Wide Scanning HF Active Array Radar for Ionospheric Probing at NARL

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Abstract:

Ionospheric research has been a continued topic of interest both for academic interest and applications. A 30-MHz radar has been developed at National Atmospheric Research Laboratory to study the low latitude ionospheric plasma irregularities. The radar has the beam steering capability to scan a larger part of the sky up to ±45^o in East-West direction, which will overcome the limitation of slit camera picture obtained by the fixed beam of the Gadanki MST radar on the ionospheric plasma irregularity/structures. The radar system employs an active phased antenna array, 7.5 kW high power solid-state Transmit-Receive modules and direct IF digital receiver. System design philosophy, realization and preliminary observations are presented in this paper.

Key Words: antenna array, TR Modules, digital receiver

I INTRODUCTION

The requirement of accurate characterization of the ionospheric background parameters and their secular variations, strong fluctuations in electron density/electric field due to various instabilities and their local time and seasonal dependence including the effects of magnetic storm become important for efficient and reliable use of the satellite based communication and navigation systems. Further, the forecasting capability became the requirement of the day for necessary correction and safety both for services and satellite based systems. Both experimental data and understanding the physical processes is required for developing a meaningful forecast. In this context, to characterize the low latitude ionospheric irregularities and their spatial and temporal variations with all time scales and develop an in-depth understanding on the governing physical processes, National Atmospheric Research Laboratory (NARL) has developed a new 30-MHz radar for strengthening the Ionosphere research activities. This radar employed state-of-the-art technologies such as solid-state transmit-receive (TR) modules, direct digital receiver, pulse compression etc. System description is presented in section II. Sample observations of E and F layers of the ionosphere are presented in section III and conclusions are given in section IV.

II SYSTEM DESCRIPTION

Functional block diagram of the radar is shown in figure-1. It comprises of antenna array, TR modules & associate power supplies, Exciter, RF distribution unit, Back-end receiver, master timing and control signal generator, direct digital receiver (DRx) and Radar controller. In the transmit path, DDS based Exciter generates the necessary RF waveforms with reference to a high stable OCXO. The Pulsed RF signal is fed to the 20 numbers of 7.5 kW solid-state TR modules via the switching and distribution network. The output from each TR Module (in-door) is passed through a long RF coaxial cable and delivered to one row (aligned in NS direction) of 8 antenna elements through an in-phase 8-way splitter/combiner

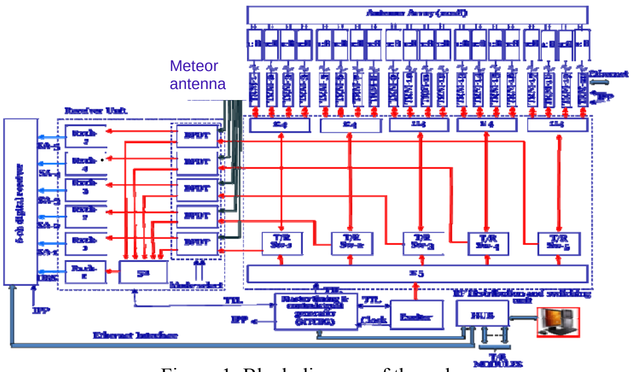

Figure-1: Block diagram of the radar

The received signal from eight-individual antenna elements corresponding to one column of antenna array is combined at 8:1 in-phase combiner and delivered to the receive sections of the corresponding TR module. Receive outputs of all the TR modules are combined in the switching/distribution network and fed to the back-end receiver unit, where it is suitably amplified and band limited before delivering to the direct digital 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 range-time-intensity (RTI) and range-time-velocity (RTV) plots. Radar controller facilitates the user to set the operational parameters and operate the radar through GUI. Pictures of the radar system are shown in figure-2. This radar has the beam steering capability in east-west (EW) direction up to ±45^o while it is fixed at 14^o North from zenith direction. Brief specifications of the system are given in Table-1. Subsystem level details are given below

Antenna array:

The antenna array comprising 160 elements is organised into a 20x8 matrix. It is spread over an area of 6300 m^2 (112m along east-west and 56m along north-south

Figure-2: Photographs of the antenna array and the instrumentation building (top panel), transmit-receive system (bottom left) and radar controller (bottom right).

