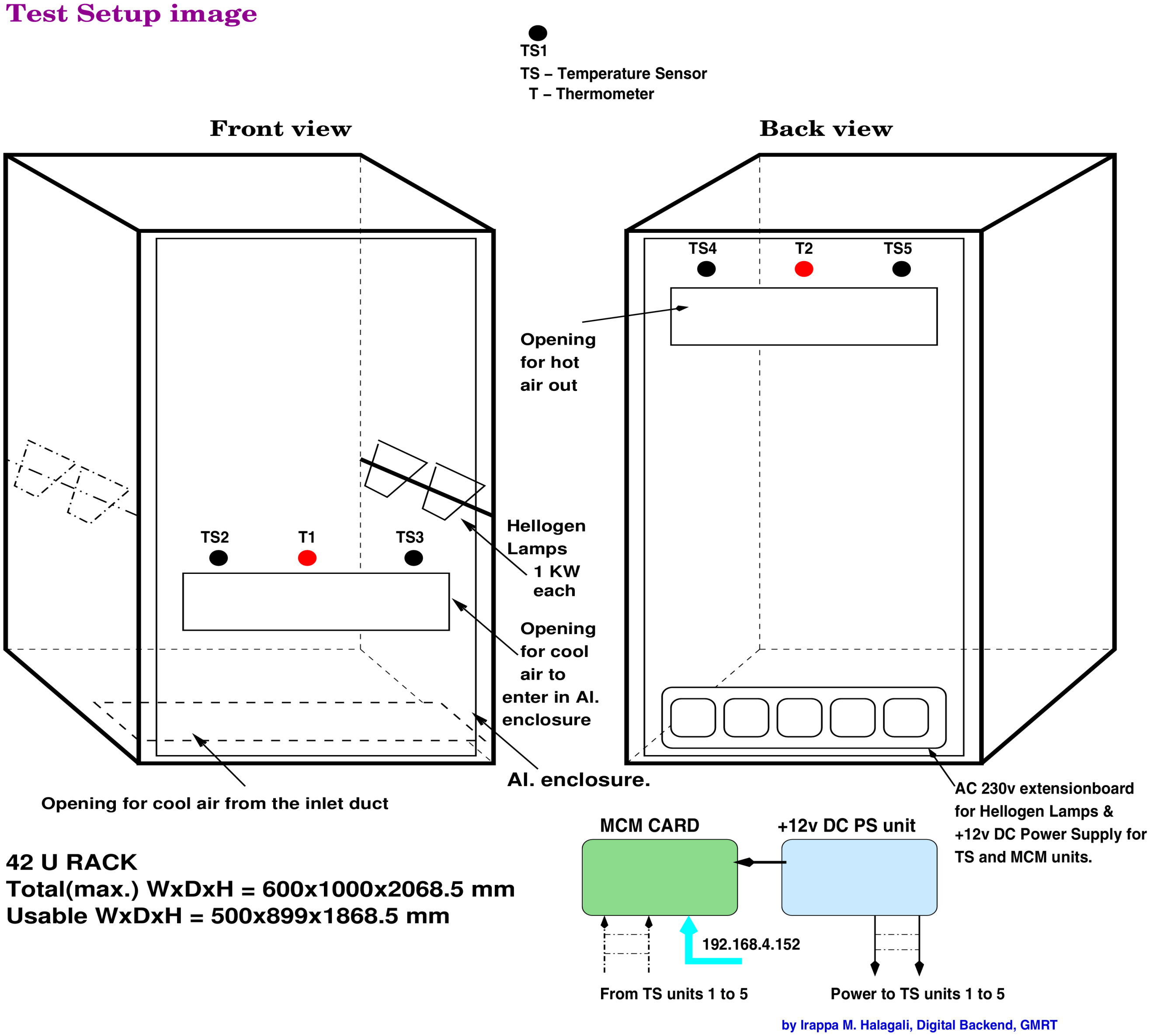
## 6. Summary of experiment results.

A quick summary of the test results is,

a. for a power dissipation of about 4KW per rack ( refer topics“4. GWB modelwise & 5. GWB rackwise Power Consumption”), the maximum outlet air temperature will be of the order of about 25 degCel., while the maximum inlet temperature is 10 degCel. More details are given in Appendix 3 : Summary of Daily Readings.

b. Volume of cool air from each duct in correlator room as per theoritical assumption is 1000cfm. It is 1600cfm as per the measurement done using air flow meter over the duct at duct no. 1 (which is 1200cfm over duct no. 3). As per the setup 3a (refer apendix II experiment setup details) , we gets a temperature difference of 9.21DegCel. This results in the volume of cool air as 812cfm. The cool air volume using meter is around 600cfm(5' away from the duct).

### Test Setup image



## C. Power Consumption Study.

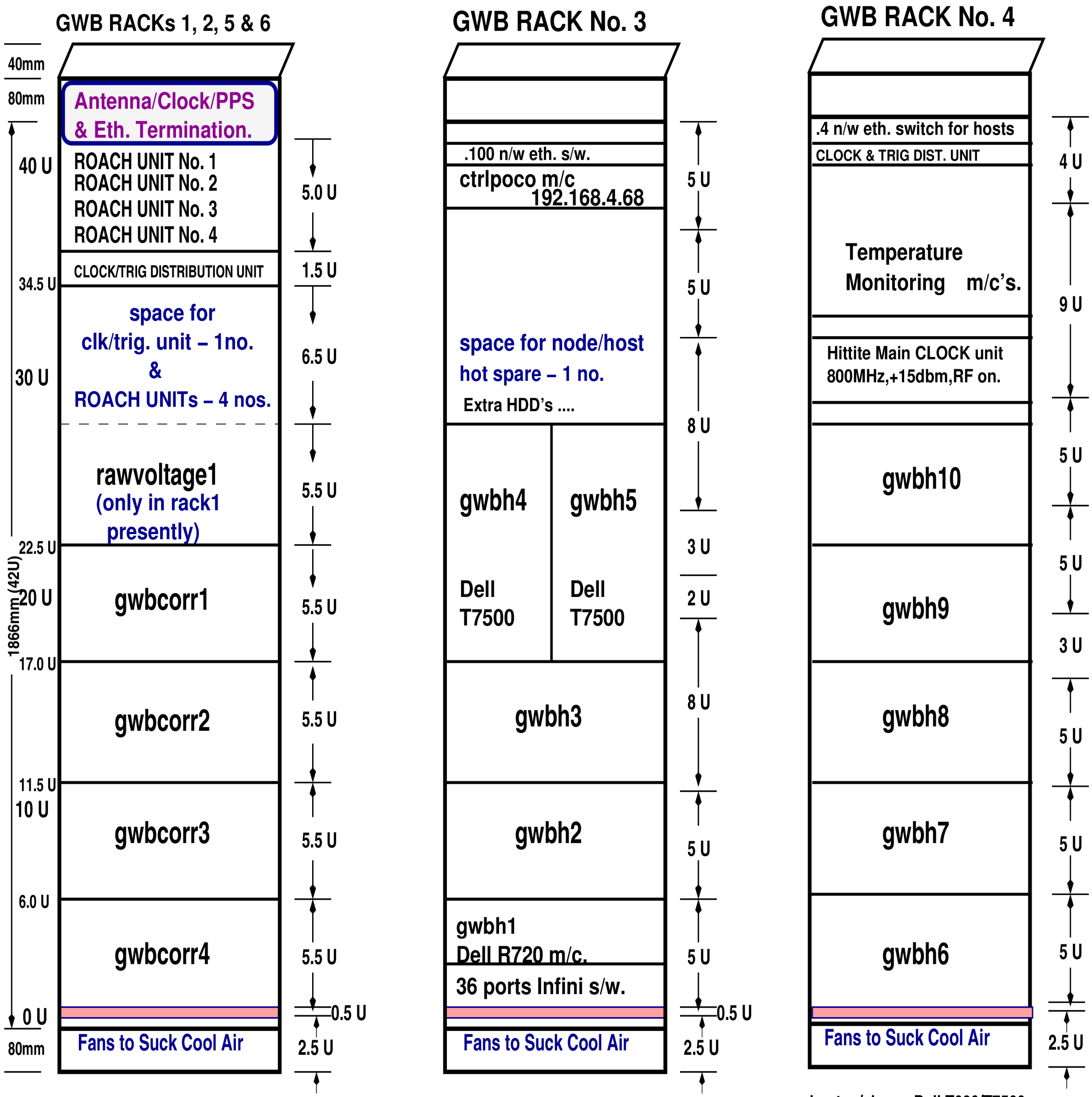
The theoretical calculations of electrical power consumption was done by refering the datasheets of each units being used in the GWB system. How many racks are required and what is the maximum and typical heat generated from each rack. Units are distributed between the racks such that the heat genereted from each rack should be almost equal and also consided other factor like internal and intra rack cables, space for future expansions/changes etc.. By considering all these points, we have decided to have 6 racks for the GWB system. The power consumption from each rack restricted to around 2.5 KW and 0.5 KW for addition in future. 20KVA UPS is feeding electrical power to the whole GWB system along with some test setups. To be safer side, we shouldn't drawn more than 16KVA ie 80% of 20KVA from this UPS.

We have measured the electrical power consumption by each GWB rack. With correlator code running, the power consumption fluctuates between 60% to 83%, and when the system isn't under use, it is around 54%.

### 1. Units/Instruments in the GWB System.

| Rack No. | | GWB 30 Antenna System |
|---|---|---|
| | Rack Name | Model/Unit Names |
| 1 | Pol.1 : C sq + E2 & E3 antenna's | Dell T620/T630 with K20/40 GPU cards - 4 nos., Dell T630 -1 no., ROACH unis with 2 iADC cards – 4 nos., .100 n/w ethernet s/w – 1 no. and Clock & Trigger Distribution unit -1 no., & Fans of 360cfm – 4nos. |
| 2 | Pol.2 : C sq + E2 & E3 antenna's | Dell T620/T630 with K20/40 GPU cards - 4 nos., ROACH unis with 2 iADC cards – 4 nos., .100 n/w ethernet s/w – 1 no. and Clock & Trigger Distribution unit -1 no., & Fans of 360cfm – 4nos. |
| 3 | Host Machines (Recording) | Dell T620/T630/T7500 w/o K20/40- 5 nos., .4 & .100 n/w eth. s/w – 1 no each., Infiniband 36p s/w–1no.,& Dell PER210 - 1no., HDD's&Fans of 360cfm–4nos. |
| 4 | Host Machines (Monitoring) | Dell T620/T630 w/o K20/40- 5 nos., .4 n/w switch – 1no., Clock and Trigger Master unit -1 no., PC's for temp monitor., & Fans of 360cfm – 4nos. |
| 5 | Pol. 1 : E4 to E6 and S & W arm antenna's | Dell T620/T630 with K20/40 GPU cards - 4 nos., ROACH unis with 2 iADC cards – 4 nos., .100 n/w ethernet s/w – 1 no. and Clock & Trigger Distribution unit -1 no., & Fans of 360cfm – 4nos. |
| 6 | Pol. 2 : E4 to E6 and S & W arm antenna's | Dell T620/T630 with K20/40 GPU cards - 4 nos., ROACH unis with 2 iADC cards – 4 nos., .100 n/w ethernet s/w – 1 no., and Clock & Trigger Distribution unit -1 no., & Fans of 360cfm – 4nos. |
| 7 & 8 | Misc.. | Extensions 1 & 2 ( Pocketized correlator etc...) & Tube lights. |

An image dipicting the units in the GWB racks.




gwbcorr node machines are Dell T620/T630.
.100 n/w eth. s/w. at rear side of clk/trig. unit in each rack.

host m/c's are Dell T620/T7500.
.4 n/w eth. s/w. at rear side of .100 n/w eth s/w.

host m/c's are Dell T620/T7500.

GWBunitsInRacks.fig
IMH 10/07/2017.

## 2. GWB Modelwise Power Consumption.

As per the datasheets or webpages the power consumption of the units used in the GWB system mentioned below.

### Model wise Power consumption by GWB 30 Ant. System.

| | Power Consumption/Model | | Total | | Total Power Consumptin | |
|---|---|---|---|---|---|---|
| **Model Name** | **Typical** | **Maximum** | **Models** | | **Typical** | **Maximum** |
| Dell T620 Nodes | 369 | 628 | 16 | | 5,904 | 10,048 |
| Dell T620 Hosts | 369 | 628 | 3 | | 1,107 | 1,884 |
| K20 GPU Cards | 105 | 225 | 32 | | 3,360 | 7,200 |
| Myricom 10GbE Single Port | 5 | 5 | 32 | | 160 | 160 |
| Melox infiniband NIC card | 2 | 2 | 19 | | 38 | 38 |
| ROACH Board (1 ADC) | 50 | 60 | 32 | | 1,600 | 1,920 |
| ADC in ROACH Boards | 1.5 | 1.5 | 32 | | 48 | 48 |
| Melox infiniband 32P Switch | 3 | 3 | 1 | | 3 | 3 |
| Signal Generator (N9310A) | 65 | 65 | 1 | | 65 | 65 |
| PPS unit & misc.. | 50 | 100 | 1 | | 50 | 100 |
| | | | | G. Total | 12,335 | 21,466 |

## 3. GWB Rackwise Power Consumption.

As per datasheets ..

