# Two decades of Indian MST Radar

T. Rajendra Prasad* and T.V. Chandrasekhar Sarma
NARL, DOS, GOI, Gadanki - 517112, http://www.narl.gov.in, e-mail: trp1910@narl.gov.in.

## 1. Introduction

The VHF radar at Gadanki (13.5ºN, 79.2ºE) is a coherent mono-static pulse-coded Doppler radar with broadside phased array antenna with an average power aperture product of $7 \times 10^8$ Wm$^2$ [1]. This radar is a unique system for scientific research of Earth atmosphere in the height regions of Mesosphere (50-100 km), Stratosphere (17-50 km), Troposphere (up to 17 km) hence named MST radar. The radar studies extend up to earth's Ionosphere, a height up to 750 km.

This complex VHF radar major sub systems are phased array with 1024 antenna elements, 32 number of triode based transmitters that are generating 2.5 MW RF power, and the control and instrumentation room that consists of a single channel receiver with -165dB sensitivity, radar controller for automated experiments and a host computer for signal, data processing and archival purposes. The main specifications of the system are shown in table 1.

The radar system is successfully operational for an average of 2500 hours each year since installation during 1987-93 and produced many peer reviewed publications on atmospheric science research. The planning and execution of continuous test maintenance activities, phase calibrations, upgrades of the radar electronic subsystems pose challenge to sustain the quality of the scientific data products with the radar. In this paper we provide the details of these activities performed on the radar subsystems for 25 years period for its continued successful operation.

This complex radar operating at a frequency of 53 MHz is distributed in radar control and instrumentation (CI) room, transmitters' (TX) rooms and antenna array that are occupying about 20,000 square meters. The antenna is a 1024-element array of Yagi-Uda antennas arranged in a square grid of 32 rows and 32 columns. Each Yagi-Uda antenna consists of a dipole, director and reflector with dimensions of about 3 meters (0.5 λ) length and inter-element spacing of 4 meters (0.71 λ). The CI room consists of exciter, radar controller, host computer, back-end receiver, signal processor and offline data processing system. The 32 no. of transmitters are distributed in four transmitter rooms, two rooms each at north and south sides of the array. Each of the transmitter room consists of 8 transmitters, signal distribution network and local processor computer for antenna phase shift loading, required for antenna beam steering.

Table 1: Specifications of MST Radar

| Aspect | Specification |
|---|---|
| Location | Gadanki (13.5°N, 79.2°E) |
| Frequency | 53 MHz |
| Average power aperture product | $7 \times 10^8$ Wm$^2$ |
| Peak power | 2.5 MW |
| Maximum duty ratio | 2.5% |
| Number of Yagi antennas | 1024 |
| Beam width | 3º |
| Number of beams for auto scan | 1-82 (within ±20º, at 1º step in EW and NS planes) |
| Pulse width | 1-32 µs |
| Pulse repetition frequency | Up to 8 kHz |
| Maximum number of range bins | 256 |
| Number of coherent integrations | User defined, in steps of 2 |
| Maximum of FFT points | User defined; maximum 512 (for online processing) |
| Radar Controller | Workstation with radar controller software |
| Data Acquisition | Two channel PCI-card based data acquisition system with 14 bit ADCs |

The subsequent sections present the details of upgrade, maintenance and calibration activities performed for quality scientific research with the radar output data products. The test-maintenance activities performed on antenna and feeder network, development activities of high power systems in transmitter rooms and the improvements on the control room instrumentation are presented. Many number of system upgrade activities have been performed to overcome the obsolescence of digital modules.

## 2. Radar calibrations, state-of-the-art instrumentation upgrades.

The radar catered about 50 satellite launch campaigns with seamless support with 100% success for 25 years, by providing aerodynamic wind load estimation on launch vehicle up to 20km altitude. The performance of the radar to measure wind vector for recent launch applications and scientific experiments proves the test and maintenance methodology adapted at Indian MST radar. A recent measurement of antenna pattern by radio source and active probing of moon showed the antenna pattern pointing accuracy to be within 1%, with a little degradation in the antenna beam width and side lobe levels, and confirmed the radar functionality in both transmit and receive beam formation [2, 3].

The MST radar has been successfully operational by adapting the state of the art technological developments, where the first and foremost one is to position antenna beam perpendicular to magnetic field lines for effective ionospheric research [4]. The extension of unambiguous Doppler window up to ±125 Hz provided additional capability to test drifts of ionospheric layers. The beam steering capability expanded from 5 beam mode to automated 82 beam mode of experiments with beam tilt of 1 degree resolution, to study the aspect sensitivity of atmospheric echoes [5]. The mitigation of interference due to crystal oscillators in microprocessor systems has solved maximum amount of interference problems [6]. The Radio acoustic sounding system expanded the radar capability for temperature measurement up to tropopause height [7].

