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Calibration of Mst Radar Using Radio Source Virgo-A With Digital Receiver

[1]T. Nirmala, [2]Prof. P. Satyanarayana, [3]T. Rajendra Prasad
[1]M.Tech student, Dept of EEE, S.V.U.College of Engineering, Tirupati, INDIA
[2]Dept of EEE, S.V.U.College of Engineering, Tirupati, INDIA
[3]Scientist, NARL, Gadanki, INDIA

Abstract: *MST Radar has been established to study the dynamics of atmospheric processes. In this paper, a method, by recording the noise temperature of a radio source during its transit over the radar, to find errors in antenna beam orientation is discussed. The source used for Radar at Gadanki is Virgo-A (3C274) which has appropriate right ascension and declination to be able to pass through the antenna array beam. This paper outlines the Indian MST Radar signal and data processing methods, method of offline data processing, VIRGO transit recording methodology with the help of digital receiver.*
Keywords: *MST, Yagi antenna, signal processing, Concept of Interferometry, Virgo-A*

I. Introduction:

The word "RADAR" is an acronym which was coined in 1942 (II World War) by the U.S.Navy for Radio Detection and Ranging. It is basically a means of gathering information about distant objects or targets by sending electromagnetic (EM) waves to them and thereafter analyzing reflected waves of the echo signals. The reflected signal received by the radar determines the location of the object and velocity of the object.

Concept Of Radars:

RADAR itself is an abbreviation for Radio Detection and Ranging. Radar systems send out modulated waveforms using antennas in order to transmit electromagnetic energy in to a specific volume of space to search for targets. if an electromagnetic wave encounters sudden change in conductivity σ, permittivity ϵ or permeability μ in the medium, a part of the electromagnetic energy gets absorbed and is re-radiated. This sudden change in the electrical property of the medium constitutes the target. The reradiated energy on being received back at the radar station gives information about the location of the target. The location of the target includes range, angle and velocity parameters. The range is the distance of the target from radar station. The angle could be azimuth or elevation angle for static targets and velocity for moving targets. If relative motion exists between target and radar, the shift in the carrier frequency of the reflected wave (Doppler effect) is a measure of target's relative (radial) velocity and may be used to distinguish moving targets from stationary objects. National Atmospheric Research Laboratory (NARL) at Gadanki (13.47° N,79.18° E) near Tirupati, India has been oprating a 53MHz atmospheric radar. (Mesosphere,Stratosphere,Troposphere radar) for studying structure and dynamics of lower, middle and upper atmosphere.

Mst Radar:

MST Radar provides estimates of atmospheric winds on a continuous basis with high temporal and spatial resolutions which is important in the study of the various dynamical processes of the atmosphere. Radar used to investigate the motions of the middle atmosphere on all temporal and spatial scales and also to study the interactions among the three different height regions namely, Mesosphere, Stratosphere and Troposphere is called MST radar. MST Radar uses the echoes obtained over the height range of 1-100km to study winds, waves, turbulence and atmospheric stability. Echoes below 50km arise primarily due to neutral turbulence where as above 50km, the echoes are due to irregularities in the electron density .In the height range 30-60km, density of the atmosphere as well as electron density are very low resulting in very weak echoes resulting in gap region in most of the MST radars.

Mst Radar Techniques:
There are two main Techniques
(i)Doppler beam swinging Technique
(ii)Spaced antenna drift Technique
<u>Doppler beam swinging Technique:</u>
The DBS technique assumes a homogeneous atmosphere over a spatial range around the radar site, but this assumption provides erroneous

results during thunderstorm and cyclonic activity. This technique uses a narrow beam pointed in at least 3 directions and measures the Doppler shift of echoes from irregularities. A beam in the zenith directions and at least two more means in scattered of f-zenith in two perpendicular directions are used to measure the radial velocity in each beam directions.

<u>Spaced antenna drift Technique:</u>

This method uses three or more spaced antennas and received signals are cross correlated to determine the offset of cross correlation functions, yielding horizontal velocity component.