### Rack wise Power consumption by GWB 30 Ant. System.

| | | Power Consumption/Model | | Total | | Total Power Consumptin | |
|---|---|---|---|---|---|---|---|
| **Rack Number** | **Model Name** | **Typical** | **Maximum** | **Models** | | **Typical** | **Maximum** |
| **1 to 4** | Dell T620 Nodes | 369 | 628 | 4 | | 1,476 | 2,512 |
| | K20 GPU Cards | 105 | 225 | 8 | | 840 | 1,800 |
| | Myricom 10GbE Single Port | 5 | 5 | 8 | | 40 | 40 |
| | Melox infiniband NIC card | 2 | 2 | 4 | | 8 | 8 |
| | ROACH Board (1 ADC) | 50 | 60 | 8 | | 400 | 480 |
| | ADC in ROACH Boards | 1.5 | 1.5 | 8 | | 12 | 12 |
| | | | | | Sub Total 1 | 2,776 | 4,852 |
| **5** | Dell T620 Hosts | 369 | 628 | 3 | | 1,107 | 1,884 |
| | Melox infiniband NIC card | 2 | 2 | 3 | | 6 | 6 |
| | Melox infiniband 32P Switch | 3 | 3 | 1 | | 3 | 3 |
| | Signal Generator (N9310A) | 65 | 65 | 1 | | 65 | 65 |
| | PPS unit & misc.. | 50 | 100 | 1 | | 50 | 100 |
| | | | | | Sub Total 2 | 1,231 | 2,058 |
| | | | | | **G. Total** | **12,335** | **21,466** |

## 4. Measurement of Power Consumption.

Measurement of electric power usage by the correlator systems.  PF = 0.8

**A. GWB system :**

**UPS 1** , max. 78% of 20 KVA, under use for tests ie 15.6KVA or 12.48 KWatts.
Row 1 (Top) : 29.2 Amps and Row 2 (Bottom) : 32.1 Amps  Total : 61.3# Amps
61.3Amps * 230Volts = 14.099 KVA   OR 11.28 KWatts  ie 71%

| Sl. No. | Distribution board | Current in Amps | Remarks |
|---|---|---|---|
| 1 | GWB rack-1 : ROW1(top), MCB No. 1 | 12.2 | P=0.8*12.2*230=2245 wats |
| 2 | GWB rack-2 : ROW1(top), MCB No. 2 | 10.6 | |
| 3 | GWB rack-3 : ROW1(top), MCB No. 3 | 3.6 | |
| 4 | Ext Board 1  : ROW1(top), MCB No. 4 | 0.6 | |
| 5 | GWB rack-4 : ROW2(top), MCB No. 1 | 7.9 | |
| 6 | GWB rack-5 : ROW2(top), MCB No. 2 | 10.1 | |
| 7 | GWB rack-6 : ROW2(top), MCB No. 3 | 10.6 | |
| 8 | Ext Board 2  : ROW2(top), MCB No. 4 | 2.4 | |
| | Grand Total | 60.0* | |

**B. GSB system :**

**UPS 3** , max.64%  of 12.5 KVA, under use for tests ie 8KVA or 6.4 KWatts
Row 1 (Only) : 29.8# Amps
29.8 Amps * 230Volts = 6.854 KVA  OR  5.483 KWatts   ie 55%

| Sl. No. | Distribution board | Current in Amps | Remarks |
|---|---|---|---|
| 1 | GSB EXT 1 : ROW1, MCB No. 1 | 0.5 | |
| 2 | GSB rack-1(EB1) : ROW1, MCB No. 2 | 4.0 | |
| 3 | GSB rack-1(EB2) : ROW1, MCB No. 3 | 6.4 | |
| 4 | GSB EXT 2 : ROW1, MCB No. 4 | 0.9 | |
| 5 | GSB rack-4(EB3) : ROW1, MCB No. 5 | 6.1 | |
| 6 | GSB EXT 4 : ROW1, MCB No. 6 | 1.9 | |
| 7 | GSB rack-4(EB2) : ROW1, MCB No. 7 | 1.8 | |
| 8 | GSB rack-4(EB1) : ROW1, MCB No. 8 | 3.7 | |
| | Grand Total | 25.3* | |

**UPS 2** , 56% of 20 KVA, under use for tests ie 11.27 KVA or 8.96 KWatts
Row 1 (Top) : 27.8 Amps and Row 2 (Bottom) : 17.0 Amps Total : 44.8 Amps#
44.8 Amps * 230Volts = 10.304 KVA OR 8.2432 KWatts ie 41.2%

| Sl. No. | Distribution board | Current in Amps | Remarks |
|---|---|---|---|
| 1 | GSB rack-2(EB3) : ROW1(top), MCB No. 1 | 7.3 | |
| 2 | GSB rack-3(EB1) : ROW1(top), MCB No. 2 | 5.8 | |
| 3 | GSB rack-2(EB1) : ROW1(top), MCB No. 3 | 5.8 | |
| 4 | GSB EXT 1 : ROW1(top), MCB No. 4 | 1.6 | |
| 5 | GSB EXT 2 : ROW1(top), MCB No. 5 | -- | |
| 6 | GSB EXT 26 : ROW1(top), MCB No. 6 | 2.1 | |
| 7 | GSB EXT 27 : ROW1(top), MCB No. 7 | 0.7 | |
| 8 | Lamps : ROW1(top), MCB No. 8 | 0.1 | |
| 9 | GSB EXT 3 : ROW1(top), MCB No. 11 | 0.2 | |
| 10 | GSB rack-3(EB2) : ROW2(Bottom), MCB No. 1 | 4.8 | |
| 11 | GSB rack-2(EB2) : ROW2(Bottom), MCB No. 2 | 7.6 | |
| 12 | GSB rack-3(EB3) : ROW2(Bottom), MCB No. 3 | 3.5 | |
| 13 | Lamps : ROW2(Bottom), MCB No. 8 | 0.2 | |
| | Grand Total | 39.7* | |

# : Maximum on this day with current usage.
* : Current varies during system use.

Note : As per UPS outputs, UPS2's 56% of 20KVA and UPS3's 64% of 12.5KVA ie. 11.27KVA & 8.0 KVA respectively. So total power consumption by GSB system is 19.27 KVA ie 15.416 KWatts .

Conclusions : So GWB & GSB respcectively consumes a power of ~12.5 KW (15.6 KVA) and ~15.5 KWatts (19.3 KVA). And total power consumption in the correlator room is ~ 28 KWatts or 35 KVA (15.6 + 11.27 + 8.0 = 35 KVA)

If Power Factor is 0.8, then total power consumption by GSB+GWB system is : 28.0 KW ie 35 KVA.

# D. GWB System Integration.

Integration of 30 antenna GWB system started with procuring 6 racks of Height x Width x Depth – 2065mm (42U+4.45 U) x 600mm x 1200mm from Jyoti Tech Industries, Rabale, Navi Mumbai. The maximum usable space is HxWxD – 1822.5mmx495mmx710mm.

While the racks getting customized at GMRT, the process of acquiring the material/units and cables required to accomplice the integration of 30 antennae GWB system was in progress. Once these works completed, we started the integration of racks one by one.

We completed intergration of 3 racks , which can work as 16 antennae GWB system was moved inside the correlator room and started testing the same for about 30 days till half yearly maintenance period. During this period of time, the required modifications done in the software and started testing the 30 antenna system (old 16 antenna and new 16 antenna). This gave us an opportunity to modify the software for the complete 30 antenna GWB system, creating the SOPs along with testing, apart from actual load test on the UPS and AC plant units. At the same time modificaiton and integration of another 3 racks also completed.

Once all the 6 racks are inside the correlator room, decommisioned the existing 16 GWB system in the half height racks and moved all the units into new racks. All the 6 racks are integrated and installed in it's final location. The arrangement to suck the cool air at the bottom-front and hot air exhaust at the top-back of racks using 360cfm fans has been done. These can been respcectively called as cool air and hot air channels/aisles. Then started the testing of GWB system. Initially made sure the working of 16 antenna GWB system is back to it's origianal status and released for observation. Then testing of next half of 16 antenna and whole of 30 antenna tests and validation started before releasing the 30 antennae GWB system for user trials and observation.

## 1. Racks requirement, configuration and modifications.

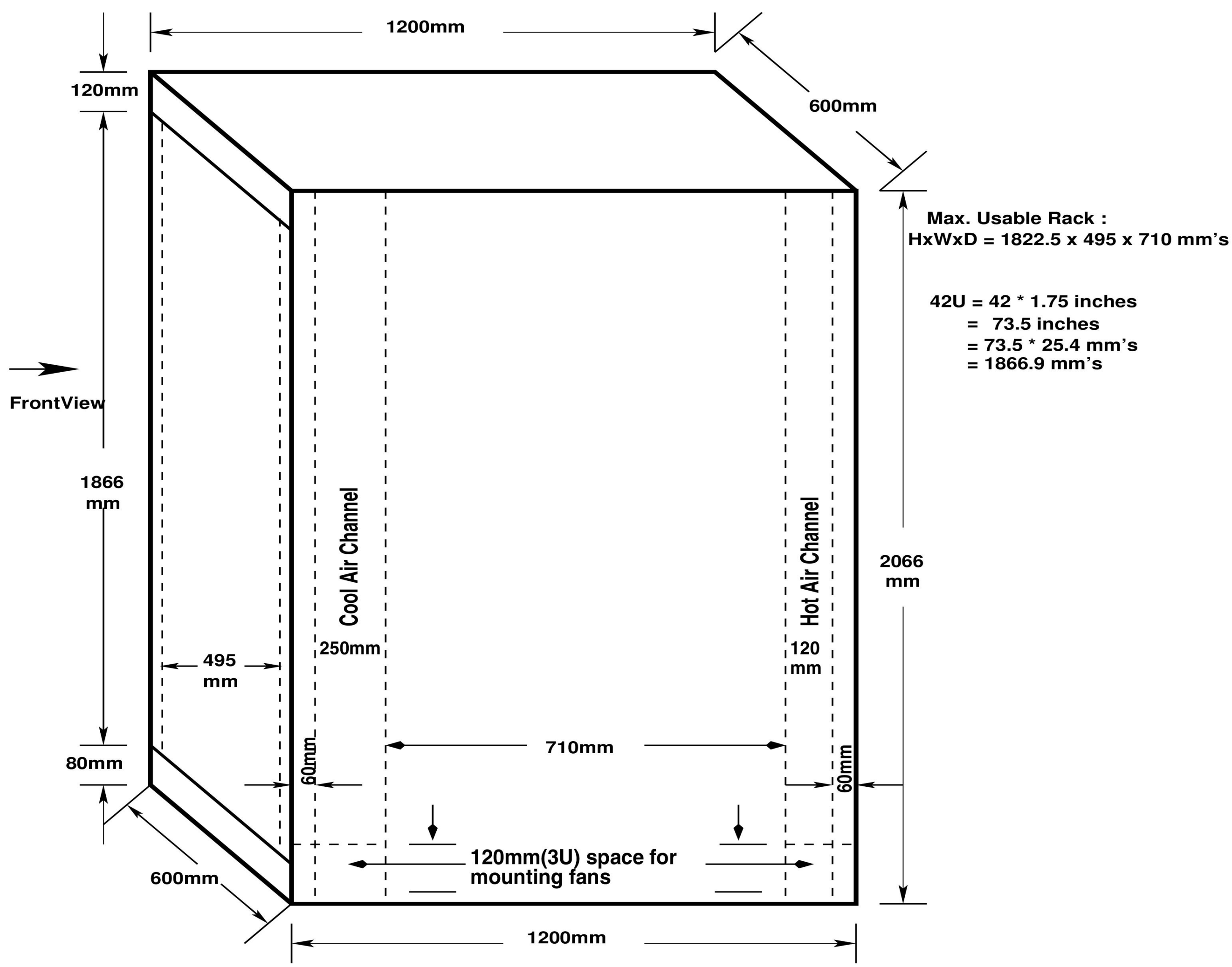
**i. Racks requirement :**

Based on the tests and design of the GWB system, the following things are the basic requirements expected in the racks.

1. **Height x Width x Depth – 2065mm (42+4.45 U) x 670mm x 1195mm**
Height – Take care of room height from false floor and also it should pass through the door.
Width – Tow fans of ~350cfm can be mounted at the front / 3 fans of 100cfm at the backside + margings between fans and at the end of rack (sliding/mounting arrangement bars)
Depth – Front Door closing clearance + ~350cfm fans mounting / cool air channel + max. Depth req. for units + Connectors / 100cfm fan mounting to suck some cool air and push the hot air up to aviod mixing / stayback of air + Back Door closing clearance.
2. Make sure the rack passes through the main door.
3. Vertical mounting arrangement for units should be in step of half a Unit ie 22.22mm. <u>Also mounting bars should be moveable horizontaly, so that we can decide the cooling and hot air channels.</u>

4. Mounting arrangement for Machines using sliding bars and ROACH/Switch using aluminum angles or readymade better options available.
5. Cable Routing inside the Rack (take care of cables length)
6. Cable In/Out from the Rack at Top & Bottom and Front & Back
7. Fans Mouning : ~350cfm at the Rack's front bottom to suck the cool air into the cool air channel, 100cfm at back bottom(if req.) and 100cfm at the back top to suck out the hot air from the rack's hot air channel.
8. Power Distribution Board's mounting arrangement at Rack's Backside.
9. Temperature Monitors in and around Rack.
10. Make sure Doors can be closed to maintain cool air inside and no leakages of cool air at front (if req. close the gaps between units at the bottom and top of the rack to force the cool air through the units
11. Rubber cushion at the rack's bottom to plug the cool air leakout between false floor and rack's bottom.
12. Hot air exhaust opening at the rack's top backside center.
13. Arrangement for conneting hot air exhaust to the exhaust ducts in the roof top.

**ii. Racks configuration :**



http://www.computerhope.com/jargon/num/1u.htm

| Unit | Dimension (W x H x D) | | | | |
|---|---|---|---|---|---|
| **1U** | 19" x 1.75" x 17.7" | | 19" x 1.75" x 19.7" | | 19" x 1.75" x 21.5" |
| **2U** | 19" x 3.5" x 17.7" | | 19" x 3.5" x 20.9" | | 19" x 3.5" x 24" |
| **3U** | 17.1" x 5.1" x 25.5" | **4U :** | 19" x 7" x 17.8" | | 19" x 7" x 26.4" |
| **5U** | 19" x 8.34" x 19.67" | | 19.1" x 8.75" x 26.4" | **6U :** | 19" x 10.5" x 19.5" |
| **7U** | 17" x 12.2" x 19.8" | | | | |

**1U = 44.45mm = 1.75 inch**		**1 inch = 25.4mm.**

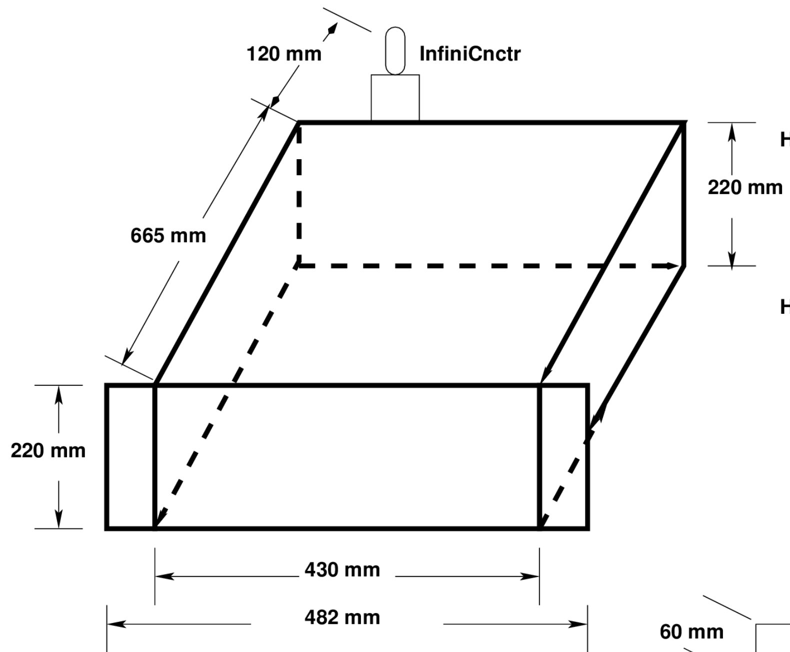
### iii. Racks modification :

The following modificaiton have been done in the new racks based on the tests and design of the 30 antenna GWB system.