The development of Adaptive Data Processor (ADP) helped in quick processing of the data products [8]. The offline data processing system was based on UNIX quick look (QLK) program. A magnetic tape data storage system used to record the digital data. Magnetic tape dimensions were 0.5-inch (12.7 mm) wide and wound on removable reels of 10.5 inches (267 mm) in diameter. The continuous update of this data archival system form tape drive to floppy disks, CD based Juke boxes and present semiconductor based data center with primary, secondary and third level data storage and decimation of the data thru firewalls to the users over internet for managing all the data collected over the years is really benefiting the users.

The radar control and instrumentation room (CI room) was initially equipped with 8086 microprocessor based exciter and coder system, a super heterodyne receiver with IF of 5MHz, LO of 48 MHz and a quadrature detector system operating at IF frequency. The two channel signal processor for time domain signal processing of the in-phase and quadrature-phase channels is based on 8086 microprocessor for analog to digital conversion, coherent integration and decoding activities. The Massachusetts Computer Corporation (MASSCOMP) mini super computer was used for FFT operations and data processing activities. A PC AT system was used for radar controller operation, for controlling the exciter, digital phase shifters and automated radar operations. This instrumentation system has been upgraded multiple times, to catch up the phenomenal changes in technology during the course of radar operation.

A PCI-bus based data acquisition card developed with two channels of 14-bit ADCs (Analog Devices AD9240). The output of each ADC is fed to a hardware transversal filer (IMS A100, 16-bit, 32-tap correlator) to achieve the decoding operation for coded transmission. The 24-bit output of the decoder is fed to a coherent integration block implemented by Analog Devices SHARC ADSP61020 chips and SRAM memory chips [9, 10]. Timing and control signal generator (TCSG) was designed around an ADSP SHARC 61020 DSP processor that is placed in the exciter subsystem. More recent activity on the receiver is the single channel IF digital receiver development with Analog Devices Tiger SHARC processors, ADC/DDC chips and the Spartron-3 FPGA modules, that is programmed for radar signal processing, radar controller and data processing activities [11]. Multi-channel digital receivers are implemented recently to cater to the spaced antenna and interferometry applications. The receiver front end RF loss before the LNA is removed by installing the new version of low noise figure LNA modules near duplexers.

The interface between radar control and instrumentation (CI) room and the transmitter rooms are 4 local processor (LPC) rooms, where phase shift data is loaded to digital phase shifters by the 8085 microprocessor with RS-232 serial link to CI room. These digital systems are upgraded by computer consisting of multiport digital card connected to CPLD based phase shifter data loading unit, digital timing signal distribution unit (IDU 1 & 2) [12]. The RS-232 connectivity is upgraded with a fiber optic Ethernet connection to the radar controller. The coaxial cable based timing signals network between the CI room and transmitter/ LPC rooms is replaced by the optical fiber based instrumentation network, to overcome the problems during the lightning strikes. The RF sub systems are also tested every year for proper power levels and all the external RF cables between the modules were replaced to overcome the connectivity problems during test and maintenance activities.

The transmitters are maintained to about 85-95% availability for each scientific experiment. The failures of active components of transmitter amplifiers triodes and duplexer pin diodes are attributed to the frequent power outing when the system is operational. About 50% of 104 triodes of transmitter amplifiers have been replaced and about 30% of anode supply high power transformers were upgraded for higher rating after the failures. The solid state amplifier (SSA) module has been upgraded by MRF 141 MOSFET based amplifier replacing BM 40-28 and BM 100 RF transistors, operating in class A, AB that provides an output power of 100 W with a bandwidth of about 8 MHz for an input signal of 0 dBm. The major problems in the transmitter high power modules are failure of Triode output RF coupling capacitors and output tank circuit ganged capacitors due to dust accumulation in the high voltage systems because of the forced air cooling system. These challenges in the failures of active components like triodes and pin diodes is overcome by the installation of the uninterrupted power supply for transmitters (except for anode supplies) and failures of high voltage capacitors by the transmitter room air-conditioning. The high power pin diode based solid state balanced duplexers and triode based high power transmitters demanded daily attention, lumped element branch line duplexers upgrade and replacement were performed.

