VHF Active Phased Array Radar for Atmospheric Remote Sensing at NARL

P Srinivasulu, P. Kamaraj, P. Yasodha, M. Durga Rao and Alla Bakash*
National Atmospheric Research Laboratory, Gadanki – 517 112, India
*Department of Physics, S V University, Tirupati – 517 502, India

pslu@narl.gov.in, sparvatala@gmail.com

Abstract:
A pilot 53-MHz 133-element active phased array radar has been developed at National Atmospheric Research Laboratory for probing the atmosphere. This radar is developed with an objective to validate the technology concepts like out-door installation of solid-state transmit-receive modules, beam steering, optical fiber network based control, interface and monitoring of the TR modules etc. This system is developed as a precursor R&D activity for the ultimate up-gradation of the existing 1024-element Indian MST radar (located at Gadanki) into a full-fledged active phased array system. System design philosophy, realization and preliminary observations are presented in this paper.

Key Words: active phased array radar, TR Modules, digital receiver

I INTRODUCTION

The Indian mesosphere-stratosphere-troposphere (MST) Radar [1], located at National Atmospheric Research Laboratory (NARL), is being operated for atmospheric research applications for two decades. The 53-MHz, 1024-element 32x32 array is energized by a peak power of 2.5 MW that is provided by 32 tube-based transmitters whose output varies from 120 kW down to 15 kW. The major challenge with the existing transmitter units is the aging and instability causing interference to radar data. Over the time the power and spectral characteristics of these transmitter units degraded due to internal vibrations and temperature variations. Due to these reasons, there is reduction in total power, deviation of amplitude distribution from the designated Taylor and degradation in radiation pattern. All these factors are responsible for overall SNR degradation of signal-to-noise ratio (SNR). Further, critical high power spare parts are getting obsolete making it difficult to sustain the radar operation. In view of these problems, an R&D project was taken up to upgrade the Indian MST radar in to an active phased array system using the solid-state transmit-receive (TR) modules.

A pilot 133-element active phased array radar has been developed with an objective to validate the technology concepts like out-door installation of TR modules, beam steering, optical fiber based control, interface and monitoring scheme etc. This radar system is developed as a precursor R&D activity for the ultimate up-gradation of the MST radar into a full-fledged active phased array system. The system is being operated in Doppler beam swinging (DBS) mode regularly since August 2012 with typical height coverage up to 8-12 km. Details of system level configuration are presented in section II. Sample radar observations of the atmosphere are presented in section III and conclusions are given in section IV.

II SYSTEM DESCRIPTION

The functional block diagram of the pilot radar is shown in the figure-1. It comprises of 133-elememt Yagi antenna array, solid state TR modules, exciter, back-end receiver, Digital receiver and radar controller. Exciter contains a reference OCXO master oscillator, which generates the reference clock to all other subsystems. 53-MHz pulse modulated bi-phase coded RF waveform is generated using DDS section in the exciter. Pulsed RF signal is fed to the RF Signal Distribution and Switching Network and routed to the out-door TR modules located in the antenna field. Each TR modules feeds 1 kW peak power to its antenna element. The received signals from the array and TR modules are combined and brought to the instrumentation room via long RF coaxial cables and delivered to the back-end receiver. The received signal is band limited and suitably amplified by the back end analog receiver and fed to the direct digital receiver (DRx) which performs the analog-to-digital conversion (ADC), digital down conversion (DDC), pulse compression, coherent averaging and FFT computation. Data processing is performed to compute and display the spectral moments and wind vector. Radar operates in Doppler beam swinging (DBS) mode to derive the wind vector. Radar controller facilitates the user to set the operational parameters and operate the radar through GUI. Photograph of the system is shown in figure-2. Brief specifications of the system are given in Table-1. Subsystem level details are given below.

