A new active phased array Indian MST radar system with multi-channel capabilities for high resolution atmospheric probing

M. Durga Rao , P. Kamaraj , K. Jayaraj , K. M. V. Prasad , J. Kamal Kumar, J. Raghavendra and P. Yasoda
National Atmospheric Research Laboratory, Department of Space, Gadanki, A.P.-517112
mdrao@narl.gov.in

Abstract:

High power VHF radar operated at around 50 MHz is a powerful tool to probe the atmosphere [1] with high temporal and spatial resolutions. Such radars have been used extensively for studying atmospheric dynamics in the troposphere, lower stratosphere and mesosphere including short and long term wind variabilities with application to satellite launch missions and developing model, understanding convective and precipitation systems, and probing ionospheric plasma irregularities that are detrimental for satellite-based communication/ navigation applications. Realizing the importance of the atmospheric dynamics and ionospheric parameters, a major project has been undertaken to develop a high power active array MST radar with incoherent scatter capability at NARL. This radar system, operating at 53 MHz, uses the existing antenna array of the Indian MST radar built in the early nineties. The new system uses solid state transmitters each feeding one antenna and multiple receivers for implementing various radar techniques, such as Doppler beam swinging (DBS), spaced antenna (SA), post beam steering (PBS), spatial domain interferometery (SDI) and imaging techniques. Importantly, the system is highly scalable depending on the scientific application. The system is also designed to be functional as an incoherent scatter radar for measuring height profiles of ionospheric electron density, electric field, wind, composition, and electron and ion temperatures, which are not being measured in our country.

This paper is meant to describe various subsystems and capabilities of the newly developed high power active array MST radar and some sample results obtained thus far. This scalability provides new insight on the optimization of such radar for wind profiler applications.

1. System description

The radar system comprises of an antenna array consisting of 1024 Yagi antenna, 1024 solid state transmit-receive (TR) modules, a multi-function exciter, RF distribution and combining network, analog back-end receivers, direct digital receivers, and a radar controller. TR modules are located in the antenna field and each TR module generates a peak power of 1kW distributed over an array of 130m x 130m. All the 1024 TR modules are controlled /communicated with web based radar controller via optical Ethernet communication. The synchronising master trigger pulses and the necessary clock signals for the distributed Timing Signal Generation cards located in TR modules are driven through optical fibre network. The functional block diagram of the active array MST radar is shown in figure-1 and Specifications of the radar system are given in Table-1.

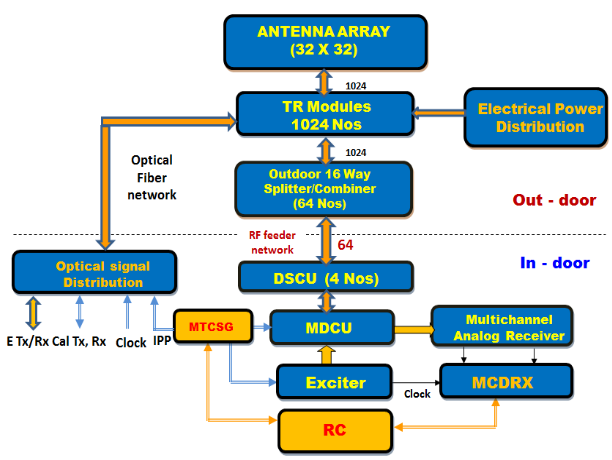


Figure 1. Functional block diagram of the active array MST radar.

