THE GMRT RADIO ARRAY

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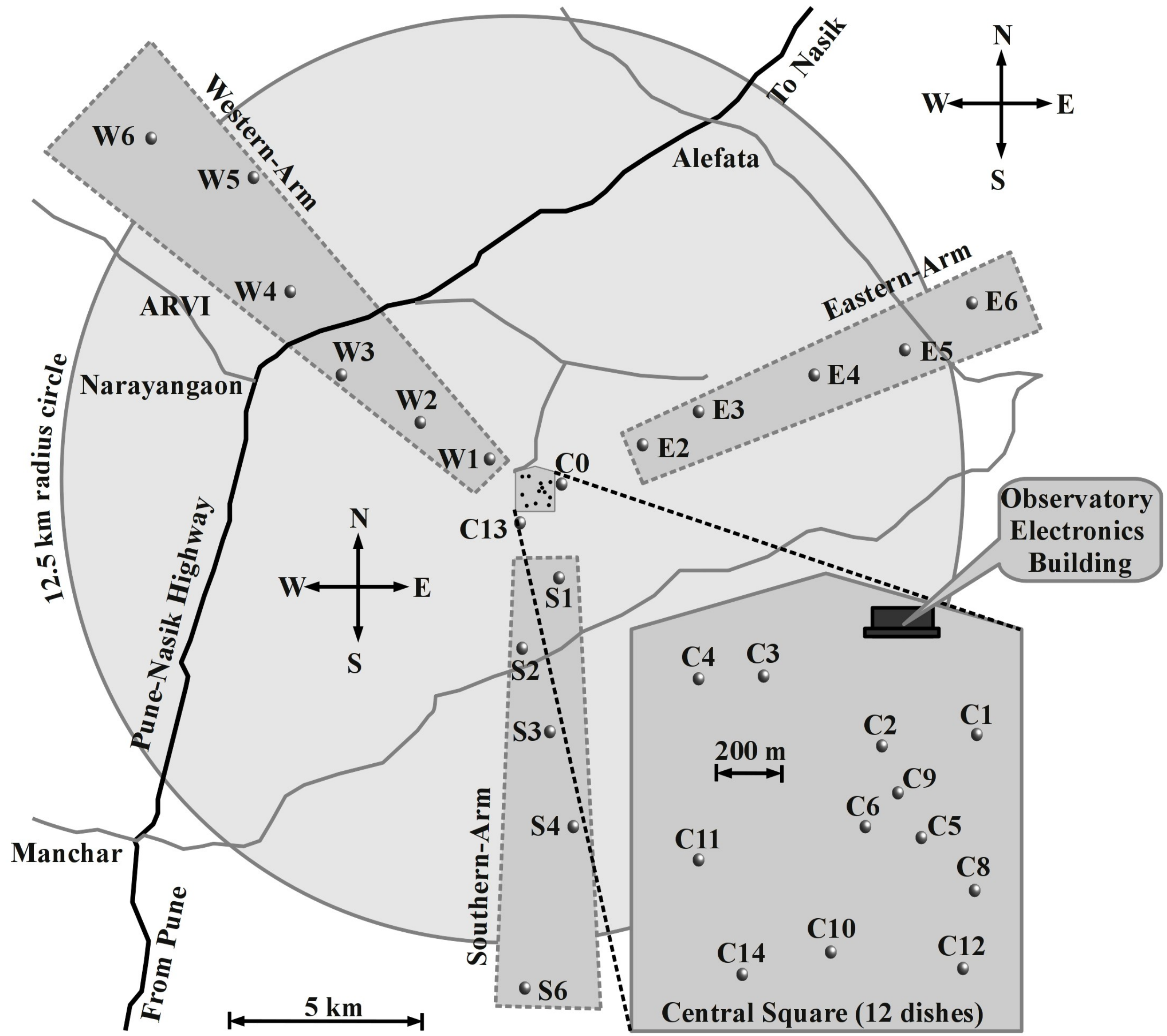
License

Introduction

The **GMRT** (Giant Meter-wave Radio Telescope) is a multiplicative interferometer array using 30 antennas spread within a radius of 15 km. 14 antennae (C-00 to C-14 with C-07 absent) are close to the observatory building and are called *central square antennas* forming a short baseline array.. C-00 and C-14, are outside the boundary area. There are three arms for longer baselines extending approximately 15 km forming an Y-shape namely:



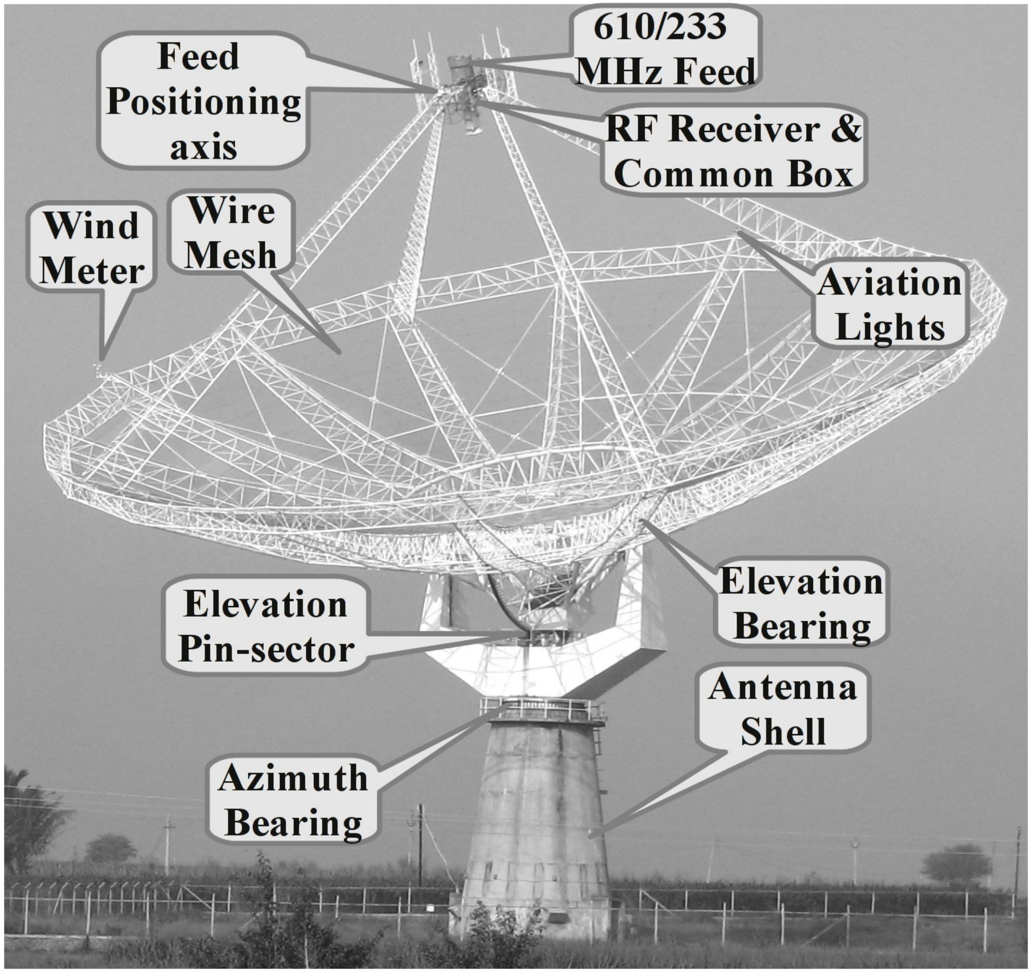
Eastern arm: 5 antennae (E-02 to E-06). E-01 does not exist.
Western arm: 6 antennae (W-01 to W-06).
Southern arm: 5 antennae (S-01 to S-04 and S-06). S-05 does not exist.

Position coordinates of GMRT antennas.

Altitude = 650 m.

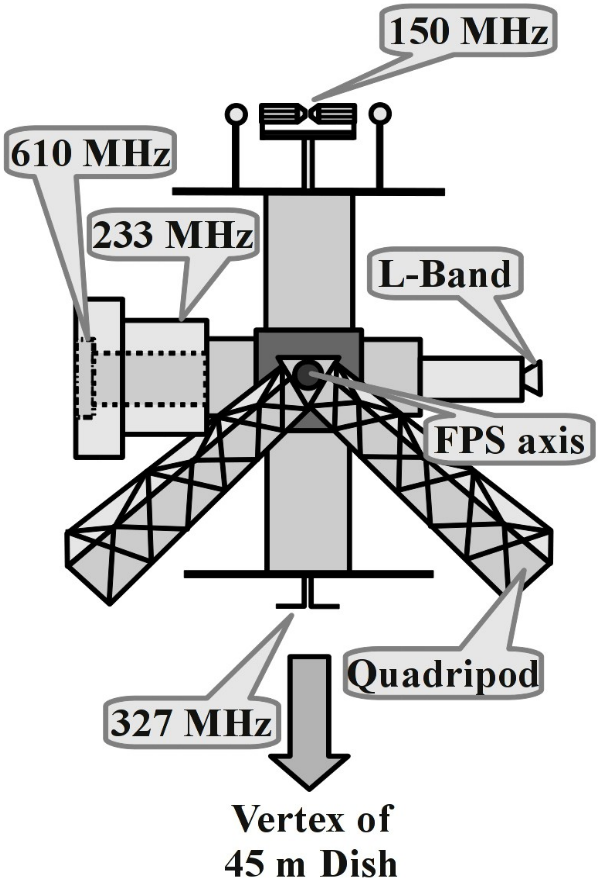
Antenna	Lat. (deg)	Lon. (deg)	Antenna	Lat. (deg)	Lon. (deg)
C-00	19.0929	-74.0570	E-02	19.1023	-74.0772
C-01	19.0927	-74.0536	E-03	19.1117	-74.0940
C-02	19.0931	-74.0505	E-04	19.1209	-74.1244
C-03	19.0944	-74.0469	E-05	19.1251	-74.1474
C-04	19.0931	-74.0505	E-06	19.1365	-74.1652
C-05	19.0908	-74.0511	W-01	19.0988	-74.0353
C-06	19.0910	-74.0502	W-02	19.1066	-74.0210
C-08	19.0893	-74.0531	W-03	19.1208	-74.0011
C-09	19.0917	-74.0509	W-04	19.1415	-73.9836
C-10	19.0875	-74.0489	W-05	19.1678	-73.9734
C-11	19.0901	-74.0447	W-06	19.1784	-73.9436
C-12	19.0871	-74.0521	S-01	19.0664	-74.0565
C-13	19.0825	-74.0444	S-02	19.0523	-74.0470
C-14	19.0871	-74.0460	S-03	19.0320	-74.0536
—-	—-	—-	S-04	19.0074	-74.0595
—-	—-	—-	S-06	18.9653	-74.0470

Details of a single dish of GMRT Array-1



(a)

A GMRT antenna (array element).



(b)

Antenna-feeds.

Half power beam-widths using Rayleigh criterion ($1{:}22\lambda/D$).