1. Two fans of 22mm dia., mounting arrangement with mesh in the backside centre of top cover. And cutting the fixing angles which obstructs the mounting of fans.
2. Two fans of 22mm dia., mounting arrangement with mesh in the bottom cover at front.
3. One hole of about 50mm diameter with rubber gland grommet for enter/exit of cables such as power, antenna signal, ethernet, RJ6 etc.., at the rack's front-top-left (front view).
4. One hole of about 40mm diameter with rubber gland grommet for infiniband cables enter/exit at the rack's rear-bottom-left (rear view).
5. Cables Termination plate with Screen Printing of name/number of Antennae at the front top. All the antenna signal, pps & clk cables entering the rack gets terminated here.
6. Fixing of all the side plates inside the rack with grub screws.
7. Slot in the side Plate (which are at front inside of rack) for cables movement.
8. An aluminium plate to close the gap between units at the middle of rack.
9. An aluminium plate to close the gap behind the fans mounted in the bottom cover.
10. An arrangement to close the gap between the rack and false wooden floor.
11. Metal block to rack's legs (4 no's per rack) to increase the height.
12. Aluminium funnel to bring the cold air from inlet ducts to the racks. One from inlet number 5 to racks 1 & 2. Another from inlet number 4 to racks 5 & 6.

## 2. Units and specifications.

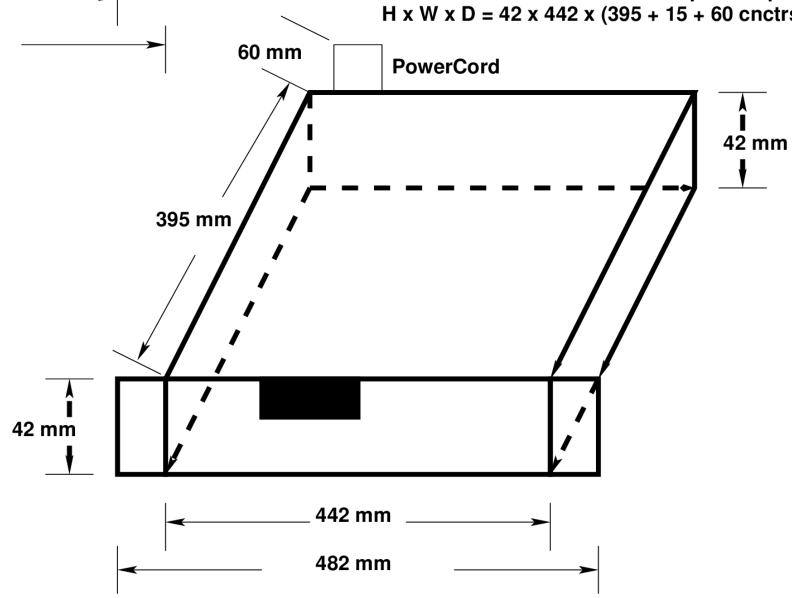
### Nodes , Host and Control Machines :




**Dell T620 Host/Node m/c.**
**Max. space required :**
**H x W x D = 220 x 482 x (630 + 110 cnctrs) mm's**

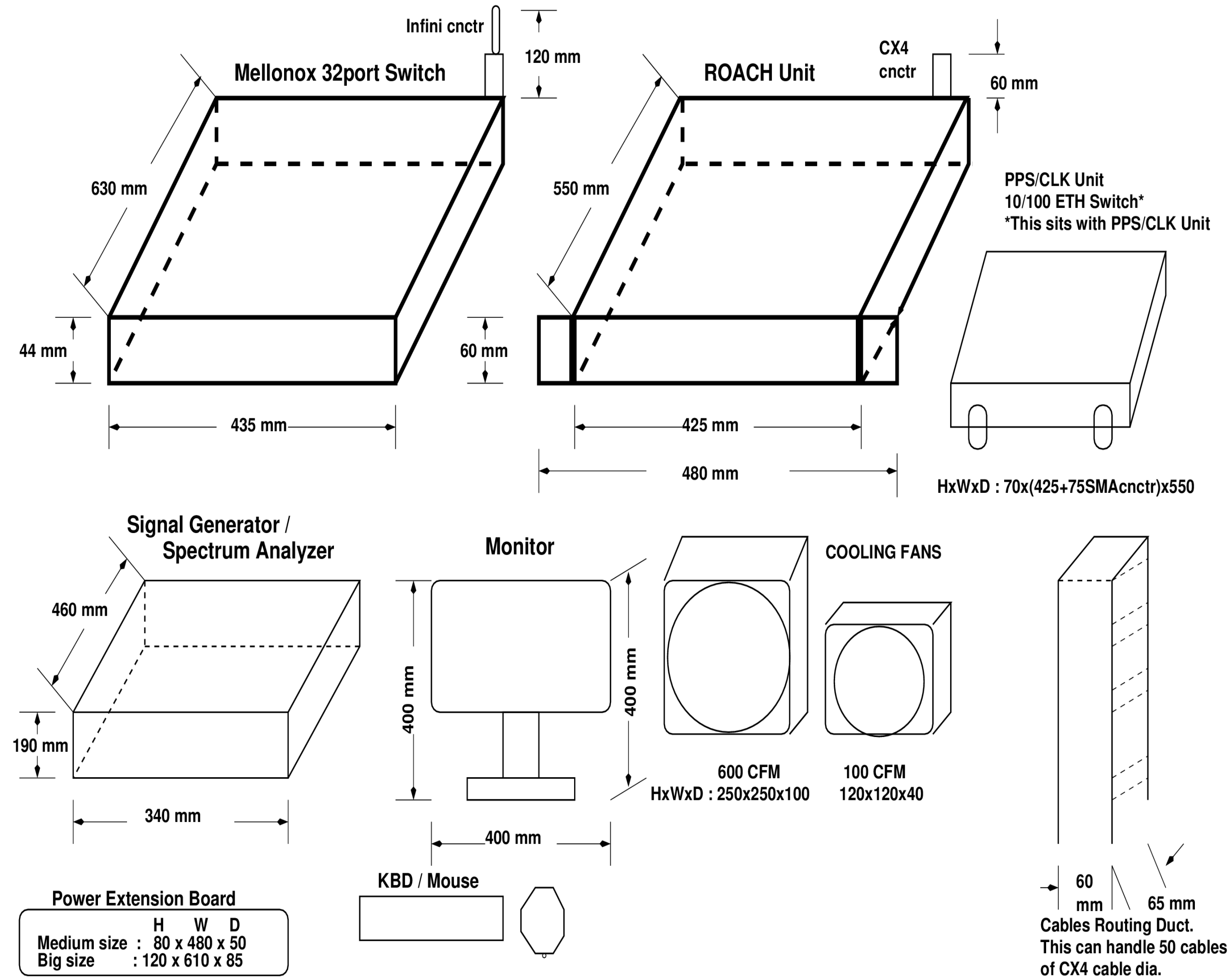
**Dell T630 Host/Node m/c.**
**Max. space required :**
**H x W x D = 220 x 482 x (750 + 110 cnctrs) mm's**

**Dell R210 1U PC for control works**
**Max. space required :**
**H x W x D = 42 x 442 x (395 + 15 + 60 cnctrs) mm's**




| Units | Size in mm | Units | Size in mm |
|---|---|---|---|
| 0.5 | 22.22 | 2.5 | 111.125 |
| 1 | 44.45 | 4.5 | 200.10 |
| 1.5 | 66.70 | 5 | 222.25 |
| 2 | 88.90 | 9 | 400.20 |

**Switch, ROACH unit, PPS/CLK unit, eth switch, Signal Generator, Monitor+KBD+Mouse, Fans, Power Extension & Distribution Boards, Cable Guide Ducts.**




| Sl.No. | Units/Machines/Instruments | Actual Size in mm | | | Remarks |
|---|---|---|---|---|---|
| | | Height (Units) | Width+ (Handle) | Depth+ (Connector) | |
| 1 | Control PC Dell R210 | 40(1) | 445(40) | 395(60^) | ^ Power Cord |
| 2 | Dell T620 Host/Node PC | 220(5) | 430(52) | 665(110^) | ^ Infiniband connector. |
| 3 | Dell T630 Host/Node PC | 220(5) | 430(52) | 750(110^) | ^ Infiniband connector. |
| 4 | ROACH Unit | 60(1.5) | 425(55) | 550(60^) | ^ CX4 cnctr |
| 5 | Melonox 36p Switch | 44(1) | 435 | 630(110^) | ^ Infiniband connectors. |
| 6 | CLK/Trig distribution unit | 70(2) | 500 | 550(100^) | ^ SMA |
| 7 | Ethernet switch | 70(2) | 500 | 550(100^) | ^ RJ45 |

| | | | | | |
|---|---|---|---|---|---|
| 7 | Monitor/KBD/Mouse | 400(9) | 400 | 400 | |
| 8 | SignalGenerator/SpectrumAnalyzer/Noise Source | 190 (4.5) | 340 | 460(60^) | |
| 9 | Power Ext'n Board (can be mounted at backside of units). | 120$ (3) | 610# | 85(60^)* | $ Make sure mountable at backside.<br># Available in many standards.<br>* shouldn't obstacle the doors. |
| 10 | Fans (2 fans of ~360cfm) | 100(2.5) | 500# | 250+120 | # 50 mm space between & ends<br># Can be Extended in LR margins |
| 11 | Left margin Space from Mounting Pole | -- | 60 | -- | |
| 12 | Right margin Space from Mounting Pole | -- | 60 | -- | |
| 13 | Front Door Margin | -- | -- | 60 | |
| 14 | Back Door Margin | -- | -- | 60 | |
| | | | | | |

**Notes :**

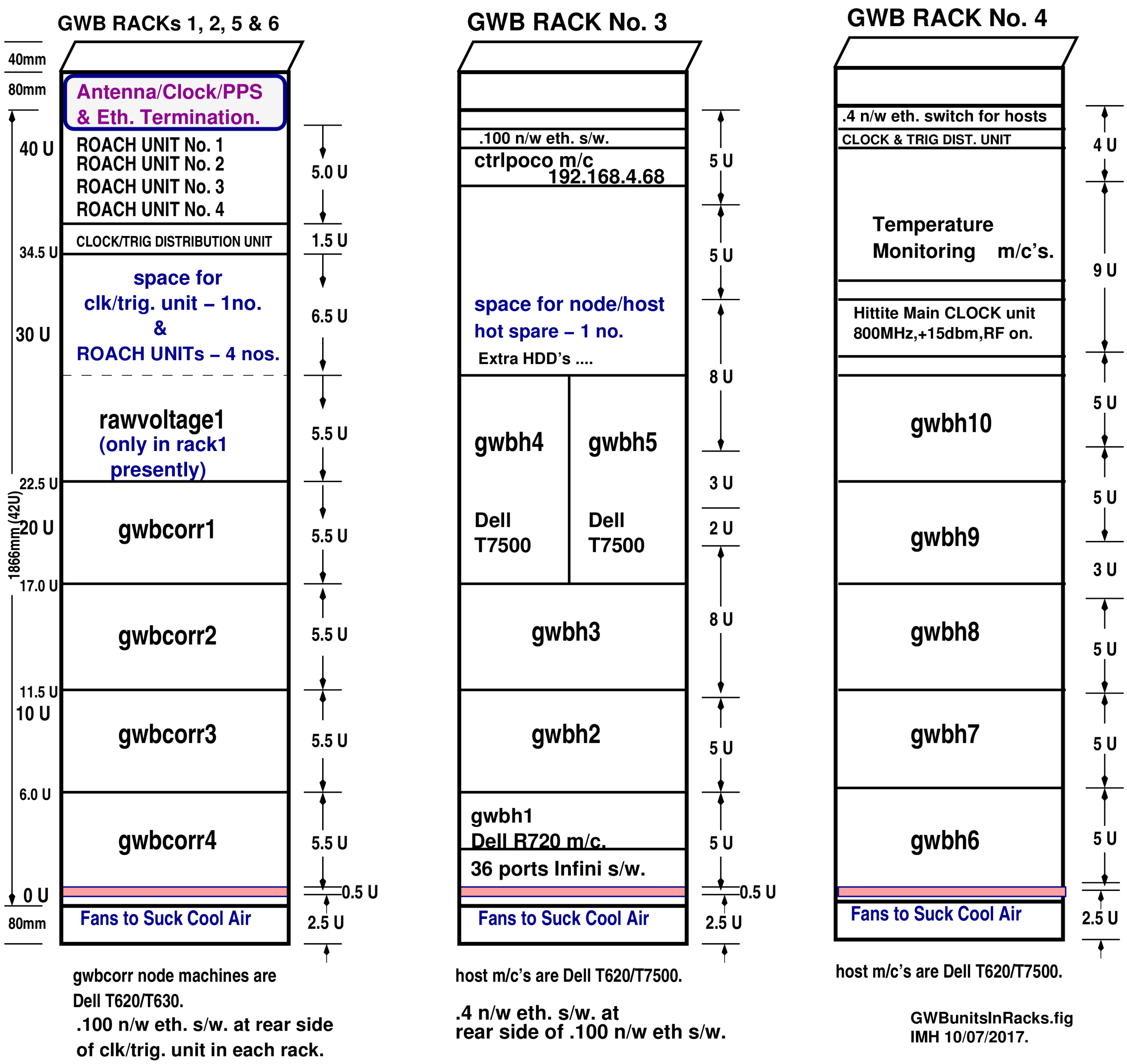
**I Width.....**

a. Margins on left side from the mounting pole = 60mm
b. Max. width of the unit (fans) = 550mm. But can be Extended in LR margins
Look for ~360 cfm fans with lesser width say 220mm.... to accommodate in 600mm rack.
c. Margings on right side from the mounting pole = 60mm
So Total Width required = 60 + 550 + 60 = 670mm

**II Depth.....**

a. Front door closing clearance - 60mm
b. Front cool air channel (~360cfm fan) / Cable Duct + margin space - 250+20= 270mm
c. Max. Unit depth (T620 PC) – 665mm.
d. Connector / Cable Duct / Hot air Channel (360cfm fan) + margin space – 100+20 =140mm
e. Back door closing clearance – 60mm
So Total Depth required – 60 + 270 + 665 + 140 + 60 = 1195mm

## 3. Units placement in the Racks.




The Units placement in the Racks is done by keeping in mind :

1. Minimum inter rack cables movement.
2. Cables (infiniband and ethernet) from 5th rack will go to T620/T630 's in the racks 1 to 4. So it is placed in between the racks.
3. By using PPS/CLK units in each racks minimizes the inter rack PPS/CLK cables.
4. Using ROACH units and Nodes required for 8 antennae in the same rack, will avoid inter rack CX4 cables movement. This is also necessary due to maximum 5 meter length of CX4 cables.
5. Best utilization of space with almost equal power consumption from all racks.