Parameter	value
Operating Frequency	53 MHz
Power aperture product	1.73 X 1010 Wm2
Tx Peak power	1024-kW
Max. Duty cycle	10%
Tx-Rx Type	Solid-state TR modules (1024 Nos)
Pulse width	1 – 500 micro sec (coded / uncoded)
Antenna	32 x 32, Phased Yagi array
Antenna gain	37 dBi
Beam width	2.5 deg
Side lobe level	-13.2 dB (Array synthesis possible)
Beam scanning capability	0-360^{o} in 1^{o} step in azimuth 0-24^{o} in 1o step from zenith
Receiver	17 direct digital receivers
Receiver gain	90 Db
Dynamic range	70 dB
Noise figure	<3 dB

Table 1. Specifications of the active array MST radar

1.1. Antenna array and feeder network

The antenna array and the TR modules, each feeding one antenna, of the MST radar is shown in Figure 2. For the application of ionospheric incoherent scattering, it has been decided to use circular polarization. This is realized using 3 dB 90 deg hybrids and necessary switching circuits to generate LCP during the transmission and RCP in reception.

In order to operate the radar in multiple operational modes, the existing 1024 crossed Yagi antenna array has been arranged in the form of 64 sub-arrays, each consisting of 4 x 4 antennas. These 64 sub arrays can be further combined into 16 sub-arrays, each of these consisting of 8 x 8 antennas, in the signal distribution and combining network. These 16 channels can be fed to the 16 direct digital receivers through the back-end receivers. Provision has, however, been made to connect the outputs of 64 sub-arrays (4x4 antennas) to 64 independent receivers. Output of these sub-arrays (4x4 antennas) can also be fed to the existing 16 receivers where required.

Figure 2. The antenna array and the TR modules, each feeding one antenna, of the MST radar.

The beam width for the 8 x 8 sub array is 9o and for 16 x 16 sub-array is 4.5o. For DBS application, signals received from all sub-arrays are combined, as shown in the feeder network. For applications, such as imaging and digital beam forming, provision has been made to form wide beam (15^{o} - 20^{o}) by phase tapering.

1.2. RF distribution and analog receiver system

Active array MST radar has dedicated TR module connected to each antenna. The function of the RF Distribution & switched combining network is to distribute the pulse coded RF signal generated by the exciter to all the TR modules located in the antenna field in Tx path as well as combine the received signals from all the 1024-elements in a desired fashion depending on the mode of operation (DBS or SA). The combining of the receive signals will be done at various levels in the splitter/combiner and switched Combining Units, which are located in the field (outdoor) and inside the building (indoor). Multichannel analog receiver system provides the required gain and band limiting of the received echoes and feed them to the digital receiver. It contains a directional coupler, blanking switch to avoid saturation, RF amplifiers, Programmable attenuator and filter bank with switches for matched filtering. Provision is made to combine the RF outputs at 4x4 sub array level (64 Nos), 8x8 sub array level (16 Nos), 16x16 sub array level (4 Nos), 32x32 array level (1 No) in order to support for SA and Imaging applications.

1.3. Transmit-Receive modules

1024 numbers of solid-state 1-kW TR modules, each feeding one antenna element, are installed in the antenna field. TR module consists of (i) transmit (Tx) section (ii) receive (Rx) front-end section, (ii) common input section, (iv) common output section, (v) timing and signal generation (TSG) card, (vi) fiber transceiver unit (FTU), and (vii) power supply unit. The input section consists of 6-bit digital phase shifter, 5-bit digital attenuator and a low-power transmit/receive (T/R) switch.

1.4. Radar Controller

Radar Controller (RC) communicates with the 1024 modules distributed over a wide area of 130m x 130m in the antenna array field through many levels of Optical Ethernet switching network for operation of the Radar. RC is a client-server application developed using web technology for rich user interface and to provide isolation between the presentation and controller backend RC's Client side front-end is designed using HTML, CSS and JavaScript web languages. Separate WebPages are used for displaying Modules Health Status and Experiment Status, So that we can have full control over the congestion of network. Server side is powered by Python- Django which is a pure python based Server side framework, MySQL Database for caching the module health status, Python Celery module for maintaining asynchronous task queue.