Though there is a threat of life in operation of the 6 KV anode supplies, just two fire accidents occurred in the transmitter anode power supply modules in the two decades of life period of transmitters due to effective functioning of safety provisions and interlocks. The anode, cathode and filament voltage / current, cavity temperature, airflow in the RF cavity, RF output power level, antenna VSWR monitoring and automated controlling of the power supplies is performed by the control and interlock system. The interlock and control systems of the transmitters were made as line replaceable units with multiple electronic cards initially. In due course of transmitter life time period, these multiple cards arrangement developed connectivity problems and a major activity has been performed to upgrade these control interlock units functionality by single electronic card with CPLD based digital system and later by ARM processor based systems [13, 14]. All the 32 transmitters control interlock units are replaced by single cards at each transmitter and these are connected to the Radar controller by Ethernet for transmitter status monitoring and centralized control action.

The annual maintenance activities of transmitters are performed by refurbishing high voltage and RF cavities, verification of electrical terminals connectivity, testing and adjusting the electrical power supplies of triodes' anode, cathode, filament to within 5% tolerance levels. Fine tuning of transmitter RF cavities are performed for required gain and bandwidth specifications for maintaining the transmitter output RF power. This rigorous activity used to take almost one month period with a team of about 10 technicians. Once in three months RF tank circuits' tuning is performed. Total radar refurbishment/preventive maintenance performed for about a month period during December/January, annually to test each subsystem and the expected problems are solved immediately. RF pulse shape, power level is monitored fortnightly. Daily monitoring of the radar health and data quality, radar performance is monitored and corrective action taken.

The Yagi-Uda antenna array phase equalization activities are called phase calibration, are performed with monthly periodicity. The antenna VSWR is being monitored regularly in the front panel meters of transmitters. Entire 2048 antenna element's RF power level and phase measurements were performed yearly to restore the Taylor power distribution of antenna array [15]. The Taylor power distribution in the sub array is maintained to be within 0.5 dB power level and the errors of phase deviation are trimmed by fine tuning the RF cable length of coupled port to limit the phase error within 10 degrees across the center fed series sub array. The coupling coefficient of dual directional couplers are being verified and fine-tuned every year for accurate transmitter power level measurement and VSWR testing. Every year disconnections of antenna elements are within 10%, which are at the peripheral areas of the antenna array, may be due to movement of working personnel. One of the major problems is failures and obsolescence of high power vacuum relays of polarization switches is overcome by efficient spare modules management.

The weather exposed three-element Yagi-Uda antennas and feeder network in the array are maintained with minimal number of spares. RF feeder network connectivity issues are obviated by yearly application of the RTV sealants' to arrest water entry into electronic modules. This extended the life of the antenna balun modules, directional couples (lumped element and distributed) and Wilkinson in-phase power dividers in the antenna feeder network. The periodic anti-corrosive paint applications protected metallic director and reflector elements of antenna array. Installation of concrete flooring to arrest weed growth in array area and strengthening the campus boundary wall eliminated feeder network connectivity problems due to movement of wild animals, man-made mistakes in the array. These activities reduced the failures of high power resister in power dividers, directional couplers and disconnection of 7/8" RF cable between lumped couplers.

The recent development of active array system with the MST radar antenna array is extending the latest technological advancements. Wind profile up to 20 km is obtained with half the rated power, eliminating RF power loss in the 100 m length cables. The Transmit/ Receive modules are placed near the antenna elements. The MST radar is operational for all the scientific and launch operations along with the parallel execution of the massive update/ development activity in the antenna array for the TR modules, underground electrical, RF and optical fiber cables installation. The radar signal processing techniques SDI/IDI/CRI and interferometer are experimented [16, 17, 18]. The radar is operational for astronomy, meteor studies in addition to atmospheric studies [19, 20].

## 3. Conclusion

The MST radar has been successfully operational by adapting the state of the art technological developments. Seamless scientific experiments delivered about a few tens of PhDs and a few hundreds of publications of high impact factor. Provided wind vector for about 50 satellite launch campaigns with 100% success for all launch missions within the time span of 25 years. The relentless efforts of maintenance and upgrade activities on the radar produced excellent scientific results.