## 4. Racks placement in the correlator room.

The Racks placement in the Correlator Room is done by keeping in mind :

1. Cool Air inlets and Exhaust ducts are near by. Usage cool air inlets 1, 4 & 5 fully and 2nd partially if required and use exhausts 2,5 & 9.
2. Rack doors opening/closing space.
3. Man-material movement space.
4. Cables movement between racks. Cables (infiniband and ethernet) from 5th rack will go to T620/T630 's in the racks 1 to 4. So it is placed in between the racks. Cables in/out will be only from top. This avoids cool air leakage at the bottom.
5. Space for packetised correlator and other racks.
6. Best utilization of space and space for future expansions.

The following table compares the various proposals for GWB racks placement in the correlator Room.

***Requirements/Features :** Noproblem=Excellent(5) & Difficult=(1)

1. Racks/Material/Man movement through door and inside the room.
2. Access of input signal panel. Noproblem=Excellent(5) & Difficult=(1)
3. Shifting of existing set-up. NotRequired/Easy=Excellent(5) & Difficult=(1)
4. Length of input signal cables. Less=Excellent(5) & More=poor(1)
5. Space for feature expansion. More=Excellent(5) & Less=poor(1)
6. Accessability of cool air inlet ducts. Near/easy=Excellent(5) & Away/difficult=(1)
7. Accessability of hot air outlet ducts. Near/easy=Excellent(5) & Away/difficult=(1)

| | *Requirements / Features. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Proposal#** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **Average1$** | **Average2$** |
| **1** | 5 | 5 | 5 | 3 | 5 | 4 | 5 | **4.25** | **4.4** |
| **2** | 5 | 4.5 | 3(^1) | 5 | 5 | 4 | 4 | **4.50** | **4.2** |
| **3** | 4 | 4.5 | 4.5(^2) | 3 | 4 | 4 | 5 | **4.00** | **4.1** |
| **4** | 5 | 5 | 5 | 3 | 5 | 4 | 4 | **4.00** | **4.2** |
| **5** | 5 | 4.5 | 3(^3) | 5 | 4 | 4 | 4 | **4.25** | **4.0** |
| **6** | 4 | 5 | 2(^4) | 4 | 3 | 5 | 5 | **4.25** | **3.8** |
| | | | | | | | | | |

Agerage1$ : This is the average of Requirements/Features points 4 to 7 only. Ignored 1 to 3, because they are not so importent technically. This needs group debate (which point among 4 to 7 carries more weightage! & there is scope for revision of marks).

Agerage2$ : This is the average of Requirements/Features points 3 to 7 only. Eventhough point 3 is non technical, still it may needs to be considered.

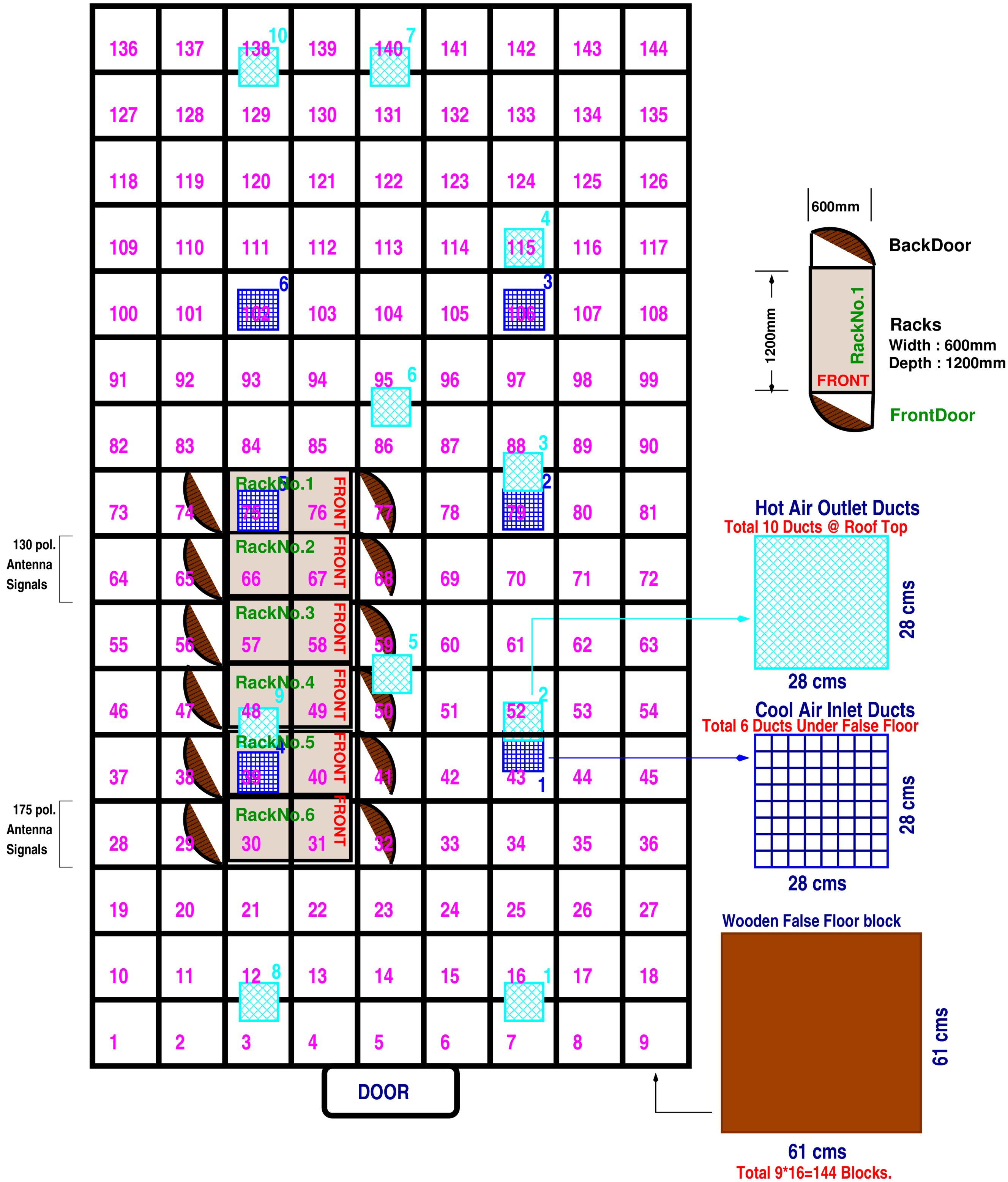
(^1) : Removing of existing GWB3 & moving of PKTZ+ racks by one tile is required.

(^2) : Removing of existing GWB3, if we use 6th rack.

(^3) : Removing of existing GWB3 & moving of PKTZ+ racks by one tile is required.

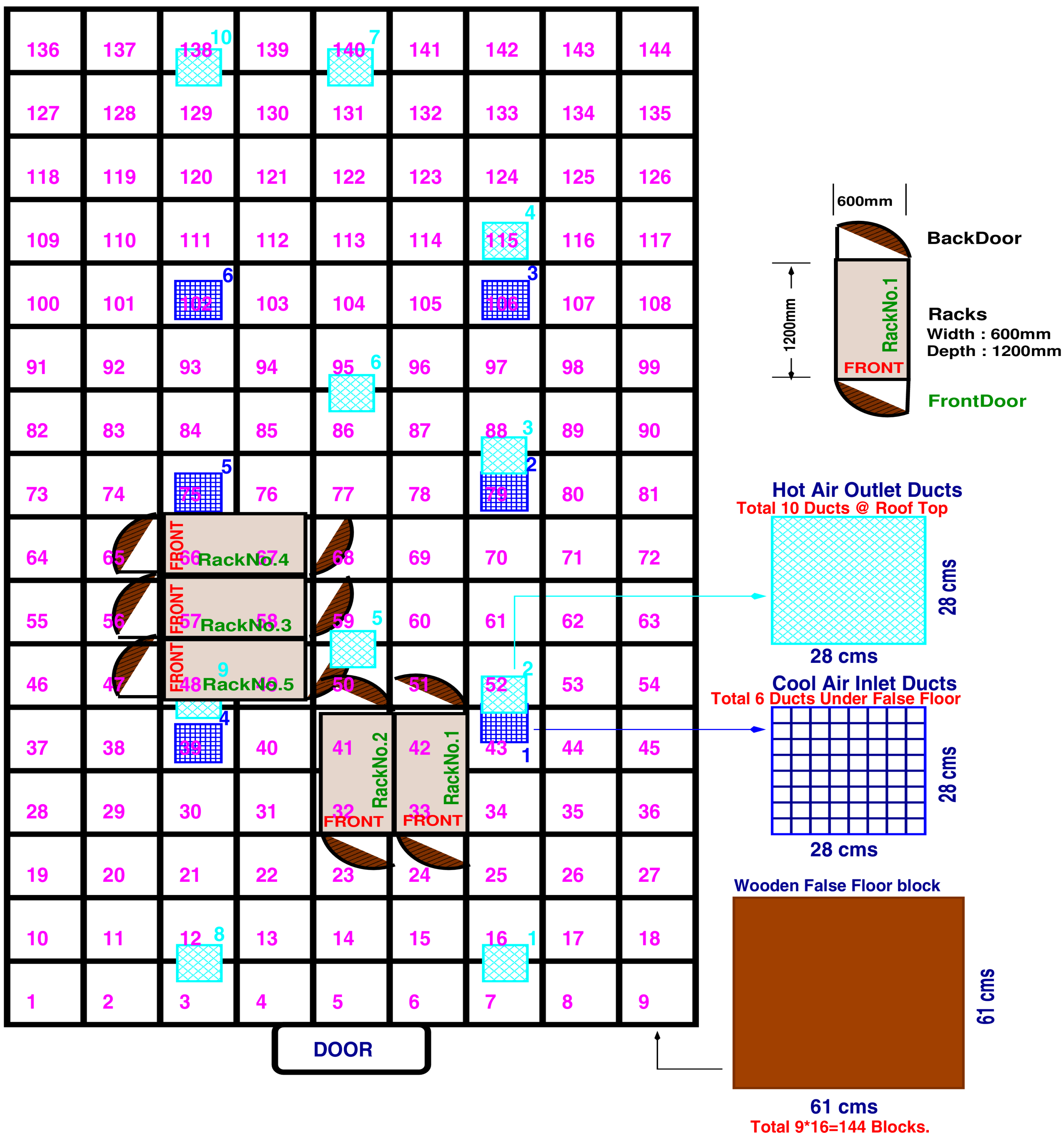
(^4) : Removing of existing GWB3 & PKTZ+ racks completly (or moving to other location)

**Proposal 1 :**



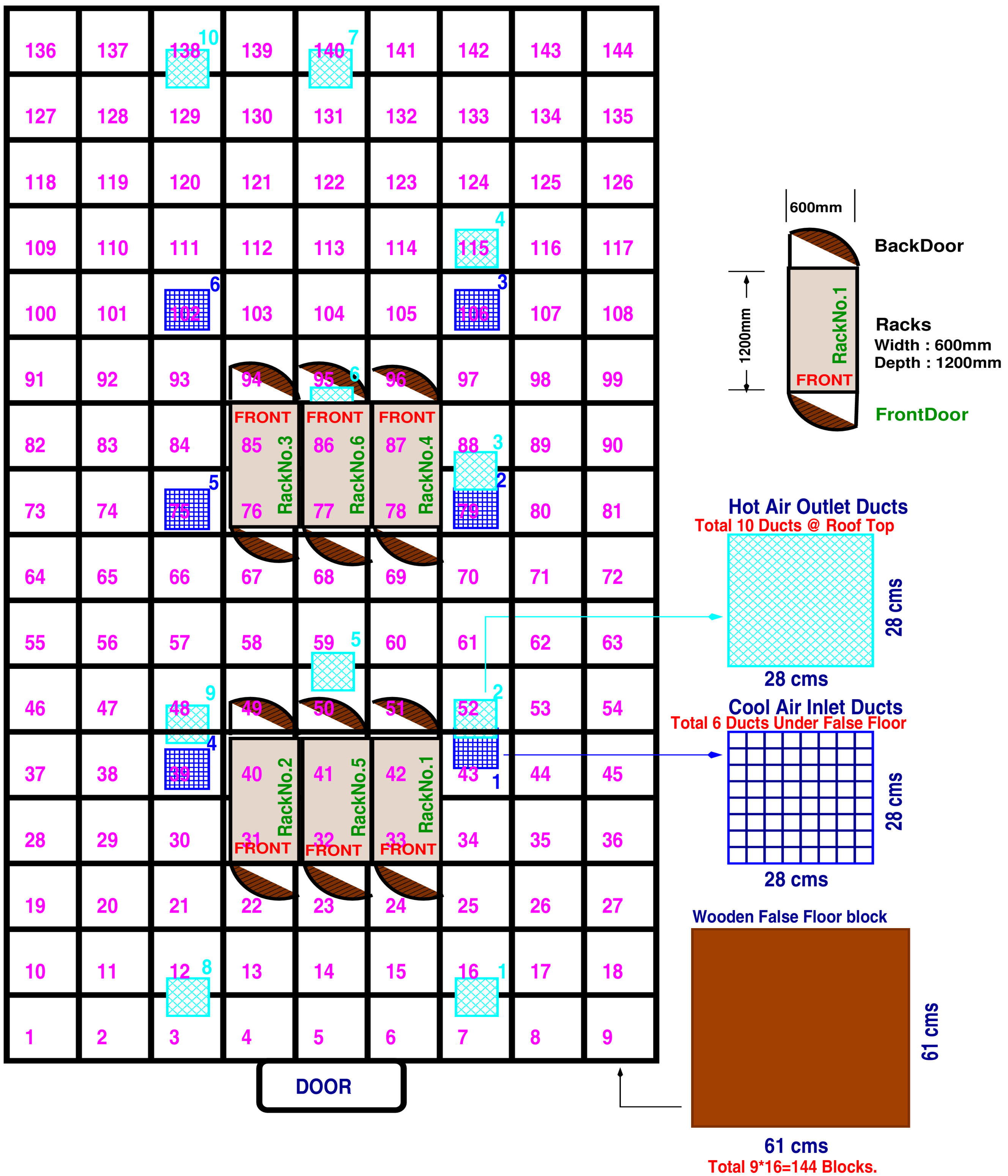
136 137 138 139 140 141 142 143 144
127 128 129 130 131 132 133 134 135
118 119 120 121 122 123 124 125 126
109 110 111 112 113 114 115 116 117
100 101 102 103 104 105 106 107 108
91 92 93 94 95 96 97 98 99
82 83 84 85 86 87 88 89 90
73 74 75 76 77 78 79 80 81
64 65 66 67 68 69 70 71 72
55 56 57 58 59 60 61 62 63
46 47 48 49 50 51 52 53 54
37 38 39 40 41 42 43 44 45
28 29 30 31 32 33 34 35 36
19 20 21 22 23 24 25 26 27
10 11 12 13 14 15 16 17 18
1 2 3 4 5 6 7 8 9
RackNo.1
RackNo.2
RackNo.3
RackNo.4
RackNo.5
RackNo.6
FRONT
130 pol. Antenna Signals
175 pol. Antenna Signals
DOOR
600mm
1200mm
BackDoor
RackNo.1
FRONT
Racks
Width : 600mm
Depth : 1200mm
FrontDoor
Hot Air Outlet Ducts
Total 10 Ducts @ Roof Top
28 cms
28 cms
Cool Air Inlet Ducts
Total 6 Ducts Under False Floor
28 cms
28 cms
Wooden False Floor block
61 cms
61 cms
Total 9*16=144 Blocks.