Freq.	150 MHz	233 MHz	327 MHz	610 MHz	1000 MHz	1200 MHz	1400 MHz
HPBW	3.10°	2.00°	1.43°	0.76°	0.47°	0.39°	0.33°

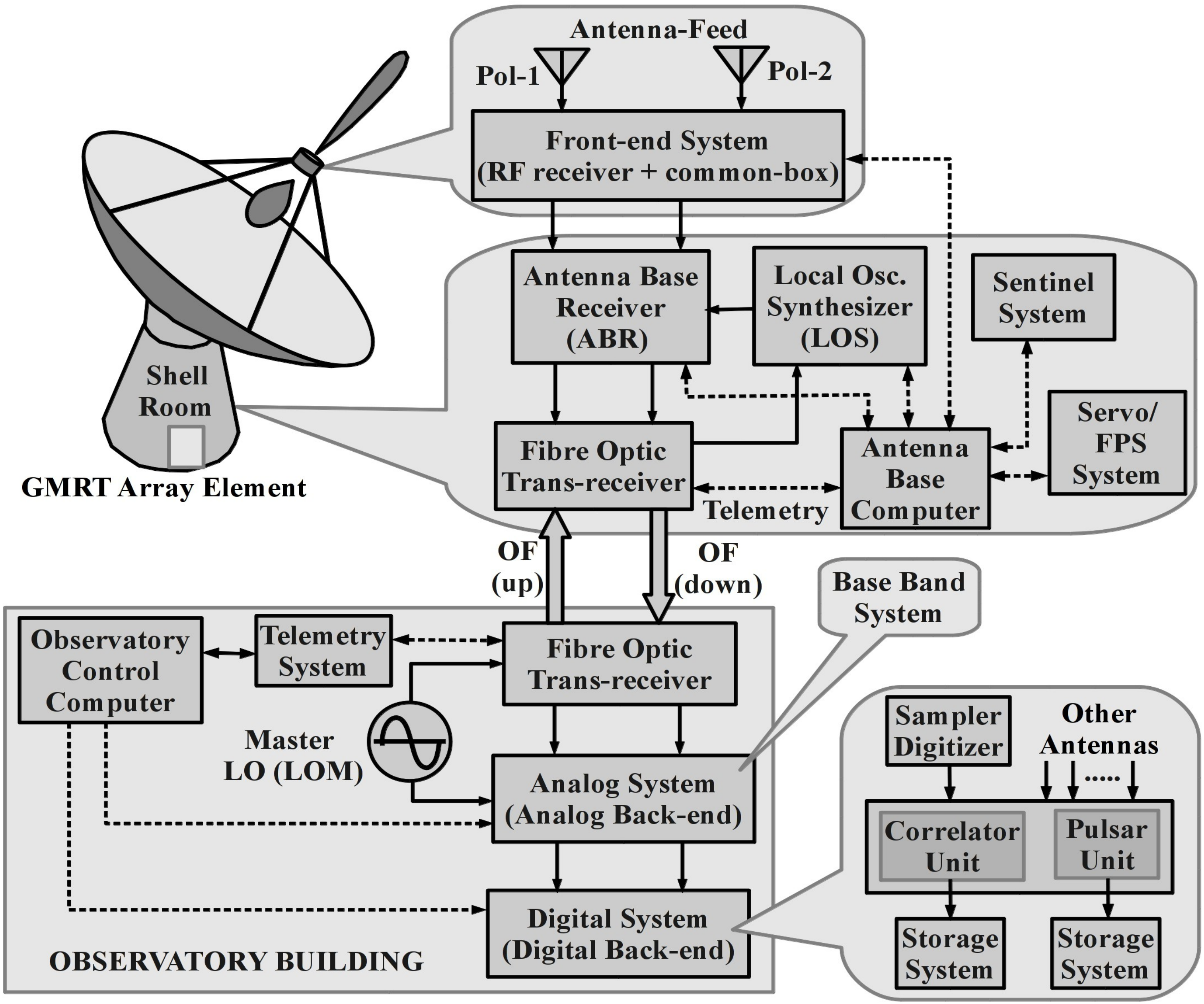
Details of a single dish of GMRT Array-2

Each GMRT array element is a dish-antenna having a diameter of 45m. There are 4 dual polarized antenna-feeds: (i) 150 MHz, (ii) 327 MHz, (iii) 610/233 MHz (dual frequency), and (iv) 1000-1450 MHz (L-band). Minimum band-width is 32 MHz.

At any given time only 1 antenna-feed can be focussed using FPS (feed positioning system). Each antenna-feed has two linear cross polarizations, namely V and H except for the L-band feed which is dual circularly polarized, namely RCP and LCP. The front-end receiving system (RF receiver) is fitted near the antenna-feeds.

Each antenna-feed uses a separate front-end RF receiver. The outputs of these are fed into a common receiver (common-box) which selects the feed to be used. Signal outputs from these are carried over to the antenna shell, where they are converted to IF and sent over through an OF (optical fiber) to the CEB (central electronics building). The antenna shell also consists of servo and feed positioning amplifiers. All of these are controlled from ABC (antenna base computer) inside the shell. The control commands to ABC from the observatory reaches through OF.

Functional Blocks of GMRT -1



Functional blocks: Telemetry, control and monitoring signals are shown by dotted lines. The RF, IF and data signals are shown by dark lines.

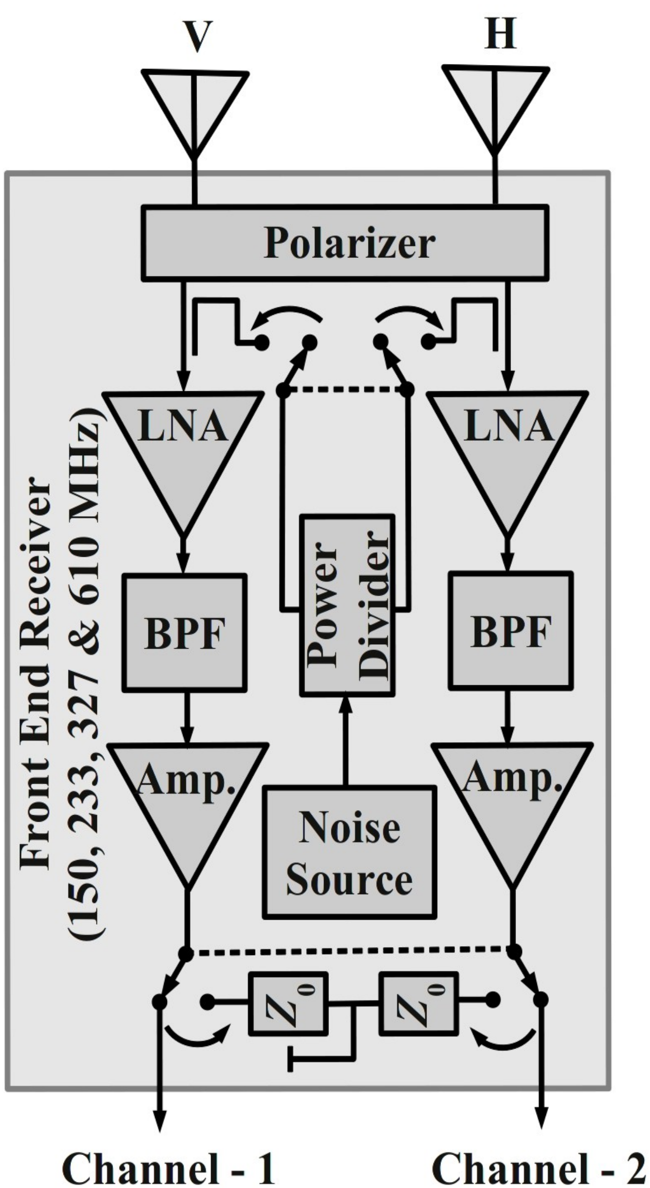
Functional Blocks of GMRT -2

The antenna-feed, RF receiver and the common-box forms the front-end RF system. RF receiver is very close to the antenna-feeds followed by common-box. V and H polarizations are and brought into ABR (antenna base receiver) inside antenna shell. These undergo two stages of mixing and finally down converted to 130 MHz and 175 MHz IF signals and passed to OF trans-receiver which sends them to CEB through OF downlink (return-link). The LO signals for down conversion are generated in a synthesizer which is locked to the LOM (master local oscillator) kept in the observatory building. The LOM signal is passed to all antennas through OF up-link (forward-link).

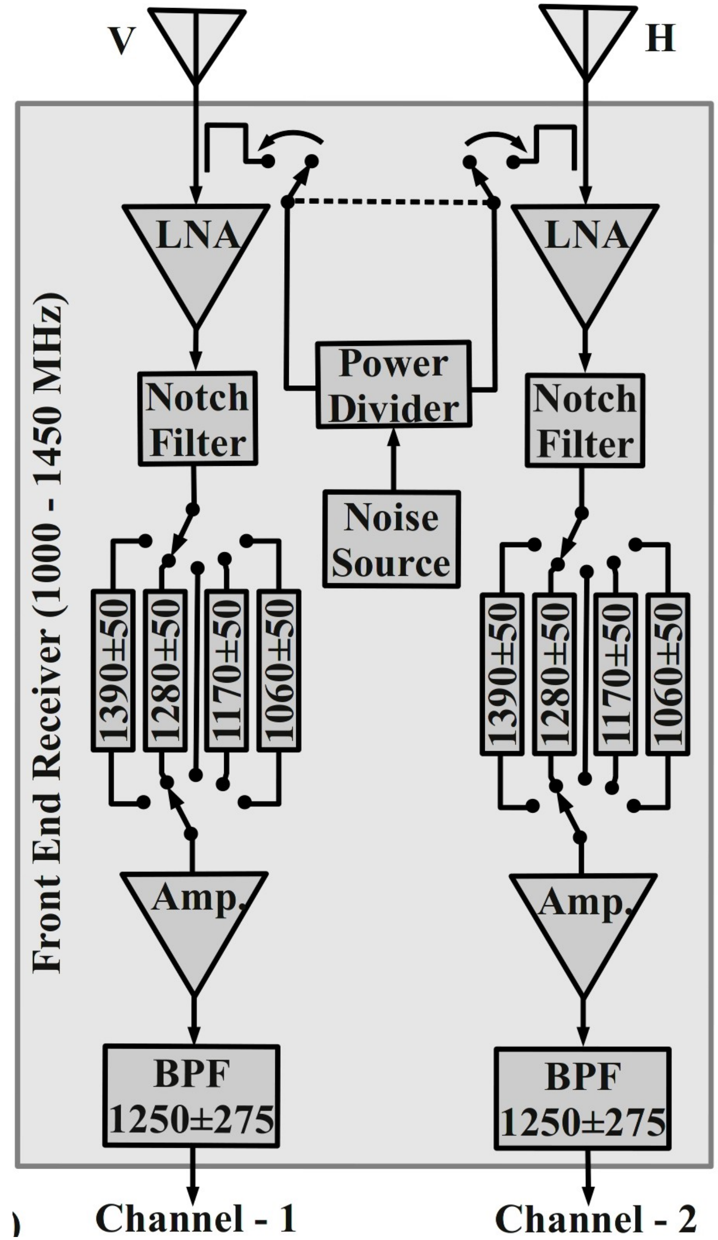
Inside CEB, IFs are recovered back from optical and fed to the analog back-end receiver system. The same LOM is used to recover the BB (base-bands) and passed to the GSB (GMRT software back-end). GSB converts BB signals into digital, correlate and save the final results or process for pulsar beam formation and save the final results.

Servo system controls the azimuth and elevation motion of the dishes. Servo amplifiers control the motor drives. The FPS is a motor driven system used to focus antenna-feeds on the dish. Sentinel system protects antenna shell electronics from fire, smoke and heat by automatically turning them off and firing alarms. Each of the systems in an antenna are controlled by telemetry signals reaching the ABC.