II. Configuration Of Indian Mst Radar:

MST radar operating at 53 MHz consists of efficient antenna system that transmits high power pulsed RF signals into the atmosphere and receives the backscattered echoes. MST technique obtains echoes from the optically clear atmosphere in the height range 1-20 km, D, E and F layers. The primary echoing mechanism involves scattering from turbulent irregularities having small size equal to one-half of the radar wavelength. The echoes from the atmosphere are due to neutral turbulence in the lower height regions and due to the irregularities in electron density in the higher altitudes.

MST radar is a high power, highly sensitive, pulse-coded, coherent Doppler radar to estimate the atmospheric wind vector using the Doppler shift in echo. Three orthogonal velocity vectors are used to find wind vector, hence antenna is steered into three orthogonal directions. The radar antenna beam pointing is critical to accurately measure the wind vector. Since the antenna far field is above 5 km, celestial sources, which appears to be point source is used to find the antenna characteristics. The method of finding the antenna look angle is performed using two receivers in interferometry mode. A digital receiver is used in addition to conventional analog receiver to obtain the antenna parameters.

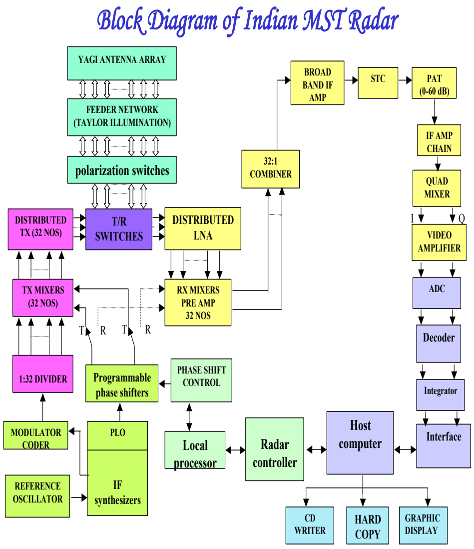


Fig.1 Block Diagram of Indian MST Radar

According to Fig.1, the block diagram consists of multiple sections. As per Damle S H, Chande J V & Ray K P the block diagram was classified into four important sections. They are

1.1 Antenna array and feeder network
1.2 Exciter and Radar controller
1.3 Transmitter system
1.4 Receiver and Signal processing

<u>1.1 Antenna array and feeder network:</u>

The phased array consists of 1024 three element yagi antennas occupying an area of 130m*130m in two orthogonal sets, one for each linear horizontal polarization (east-west, north-south orientation). An inter antenna spacing of 0.71λ is used in both scanning upto an angle of about 20 deg from zenith.The feeder network consists of two orthogonal sets of 32 parallel runs of center-fed series structure sub arrays. The RF is fed to high power polarization relays and to a 3-db in–phase power divider (combiner for reception) and distributed along the sub array through appropriate couplers of the feeder line. The power distribution across the array follows an approximation to modified Taylor weighting in both principle directions. The radar beam generates a radiation pattern with a main beam of 2.8deg, gain of 36 db, and a side lobe level of -20 db. In order to have a desired radiation pattern, phase calibration etc is done using special methods. Electronic scanning of radar antenna beam is performed in 5 pre defined positions- Zenith, 10 deg off vertical towards north, south, east, west directions.

1.3 Exciter and Radar controller:

The exciter unit generates all the RF and timing and control signals for radar. It comprises a master reference oscillator, a two frequency synthesizers' one each for IF and LO, a ADSP-21060SHARC processor controlled timing and control signal generator (TCSG), and a bi-phase coder / BPSK modulator. The 48MHz signal serves as LO for up conversion while transmitting and down conversion while receiving. The bi phase coder generates a 5MHz complimentary coded pulse taken from the 5MHZ signal and the complementary code sequence from TCSG. TCSG supplies control signals for synchronizing the operations of various subsystems of the radar .The output from the TCSG includes Tx & Rx gate signals, duplexer signal, coder and ADC sample clocks, and control signals to data acquisition card.