**Proposal 2 :**

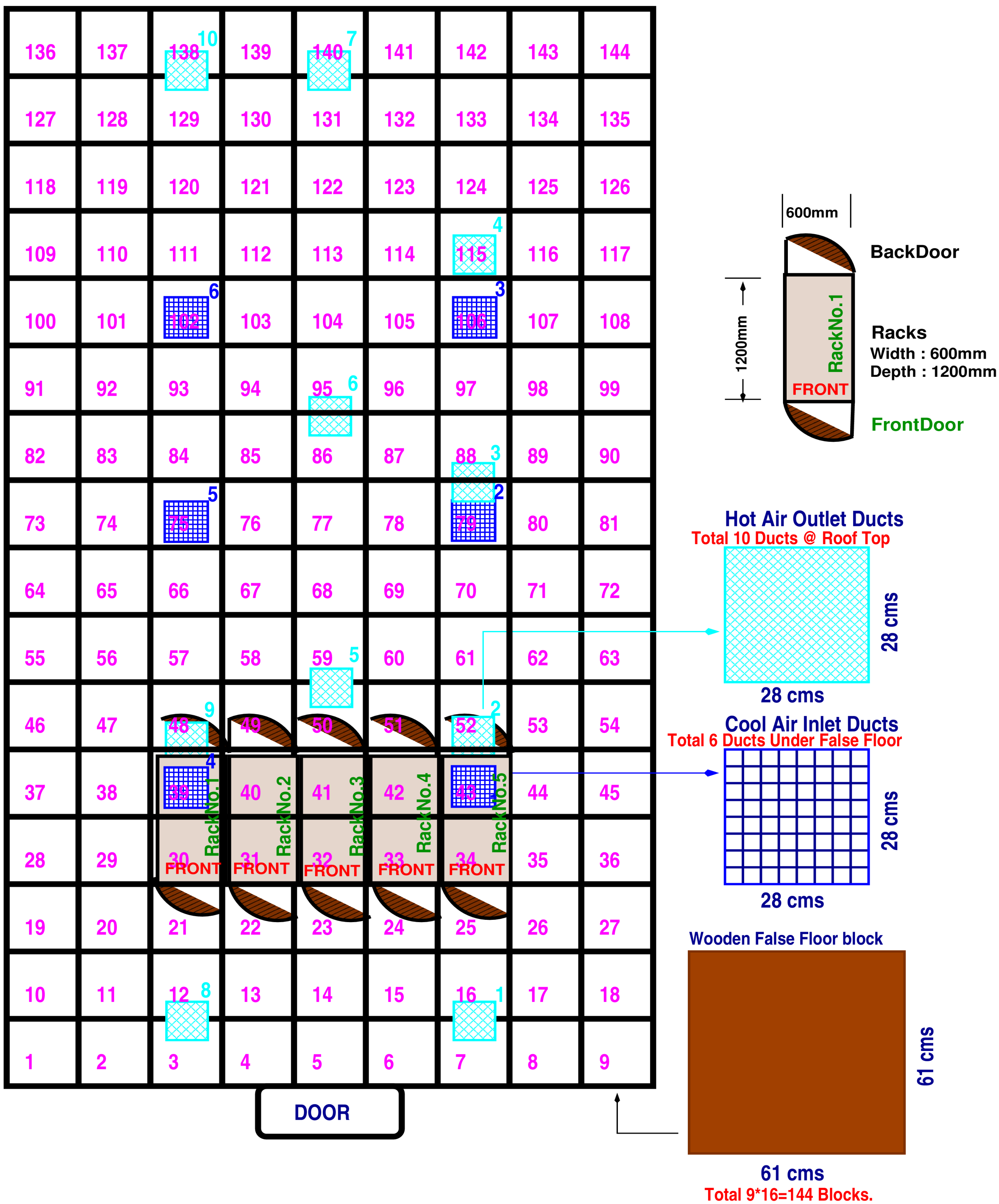


136 137 138 139 140 141 142 143 144
127 128 129 130 131 132 133 134 135
118 119 120 121 122 123 124 125 126
109 110 111 112 113 114 115 116 117
100 101 103 104 105 107 108
91 92 93 94 95 96 97 98 99
82 83 84 85 86 87 88 89 90
73 74 76 77 78 80 81
64 65 68 69 70 71 72
55 56 59 60 61 62 63
46 47 50 51 52 53 54
37 38 40 41 42 43 44 45
28 29 30 31 32 33 34 35 36
19 20 21 22 23 24 25 26 27
10 11 12 13 14 15 16 17 18
1 2 3 4 5 6 7 8 9
RackNo.4
RackNo.3
RackNo.5
RackNo.2
RackNo.1
FRONT
DOOR
600mm
1200mm
BackDoor
Racks
Width : 600mm
Depth : 1200mm
FrontDoor
Hot Air Outlet Ducts
Total 10 Ducts @ Roof Top
28 cms
28 cms
Cool Air Inlet Ducts
Total 6 Ducts Under False Floor
28 cms
28 cms
Wooden False Floor block
61 cms
61 cms
Total 9*16=144 Blocks.

Proposal 3 :


136 137 138 139 140 141 142 143 144
127 128 129 130 131 132 133 134 135
118 119 120 121 122 123 124 125 126
109 110 111 112 113 114 115 116 117
100 101 102 103 104 105 106 107 108
91 92 93 94 95 96 97 98 99
82 83 84 85 86 87 88 89 90
73 74 75 76 77 78 79 80 81
64 65 66 67 68 69 70 71 72
55 56 57 58 59 60 61 62 63
46 47 48 49 50 51 52 53 54
37 38 39 40 41 42 43 44 45
28 29 30 31 32 33 34 35 36
19 20 21 22 23 24 25 26 27
10 11 12 13 14 15 16 17 18
1 2 3 4 5 6 7 8 9
FRONT
RackNo.3
RackNo.6
RackNo.4
RackNo.2
RackNo.5
RackNo.1
DOOR
600mm
1200mm
BackDoor
Racks
Width : 600mm
Depth : 1200mm
FRONT
FrontDoor
Hot Air Outlet Ducts
Total 10 Ducts @ Roof Top
28 cms
28 cms
Cool Air Inlet Ducts
Total 6 Ducts Under False Floor
28 cms
28 cms
Wooden False Floor block
61 cms
61 cms
Total 9*16=144 Blocks.

**Proposal 4 :**



DOOR
600mm
1200mm
BackDoor
RackNo.1
FRONT
Racks
Width : 600mm
Depth : 1200mm
FrontDoor
Hot Air Outlet Ducts
Total 10 Ducts @ Roof Top
28 cms
28 cms
Cool Air Inlet Ducts
Total 6 Ducts Under False Floor
28 cms
28 cms
Wooden False Floor block
61 cms
61 cms
Total 9*16=144 Blocks.

## 5. Cool air utilization in the correlator room

Two cold air ducts are running parallel to each other from the AC plant room to the correlator room under ground. Each duct has 3 vents of 28 sq.cms in the correlator room. For the sake of identification they are numbered as 1 to 3, those are right side of the room entrance door and 4 to 6, those are left side. Vent number 3 is used to feed the cold air to racks 3 & 4 and vent number 6 is used for racks 1 and 2 of GSB system through the ducts placed below the false floor, from vents to the bottom of the racks. 2 fans of 360 cfm each are placed in the bottom of rack's front, in all the racks to draw the cold air into the racks from this duct cum tray below it.

GWB racks 1 & 2 gets cold air from the vent number 5 and racks 5 & 6 from the vent number 4 through the ducts placed below the false floor from vents to the bottom of racks. Here this duct is divided from vent to racks to split the air between two racks by half. Here also 2 fans of 360 cfm each are placed in the bottom of rack's front in all the racks to draw the cold air into the racks from the duct below it. Here duct directly opens below the fans.

GWB racks 3 & 4 respcectively called as host(recording) and host(monitoring) are getting air from vent number 1 & 2 , but without any duct between them.

The gap between the front door and the units is called as cold air aisle and the space between the rear door and unit's back end as hot air aisle. The cold air comming out from each vent is about 1000cfm. About 500cfm is drawn into the racks by using 2 fans of 360cfm.

The heat generated by a GWB rack (number 1,2,5 or 6) is 32,180 calories/sec., which draws a current of 12.2amps ie P=0.8*12.2*230=2245 watts. 280 cfm of cool air is sufficient to takeout the heat of 2245 watts ie 32,180 calories/sec., with a temperature difference of 15DegCel between the inlet cool air and exhaust hot air. For every 1000 watts ie 14,400 calories/sec., about 125 cfm of cold air is necessary to dissipate the heat with a temperature difference of 15DegCel.

Total heat generated by a 30 antenna GWB system is about 1,80,000 calories/sec., which draws a current of 61amps ie 12,500 watts. 2 cold air inlets of 1000cfm are required. If cold air from cold air inlets is around 600cfm, then 3 inlets will be required to take this heat.

Total power consumption by GSB+GWB system is : 28.0 KW (35 KVA) ie about 4,00,000 calories/sec.,

Use the calc provided with this document for automatic calculations “auto_calc1.ods”.

## 6. Bill of material.

| Sl.No. | Items | Qty Required | Qty (20%) Spare | Total Required | Remarks |
|---|---|---|---|---|---|
| 1 | Racks 42U and 1200mm depth std., | 06 | 01* | 06 | GWB Racks |
| 2 | Dell R210 poweredge 1U PC | 01 | 01* | 02 | Control PC |
| 3 | Dell T620/T630 Node machines | 16 | 01# | 17 | |
| 4 | Dell T620 Host machines | 03 | 01# | 04 | |
| 5 | K20/K40 GPU Cards | 32 | 06 | 38 | |
| 6 | Myricom 10Gbe Single Port cards | 32 | 06 | 38 | |
| 7 | Mellanox Infiniband NIC Cards | 19 | 04 | 23 | |
| 8 | Mellanox 32p Switch | 01 | 01* | 02 | |
| 9 | ROACH Units | 32 | 06 | 38 | |
| 10 | ADC Cards | 64 | 13 | 77 | |
| 11 | CLK/Trig distribution Units | 04+01 | 01# | 06 | 1 is the master unit. |
| 12 | Signal Generator | 01 | 01* | 02 | |
| 13 | DSO | 01* | 00 | 01 | |
| 14 | SpectrumAnalyzer | 01* | 00 | 01 | |
| 15 | 1Gbps ETH switches | 06 | 01* | 07 | |
| 16 | Power Extension Boards (10 sockets) | 18 | 03* | 21 | |
| 17 | Cooling Fans 360 CFM | 12 | 03 | 15 | |
| 18 | Cooling Fans 100 CFM | 10 | 05 | 15 | |
| 19 | Monitor | 01 | 01* | 02 | |
| 20 | Key Board | 01 | 01* | 02 | |
| 21 | Mouse | 01 | 01* | 02 | |
| 22 | Cables Routing Duct 60x65 | 20 | 01 | 21 | Hadles ~50cables of CX4 dia. |
| 23 | TNC to SMA Cables – 5 mtrs | 60 | 12 | 72 | Input to ADC's. |
| 24 | CX4, 5 mtr Cables | 64 | 13 | 77 | ROACH to Nodes. |
| 25 | Infiniband Cables | 19 | 04 | 23 | Nodes/Hosts to Infiniband s/w |
| 26 | Ethernet Cables (5 mtr) | 62 | 12 | 74 | Switch to Nodes/ROACH |
| 27 | Ethernet Cables (>20mtr) | 08 | 01 | 09 | Network to Switches |
| 28 | Power Cords | 83 | 17 | 100 | 2 for Dell T series and 1 for all |
| 29 | Aluminum angles | | | | For ROACH units |
| 30 | Aluminum angles | | | | For PPS-CLK unit/Eth s/w, SignalGenerator/ Noise Source/ Monitor /HDD/ temperature monitoring machines etc.. |

**Note : Spare quantity taken as 20% , except costly items like Rack, Dell T620 PC's & 32pSwitch.**

* Spare may be shared with other activities. # Hot spare should be in the working Rack.

## 7. Electrical connections.

UPS 1 of 20 KVA has been used to feed the electrical power to this GWB 30 antenna system. Each rack has 3 power extension boards each having 10 sockets at top, middle and bottom of the racks. The frist 3 MCB's of top row feeds electrical power to first 3 racks and first 3 MCB's of bottom row feeds electrical power to next 3 racks. Each rack gets 2 copper cables of dia. 2.5 sq.mm from the 25amps MCB at UPS1 power distribution box inside the correlator room near the main entrance door. These two copper cables are connected to the top and bottom power extension boards in the racks.

The middle power extension board is now unused. It is reserved for getting the electrical power from another UPS. So in the event of power cut from the UPS1 due to any reason, the node/host machines will get power from this machine, because these Dell T620/T630 machines have provision of automatic switch over between the two AC power inputs. Also to maintain atleast one of the two fans at the front bottom and backside top of the racks is working, one of the two fans will get power from the middle power extension board ie from second UPS.