Table-1: Specifications of HF Radar

Frequency	:	30 MHz
Bandwidth	:	1.5 MHz
Technique	:	DBS/RI/Scanning/Meteor
Antenna	:	20x8 array (112 m X 56 m)
Peak power	:	150 kW @ 5% DR
Pulse width	:	1- 500 µs
Range coverage	:	3 – 600 km

directions). The antenna beam is tilted at 14^o North from zenith direction so that the antenna beam satisfies the perpendicularity condition for the detection of irregularities from the ionospheric E and F regions. The antenna element is a 14^0-oriented (from horizontal) two-element Yagi antenna. The array is organised into 20 columns (along the East-West direction) each consisting of 8 antenna elements (along the North-South direction). The inter-element spacing is 0.56λ in East-West direction and 0.7λ in North-South direction (λ is the operating wavelength). The group patterns of the 8-element NS linear arrays are oriented 14^0 north to satisfy the perpendicularity condition for ionosphere. This is achieved by employing proper cable lengths for the feeder network from the RF splitter to antenna along each row of 8 antennas. The expected phase gradient is 60.9^0 and the measured phase gradient is found to be 59.99^0 across the entire array. Yagi antenna element consists of 3-m vertical boom, with a firm base made of Seamless Steel material attached with the two elements (reflector & dipole) along with the Balun box. The array grid configuration and array factors (in EW plane) are shown in figure-3. Beam width of the array is 4.5^0 and 9^0 in EW and NS planes respectively.

RF Switching and Distribution unit:

This unit distributes the exciter output signal to TR modules in transmit mode by using 1:5 and 1:4 power dividers through T/R switches. In receive mode, the received signals from each TR module are combined and given back to the receiver Backend Unit. Each four out of twenty TR modules are combined first at 4-way power combiners. The combined outputs are fed to the multi-channel receiver back end unit, where they are combined in a 5-way combiner as illustrated in figure-1.

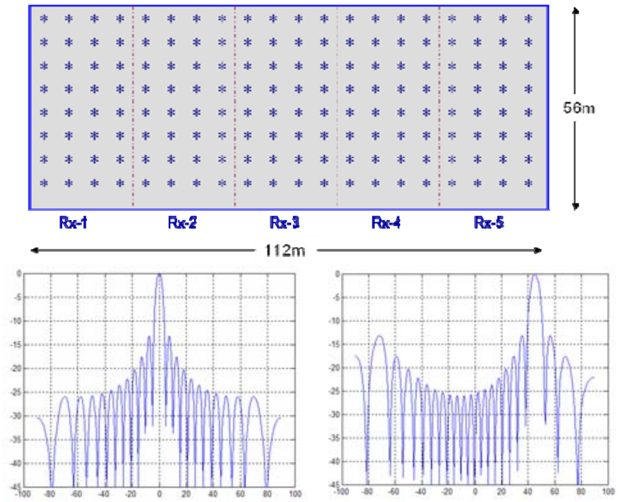

Figure-3: (a) antenna array grid diagram (b) radiation pattern for 0^o (left) and 45^o (right) scan angles

TR modules:

A total peak power of 150 kW is generated by 20 numbers of 7.5- kW solid-state TR Modules, each feeding a column of 8 antenna elements in North-South direction. Figure-4 shows the block diagram of the TR module.

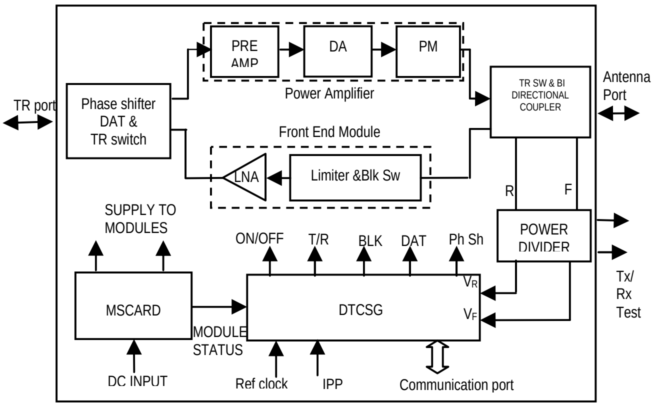

Figure-4: Block diagram of TR module

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 control signal generator (TCSG) card and (vi) power supply unit. The input section consists of 8-bit digital phase shifter, 6-bit digital attenuator and a low-power transmit/receive (T/R) switch. The Tx section comprises of a pre-driver, driver and power amplifier. The total output power of 8-

Kw is achieved by using 8 high power MOSFETs, each one is capable of producing approximately 1.25kW with a power gain of 17dB. Copper spreader is used for avoiding the thermal hot spots beneath the power device. The outputs of power amplifiers are combined at 8-way power combiner, to produce the combined output of more than 8kW. The combiner is designed for low insertion loss and high isolation over the band and high power resistors are used for isolation. The Rx section contains the limiter, blanking switch and low noise amplifier (LNA). The output section consists of a high-power passive T/R switch and a dual-directional coupler (DDC) realized using transformer coupling. TSG card performs the control and monitoring of different parts of the TR module. 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 twisted pair cables. The photographs and sample test results of the TR module are shown in figure 5. TR modules are designed for forced-air cooling and kept in the air-conditioned room.