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## 5. References

1. P. B. Rao, A. R. Jain, K. Kishore, P. Balamuralidhar, S.H. Damle, G. Viswanathan, “Indian MST radar system 1, System description and sample wind measurements in ST mode,” *Radio Sci.,* **30**, 1995, pp. 1125–1138.
2. T. Rajendra Prasad, A. K. Patra, V. K. Anandan and P. Sathyanarayana, "Employment of New Techniques for Characterizing Indian MST Radar Phased Array", *IETE Technical Review*, **33**, 2016, pp. 584-595, doi:10.1080/02564602.2015.1130594.
3. T. Rajendra Prasad, A. K. Patra, “Moon echoes from the 53 MHz MST radar at Gadanki, India,” *Current Science*, **111, 1,** January 2016, doi: 10.18520/cs/v1.
4. T. V. Chandrasekhar Sarma, “Extension of the unambiguous Doppler window up to ±125Hz”, *Technical Report, National MST Radar Facility*, Gadanki, India, 1994.
5. T. V. Chandrasekhar Sarma, and Mukund B. Vaidya, “Upgradation of MST Radar LPC firmware and Radar Controller for beam positioning at 1$^o$ step,” *Technical Report, National MST Radar Facility*, Gadanki, India. 1995.
6. T. V. Chandrasekhar Sarma, “MST radar interference: nature, likely sources and methods of mitigation,” *Technical Report, National MST Radar Facility*, Gadanki, India, 1998.
7. T. V. C. Sarma, D. Narayana Rao, J. Furumoto, T. Tsuda, “Development of radio acoustic sounding system (RASS) with Gadanki MST radar – first results”, *Annales Geophysicae*, **26,** 9, , 2008, pp.2531-2542.
8. V. K. Anandan , P. Balamuralidhar, P. B. Rao, A. R. Jain, and C. J. Pan, “An adaptive moment’s estimation technique applied to MST radar echoes”, *Journal of Atmosphere and Oceanic Technology*, **22**, 2005, pp.396–408.
9. V. K. Anandan, P. B. Rao, A. R. Jain, and T. V. C. Sarma, “A new ADSP21060 based signal processor for atmospheric radar”, *Proc. Eleventh International Workshop on Technical and Scientific Aspects of MST Radar*, 13-18 Mar, 2000, pp. 511-514, Toulouse, France,.
10. V. K. Anandan, T. V. C. Sarma, Mukund B. Vaidya, “New Signal Processing System for MST Radar”, Technical Report, National MST Radar Facility, 1997.
11. T. Rajendra Prasad, P. Satyanarayana, P. Srinivasulu, Satish Godbole, A. Jayaraman, V. K. Anandan, “Indian MST Radar Digital Receiver First Results”, *Proceedings of IEEE 15th International Conference on Advanced Computing Technologies (ICACT-2013)*, 2013, **doi:** 10.1109/ICACT.2013.6710541.
12. T. V. Chandrasekhar Sarma, Jojo Joseph, Manas Ranjan Padhy, T. Rajendra Prasad, and P. Srinivasulu, “Design of new LPC interface and driver units,” *Technical Report, National MST Radar Facility*, Gadanki, India. 2001.
13. R. Lakshmi Narayana, K. Nagabhushan Raju, T. Rajendra Prasad, D. Chandrasekhar Reddy, K. Chaitanya Pavan, “Development of Ethernet based remote monitoring and controlling of MST radar transmitters using ARM Cortex microcontroller”, *Sensors and Transducers,* 148, 2013, pp. 40-46, ISSN 1726-5479.
14. K. Nagabhushan Raju, K Nagabhushan, C. Manikumar, T. Rajendra Prasad, “Design of control and interlocking system for a typical radar transmitter”, *Sensors and Transducers,* **118,** 2010, pp. 131-135, ISSN 1726-5479.
15. B. K. Sarkar, P.B. Tole, and A. Agarwal, “Feeder network for the Indian MST radar”, in *Handbook for MAP*, edited by C. H. Liu and B. Edwards, **28**, 1988, pp. 523- 527, SCOSTEP Sect., Urbana, Illinois.
16. T. V. Chandrasekhar Sarma,, and V.M. Gadre, “VHF radar meteor trail detection using wavelets,” *Proc. International Radar Symposium India*, P-40, 11-14 Dec,2001., Bangalore.
17. T. V. Chandrasekhar Sarma, “4 x 4 array for interferometry,” *Technical report, National MST Radar Facility*, Gadanki, India, 2001.
18. P. Srinivasulu, T. V. Chandrasekhar Sarma, V. K. Anandan, A. K. Patra, T. Rajendra Prasad, P. Yasodha, “Upgradation of MST Radar for observations in SDI/IDI/CRI modes,” *Preliminary Design Report, National MST Radar Facility,* Gadanki, India, 2003.
19. M. Srikumar Menon, D. Anish Roshi and T. Rajendra Prasad, “A search for the 53-MHz OH line near G48.4−1.4 using the National MST Radar Facility”, *Mon. Not. R. Astron. Soc.,* **356,** 2005, pp. 958–962, doi:10.1111/j.1365-2966.2004.08517.x.
20. S. Kirkwood, E. Belova, K. Satheesan, T. Narayana Rao, T. Rajendra Prasad, and S. Satheesh Kumar, “Fresnel scatter revisited – comparison of 50MHz radar and radiosondes in the Arctic, the Tropics and Antarctica”, *Annales Geophysicae,* **28,** 2010, pp. 1993–2005, doi:10.5194/angeo-28-1993-2010, ISSN 0992-7689.