## 8. Inter rack connections.

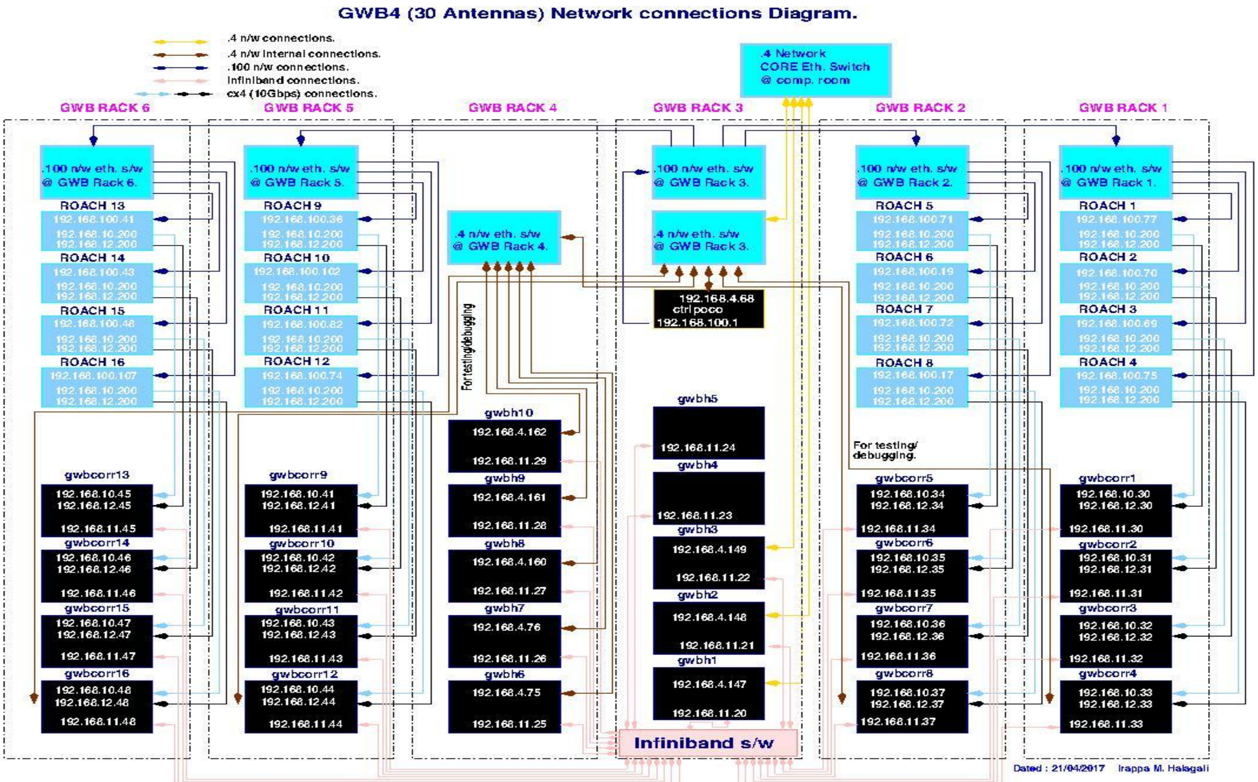
All racks have 50mm diameter hole at the rack's top left (front view) and about 40mm diameter hole at the rack's rearside, bottom, left (rear view) in all the racks for inter rack cable movements listed below. Only infiniband cables enter/exit through the rack's rear bottom hole.

| Rack# | Cables entering the rack | Cables exiting the rack |
|---|---|---|
| 1 & 2 | Electrical power cables – 2 nos.<br>Antenna signals from Rx system – 16 nos*,<br>Clock & PPS signals from rack 4 – 1 each,<br>.4 n/w & .1001 n/w eth cable -1 no. each, & Infiniband cables – 4 no's** from rack 3. | |
| 5 & 6 | Electrical power cables – 2 nos.,<br>Antenna signals from Rx system – 16 nos*,<br>Clock & PPS signals from rack 4 – 1 each,<br>.4 n/w & .1001 n/w eth cable -1 no. each, & Infiniband cables – 4 no's** from rack 3. | |
| 3 | Electrical power cables – 2 nos.,<br>.4 n/w eth cable from core s/w – 4 no's.,<br>Infiniband cables to nodes/host m/c's in all racks ie. 1 to 6 – 1 each**. | .4 n/w eth cable to all other racks -1 each for debugging/testing purpose.<br>.100 n/w eth cables to racks 1,2,5 & 6 – 1 each to .100 n/w distribution s/w in respective racks. |
| 4 | Electrical power cables – 2 nos., .4 n/w n/w eth cable -1 no.,10MHz ref. Signal to 800MHz main clock generator Hittite instrument from Rx room – 1 no., & Infiniband cables – 4 no's** from rack 3. | PPS and Clock signals to racks 1,2,5 & 6 – 1 each to clk & pps distribution units in respective racks. |

** - Infiniband cables (orange colour, thin cables) are entering/exiting the rack through the holes made at the rack's rear bottom, left side.

## 9. Intra rack connections.

The following image divulge the details of cables movement between units with in the racks 1 to 6.




## 10. Integration of system.

The racks were modified and all the required units and components were acquired, integrated the 16 antenna GWB system in the 3 racks. Tests were carried out along with the existing 16 antenna GWB system, which was integrated in the racks available with us after dismantling the old hardware correlator system. This gave us an opportunity to modify the software for the complete 30 antenna GWB system, creating the SOPs along with testing, apart from actual load test on the UPS and AC plant units.

The 30 Antenna GWB system has been integrated in it's final position in the correlator room and necessary tests have been carried out to confirm it's working. The 30 antennae GWB system has 6 racks. Racks 1, 2, 5 & 6 are integrated with 4 numbers of Dell T620 or Dell T630 as compute nodes with 2 numbers of K20/K40 nVIDIA GPU cards. At the top of the rack, one PPS/Clock distribution unit & 4 numbers of ROACH units with 2 iADC cards are integrated. Rack 1 has, one additional T630 machine for raw voltage recording.

The rack number 3 has five host machines (recording). Also has control 1U machine and two switches for .4 and .100 ethentet network distribution between units and racks and one 36 ports infini band switch for high speed data transfer between the compute and host nodes.

The rack number 4 has five host machines (monitoring) 800Mhz, +15dbm main clock generator synchronized with the 10MHz signal, clock and pps distribution units to distribute the same to racks numbers 1, 2, 5 & 6. And has one .4 network ethernet switch for host nodes in the same rack. Also has computers for temperature monitoring.

Few snaps of the 30 antenna GWB system.

***Image 1 : 30 Antenna GWB system integrated in 6 racks..***

*Image 2 : Back view of the 30 Antenna GWB system with outlet hot air duct above the racks.*

## 11. SOP's and Testing.

Rack number 1 processes the polarization 1 signals from 14 Central square antenna's, E02 & E03. Rack number 2 processes the polarization 2 signals from the same antenna's. Rack number 5 & 6 respctively processes the polarization 1 & 2 signals from the antenna's E4 to E6, South & West arm and also 2 spares.

The 30 antennae GWB system has 6 racks. Racks 1, 2, 5 & 6 are integrated with 4 numbers of Dell T620 or Dell T630 as compute nodes with 2 numbers of K20/K40 nVIDIA GPU cards, two Myricom 10Gbe Single Port cards and one Myricom 10Gbe Single Port card. At the top of the rack, one PPS/Clock distribution unit & 4 numbers of ROACH units with 2 iADC cards are integrated. Rack 1 has, one additional T630 machine for raw voltage recording.

The rack number 3 has five host machines (recording) Dell T620/T630 with one Myricom 10Gbe Single Port card. Also has control 1U machine and two switches for .4 and .100 ethentet network distribution between units and racks and one 36 ports infini band switch for high speed data transfer between the compute and host nodes.

The rack number 4 has five host machines (monitoring) Dell T620/T630 with one Myricom 10Gbe Single Port card, Hittite instrument for main clock generator 800Mhz, +15dbm synchronized with the 10MHz signal and clock & pps distribution units to distribute the same to racks 1, 2, 5 & 6. And also has one .4 network ethernet switch for host nodes in the same rack and computers for temperature monitoring. 

## E. Conclusion

**A.** Theoratically each inlet gives 1000CFM of cool air. So we need 2.68 cool air inlets to absorb the heat generated by GWB system of 21,500 Watts ( 3,08,185 calories/minute). But practically, with 3fans of 100cfm each to suck the cool air into the al. cage, we need 5.38 cool air inlets. This is doubble the theoratical requirement. So we have to find out the reasons, which could be as follows ;

1. Actual cool air spilt for the correlator room may not be 6000 CFM.
2. There may be leakeages between the AHU and correlator room inlets.
3. May be considerable leakages at the bottom of the rack.
4. May be adjustment of locations of the heat load is required in the rack, in order to utilize the cool air efficiently.
5. May be adjustment of locations of the input/output thermometers is required to findout the actual volume of the cool air, which may be more than 482 CFM.
6. If possible and not harmful to the system, increase the humidity of the cool air (decrease the temperature of the cool air comming out of the inlets).

**B.** We found the following things are useful in utilising the cool air efficiently.

1. We have replaced the 3 fans of 100cfm each to suck the cool air into the al. cage by 2 fans of 600cfm at 2' height in the al. cage.
2. Made sure the cool air entered in the rack, shouldn't leakout.
3. And also took care of no obstacles in the cool air flow towards the exit in the rack.

Enenthough the rack is kept 5 feet away from the cool air duct and without any aluminium cage/duct to bring the cool air from the inlet(setup No. 3a), we got a averaged temperature difference of 5.4 degCel.

If we move these fans from the al. cage to the bottom of the rack and keep the slot in the al. cage @ 2' height open, then the temperature difference increses to 9.21 degCel.

This temperature increases by around 1 degCel, if we put 3 fans of 100cfm each at the open slot in the al. cage!

If we take maximum of these ie 9.21 DegCel, then the volume of cool air from the outlet is 812cfm.

So we need 3.19 inlets of 1000cfm cool air to dissipate 21,500KW heat from GWB system.

**Appendices :**

**1 Auto calculator**

Usage : “auto_calc1.ods “ is an auto calculator as copy-pasted below, is for calculating the output parameters by providing input parameters.

| **User Parameters :** | **INPUTS** | **Output Parameters** | **OUTPUTS** |
|---|---|---|---|
| PowerConsumption in Watts --> | 12500 | **Total Heat Energy** in calories/minute --> | **1,79,177** |
| Difference in Temperature --> | 15 | **Heat Absorption of Cool Air cal/min -->** | **69,042** |
| Volume of Cool Air in ft^3 /inlet in corr. room--> | 600 | **Number of cool air inlets required..** | **2.60** |
| Heat to be absorbed in watts --> | 2,245 | | |
| Temperature Difference in deg. Cel.permitted --> | 15.00 | **Volume of Cool Air in ft^3 to absorb the heat :** | **280** |

| **Constant Parameters :** | **Constant Values** | **Intermittent Calculation Parameters :** | **int'nt. results** |
|---|---|---|---|
| 1 Joule equal to --> Calories | 0.2389029576 | Volume of Cool Air in mtr^3 --> | 16.992 |
| 1 Cubic feet equal to --> Cubic mtr | 0.02832 | Mass of cool air in kg/minute --> | 19.178304006 |
| Air Density kg/mtr^3 @ 25dC & 1 Pascal | 1.128666667 | | |
| Specific Heat of Air cal/kgdC @ 20dC & 1 Pascal | 240 | | |

## Tables :

| **Total Heat Energy in Cal./min.** | |
|---|---|
| For 1000 watts of Power Consumption --> | 14,334 |
| For 1500 watts of Power Consumption --> | 21,501 |
| For 2000 watts of Power Consumption --> | 28,668 |
| For 2500 watts of Power Consumption --> | 35,835 |
| For 3000 watts of Power Consumption --> | 43,003 |
| For 3500 watts of Power Consumption --> | 50,170 |
| For 4000 watts of Power Consumption --> | 57,337 |
| For 4500 watts of Power Consumption --> | 64,504 |
| For 5000 watts of Power Consumption --> | 71,671 |

| **Volume of Cool Air in ft^3 @1KW heat if :** | |
|---|---|
| Temperature difference of 3 deg. Cel. | 1,398 |
| Temperature difference of 3.5 deg. Cel. | 1,199 |
| Temperature difference of 4 deg. Cel. | 1,049 |
| Temperature difference of 4.5 deg. Cel. | 932 |
| Temperature difference of 5 deg. Cel. | 839 |

| **Heat Absorption of Cool Air in cal./min.** | **For 1000ft^3/ min. Cool air** |
|---|---|
| For Temperature difference of 1 deg.Cel. | 4,603 |
| For Temperature difference of 1.5 deg.Cel. | 6,904 |
| For Temperature difference of 2 deg.Cel. | 9,206 |
| For Temperature difference of 2.5 deg.Cel. | 11,507 |
| For Temperature difference of 3 deg.Cel. | 13,808 |
| For Temperature difference of 3.5 deg.Cel. | 16,110 |
| For Temperature difference of 4 deg.Cel. | 18,411 |
| For Temperature difference of 4.5 deg.Cel. | 20,713 |
| For Temperature difference of 5 deg.Cel. | 23,014 |
| For Temperature difference of 5.5 deg.Cel. | 25,315 |
| For Temperature difference of 6 deg.Cel. | 27,617 |
| For Temperature difference of 6.5 deg.Cel. | 29,918 |
| For Temperature difference of 7 deg.Cel. | 32,220 |
| For Temperature difference of 7.5 deg.Cel. | 34,521 |
| For Temperature difference of 8 deg.Cel. | 36,822 |
| For Temperature difference of 8.5 deg.Cel. | 39,124 |
| For Temperature difference of 9 deg.Cel. | 41,425 |
| For Temperature difference of 9.5 deg.Cel. | 43,727 |
| For Temperature difference of 10 deg.Cel. | 46,028 |

## 2 Experiment setup details

The following setups were done with the help of mechanical and electrical sections. These setups were used to study the effects of cooling over varying temperature under different conditions like when the rack is placed over the inlet cool air duct or 5 feet away from it and so on.... A total of 8 setups were created to study the possible conditions to make out the rise in temperature at the output over input ie difference in temperature of the air entering the rack and exiting the rack.

**Setup 1 :** 42U Rack directly on the cool air inlet in the corr room with all the leakages at the bottom closed. The cool air enters the rack from the front bottom opening and enters the aluminium cage through a window provided in the cage at a height of about 2 feet. One thermometer(T1) and two temperature sensors (S2 & S3) are present at this opening to measure the inlet temperature. Inside the al. cage about a feet high 4 hellogen (with seperate ON-OFF switches in the two extension boards having current carrying capacity of 16amps. These two extension boards are getting power from MSEB metal MCB box through 25amps MCB) lamps of 1 KW each are mounted. Some 3 feet above these lamps there is window in the al cage at the backside for heated air to exhaust. At this poist also one thermometer (T2) and two sensors (S4 & S5) are mounted. Sensor S1 is outside and near to this rack.