Figure 3. User interface (UI) of Radar Controller

1.5. Timing Signal Generation

Depending on the data received from the master radar controller, TSG card generates timing and control signals in synchronization with IPP trigger pulse received from radar controller. The phase shifter data corresponding to the beam direction are stored in the module and beam direction will be controlled from IPP to IPP. Data for phase shifter is provided by Radar controller. Interlocks generation for excess input RF drive, excess junction temperature of the SSPA devices, failure of control signals, excess duty ratio, excess VSWR are provided to safeguard the TR module.

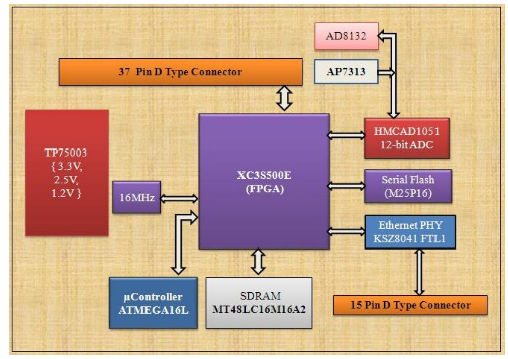


Figure-4: TCSG Block Diagram

1.6. Direct Digital Receiver System

Direct digital receiver [3] digitizes the received RF signal, convert the same into base band complex signal and performs pulse compression, coherent averaging, clutter removal and Doppler spectrum computation. The input signal bandwidth is about 5MHz, input sampling rate 80MSPS and the measured dynamic range is about 80 dB. The functions of down conversion, filtering, sample-rate. reduction are performed by DDC to reduce the load of software processing considerably. The ADSP-TS201S- Tiger SHARC processor performs pulse-compression, coherent averaging, FFT on the base band data.

2. Initial results

The installation, testing of all the 1024 TR modules are completed successfully and the trial runs are carried out in Tropospheric mode, lower stratospheric mode, Mesospheric and Ionospheric modes and the initial scientific results are very much encouraging. Some of the results are shown in this section.

Figure 5 shows height profiles of Doppler power spectrum observed in five beam directions (east, west, zenith, north and south beams) on 30th May 2017.

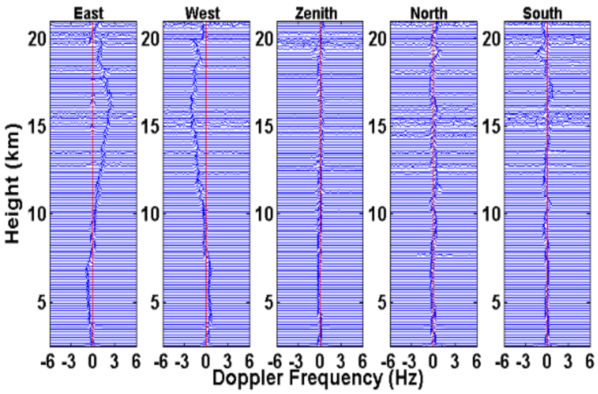


Figure 5. Height profiles of Doppler spectrum observed in the five beams in DBS mode

From figure-5, the opposite Doppler in the conjugate beams, indicating that the radar system is functioning correctly. The wind speed and direction comparison of AAMSTR with co-located GPS Radio Sonde is shown in Figure 6 and Figure 7

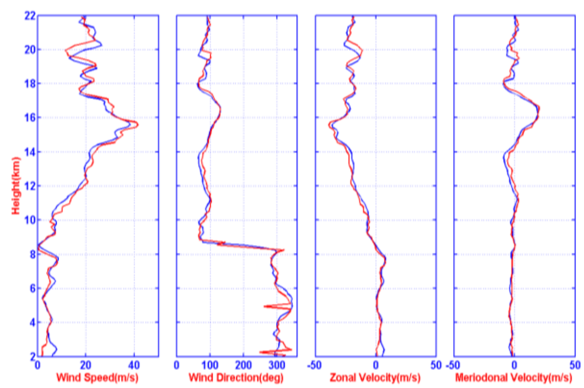


Figure 6. Comparison of winds obtained by AAMSTR with co-located GPS Radio Sonde on 23rd August 2017.