Antenna array

The 133-element array is organized into seven segments each being a hexagonal shaped sub-array of 19 elements. Equilateral triangle grid is used with an inter-element spacing of 0.7λ which is 4m. The antenna element is a three-element Yagi. The array is quasi-circular in shape with a diameter of about 50m.

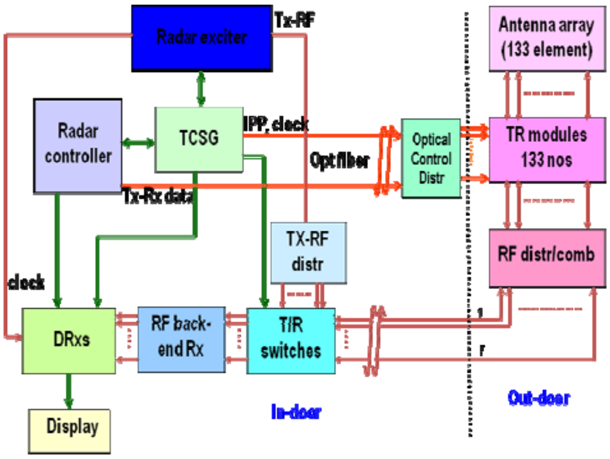

Figure-1: Block diagram of the pilot active array radar.

Figure-2: Photographs of the pilot active phased antenna array (top), individual TR Module (bottom left) and Control & Instrumentation (bottom right)

Table-1: Specifications of Pilot VHF Radar

Frequency	:	53 MHz
Bandwidth	:	3.4 MHz
Technique	:	DBS
Antenna	:	133-el array (50 m)
Peak power	:	133 kW @ 10 % Duty ratio
Pulse width	:	1- 64 µsec
Noise figure	:	2.5 dB
Range coverage	:	1.6 – 12 km
Range resolution	:	150 m
Time resolution	:	3 min

Figure-3 shows the array grid configuration and the array pattern. The beam width of the array is 6.5^0 and the side lobe level (SLL) is about 16.5 dB. Gain of the array is about 28 dB. The beam can be tilted up to 30^0 from zenith (broadside) direction.

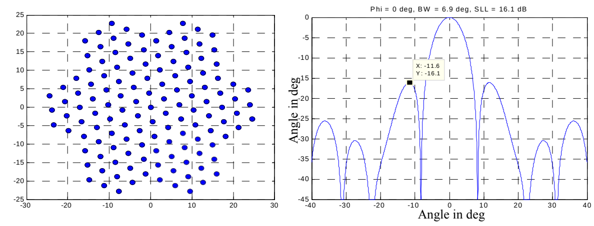

Figure-3: (a) 133-element Pilot array and (b) radiation pattern of the pilot array

One of the three axes of the array grid is aligned 6.5^0 West of North. The antenna center array is located at about 100 m distance from the control and instrumentation room. Each antenna element is connected to a dedicated TR Module. The 19 TR modules in the sub-arrays are fed by the respective collocated 19-way in-phase divider/combiners. The TR modules in the antenna field are connected to the radar exciter/receiver located in the instrumentation room via seven long RF cables and a 7-way splitter/combiner located in the instrumentation room.

TR Modules

133 numbers of solid-state 1-kW TR modules [2], 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.

The Tx section comprises of a pre-driver, driver and power amplifier (1 kW) where as the Rx section contains the limiter, blanking switch and low noise amplifier (LNA). The output section consists of a high-power T/R switch and a dual-directional coupler (DDC). TSG card performs the control and monitoring of different parts of the TR module. The TR module generates a peak power of 1 kW with a maximum duty ratio of 10%. The harmonic suppression is better than 40 dB. The receive path gain is 30 dB and noise figure is 2.5 dB.

The TR modules are controlled directly by the Radar Controller (RC) PC located inside the instrumentation room. The Ethernet Tx/Rx communication signals, trigger inter-pulse-period (IPP) pulse and clock signals are given to the TR modules through optical fibers. The FTU converts the optical signals into electrical form and vice versa. TR module is designed for convective passive cooling. A mechanical stand and rain canopy are designed (as shown in figure-1) to protect the TR module from the environment (like rain and sun light). The photographs of the TR module and the sample test results are shown in figure 4.