Rabbit card gets input on pin numbers 1 to 5 on 64pin FRC male connector from sensors S1 to S5 respectively. +11 volts power has been given to this rabbit card as well all to all temperature sensor cards. An ethernet cable with ip 192.168.4.152 has been connected to this rabbit card for web based monitoring of temperature.

**Setup 2 :** setup 1 with 3 fans of 100cfm each, mounted at the height of about 2 feet front side, to suck air in the aluminium cage.

**Setup 2a :** setup 2 with 2 fans of 600cfm each, mounted at the height of about 2 feet front side, to suck air in the aluminium cage. This is done with and without aluminium plate in al. cage to abstruct the air.

**Setup 3 :** setup 1 & 2 with whole setup moved about 5 feet away from cool air inlet duct. Cool air brought to the rack's inlet using aluminium sheet enclosure underneath the false flooring.

**Setup 3a :** setup 3 with 2 fans of 600cfm each instead 3 fans with 100cfm each and without al. enclosure to bring the cool air to rack.This is done with and without an aluminium plate in the al. cage in the rack, to be an obstacle in the air flow.

**Setup 3b :** setup 3a with 2 fans of 600cfm each, moved to bottom of the rack with opening @ 2' height. This is done with and without an aluminium plate in the al. cage in the rack, to be an obstacle in the air flow.

**Setup 4 :** setup 3 without fans to suck the cool air in the aluminium cage at 2 feet height.

**Setup 5 :** setup 3 without aluminium sheet enclosure underneath the false flooring to bring the cool air from the inlet duct to the rack and with fans to suck the air in the aluminium cage at 2 feet height.

**Setup 6 :** setup 5 but without fans to suck the cool air in the aluminium cage at 2 feet height.

**Setup 7 :** Rack without any modifications (aluminium cage in the rack removed). Kept 5 feet away from the cool air inlet duct. Input temperature monitoring about 2 feet high at the frontside. Four hellogens of 1 KW each mounted at the centre of the rack. And output temperature monitoring at the top of the rack's rear side.

**Setup 8 :** Rack without any modifications (aluminium cage in the rack removed). Kept over the cool air inlet duct. Input temperature monitoring about 2 feet high at the frontside, where cool air blows in the rack's bottom. Four hellogens of 1 KW each mounted at the centre of the rack. And output temperature monitoring at the top of the rack's rear side.

**T – Thermometer readings average. & S – Temperature Sensors readings average in Deg. Cel.**
**LH – Left Hand side RH – Right Hand side (from back) F- Front of rack B – Back of rack.**

## 3 Summary of Daily readings

| Setup No. | Measuring Instrument | Average temp. readings for 1KW | 2KW | 3KW | 4KW | Max. output temp. for 4KW | Termp. Sensor minus Thermometer readings. |
|---|---|---|---|---|---|---|---|
| I | Themometer | 3.0 | 6.6 | 11.2 | -- | 20.0 | 1.2 |
| | Temperature Sensor | 4.2 | 8.2 | 12.2 | -- | | |
| II | Themometer<br>Temperature Sensor | 2.6<br>4.3 | 6.3<br>8.2 | 9.0<br>11.7 | 11.7<br>14.2 | 22.5 | 2.2 |
| IIa | Themometer/TempSe<br>Themometer/TempSe | 6.23<br>3.50 | 8.89<br>6.06 | with al. plate<br>w/o al. plate | | 16.00<br>17.00 | 2.26<br>2.56 |
| III | Themometer | 2.8 | 7.3 | 12.5 | 14.8 | 25.5 | 2.6 |
| | Temperature Sensor | 5.3 | 10.0 | 14.9 | 17.6 | | |
| IIIa | Themometer/TempSe<br>Themometer/TempSe | 9.21<br>6.12 | 9.23<br>5.33 | with al. plate<br>w/o al. plate | | 20.00<br>21.00 | 0.02<br>-0.79 |
| IIIb | Themometer/TempSe<br>Themometer/TempSe | 10.64<br>10.82 | 13.26<br>12.84 | with al. plate<br>w/o al. plate | | 20.50<br>20.00 | 2.62<br>2.02 |
| IV | Themometer | 3.5 | 10.0 | 14.1 | 18.5 | 28 | 2.8 |
| | Temperature Sensor | 6.4 | 12.6 | 17.1 | 21.4 | | |
| V | Themometer | 4.8 | 9.5 | 11 | 18.4 | 33 | -3.0 |
| | Temperature Sensor | 3.8 | 6.5 | 9.3 | 12.1 | | |
| VI | Themometer | 8.0 | 18.2 | 24.8 | 31.7 | 46 | 1.8 |
| | Temperature Sensor | 10.5 | 20.0 | 26.8 | 32.7 | | |
| VII | Themometer | -5.2 | -3.2 | -1.3 | -1.1 | 31.5 | 1.9 |
| | Temperature Sensor | -0.8 | -1.3 | -2.3 | +1.2 | | |
| VIII | Themometer | -2.2 | -3.1 | -3.1 | -2.8 | 9.0 | 1.0 |

**Note : Thermometer readings are considered.**

## 4 Average of Daily readings

# SETUP : 1

**42U Rack directly placed on the cool air inlet in the correlator room with all the leakages at the bottom closed. Aluminium cage with cool air in and hot air out and load in the centre of the cage.**

| Date | Difference in Temperature Readings T | S | Heat load of KW's | Time | Remarks | |
|---|---|---|---|---|---|---|
| 10/10/2014 | 4 | 4 | 1 | 12 – 17 | Readings every half an hour | |
| 11/10/2014 | 7 | 8.5 | 2 | 11 - 17 | “ | |
| 13/10/2014 | 3 | 4 | 1 | 10 – 17 | “ | |
| 14/10/2014 | 8 | 8.5 | 2 | 10 – 17 | “ | |
| 15/10/2014 | 3.5 | 4 | 1 | 10 – 17 | “ | |
| 16/10/2014 | 2.5 | 4.5 | 1 | 10 – 17 | “ | |
| 18/10/2014 | 3 | 4.2 | 1 | 10 – 17 | “ | |
| 20/10/2014 | 2 | 4 | 1 | 10 – 15 | “ | |
| 21/10/2014 | 3 | 4.5 | 1 | 10 - 12 | LH-1 | every 5 min. |
| | 10.5 | 11.5 | 3 | 12 - 13 | LH-1 + RH-2 | “ |
| 22/10/2014 | 6 | 8 | 2 | 10 - 12 | LHB + RHB | every 10 min. |
| | 5.5 | 8 | 2 | 12 - 13 | LHF + RHF | “ |
| | 12 | 13 | 3 | 14 - 15 | LH-2 + RH | “ |

**Average Readings in degCel.**

| | 1KW | 2KW | 3KW | 4KW |
|---|---|---|---|---|
| **Themometer** | **3** | **6.6** | **11.2** | **18** |
| **Temp. Sensors** | **4.2** | **8.2** | **12.2** | **21** |

**Conclusions : Temperature Sensor results are about 1.2degCel. more than the Themometer readings. And maximum output temperature for 4 KW is about 20 degCel.**

# SETUP : 2

**setup 1 with 3 fans of 100cfm mounted at the height of about 2 feet front side, to suck air in the aluminium cage.**

| Date | Difference in Temperature Readings T | S | Heat load of KW's | Time | | Remarks |
|---|---|---|---|---|---|---|
| 28/10/2014 | 2 | 4.2 | 1 | 10:00 - 11:40 | LHB | every 10 min. |
| | 8.5 | 9 | 2 | 11:45 - 13:00 | LHB + RHB | “ |
| | 10 | 12.5 | 3 | 14:10 - 15:30 | LH-2 + RH | “ |
| | 13 | 15.5 | 4 | 15:40 - 16:40 | All | “ |
| 29/10/2014 | 11 | 13.5 | 4 | 09:40 - 11:30 | All | every 10 min. |
| | 10 | 12.5 | 3 | 11:40 - 13:00 | LH-2 + RHF | “ |
| | 7.5 | 9.5 | 2 | 14:20 - 15:20 | LHB + RHB | “ |
| | 2.5 | 4.5 | 1 | 15:55 - 17:10 | LHB | “ |

| | | | | | | |
|---|---|---|---|---|---|---|
| 30/10/2014 | 2 | 4.2 | 1 | 09:45 - 10:40 | LHF | every 10 min. |
| | 2 | 4 | 1 | 10:50 - 11:45 | RHF | " |
| | 4 | 5.2 | 1 | 12:00 - 12:55 | RHB | " |
| | 2.5 | 4 | 1 | 14:10 - 15:00 | LHB | " |
| | 5 | 7 | 2 | 15:30 - 16:10 | LH-2 | " |
| | 5.5 | 8 | 2 | 16:20 - 17:20 | RH-2 | " |
| 31/10/2014 | 6.2 | 7.7 | 2 | 09:50 - 11:30 | LHF+RHB | every 10 min. |
| | 5.2 | 7.7 | 2 | 11:35 - 14:20 | LHB+RHF | " |
| | 7.2 | 10.3 | 3 | 14:25 - 16:40 | LH-2+RHF | " |
| 31/10/2014 | 11 | 13.5 | 4 | 09:45 - 16:00 | All | every 10 min. |
| 26/05/2015 | 8.0 | 10.5 | 4 | 14:30 - 16:50 | All | every 10 min. |
| Page 19 | | | | w/o al. plate obstacke in the al. cage. | | |

**Average Readings in degCel.**

| | **1KW** | **2KW** | **3KW** | **4KW** |
|---|---|---|---|---|
| **Themometer** | **2.6** | **6.3** | **9.0** | **11.7** |
| **Temp. Sensors** | **4.3** | **8.2** | **11.7** | **14.2** |

**Conclusions : Temperature Sensor results are about 2 degCel. more than the Themometer readings. And maximum output temperature for 4 KW is about 22.5 (1/11/2014@14:50hrs) Alos noted a decrease of temperature by 3 degCel if remove the al. plate in the al. cage.**

## SETUP : 2a

**setup 2 with 2 fans of 600cfm mounted at the height of about 2 feet front side, to suck air in the aluminium cage.**

| **Date** | **Difference in Temperature Readings T** | **S** | **Heat load of KW's** | **Time** | | **Remarks** |
|---|---|---|---|---|---|---|
| 03/06/2015 | 6.23 | 8.89 | 4 | 12:40 - 17:00 | All | every 10 min. |
| Page 20 | | | | with al. plate obstacke in the al. cage. | | |
| 05/06/2015 | 3.50 | 6.06 | 4 | 10:20 - 17:00 | All | every 10 min. |
| Page 20 | | | | w/o al. plate obstacke in the al. cage. | | |

## SETUP : 3

**setup 1 & 2 with whole setup moved about 5 feet away from cool air inlet duct. Cool air brought to the rack's inlet using aluminium sheet enclosure underneath the false flooring.**

| Date | Difference in Temperature Readings T | S | Heat load of KW's | Time | | Remarks |
|---|---|---|---|---|---|---|
| 07/11/2014 | 6.8 | 9.3 | 2 | 15:20 - 17:10 | RHB+RHF | every 10 min. |
| Sheet 1 | | | | | | |
| 10/11/2014 | 16.0 | 17.82 | 4 | 10:00 - 13:00 | All | “ |
| sheet 2 | 12.72 | 15.25 | 3 | 14:15 – 17:10 | LH-2+RHB | “ |
| 11/11/2014 | 2.28 | 5.12 | 1 | 10:00 – 14:20 | LHF | “ |
| sheet 3 | 6.50 | 8.74 | 2 | 14:50 – 17:15 | RH-2 | “ |
| 12/11/2014 | 6.19 | 9.36 | 2 | 10:00 – 14:20 | LH -2 | “ |
| sheet 4 | 7.00 | 10.08 | 2 | 14:10 – 15:15 | LHB+RHF | “ |
| 13/11/2014 | 7.50 | 10.54 | 2 | 09:50 – 14:35 | LHF+RHB | “ |
| sheet 5 | 1.93 | 4.04 | 1 | 14:40 – 17:10 | RHF | “ |
| 14/11/2014 | 3.93 | 6.13 | 1 | 10:20 – 14:40 | RHF | “ |
| sheet 6 | 2.81 | 5.53 | 1 | 14:45 – 17:20 | LHB | |
| 15/11/2014 | 3.30 | 5.95 | 1 | 10:10 – 11:30 | RHB | “ |
| sheet 7 | 9.64 | 12.02 | 2 | 11:35 – 14:20 | LHB+RHB | |
| | 12.33 | 14.63 | 3 | 14:30 – 15:50 | LHB+RH-2 | “ |
| | 13.70 | 16.38 | 4 | 15:55 – 17:20 | All | |
| 16/11/2014 | 14.79 | 18.67 | 4 | 09:25 - 20:10 | All | “ |
| sheet 8 | | | | | | |

| | Average Readings in degCel. 1KW | 2KW | 3KW | 4KW |
|---|---|---|---|---|
| **Themometer** | **2.8** | **7.3** | **12.5** | **14.8** |
| **Temp. Sensors** | **5.3** | **10.0** | **14.9** | **17.6** |

**Conclusions : Temperature Sensor results are about 2.5 degCel. more than the Themometer readings. And maximum output temperature for 4 KW is about 25.5 (16/11/2014@12:00hrs sheet no. 8 of temp_readings.ods file.)**

**Setup 3a :** setup 3 with 2 fans of 600cfm each instead 3 fans with 100cfm each.

| Date | Difference in Temperature Readings T | S | Heat load of KW's | Time | Remarks |
|---|---|---|---|---|---|
| 08/06/2015 | 6.12 | 5.33 | 4 All | 15:10 - 17:10 | every 10 min. |
| Page 21 | | | | w/o al. plate obstacke in the al. cage. | |
| 09/06/2015 | 9.21 | 9.23 | 4 All | 10:00 - 17:10 | every 10 min. |
| Page 21 | | | | with al. plate obstacke in the al. cage. | |
| 16/06/2015 | 9.89 | 12.74 | 4 All | 14:40 – 17:10 | with plate “ |
| page 22 | | | | | |

**Setup 3b :** setup 3a with 2 fans of 600cfm each moved to bottom of the rack with opening @ 2' height.

| | | | | | |
|---|---|---|---|---|---|
| 17/06/2015 | 10.64 | 13.26 | 4 All | 10:10 - 17:10 | every 10 min. |
| Page 22 | | | | with al. plate obstacke in the al. cage. | |
| 18/06/2015 | 10.82 | 12.84 | 4 All | 10:00 - 17:10 | every 10 min. |
| Page 23 | | | | w/o al. plate obstacke in the al. cage. | |