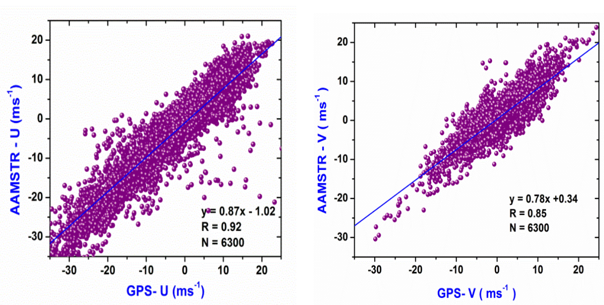


Figure 7. Scatter plots comparing winds with GPS Sonde

The figure-8shows height-time variations in the SNR of E region field-aligned plasma irregularities around 100 km and 150 km observed on 31st July 2017.

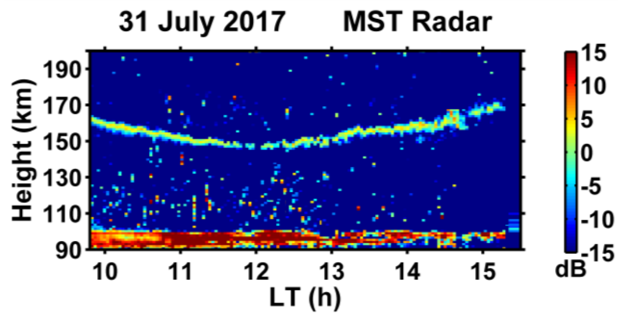


Figure 8. Test results on the height-time variations in SNR of E region field-aligned plasma irregularities observed on 31st July 2017.

The velocity azimuth display mode of operation with multiple beams along various azimuth and elevation angles (as shown in figure-8) has been carried out. The sample derived winds along zonal, meridional and vertical directions has been shown in figure-9.

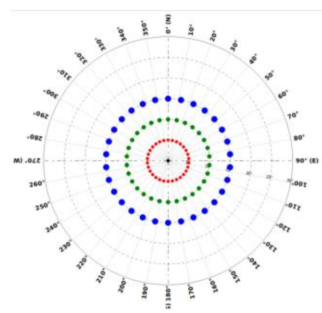


Figure-8: Multiple beam locations along various azimuth and elevation directions

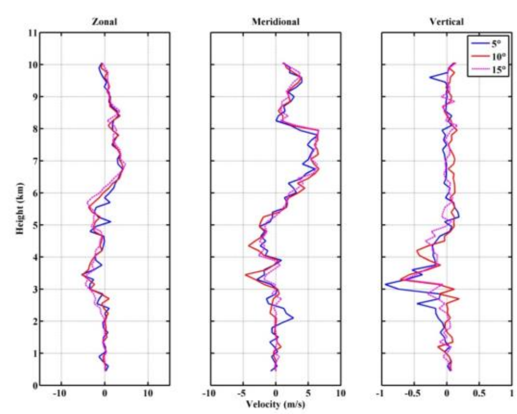
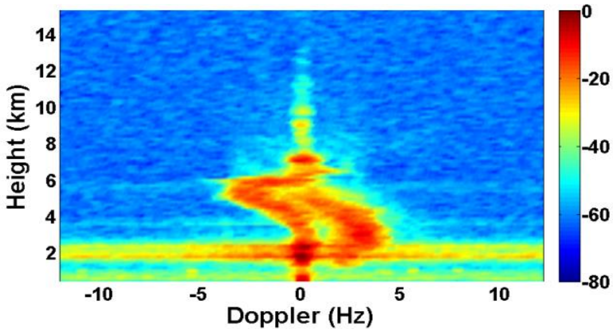


Figure-9: sample comparison of derived zonal, meridional and vertical velocities.