Front-end RF System (before common box)



(a) System blocks used with 150 MHz, 233/610 MHz, and 327 MHz antenna-feeds.



(b) System blocks used with the L-band (1000 - 1450 MHz) antenna-feed.

FES (before common box) -2

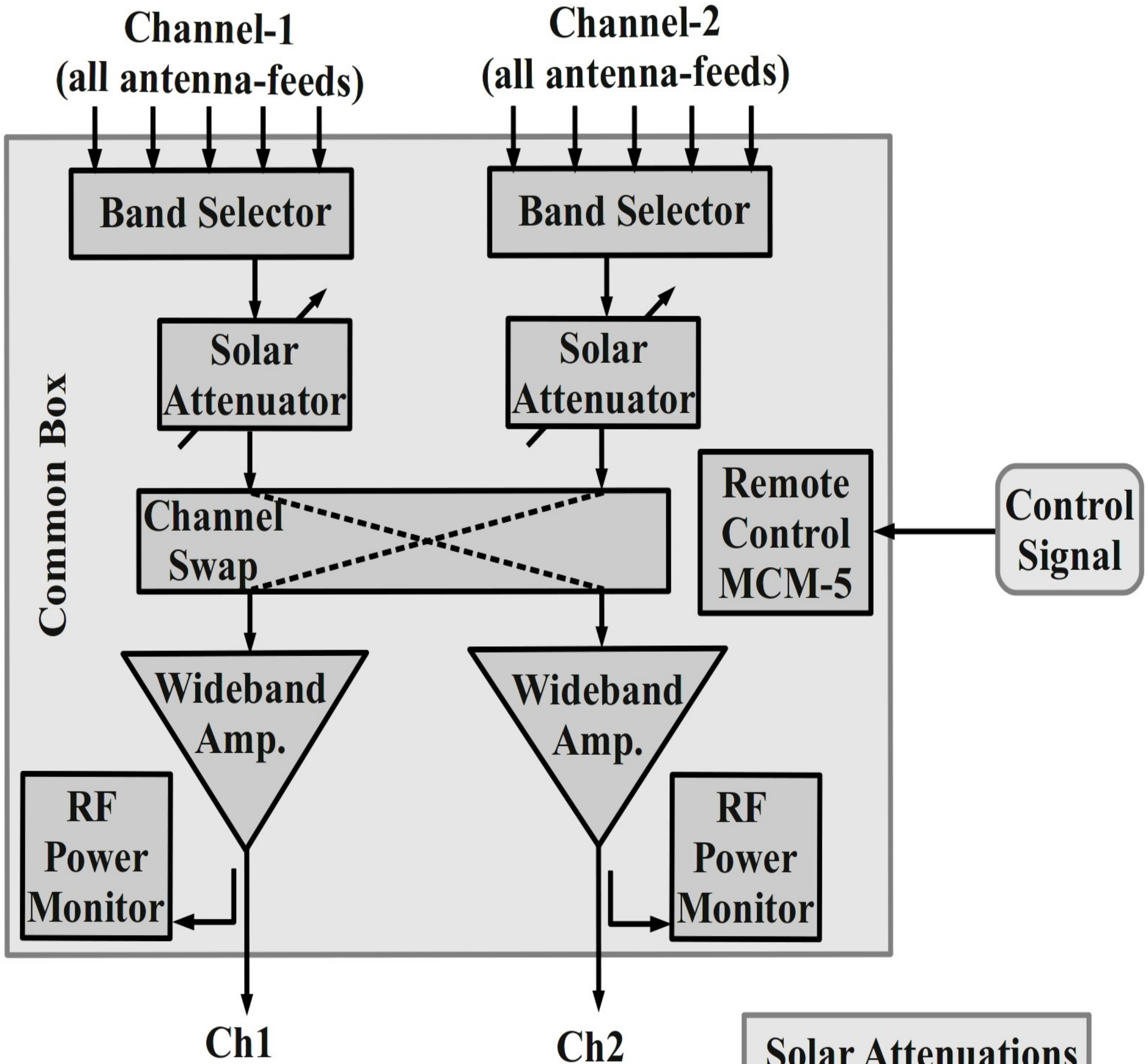
[FES: Front-end RF System]

Front-end low noise receiving are used next to the antenna-feeds (before the common-box). Linearly cross polarized outputs (V and H) from antenna-feed converted to circular (RCP and LCP) using polarizer and sent to LNAs followed by BPFs which filters unwanted signals. After amplification comes out as channels 1 and 2 and go to common-box. They can be terminated to matched loads using a RF SP2T switch for testing.

For L-band antenna-feed, polarizer is not used. Notch filters are used to prevent the GSM signals from entering. Any of the 4 BPFs (100 MHz band-width) centered at 1060, 1170, 1280 and 1390 MHz may be chosen for observations. A direct path is also provided for by-passing these filters. The two polarized outputs (channels 1 and 2) are passed to the common-box.

In both modules, a noise source is used for calibration by coupling equal amount of coherent noise in both the channels using directional couplers. The noise source is turned on and a SPDT switch is used to connect the outputs to the directional couplers.

FES (common box)



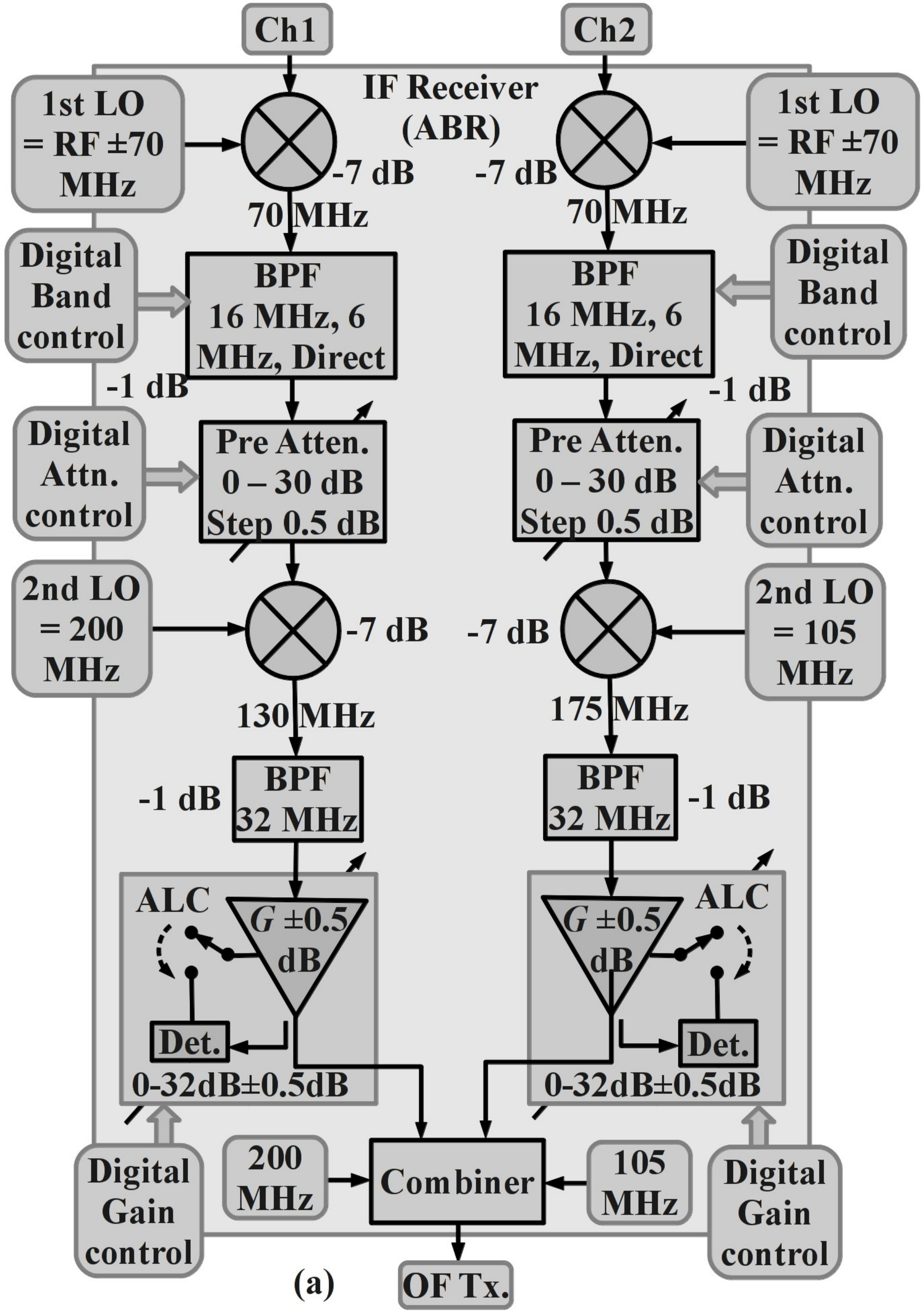
Common-Box (channel multiplexer and variable gain/attenuator).

Solar Attenuations
(*i*) 0 dB
(*ii*) 14 dB
(*iii*) 30 dB
(*iv*) 44 dB
(*v*) Teminated

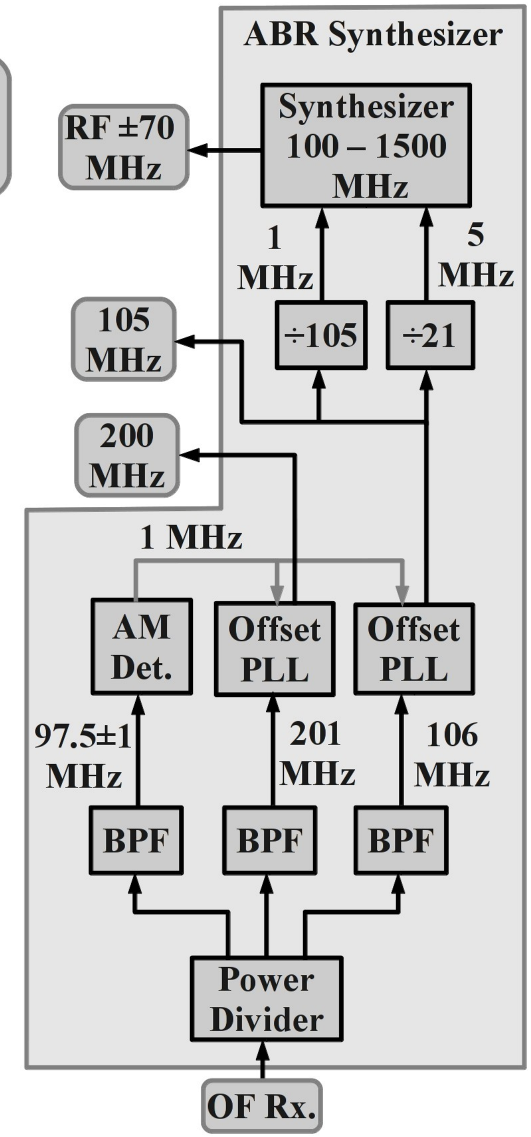
Common-box selects the antenna-feed and sets required BPF and attenuations. The operational commands to the common-box are decoded by a MCM (machine control and monitoring) card. The common-box can swap the polarized channel outputs (1 and 2) on requirement. It can provide some specific attenuation (0 dB, 14 dB, 30 dB and 44 dB) using the solar attenuators. Some times, it is required to check the authenticity of an interfering signal (whether generated within the system or coming through the antenna from outside). This is done by terminating the front-end input in the attenuator setup.