## SETUP : 4

**setup 3 but without fans to suck the cool air in the aluminium cage at 2 feet height.**
**{Sheet number 13 & 14 in the temp_readings.ods file}**

| Date | Difference in Temperature Readings T | S | Heat load of KW's | Time | | Remarks |
|---|---|---|---|---|---|---|
| 26/12/2014 | 18.00 | 21.30 | 4 | 11:50 - 15:30 | All | every 10 min. |
| Sheet 13 | 14.80 | 17.69 | 3 | 15:40 – 17:10 | LH-2+RHF | “ |
| 27/12/2014 | 11.54 | 13.33 | 2 | 09:55 - 12:00 | LHB+RHB | every 10 min. |
| Sheet 13 | 04.53 | 06.61 | 1 | 12:10 – 16:10 | LHB | “ |
| | 18.33 | 21.15 | 4 | 16:20 - 21:00 | All | |
| 28/12/2014 | 13.44 | 16.48 | 3 | 12:20 – 15:00 | LHF+RH-2 | every 10 min. |
| Sheet 14 | 08.57 | 11.99 | 2 | 15:10 - 16:30 | LHF+RHF | “ |
| | 02.50 | 06.15 | 1 | 16:40 – 20:30 | RHF | “ |
| 29/12/2014 | 19.21 | 21.70 | 4 | 10.10 - 16:40 | All | every 10 min. |
| Sheet 14 | | | | | | |

Note : In this setup when bottom of the rack wasn't packed properly, so cool air was passing there. The average readings were about 1 to 4 degrees higher than the above mentioned ( Readings in the Sheet number 9 of temp_readings.ods file) readings for 1KW to 4KW load resp.. Above readings are taken again after packing the rack bottom with the floor.

| | Average Readings in degCel. 1KW | 2KW | 3KW | 4KW |
|---|---|---|---|---|
| **Themometer** | **3.5** | **10.0** | **14.1** | **18.5** |
| **Temp. Sensors** | **6.4** | **12.6** | **17.1** | **21.4** |

**Conclusions : Temperature Sensor results are about 1.2degCel. more than the Themometer readings. And maximum output temperature for 4 KW is about 28.0 (26,27,29/11/2014 sheets 13 & 14)**

## SETUP : 5

**setup moved 5 feet away from the inlet cool air duct, without aluminium duct between cool air inlet and rack but fans to suck air at the aluminium cage present.**
**{Sheet number 11 in the temp_readings.ods file}**

| Date | Difference in Temperature Readings T | S | Heat load of KW's | Time | | Remarks |
|---|---|---|---|---|---|---|
| 26/11/2014 | 11.90 | 08.23 | 3 | 09:50 - 11:30 | LHF+RH-2 | every 10 min. |
| Sheet 11 | 09.60 | 06.86 | 2 | 12:00 - 13:00 | LHF+RHF | “ |
| 27/11/2014 | 17.95 | 11.33 | 4 | 11:30 - 13:00 | All | every 10 min. |
| Sheet 11 | 06.45 | 05.35 | 1 | 14:20 - 16:00 | LHB | “ |
| | 09.20 | 06.14 | 2 | 16:30 – 17:10 | LHB+RHF | “ |
| 28/11/2014 | 18.31 | 11.37 | 4 | 10:20 - 12:50 | All | every 10 min. |
| Sheet 11 | | | | | | |
| 31/12/2014 | 18.73 | 12.17 | 4 | 10:30 – 16:30 | All | “ |
| sheet 16 | | | | | | |
| 01/01/2015 | 10.14 | 10.44 | 3 | 10:00 – 11:30 | LH-2+RHB | “ |
| sheet 16 | 9.63 | 06.44 | 2 | 14.15 – 16:00 | LHF+RHB | “ |
| 02/01/2015 | 3.22 | 02.18 | 1 | 10:10 – 14:10 | RHF | “ |
| sheet 16 | 17.79 | 12.38 | 4 | 15:00 – 16:00 | All | “ |
| 03/01/2015 | 19.14 | 13.14 | 4 | 10:00 – 12:10 | All | “ |

Note : In this setup Thermometer reading are higher than the sensor readings!

| | Average Readings in degCel. 1KW | 2KW | 3KW | 4KW | Max. o/p temp. 4KW | Themometer +/- Temp. Sensor |
|---|---|---|---|---|---|---|
| **Themometer** | **4.8** | **9.5** | **11** | **18.4** | | |
| **Temp. Sensors** | **3.8** | **6.5** | **9.3** | **12.1** | | |

**Conclusions : Temperature Sensor results are about 1 to 6 degCel. less than the Themometer readings. And maximum output temperature for 4 KW is about 33degCel (sheets 11 and 16)**

## SETUP : 6

**setup 5 but without fans to suck the cool air in the aluminium cage at 2 feet height.**
**{Sheet number 12 in the temp_readings.ods file}**

| Date | Difference in Temperature Readings T | S | Heat load of KW's | Time | | Remarks |
|---|---|---|---|---|---|---|
| 28/11/2014 | 08.00 | 10.55 | 1 | 14:30 - 16:00 | LHF | every 10 min. |
| Sheet 12 | 18.70 | 20.61 | 2 | 16:20 - 17:00 | LHF+RHB | “ |

| | | | | | | |
|---|---|---|---|---|---|---|
| 01/12/2014 | 23.85 | 26.10 | 3 | 10:00 - 12:00 | LHF+RH-2 | every 10 min. |
| Sheet 12 | 18.18 | 19.96 | 2 | 12:10 - 14:50 | LHB+RHF | “ |
| 02/12/2014 | 32.36 | 34.08 | 4 | 10:00 - 12:50 | All | every 10 min. |
| Sheet 12 | 17.67 | 19.64 | 2 | 14:10 - 15:30 | LH-2 | “ |
| 30/12/2014 | 30.11 | 30.20 | 4 | 12:20 - 15:50 | All | every 10 min. |
| 03/01/2015 | 32.56 | 33.87 | 4 | 12:30 – 17:00 | All | “ |
| 05/01/2015 | 25.84 | 27.50 | 3 | 12:10 – 17:10 | LHF+RF-2 | “ |
| sheet 15 | | | | | | |

**Average Readings in degCel.**

| | 1KW | 2KW | 3KW | 4KW |
|---|---|---|---|---|
| **Themometer** | **8.0** | **18.2** | **24.8** | **31.7** |
| **Temp. Sensors** | **10.5** | **20.0** | **26.8** | **32.7** |

**Conclusions : Temperature Sensor results are about 1 to 2 degCel. more than the Themometer readings. And maximum output temperature for 4 KW is about 46 degCel. (sheet no. 12)**

## SETUP : 7

**Rack without any modifications (aluminium cage in the rack removed). Kept 5 feet away from the cool air inlet duct. {Sheet number 17 in the temp_readings.ods file}**

| **Date** | **Readings** T | S | **Heat load of** KW's | **Time** | | **Remarks** |
|---|---|---|---|---|---|---|
| 22/01/2015 | -1.14 | 1.24 | 4 | 11:40 - 16:00 | All | every 10 min. |
| Sheet 17 | | | | | | |
| 23/01/2015 | -1.26 | 2.27 | 3 | 10:00 - 14:20 | LHB+RH-2 | every 10 min. |
| Sheet 17 | -3.22 | 1.27 | 2 | 14:30 - 15:50 | LHB+RHB | “ |
| | -5.25 | -0.79 | 1 | 16:00 - 17:20 | RHB | “ |

**Average Readings in degCel.**

| | 1KW | 2KW | 3KW | 4KW |
|---|---|---|---|---|
| **Themometer** | **-5.2** | **-3.2** | **-1.3** | **-1.1** |
| **Temp. Sensors** | **-0.8** | **-1.3** | **-2.3** | **+1.2** |

**Conclusions : Temperature Sensor results are about 1 to 4 degCel. less than the Themometer readings. And maximum output temperature for 4 KW is about 31.5 on 22/01/2015 sheet no. 17.**

## SETUP : 8

**Rack without any modifications (aluminium cage in the rack removed). Kept over the cool air inlet duct. {Sheet number 17 in the temp_readings.ods file}**

| **Date** | **Difference in Temperature Readings** T | S | **Heat load of** KW's | **Time** | | **Remarks** |
|---|---|---|---|---|---|---|
| 24/01/2015 | -2.78 | -3.35 | 4 | 12:30 - 17:10 | All | every 10 min. |
| Sheet 18 | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 30/01/2015 | -3.17 | -2.20 | 3 | 10:30 - 14:50 LHB+RH-2 | " |
| Sheet 18 | -3.21 | -1.70 | 2 | 15:00 – 17:10 LHB+RHB | " |
| 02/02/2015 | -2.21 | -0.50 | 1 | 10:00 - 12:00 LHF | " |
| Sheet 18 | -3.04 | -1.10 | 2 | 12:10 – 15:00 LH-2 | " |
| | -3.14 | -1.68 | 3 | 15:10 – 17:20 LH-2+RHB | " |

**Average Readings in degCel.**

| | 1KW | 2KW | 3KW | 4KW |
|---|---|---|---|---|
| **Themometer** | **-2.2** | **-3.1** | **-3.1** | **-2.8** |
| **Temp. Sensors** | **-0.5** | **-1.4** | **-2.0** | **-3.3** |

Conclusions : Temperature Sensor results are about 1.5 degCel. more than the Themometer readings. And maximum output temperature for 4 KW is about 9.0 degCel 24/01/2015 sheet no. 18.

## Conclusions :

**Temperature Difference Range, for the Heat Load of**

| Setup No. | 1 KW | 2 KW | 3 KW | 4 KW | Remarks |
|---|---|---|---|---|---|
| 1 | 2 – 4 | 5.5 – 8 | 10.5 – 12 | not done | Thermometer |
| | 4 – 4.5 | 8 – 8.5 | 11.5 – 13 | not done | Temp. Sensors |
| **Average** | **3.2** | **7** | **11.7** | **not done** | |
| 2 | 2 – 4 | 5 – 8.5 | 7.2 – 10 | 11 – 13 | Thermometer |
| | 4 – 5.2 | 7 – 9.5 | 10.3 – 12.5 | 13.5 – 15.5 | Temp. Sensors |
| **Average** | **3.6** | **7.2** | **9.8** | **13.2** | |
| 3 | 2 – 4 | 6 – 9.5 | 12.3 – 12.7 | 13.7 – 16.0 | Thermometer |
| | 4 – 6 | 8.7 – 12 | 14.6 – 15.3 | 16.4 – 18.7 | Temp. Sensors |
| **Average** | **4** | **8** | **13.8** | **16.2** | |
| 4 | 2.5 – 4.5 | 8.5 – 11.5 | 13.5 – 14.8 | 18.0 – 19.2 | Thermometer |
| | 6.2 – 6.6 | 12.0 – 13.3 | 16.5 – 17.7 | 21.2 – 21.7 | Temp. Sensors |
| **Average** | **4.6** | **10.9** | **15.6** | **19.8** | |
| 5 | 3.2 - 6.4 | 9.2 – 9.6 | 10.1 - 11.9 | 17.8 - 19.1 | Thermometer |
| | 2.2 - 5.3 | 6.1 - 6.8 | 8.2 – 10.5 | 11.4 – 13.1 | Temp. Sensors |
| **Average** | **4.3** | **7.8** | **10.0** | **10.4** | |
| 6 | 8.0 | 17.7 – 18.7 | 23.8 - 25.9 | 30.1 - 32.5 | Thermometer |
| | 10.5 | 19.6 – 20.6 | 26.1 - 27.5 | 30.2 - 34.0 | Temp. Sensors |
| **Average** | **9.2** | **19.2** | **25.8** | **32.0** | |
| 7 | -5.25 | -3.22 | -1.26 | -1.14 | Thermometer |
| | -0.79 | 1.27 | 2.27 | 1.24 | Temp. Sensors |
| **Average** | **- 3.02** | **- 1.0** | **- 0.5** | **0.05** | |

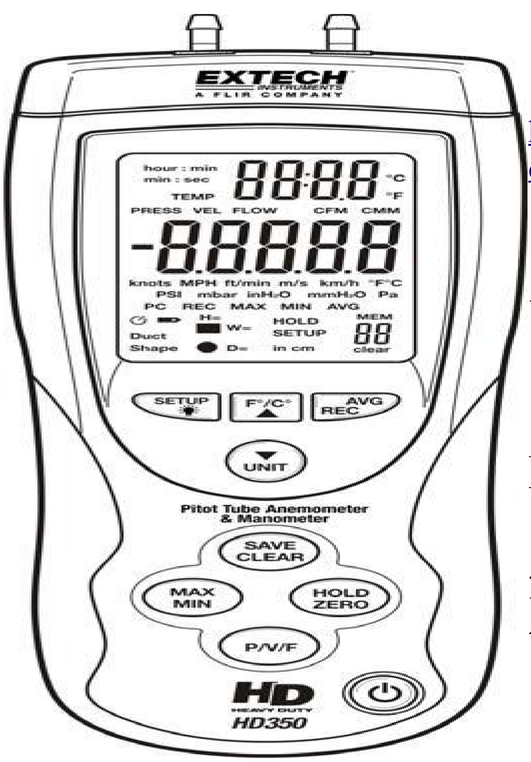
| | | | | | |
|---|---|---|---|---|---|
| 8 | -2.21 | -3.04 - -3.21 | -3.08 - -3.14 | -3.35 | Thermometer |
| | -0.50 | -1.10 - -1.70 | -1.68 - -2.20 | -2.78 | Temp. Sensors |
| **Average** | **-1.35** | **-2.15** | **-2.41** | **-3.1** | |

| **Setup#** | **with al. plate** | **w/o al. plate (inside the al. cage which obstructs the air flow)** | |
|---|---|---|---|
| | **Ther / T.Sensor** | **Ther / T.Sensor** | **Remarks** |
| **2a** | **6.23 / 8.89** | **3.50 / 6.06** | **--** |
| **3a** | **9.55 / 10.98** | **6.12 / 5.33** | **--** |
| **3b** | **10.64 / 13.26** | **10.82 / 12.84** | **slot in the al. cage at 2' height open. This temp. diff. increases by 1 degCel., if we put 3 fans of 100cfm at open slot.** |

## 5 Daily Readings

**Please refer the file temp_readings.ods attached with this report.**

## 6 Air Flow meter User Manual




Visit the webpage :
http://www.extech.com/instruments/product.asp?catid=1&prodid=600
and click at the

**English User's Manual**

**under Downloads & Software**

**for complete User Manual.**

**OR**

**Documents available with the Meter.**

**OR**

**file “HD350_UM.pdf” attached with this Report.**

**Introduction :**

Congratulations on your purchase of the Extech HD350. This handheld meter measures and displays air velocity (speed), air flow (volume), ambient air temperature, and gauge/differential pressure. This meter is shipped fully tested and calibrated and, with proper use, will provide years of reliable service.