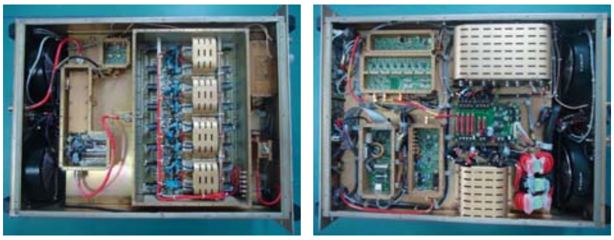

Figure-5: photographs of TR module (a) Top view and (b) bottom view

Phase shifter and digital attenuator are used to set the phase and amplitude values of the TR modules in both receive and transmit paths for beam formation. The DDC is used for monitoring the forward and reverse power and to generate excess VSWR interlock. Depending on the data received from the remote RC, TCSG 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. NTC thermistor is used to sense the temperature of the copper spreader and in case of any alarm, the control card immediately turns OFF the TR Module and displays the module status through LEDs.

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 calibration unit located at control instrumentation room through a dedicated RF cable for measuring the amplitude and phase. In the receive mode, the simulated RF pulse is injected into the TR module forward coupled port from the calibration unit located in the control instrumentation room. this signal passes through the RX chain and sent back to the instrumentation room for measuring the amplitude and phase.

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 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

Master timing and control signal generator (MTCSG):

Generates the trigger pulse (IPP marker), generates the timing and control signals for the RF distribution and switching network, Receiver unit, multi-channel digital receiver system and phase monitoring unit. It is directly controlled by master control PC.

Distributed TCSG units (DTCSGs):

The TCSG cards located inside the TR modules distributed in the antenna field are referred as distributed TCSG units. DTCSG consists of CPLD and Rabbit processor. CPLD generates the necessary timing and control pulses such as Tx ON, T/R select, Blanking SW etc and control words for phase shifter and attenuator (needed within the TR module) with reference to the incoming IPP trigger pulse coming from TCSG. Rabbit processor is used for communicating with the RC through Ethernet. DTCSG is also monitors the status and generates the necessary alarms.

Timing signal splitter:

Reference trigger pulse and clock signal are divided and distributed to Exciter, MTCSG, Digital receiver and all the TR modules.

Ethernet switch with 24 ports:

Master radar controller is connected with DTCSGs (TR Modules), MTCSG and multi-channel digital receiver system through an Ethernet switch.
Multiple experiments can be run in cyclic manner.

Direct IF 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.

Data Processing:

Signal power, mean Doppler, Doppler width and SNR are estimated for each range bin in each beam direction. 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

Test experiments were conducted with a single-beam in N14 ZENITH angle to have better returns from the ionosphere with experimental specifications shown in table-3.

Table-3: Experimental Specifications of HF Radar

Parameter	E-layer experiment	Spread-F experiment
Pulse width	8/16 µs uncoded	16us uncoded/ 64 µs coded
IPP	1400 µs	5000 µs
Coherent int	4	4
FFT points	256	256
Incoh int	1	1
Beam position	14^0 North	14^0 North
Range	70-140 km	250-600 km
Range resolution	1.2/2.4 km	2.4 km

Figure-6 and figure-7 show range-time variation of SNR obtained by both the new 30-MHz ionospheric radar and the existing 53-MHz MST radar for E and F regions respectively. very good similarity may be noticed between the two radar SNR maps. Figure-8 shows the F-region SNR profile obtained with 16-µs un-coded pulse and 64-µs coded pulse operations. The difference in SNR is about 6.5 dB which is very close to the theoretical value of 6 dB. Finally figure-9 shows the angular scan capability of the radar. The beam is scanned from East 43^0 to West 43^0 with an angular resolution of 2^0. The complete scan of E-region SNR map is obtained in about 1 minute time. The horizontal extant of the E-layer may be seen at about 100 km height. This feature is not available with the existing Gadanki MST radar. These results demonstrate the satisfactory performance of the radar.