IF Receiver at Antenna Shell

In ABR (antenna base receiver), FE outputs (Ch1 and Ch2) undergoes 1st mixing (LO = RF±70 MHz) to produce 70 MHz IF. They again undergo 2nd mixing (LO = 200 and 105 MHz) to produce 130 and 175 MHz IFs. These are sent to OFS and transmitted to CEB. Bandwidths and attenuation levels at different stages, and ALC (automatic level control) on/off are controlled by digital signals.



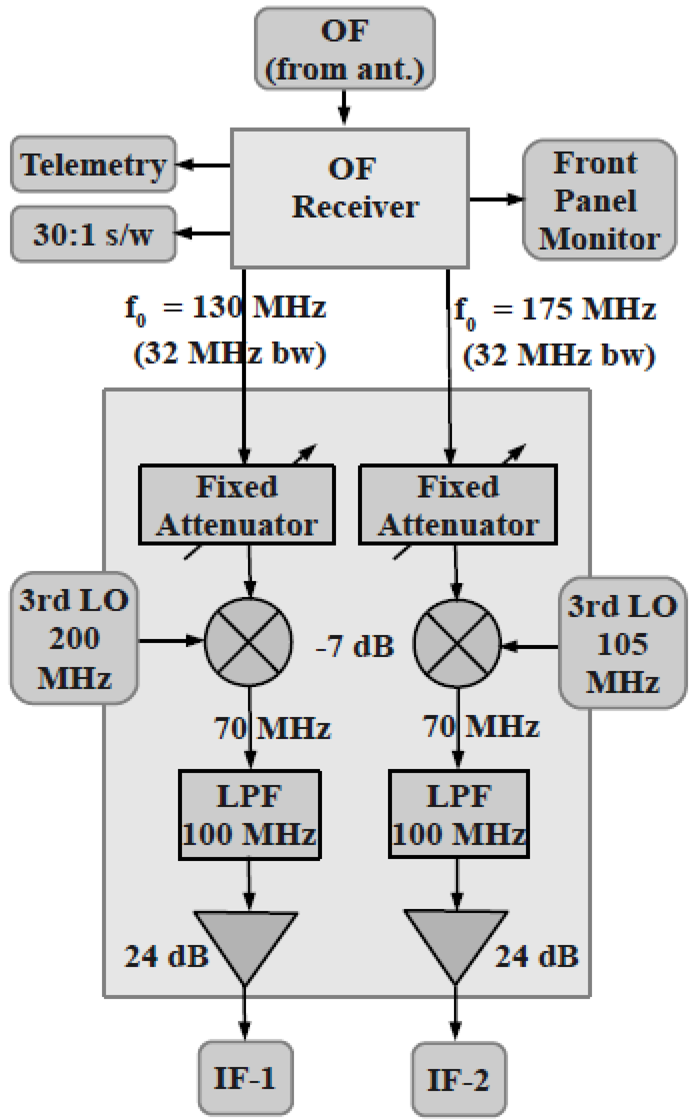
Antenna base receiver (ABR).



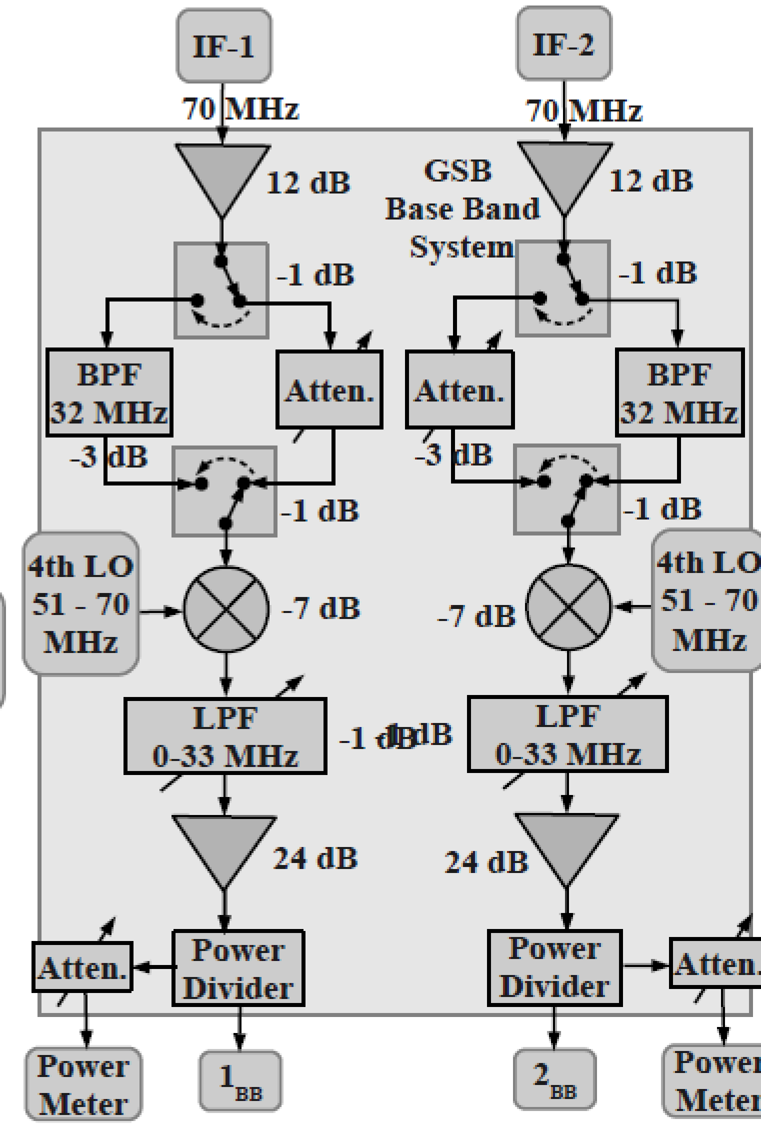
LO reference generation (LOR) in antenna shell.

Base-band System at CEB

The 130 and 175 MHz IF signals are separated in the OF receiver and fed to the mixer-PIU at CEB. These are mixed with the 3rd LOs (200 and 105 MHz) such that 70 MHz IF is produced for both channels. These two are fed to the new IF-conversion-PIU, where it undergoes mixing with the 4th LO and produces two base-band outputs (1_{BB} and 2_{BB}) with required bandwidth.



Mixing with 3rd LO (Mixer-PIU).

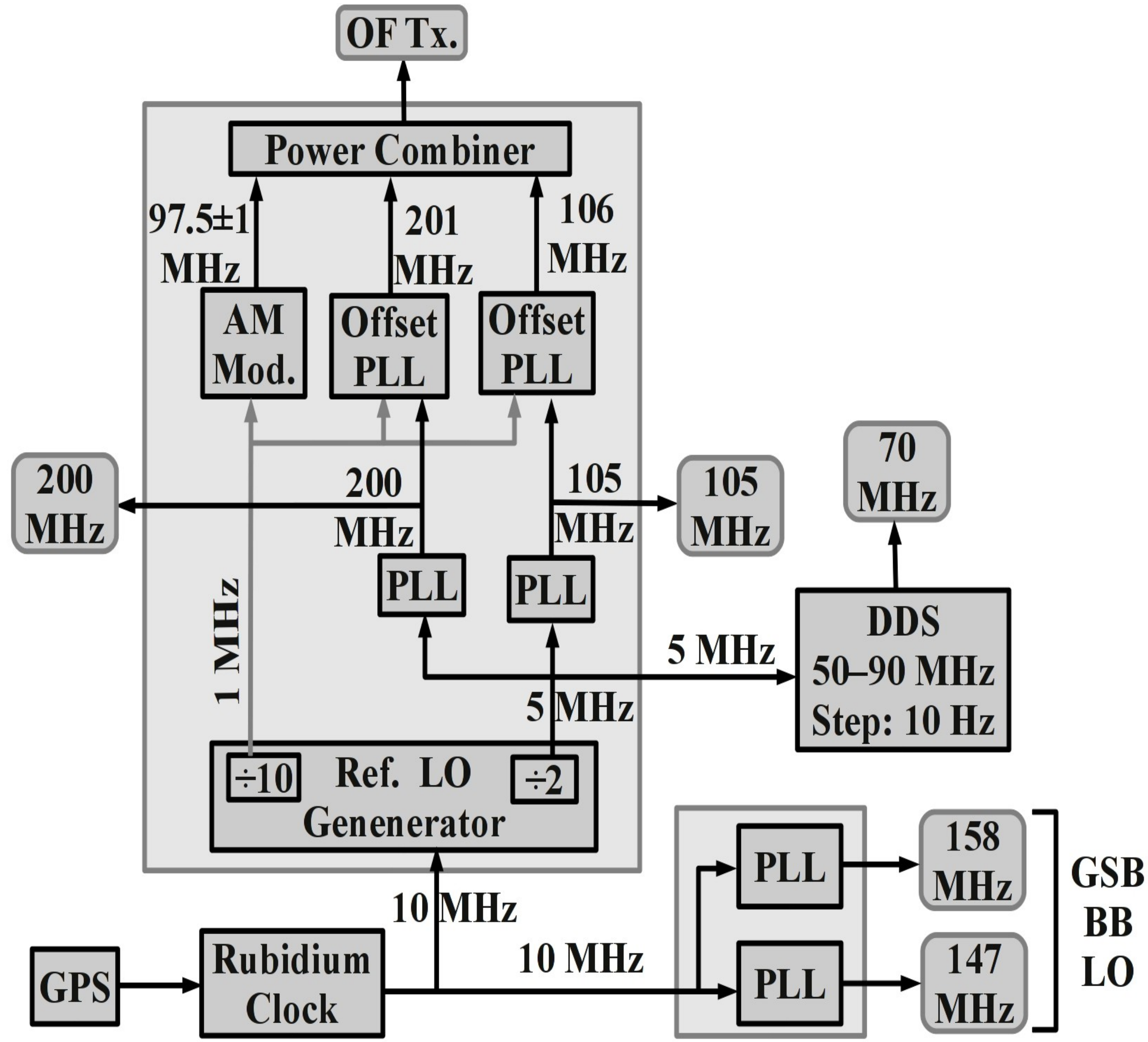


Mixing with 4th LO (New IF conversion PIU).