The digital attenuator and the phase shifter are used to set the amplitude and phase values of the TR modules in both receive and transmit paths for beam formation. The dual directional coupler (DDC) is used for forward and reverse power monitoring and to generate excess VSWR interlock.

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.

The forward coupled port of the TR module is used for testing, monitoring and calibration purposes. The RF signal from the coupled port is brought to the optical transceiver unit via the SPDT switch. The SPDT SW is switched between the Tx and Rx mode. During the transmit mode, the output of the SPDT SW is converted into optical signal and sent to the instrumentation room through optical fiber cable for measuring the amplitude and phase. In the receive mode, the simulated RF pulse is injected into the TR module via the optical fiber, converted into RF pulse and fed to the forward coupled port through SPDT SW. this signal passes through the RX chain and sent back to the instrumentation room for measuring the amplitude and phase.

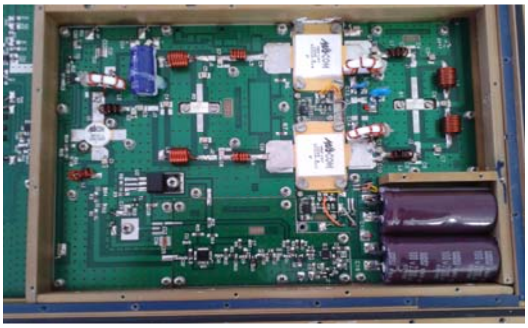

Figure-4: Photograph of the TR module

Direct digital receiver and signal processing 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 measured dynamic range is about 70 dB. The DRx is built around Analog Devices AD 6654 “IF to baseband receiver”, ADSP-TS201S Tiger SHARC DSP processor and Xilinx VIRTEX II (1.5V) XC2V500 FPGA. 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.

Radar Controller:

Radar controller (RC) and master timing and control signal generator (TCSG) will work together in co-ordination. The PC-based RC Radar Controller performs the following basic functions. (i) RC allows the user to set the experimental parameters and beams required for operation of the radar, through the GUI, (ii) Stores the calibration phase data and generates phase correction file. Generates the phase data required for each TR module for the beams selected, (iii) Pre-loads the experimental parameters and phase data into the TR modules through the Optical Ethernet Switching Network, (iv) Reads the status data from the TR modules during operation and displays the status data through the GUI, and (v) Sends the experimental parameters to Digital Receiver through Ethernet switch before starting the radar operation and communicates during the operation

Data Processing:

Doppler beam swinging (DBS) technique [3] is used to derive the wind vector. Radar beam is sequentially switched in five directions. Signal power, mean Doppler, Doppler width and SNR are estimated for each range bin for each beam direction. Doppler obtained in these directions is used to derive the three (x, y and z) components of the wind vector. Software is developed in VC++. GUI is used to select the display mode, that is, the raw data, spectral data in 2D and 3D, moments and winds.

III PRELIMINARY OBSERVATIONS

The pilot radar is expected to give height coverage up to 10-12 km for the clear-air atmosphere for the peak power and antenna size adopted. It is necessary to operate the radar in three or five non co-planar beams to derive the wind vector using DBS technique. Radar is operated with five-beams; one Zenith (vertical), and four off-zenith (15^o away from zenith) beams along the North, South, East and West directions. The experimental parameters are shown in the table-2. Sample range-Doppler spectra obtained in the five radial beam directions are shown in figure-5. It may be noted that the clear-air case Doppler spectra for the two opposite beams are mirror image to each other suggesting that radar is basically functioning normal. Figure-6 and figure-7 shows comparison of winds measured by the pilot radar with those measured by the collocated GPS Radiosonde and the present MST radar respectively, which are operated regularly at NARL.

