Development of 30-MHz radar system with wide scanning capability for dedicated probing of ionosphere

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Abstract:
A 30 MHz radar has recently been established at Gadanki (13.5ºN, 79.2ºE; 6.5ºN mag. lat.) to make unattended observations of the ionospheric field-aligned irregularities (FAI). This radar, called the Gadanki Ionospheric Radar Interferometer (GIRI), has been designed to have scanning capability of 100º in the east-west plane perpendicular to earth's magnetic field and interferometry/imaging system to study drifts and spatial distribution of plasma irregularities at both large and small scales. System design philosophy, realization and preliminary observations are presented in this paper.

Key Words: antenna array, TR Modules, digital receiver

I INTRODUCTION

Equatorial plasma bubbles are detrimental for satellite based navigation applications. Plasma bubbles are the regions of deep plasma density depletions in the equatorial ionospheric F region and are generated by Rayleigh-Taylor type plasma instability process during the post-sunset hours [Kelley, 2009]. While the physical processes responsible for their occurrence are fairly known, prediction of their occurrence and vigor on a given night remains challenging. To gain insight on the spatial-temporal behavior of the plasma bubble and to link these features with the background ionospheric state parameters that govern the underlying instability process, a new 30 MHz radar system, called the Gadanki Ionospheric Radar Interfereometer (GIRI), has been established at NARL.

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

The radar system 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 8-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.

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-1. This radar has the beam steering capability in east-west (EW) direction up to ±50º while it is fixed at 14º North from zenith direction. Brief specifications of the system are given in Table-1. Subsystem level details are given below

Figure-1: Photographs of the antenna array and the instrumentation building (top panel), transmit-receive system (bottom left) and radar controller (bottom right).

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 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.

Frequency	:	30- MHz
Antenna	:	20x8 yagi antenna array
Antenna aperture	:	6272 m^2
Beam width (3dB)	:	4.5° in E-W and 9° in N-S
Beam direction		
in azimuth	:	(±50o with respect to14oN)
Bandwidth	:	1.5 MHz
Technique	:	DBS/RI/Scanning/Meteor
Peak power	:	160 kW @ 5% DR
Pulse width	:	1- 500 µs
Inter-pulse period	:	200 µs - 10 ms
Receiver	:	6 direct digital receivers
Bandwidth	:	1.5 MHz
Dynamic range	:	70 dB
Pulse compression	:	Complementary and Barker

Table-1: Specifications of HF Radar

***TR modules*:**

A total peak power of 160 kW is generated by 20 numbers of 8- kW solid-state TR Modules, each feeding a column of 8 antenna elements in North-South direction.

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. 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 2. TR modules are designed for forced-air cooling and kept in the air-conditioned room.

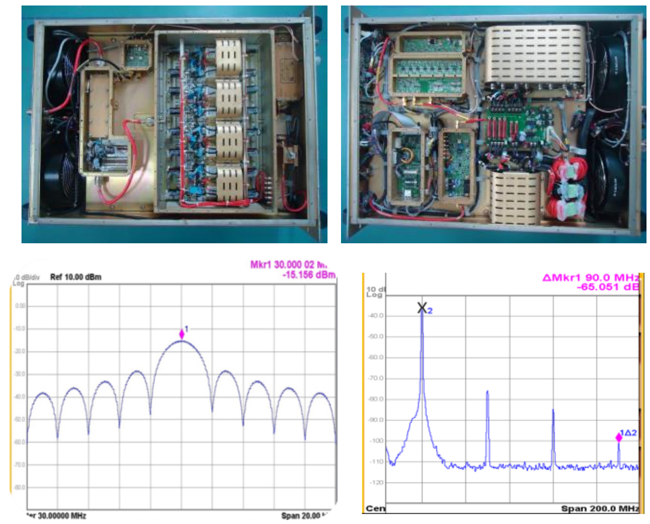

Figure-2: photographs of TR module (top panel) and pulse spectrum and harmonics (bottom panel)

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 Scientific Results

Test experiments were conducted with N14 ZENITH angle to have better returns from the ionosphere. The sample observations are shown in this section. The day time E-region field-aligned irregularities observed by the radar with good SNR is shown in figure-3.

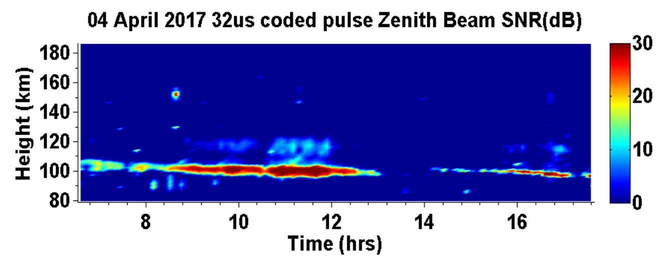

Figure-3: SNR maps of E region field-aligned plasma irregularities during the day time

The daytime 150-km observations for the first time at 30-MHz frequency observed the GIRI is shown in figure-4. The capability of the system to observe very weak echoes at this height can be observed here.

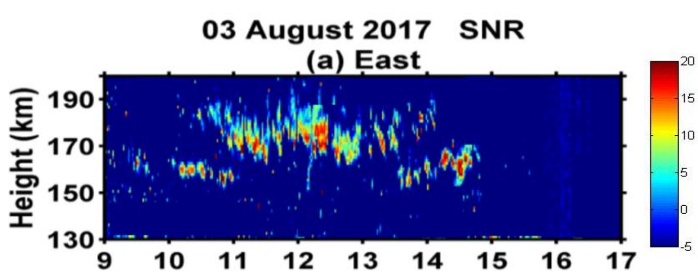

Figure-4 :range-time variation of 150-Km echoes

The spread-F event observed by GIRI with good SNR during the night time is shown in figure-5. Finally figure-6 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. These results demonstrate the satisfactory performance of the radar.

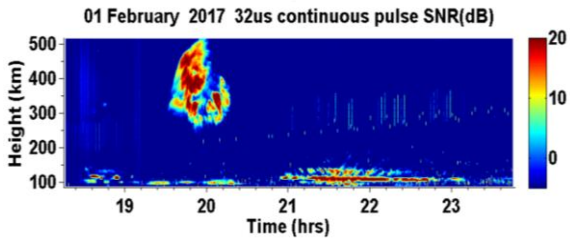

Figure-5: SNR maps of F-region during the Spread-F event

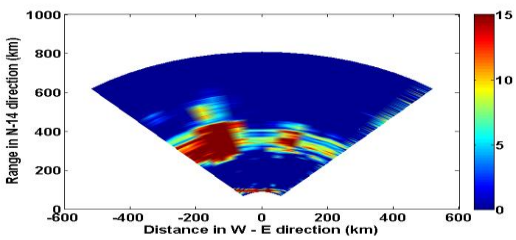

Figure-6: Angular scan profile of F-region SNR in East-West direction from West-43^0 to East-43^0

IV CONCLUSION

30 MHz radar system for ionosphere research has been designed, developed and the performance is demonstrated at NARL. It employs the state-of-the-art technologies such as solid-state active antenna array, Direct IF DRx etc. The radar is yielding very sensitive high resolution E &F region Range-Time-Intensity maps. The basic characteristic of the echoes are consistent with those expected from Ionosphere field aligned irregularities. In order to provide the meteor detection capability at this frequency, meteor antenna system is being augmented with GIRI.

REFERENCES

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