LOM & reference LO generator at CEB

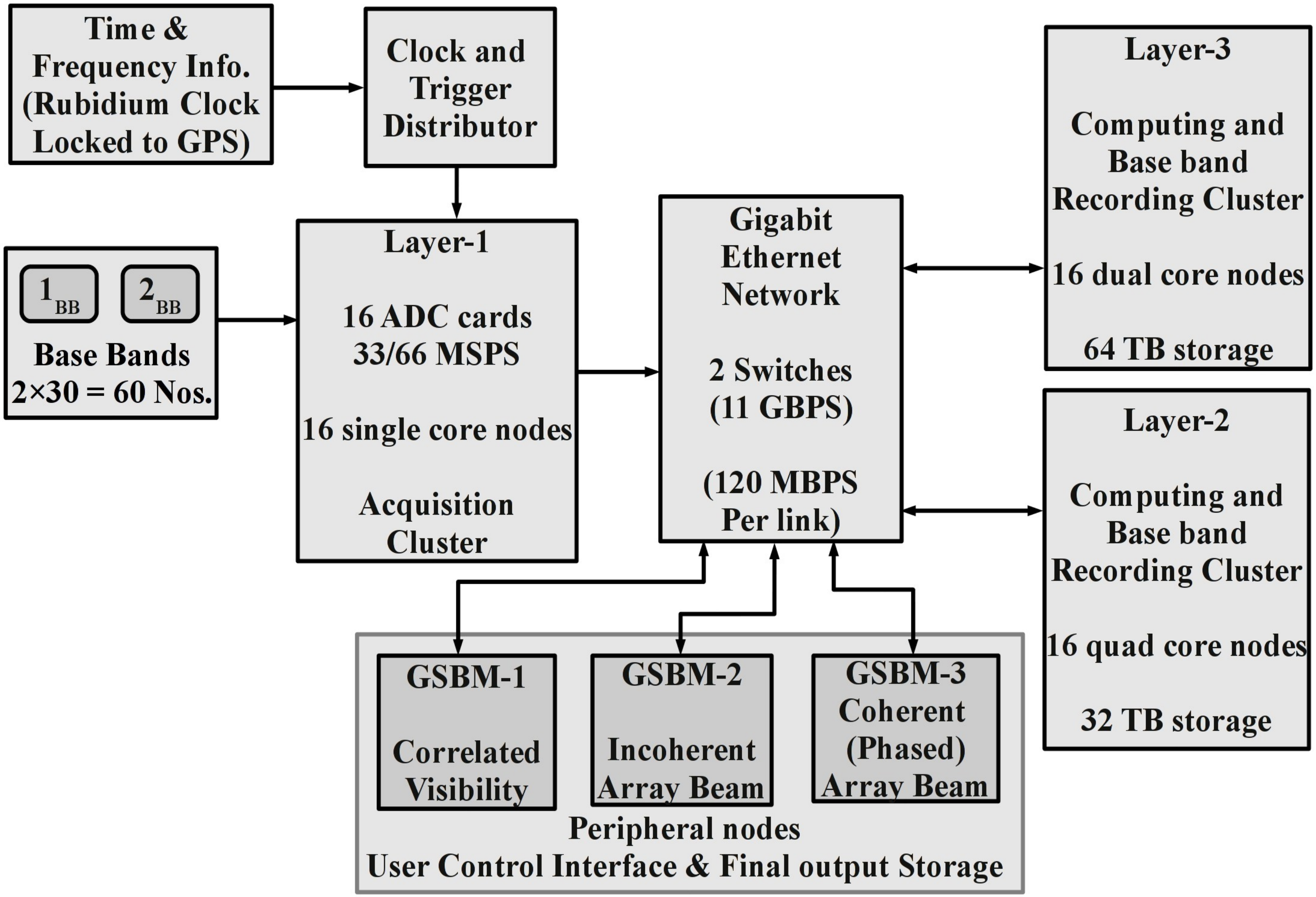
[LOM: Master LO (local oscillator)]

Rubidium master clock is kept synchronized with GPS. Its 10 MHz output goes to a reference generator which gives two frequencies (1 MHz and 5 MHz) by division. The 5 MHz signal generates 200 MHz and 105 MHz using PLL. From these frequencies. using offset PLL, 201 MHz and 106 MHz are generated with the 1 MHz signal offset. The 1 MHz signal amplitude modulates a carrier of 97.5 MHz. The modulated output is combined with the 201 MHz and 106 MHz signals and sent to the optical transmitter for transmission to the antennas using up-link fiber.



GSB Correlator & Pulsar Receiver -1

[GSB: GMRT Software Backend]



The base-band from each antenna is of 32 MHz bandwidth for each polarization. There are 60 base-band inputs for all 30 antennas. Each antenna produces two polarizations (1_{BB} and 2_{BB}). The time and frequency information is derived from the Rubidium clock of LOM.

GSB Correlator & Pulsar Receiver -2

There are 16 ADC cards, 48 Linux PCs and 2 independent 48 port Giga-bit switches. Three distinct groups of PCs each consisting of 16 PCs are formed (described as Layer-1, Layer-2 and Layer-3). All these PCs are inter-connected using the 2 Giga-bit switches. These PCs are also called nodes. There are also few peripheral nodes attached to the system.

Layer-1 PCs (16 single core): Contain PCI-ADC cards. Each card can sample 4 analog inputs, operating in: (i) 33 MHz bandwidth with 4 bit digital conversion, or (ii) 16 MHz bandwidth with 8 bit digital conversion. Thus, 16 cards can take 64 analog inputs. The base-bands (1BB & 2BB) after digitization by ADCs are tramsfered to Layer-1 at a rate of 132 MBPS (effective data rate: 2 GBPS).

Layer-2 PCs (16 quad core dual processor): Major part of the computations are done by these.

Layer-3 PCs (16 dual core dual processor): Each has 4 TB storage capacity. Records data in raw dump mode.

GSB: Correlator & Pulsar Receiver -3

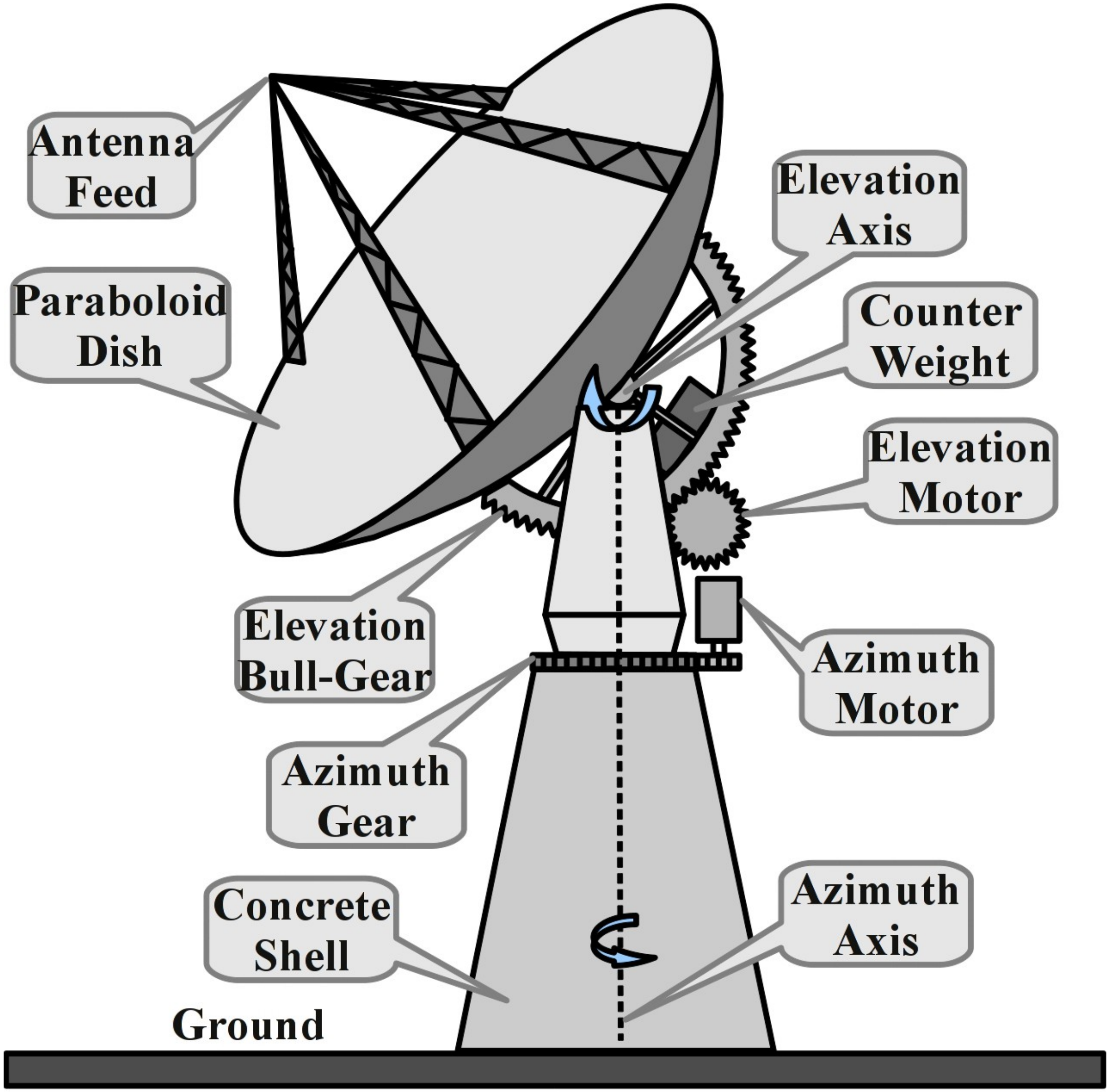
Additional nodes (GSBM-1, GSBM-2, and GSBM-3)

GSBM-1 forms the primary interface to the outside world. It provides control and configuration information, including antenna connectivities to acquisition nodes, current frequency and source settings of all antennas, updates of antenna specific gain and phase, etc. It takes commands to start data recording of new scans and does other related operations. It obtains the final results of computation (visibility) and sends them for long term accumulation and recording in another computer.

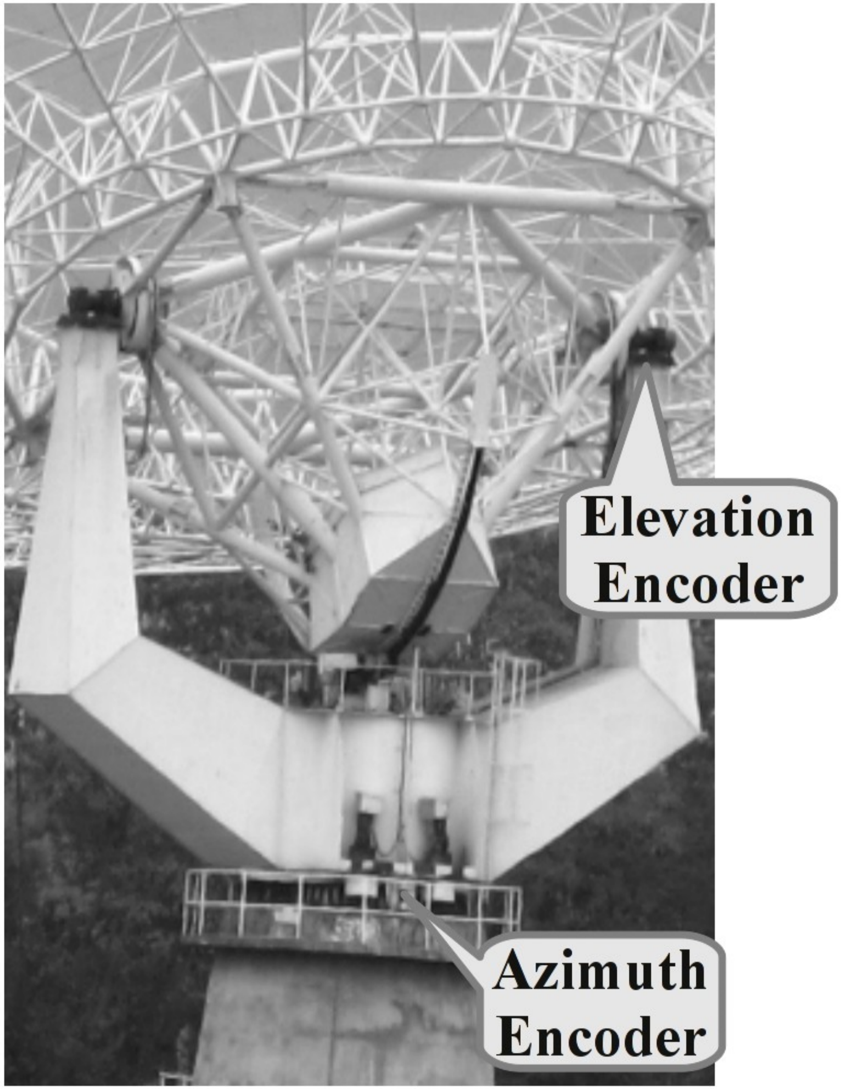
GSBM-2 receives the pulsar data of incoherent beam formation.