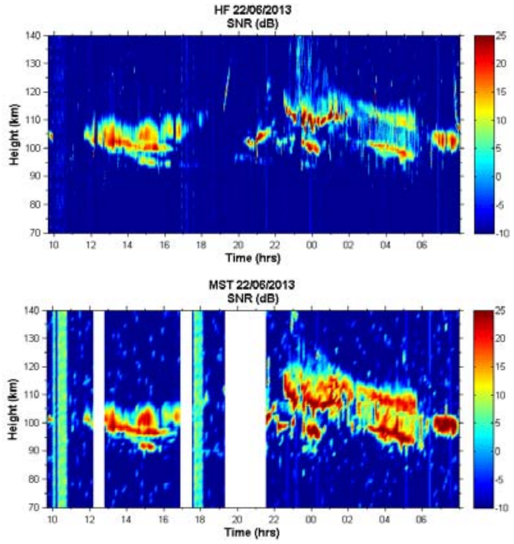

Figure-6: SNR maps of E-region observed by new 30-MHz radar (top) and 53-MHz MST radar (bottom)

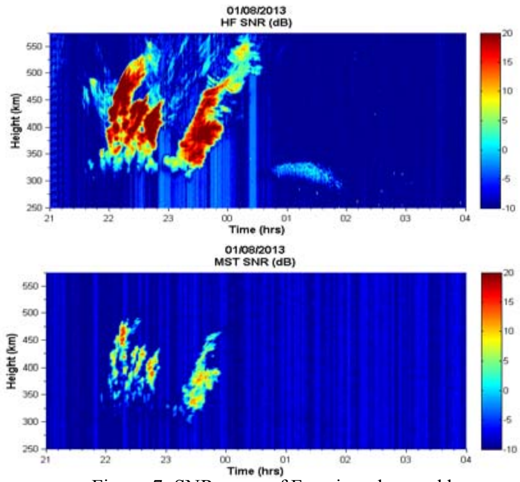

Figure-7: SNR maps of F-region observed by new 30-MHz radar (top) and 53-MHz MST radar (bottom)

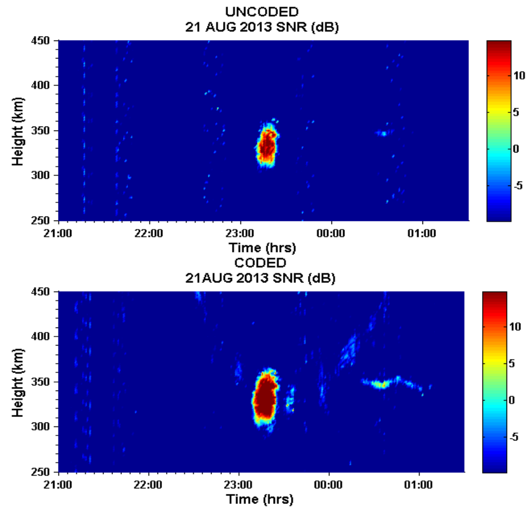

Figure-8: SNR maps of F-region observed by 30-MHz radar for 16-µs un-coded (top) and 16-µs coded (bottom) pulses

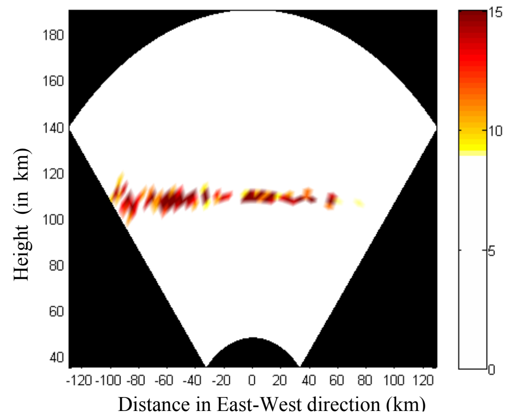

Figure-9: Angular scan profile of E-region SNR in East-West direction from West-43^0 to East-43^0

IV CONCLUSION

30 MHz radar system for ionosphere research has been designed, developed and installed at NARL. It employs the state-of-the-art technologies such as solid-state active antenna array, Direct IF DRx etc. Test runs performed with this radar to detect the E &F region echoes have been quite successful. The basic characteristic of the echoes are consistent with those expected from Ionosphere field aligned irregularities. A detailed test &evaluation of the system and observations made using different modes of operation are to be carried out.

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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.

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