Figure-8 shows the scatter plot comparing the zonal and meridional winds obtained by pilot radar with those measured by GPS Sonde (top) and MST radar (bottom). The comparison shows a very good agreement between the three measurements validating the observations made by the pilot radar. Sample Ionosphere observation is shown in figure-9, which shows the range-time SNR variation of the E-region.

Table-2: Experimental parameters

PW	:	8 micro sec coded
IPP	:	125 µs (clear air)
NCI	:	256
NFFT	:	256
NICI	:	4
No of beams	:	5
Beam tilt angle	:	15°
Start range :	:	1.6 km
Stop range :	:	12.85 km
Range resolution	:	150 m
Time resolution	:	3 min

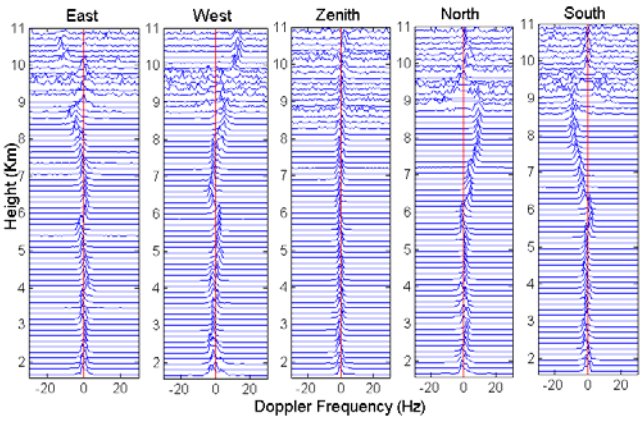

Figure-5: Sample Range- Doppler spectra observed on 7 March 2013

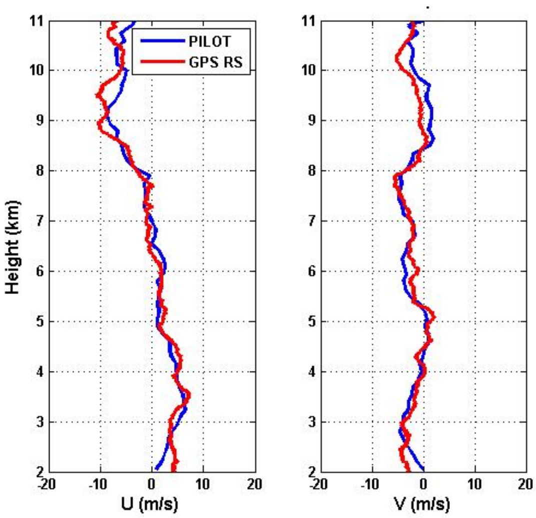

Figure-6: U,V comparison of Pilot radar with GPS RS observed on 5 September 2013

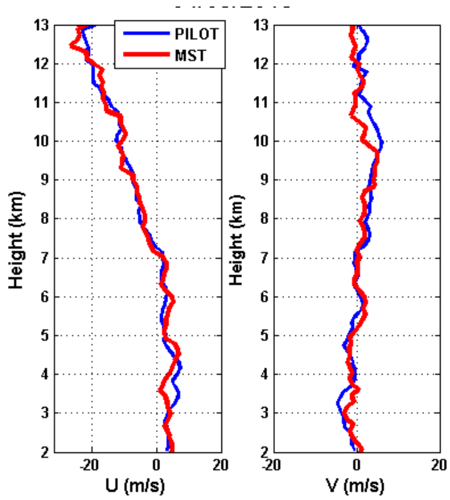

Figure-7: U,V comparison of Pilot radar with co-located MST Radar observed on 4 September 2013