The capability of the radar to observe precipitation events has been explored. Rain event on July 19th 2017 captured by AAMSTR has been shown in figure-10. In order to observe the data from the lower height, the flexible configuration of the antenna array to select one fourth of the total system where 256 elements in 16 x 16 configuration with 2us pulse width has been used.

Figure-10: Sample SNR plot during the rain event.

3. CONCLUSION

Active Phased Array MST radar with 1024 TR modules in the outdoor antenna array been designed, developed, and successfully operated to probe the atmosphere up to an altitude of 22 km in Troposheric and lower stratospheric mode of operation. The complex system with 1024 clients in the field is successfully controlled with the in-house developed radar controller beam steering software.

Currently AAMSTR is providing wind information to ISRO satellite launch programs apart from the other major scientific experiments.

4. References

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[2] “Active Array MST Radar Technical report,” vol.1 Sep 2013.

[3] M. Durga Rao, P. Kamaraj,et.all, “Active Phased Array MST radar system with enhanced capability for high resolution atmospheric observations”, 15th international workshop on Technical and Scientific Aspects of MST Radar (MST15/iMST2) held at Tokyo, Japan 2017.

BIOGRAPHY:

M. Durga Rao, born in 1980, passed B.E.(E.C.E) at Sir. C.R.R. College of Engineering, Andhra University in 2002 and M.Tech at NIT, Rourkela, in 2005. He worked at Vikram Sarabhai Space Centre, Trivandrum, during the period 2004-2010 and joined NARL in 2010. He is involved in the radar developmental activities. As a project leader he has designed and developed active phased array MST radar, Gadanki Ionospheric Radar Interferometer (30-MHz Radar) at NARL. His areas of interest include development of active phased array electronic weather radars.

P.Kamaraj, born in 1975, passed B.E.(E.C.E) at Anna University, Chennai, in 2004 and M.E (VLSI) at Anna University in 2009. He joined NARL in 2006. He is involved in the development, installation and commissioning of the wind profilers, Active phased array VHF Radar, HF Radar Interferometer at NARL. His areas of interest include active phased array radars and radar calibration.

K. Jayaraj born in 1974, passed AMIE in 2014 under Institute of Engineers (India) and M. Tech in Digital Electronics and Communication Systems at Swetha Institute of Technology and Science, JNTU Ananthpur. He joined at NARL IN 2008. He is involved in the development, installation and commissioning of the wind profilers, Active phased array VHF Radar, HF Radar Interferometer at NARL.

K.M.V.Prasad received his B.Tech. degree in Electronics and Communication Engineering from Sri enkateswaraUniversity College of Engineering (SVUCE) SV University (SVU), Tirupathi. He joined NARL in April 2014. His areas of interests include digital implementation of controllers using FPGA devices, digital signal processing, data acquisition systems and Radar systems.

Jeldi Kamal Kumar born in 1991. Passed B.Tech (Avionics) from IIST, Trivandrum. Joined semi-conductor laboratory at Mohali in November, 2013 and at NARL in December 2014. His areas of interest include development of radar controllers and health status monitoring tools for Active Array Radars.

J.Raghavendra, born in 1981, passed B.E.(E.C.E) at JNT University, Hyderabad, in 2012 and M.Tech (Signal Processing) at SV University in 2016. He joined NARL in 2007. He is involved in the development, installation and commissioning of the wind profilers, Active phased array VHF Radar, HF Radar at NARL. His areas of interest include active phased array radars, Data acquisition systems and digital signal processing.

P. Yasodha, born in 1975, completed Diploma in Electronics and Communications Engineering at SPWP, Tirupati and B.Tech in Electronics and Communication Engineering from JNTU, Hyderabad and M.Tech from IIT,Chennai. She joined NARL in 1998. Since then she is involved in radar developmental activities. Her areas of interest include active array radars, radar calibration, radar signal and data processing.