GSBM-3 receives the pulsar data of coherent beam formation. Both of these nodes record the data on local hard drives after some pre-processing if required.

Servo System for Antenna Positioning -1



Motor driven arrangements for azimuth and elevation movements.



Locations of azimuth and elevation encoders.

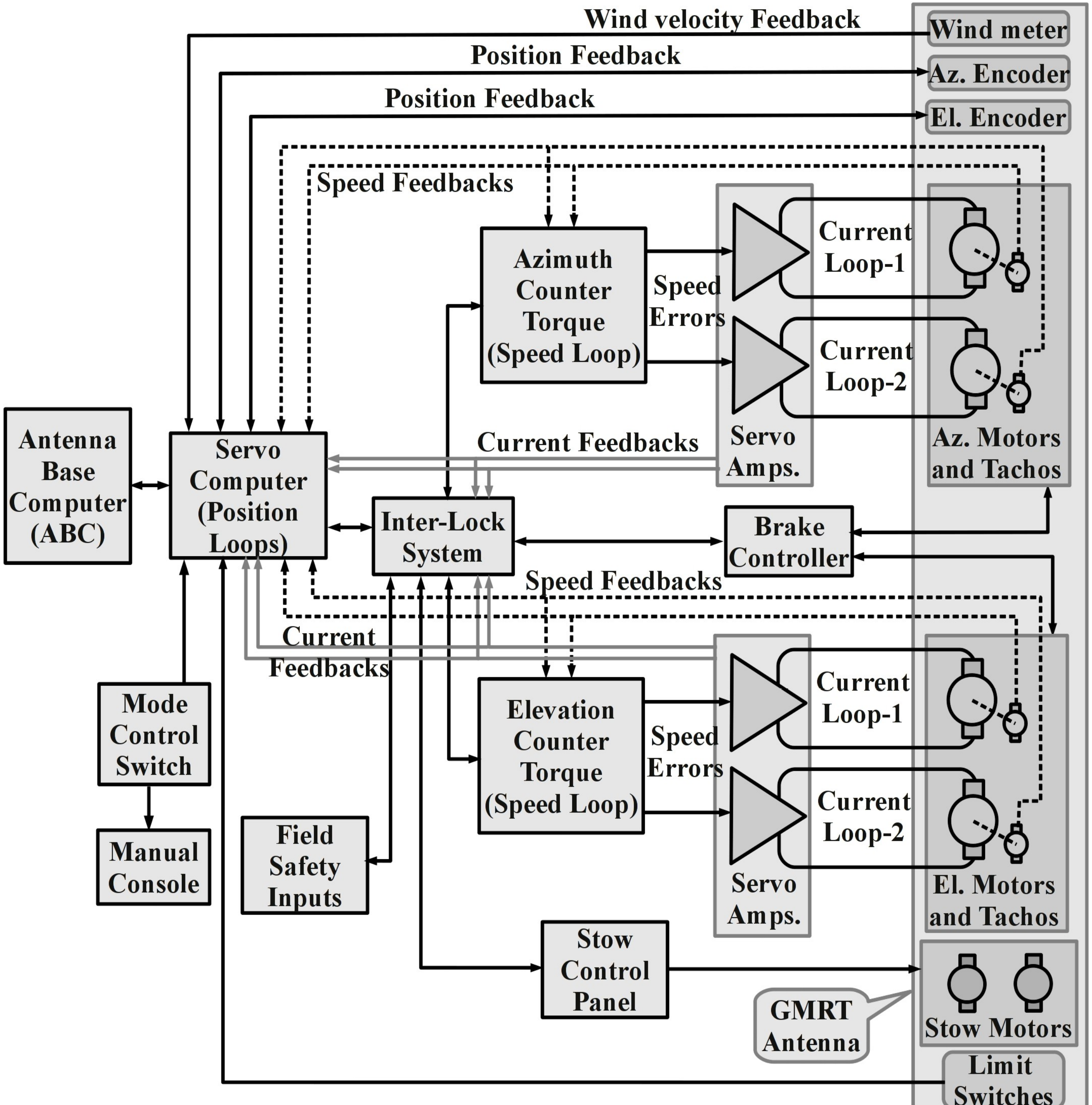
Servo System for Antenna Positioning -2

Both the elevation and azimuth rotations are performed with motors controlled by servo amplifiers using current loops. The control over current loops comes from the speed error feedbacks.

There are four motors (two for azimuth and two for elevation movements). Each of these motors are fitted with tachos which generates signals carrying speed informations. These are used to control the rotation speeds of dish. The two azimuth and elevation encoders send the respective angular positions of the antenna with respect to antenna shell and horizontal directions respectively. The interlock system is the final authority to decide whether the antenna should be moved or not.

The ABC (antenna base computer) receives commands from the observatory through OF and passes them to the servo computer. Based on the commands and the various other inputs like speed and position feedbacks, it communicates with the interlock system which checks if it is safe to rotate the antenna. If all is well it releases the brakes and sets up the current loops using azimuth and elevation counter torque systems. The antenna can also be controlled manually from the shell after bypassing the observatory commands reaching the servo computer. This is usually done during maintenance using the manual console which sets changes to manual mode using the mode control switch.

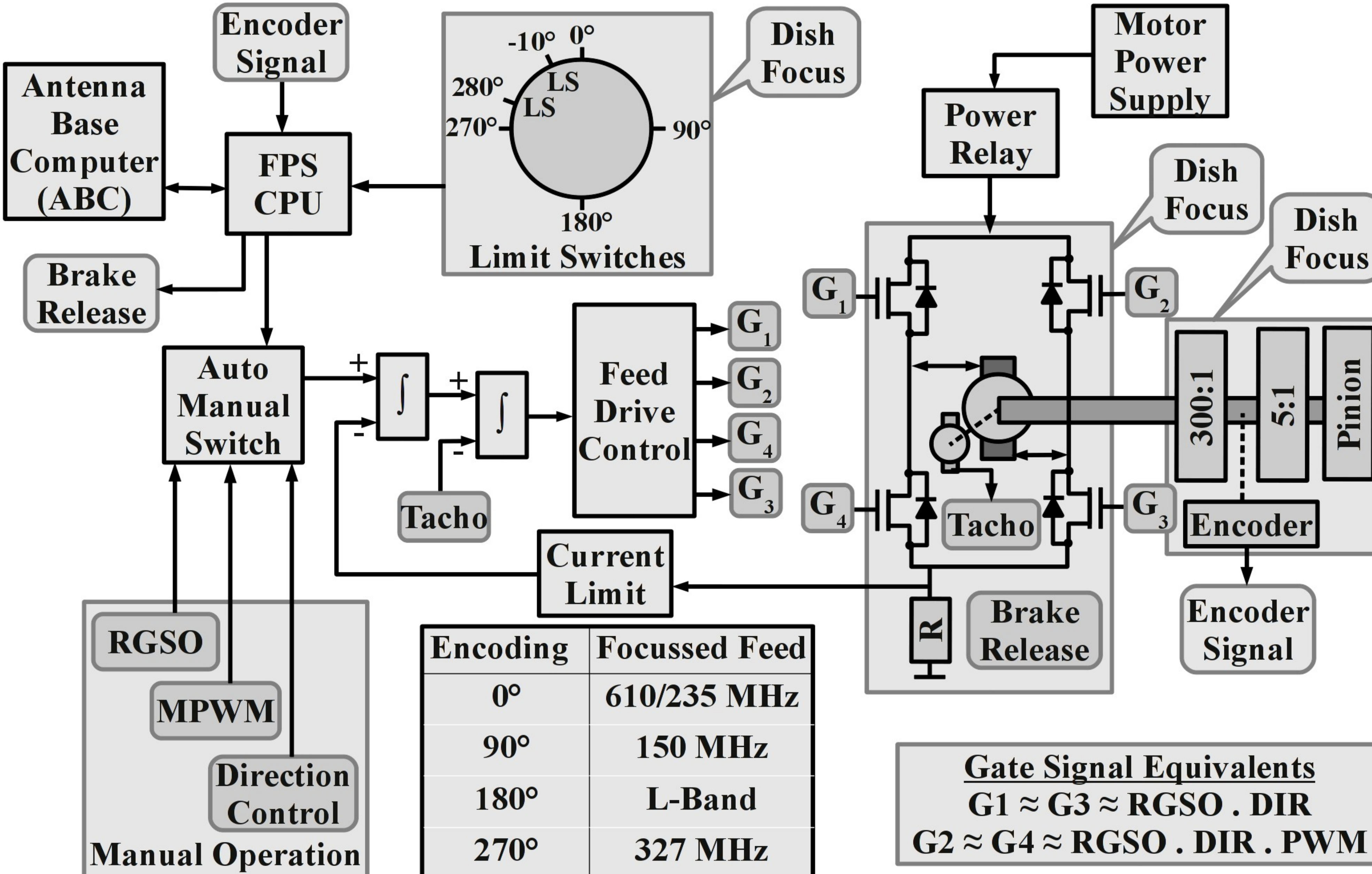
Servo System for Antenna Positioning -3



Limit switches restricts the azimuth rotation within 270° and elevation rotation within 110°. Crossing any of these limits activates signals from the respective limit switch and sent to the servo computer which prevents any further rotation in that direction. During high wind speeds (above 40 km/h), the antennas parked in a position facing the zenith called *stow position*, and mechanical locks are applied automatically.

Functional blocks of the GMRT servo system.

Antenna-Feed Positioning System -1



Encoding	Focussed Feed
0°	610/235 MHz
90°	150 MHz
180°	L-Band
270°	327 MHz

Gate Signal Equivalents

$G1 \approx G3 \approx RGSO \,.\, DIR$

$G2 \approx G4 \approx RGSO \,.\, DIR \,.\, PWM$

Functional blocks of the feed positioning system.