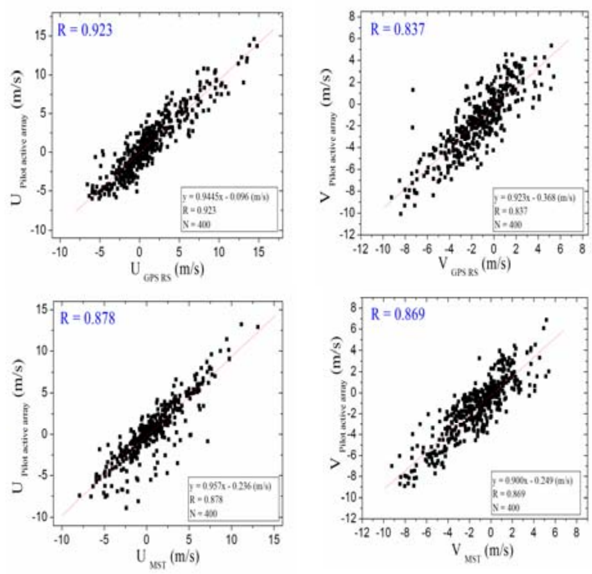

Figure-8: Scatter plots comparing winds with GPS Sonde (top) and MST Radar (bottom)

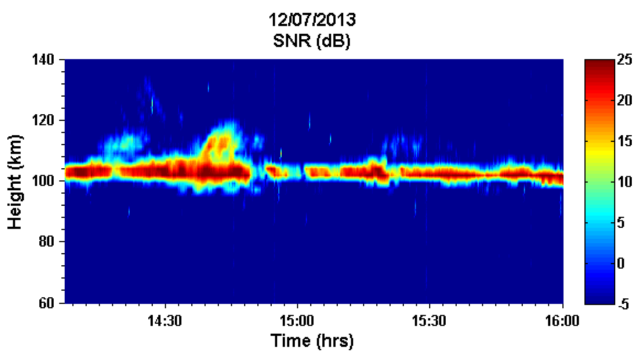

Figure-9: Ionosphere probing with pilot active array radar

IV CONCLUSION

A 53-MHz pilot active phased array radar has been designed, developed, and successfully operated to probe the atmosphere up to an altitude of 10-12 km. All the technological concepts like out-door installation of solid-state transmit-receive (TR) modules, beam steering, optical fiber based control, interface, and monitoring etc, have been demonstrated. This system has survived unprecedented heavy lightning/ severe thunderstorms (occurred at NARL) without any difficulty owing to the optical fiber based network adopted between the out-door TR modules and in-door master controller PC for control, interface and monitoring.

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BIO DATA OF AUTHOR(S)

Parvathala Srinivasulu, born in 1967, passed B.Tech (ECE) at REC Warangal and M.Tech(Microwave Engineering) at IIT Kharagpur in 1989 and 1991 respectively. He joined NARL in 1991. He is involved in the installation and commissioning of the VHF Indian MST Radar and L-band Boundary Layer Radar at NARL. He successfully developed active array atmospheric radars at HF, VHF and L-band frequencies. Currently he is leading active array radar projects for atmospheric/weather research application. His areas of interest include active aperture radars, 3-D radar imaging and radar calibration.

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 L-band radar wind profilers, Pilot active phased array VHF Radar, HF Radar Interferometer at NARL. His areas of interest include active phased array radars and radar calibration.

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. 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.

M. Durga Rao, born in 1980, passed B.E.(E.C.E) at Sir. C.R.R. College of Engineering, Eluru in 2002 and M.Tech (Electronic System design and Communication Engineering) at NIT, Rourkela, in 2005. He worked at Vikram Sarabhai Space Centre, Trivandrum, during the period 2004-2010 and joined NARL in December 2010. He is involved in the development, installation and commissioning of the HF Radar Interferometer and pilot active phased array VHF Radar at NARL. His areas of interest include development of active phased array radars.

S Allabakash, born in 1987, completed M.Sc. in Electronics at Sri Venkateswara University, Tirupati. He is presently doing Ph.D in the Department of Physics, Sri Venkateswara University