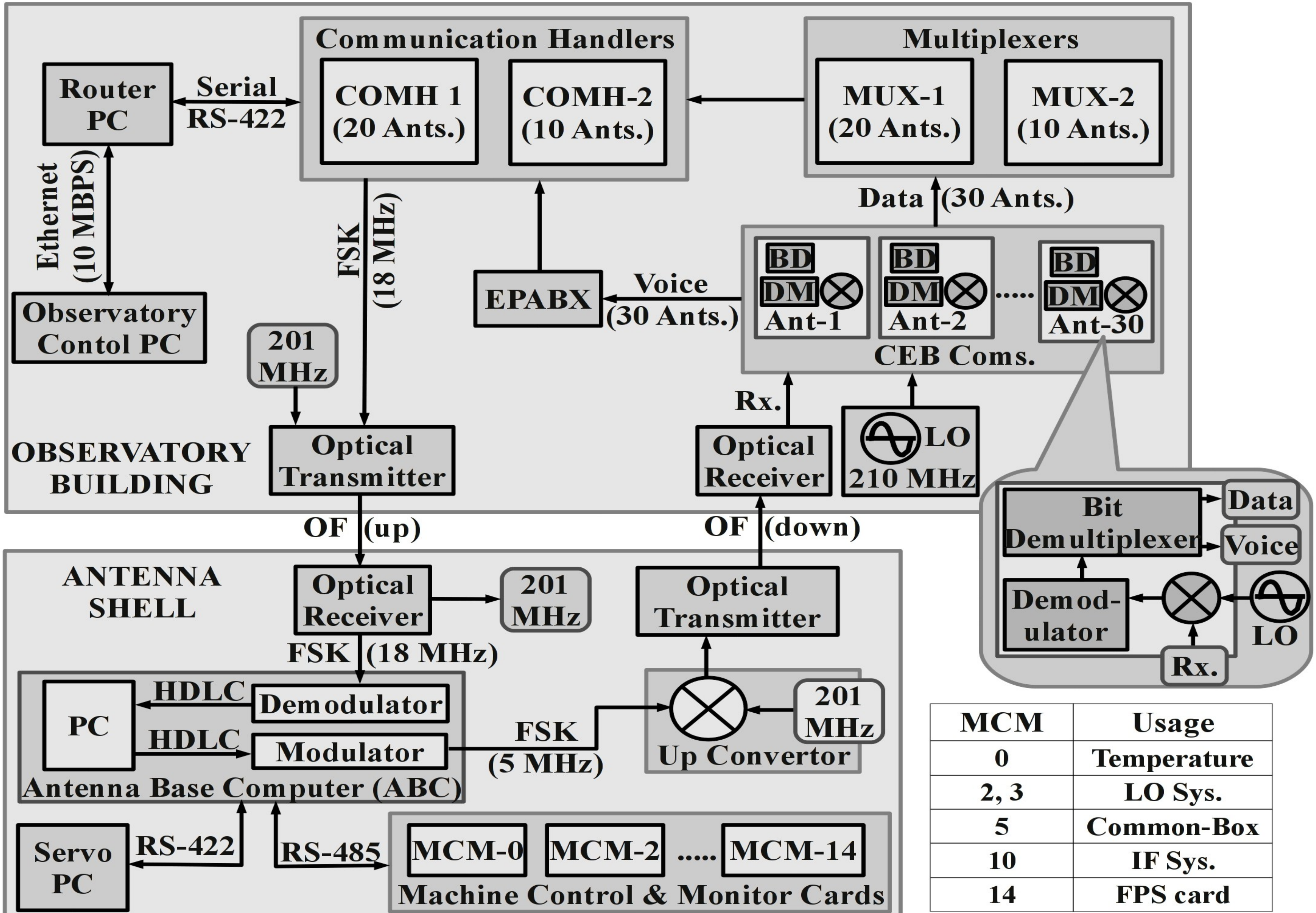
Antenna-Feed Positioning System -2

Any GMRT antenna-feed can be focussed (facing the vertex). A bidirectional motor is used. Speed and rotations are controlled by a MOS-FET bridge with free-wheeling diodes. A resistance R (inside bridge) sends a feed-back voltage proportional to motor current. Motor speed is monitored by a tacho meter output in the feed-back path. A gear box with 500:1 gear ratio is used to reduce the rotation speed in the first level which is coupled to the encoder. Another gear box having a gear ratio 5:1 further reduces the speed (second level). Limit switches prevent excess rotation.

Feed positioning commands from CEB reach the ABC via OF and passed to the FPS CPU through RS-485 serial line. The CPU takes inputs from the limit switches and then determines the current feed-position from the encoder signal. It then releases the brakes of the motor and signals the feed drive control through two difference integrators. The first integrator generates a difference integrated output between the driving signal and current through the motor. The output is again compared with the speed voltage from the tacho meter and their difference is integrated. It is sent to the feed drive control which controls the MOS-FET bridge using PWM (pulse width modulation).

The gate signals (G1, G2, G3 and G4) are logically dependent on the PWM, RGSO (remote gate shut off) and DIR (direction of motor rotation) as tabulated on the figure.

Control and Monitoring System -1



MCM	Usage
0	Temperature
2, 3	LO Sys.
5	Common-Box
10	IF Sys.
14	FPS card

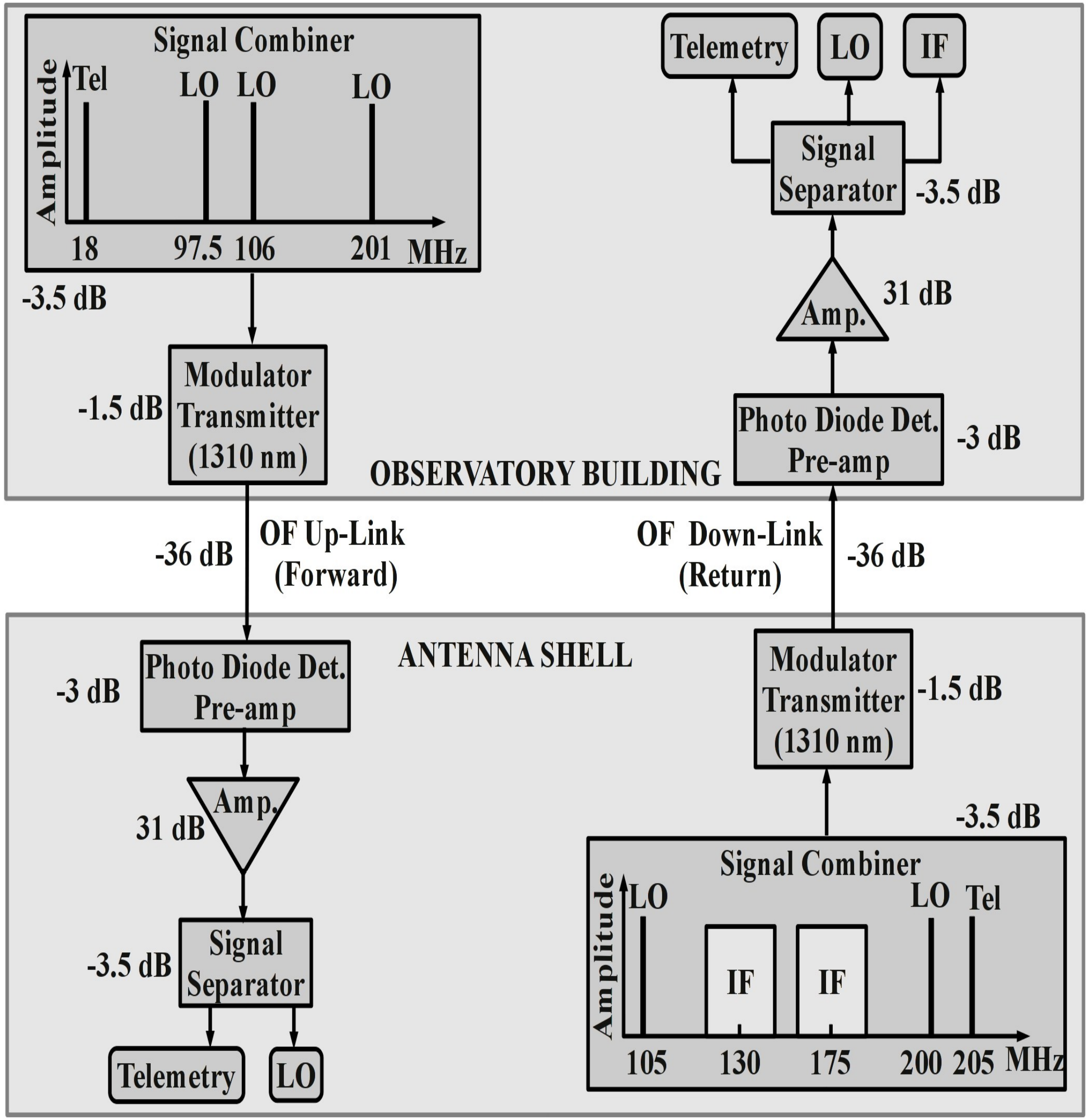
Functional blocks of the control and monitoring (telemetry).

Control and Monitoring System -2

It remotely controls all other systems and monitors various parametes like temperature, speed, etc. at the antennae from CEB. Two links are set, for sending and receiving information from the antennas. Several MCM (machine control and monitor) cards operate and monitors the antenna electronics. Control and monitoring system sets up a link between the MCM cards and CEB.

CEB sends its commands to two communication handler systems (COMH-1 and COMH-2) through RS-422 link. After conversion to 18 MHz FSK, these are broadcasted to all antennae through OF. At antennae, they are converted back to FSK and sent to the demodulator. The HDLC (high level data link control) packets are recovered and send to ABC which checks if it is meant for the same antenna. If so, it then identifies the signal (servo or MCM) and channelizes accordingly. Monitored data (from various points) collected by the MCM cards (including FPS) are sent back to the ABC through the RS-485 link. These are reconverted to HDLC and converted to a 5 MHz FSK which is up converted and sent to OF transmitter. These are received at CEB and handled separately using 30 communication receivers (CEB-coms) where telephone and data signals are separated and sent respectively to EPABX and multiplexers. The multiplexed signals come back to the COMHs which sends the data to the control computer using RS-422 link.

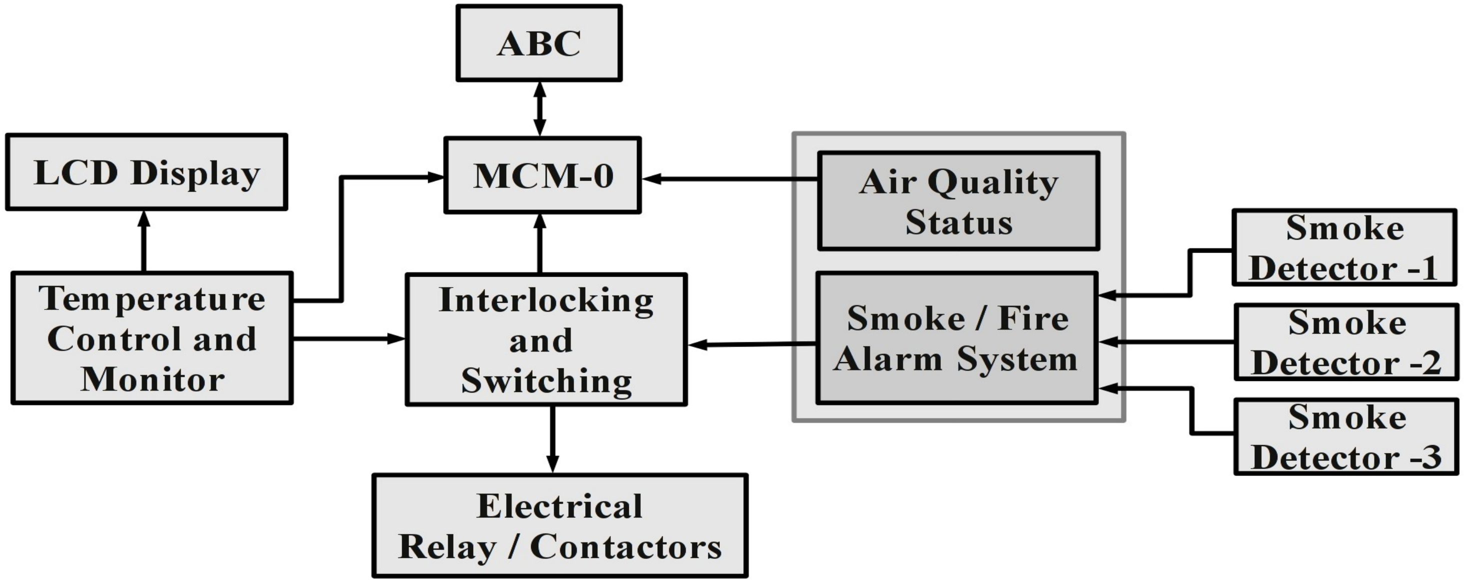
Optical Fibre System



Functional blocks of the optical fiber up (forward) and down (return) links between the observatory and the antennas.

OFS (optical fiber system) provides two links between any antenna and CEB: up (forward) and down (return) links. The telemetry signal (18 MHz FSK), LO signals (97.51 MHz, 106 MHz and 201 MHz) are combined (added) and sent to antennae via up-link. At antenna, telemetry and LO signals are separated. The down links from the antennae to CEB follow a similar arrangement. Here, the two LO frequencies, the two IF bands corresponding to two polarizations and the telemetry signals are combined and sent.

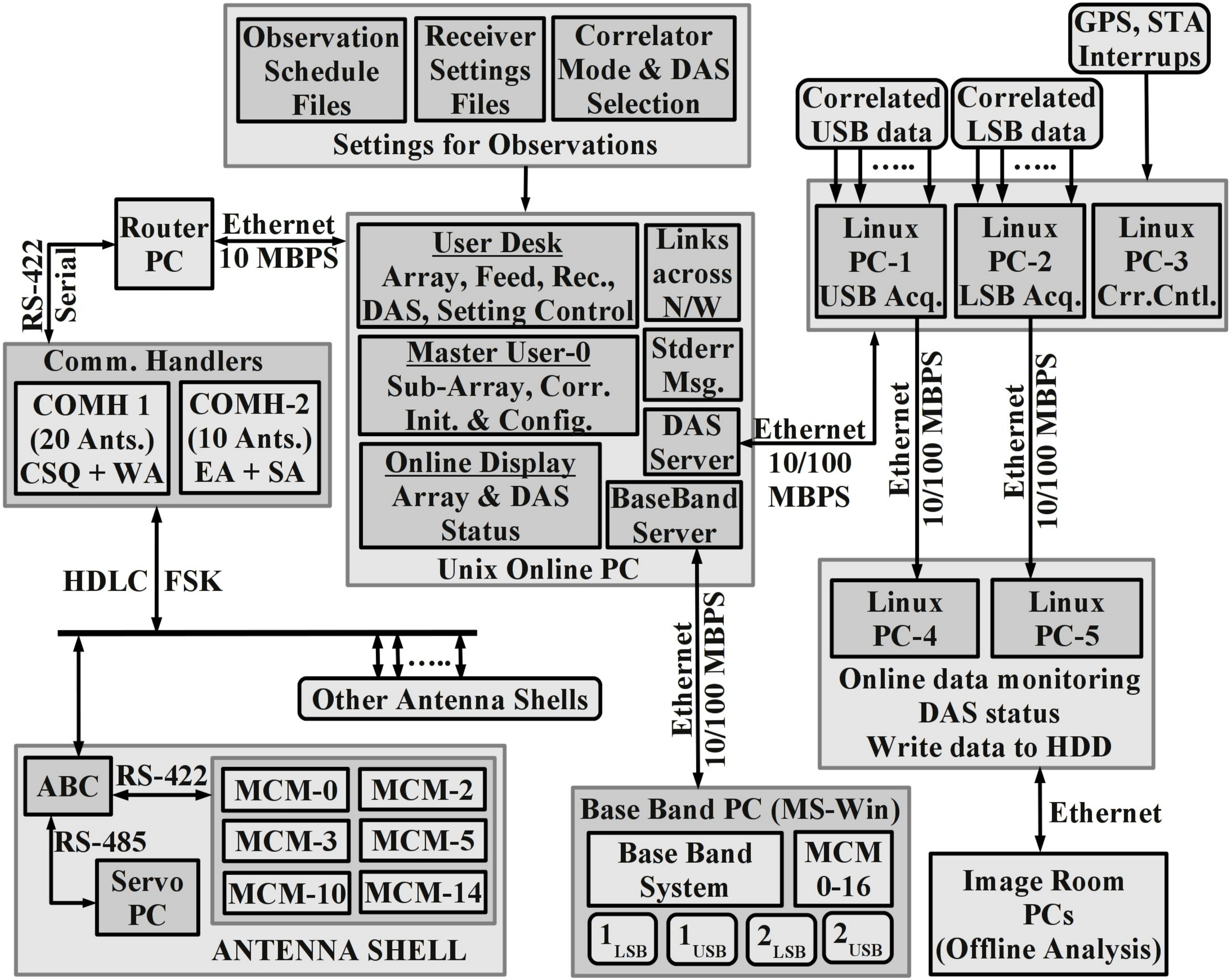
Sentinel System



Functional blocks of the GMRT sentinel system at the antenna shell.

It protects antennae from hazards caused by increase in temperature, fire and smoke. Inside each antenna shell there are three smoke detectors at different locations and a temperature monitor. The temperature of the antenna shell electronics room is displayed there on a LCD display. Continuous monitoring of temperature and air quality (smoke free) is monitored and sent to the observatory using the MCM-0 card connected to the ABC. Also if any of these figures exceeds the allowable safety limits, the interlocking and switching system is activated. This in turn shuts down all the electrical and electronic systems within the antenna shell through relays and electrical contactors. The alarm systems are also simultaneously switched on.

Online Control Software -1



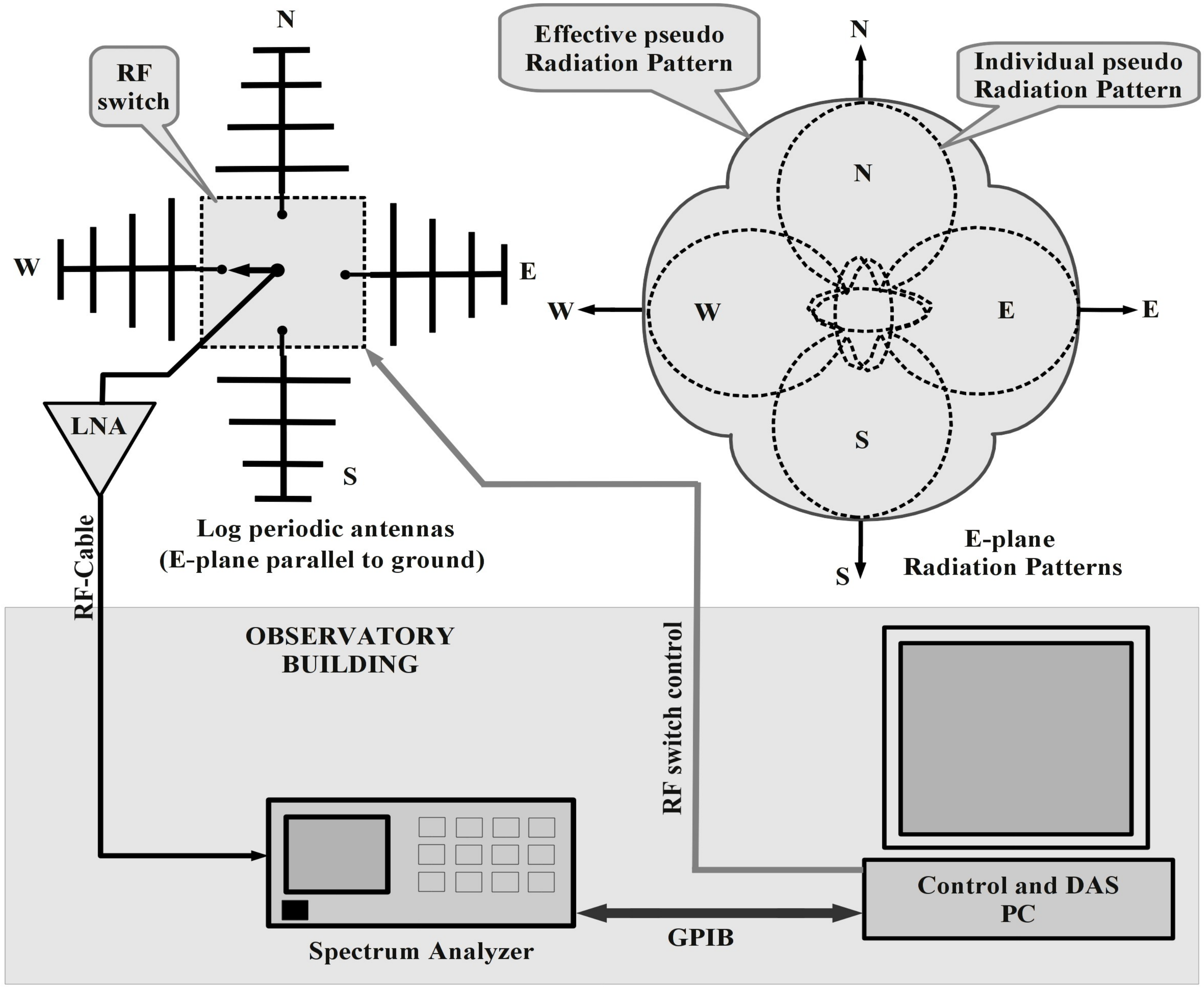
Functional blocks of online control of the observatory from control-room.

Online Control Software -2

All systems are controlled from the control-room of CEB from a main Unix online-control PC. It is connected to several other supporting Linux PCs (1, 2, 3....), BB PC and COMH PC through a router PC. Linux PCs 1 and 2 receives correlated USB and LSB data. The GPS and STA (short term acquisition) interruptions occur to all these three PCs. Data from PCs 1 and 2 goes to 3 and 4 respectively for writing in HDDs. PCs 3 and 4 also monitors online data and reports the status of DAS (data acquisition system). The base-band PC controls the base-band system using MCM (0 to 16). All are interconnected via ethernet.

For antenna control, the Unix PC reaches them via router PC and COMH using a HDLC-FSK network. COMH-1 handles the central square and West-arm, whereas COMH-2 handles East-arm and South-arm. In each antenna shell there are several MCM (0, 2, 3, 5, 10 and 14) which control the systems like FPS, common-box, etc. Servo PC operates on a RS-485 link, MCM operate on a RS-422 link. The terminals of the five Linux PCs and the base-band PC are opened on the Unix PC and commands are set. The observation, receiver and data acquisition settings are usually supplied as files to the Unix PC. These are used to focus the proper antenna-feed, select the proper RF front-end, set the different LO, band-widths, attenuation, ALC (on or off) etc. The observations are continuously monitored for any error in the antennas, correlator, base-band output, RFI etc.

Spectrum Monitoring System -1



Omnidirectional Spectrum monitoring system of GMRT near CEB.

Spectrum Monitoring System -2

There are 4 log periodic dipole arrays (100 MHz to 1500 MHz) pointed in East, West, North and South directions fitted on top of a tower of 20m height. The polarizations are parallel to the ground. A 4PST RF switch multiplexes the antenna outputs and after amplification (LNA) sends it to a spectrum analyzer inside the observatory building. The control and DAS computer controls the sequence of the switching and also controls the spectrum analyzer (settings and data acquisition) using a GPIB interface. Effectively, if the power amplitude patterns of the antennas are added, a more or less omnidirectional pattern is formed as shown. The data is stored in the control and DAS PC for further processing like direction finding, omnidirectional spectrum, broad-band and narrow-band spectrum separation, probability of occurrence (spectral occupancy) etc.

THANK YOU