1.3 Transmitter system:

The peak power of 2.5 MW is generated by 32 transmitters ranging in power from 15 KW to 120 KW, each feeding a sub array of 32 elements. It has four amplifier stages and associated power monitoring and controlling, and safety interlock circuits. The amplifier chain consists of a solid state amplifier (SSA), pre-driver (PDR), driver (DR) and high power amplifier (HPA). The PDR, DR, and HPA operate in class C mode. The transmitter output power maintained to within ±1dB of the specified level by adjusting the input to SSA by PIN attenuator. The local processor controls all operations of transmitters, in addition to providing control signals to duplexers, polarization switches and 8-bit phase shifters.The input to the transmitters is a low level (1 m watt) pulse modulated (coded, un coded) signal at 53 MHz. This RF is generated by mixer, which receives as inputs, a pulse modulated 5 MHZ signal and an appropriately phase shifted 48 MHZ local (LO) signal. The transmitters operate up to a duty cycle of 2.5%, limiting the total average power to about 60 kW.

1.4 Receiver and Signal processing:

The receiver is a phase coherent receiver with quadrature channels, having an overall gain of 120dB, a dynamic range of 70dB, and a bandwidth matched to the baud length of the coded pulse. The front end units of the receiver, consisting of a blanking switch, a low noise amplifier (LNA), and a mixer preamplifier for each of the 32 channels. The output of LNA is mixed with phase shifted 48 MHz LO signal and amplified in a mixer preamplifier having an effective gain of 7dB. The IF outputs from 32 rx channels are combined. The combined IF signal is amplified in broad band amplifier with a gain of about 15dB.The signal then filtered to a bandwidth of 1.7MHz.In this project a conventional **analog IF receiver** and a **digital IF receiver** are used to process the signals.The analog receiver, IF signal is split and applied to pair of quadrature mixers which mix them with 5 MHz LO signals having quadrature phase of 0^0 and $90^{\,0}$. The quadrature signals from the mixers are fed to two identical channels of low pass filters (LPF) and video amplifier to obtain the two bipolar video signals of A cosθ and A sinθ at the output. These quadrature (I and Q) outputs of the receiver are limited to ±5V and given to I and Q channel of data acquisition card in echo processing system.The digital IF receiver performs the digitization of input at 5MHz IF and then signal down conversion to the baseband is done by digital down converter (DDC) in digital domain.. The processed data is transferred to PC on USB2.0 for archival & display purpose.

Virgo-A

Virgo- A is a super giant elliptical galaxy that is the most powerful known source of radio energy. This galaxy is the largest and brightest galaxy that is a strong source of multi wavelength radiation, particularly radio waves. This is the largest giant elliptical galaxy near Earth and is one of the popular targets for astronomy study. The Radio source 3C274 (Messier 87) was identified with the strong radio source Virgo-A. The declination of Radio source is +12° 23′ 28.0439″is within the zenith beam of MST Radar located at +13° 27' 21.60"N, +79° 10' 32.52"E latitude, longitude respectively. Hence this radio source is ideally suited for calibration of MST Radar antenna. The source transits over the radar everyday due to earth's rotation. The transit time at particular location is accurately calculated with RA and Dec of source.

III. Concept Of Interferometer:

The MST radar antenna characteristics are obtained by interferometer technique. For obtaining the exact antenna look angle, MST Radar antenna is separated into two smaller antennas of half size, aligned in East and West halves. The technique makes use of these two spaced antennas to produce an interference pattern. Data received by the antennas during transit of the radio source is used to generate SUM pattern and Difference patterns of the two antennas received signals. The MST Radar phased array for Radiometer uses the 32*32 yagi antenna array is splitted into two arrays each having 16*32 yagi elements. Each of these arrays (that is 16 sub arrays of 32 elements each) is provided separately to two different Receivers at IF 5MHz. East antenna signal is connected to conventional analog receiver, West half antenna IF signal is connected to Digital Receiver. The time series data is obtained from both the receivers is processed offline to get the SUM, Difference and SUM-Difference patterns.By this means it is possible to displace the interference pattern so that, the new maxima corresponds to the minima of the original pattern. Where the envelope of the interference patterns is determined the reception pattern A(ɵ)of individual antennas. The SUM pattern power (reception when the antennas are in phase, with two rx signals added) is given by

SUM = A(ɵ)[1+cos{(2nd/λ) sin ɵ}] → 1

the DIFFERENCE pattern (when antennas are connected out of phase or the rx signal are subtracted from one another), the receptivity is

DIFF = A(ɵ)[1-cos{(2nd/λ) sinɵ}] → 2

Where ɵ is the angle between the source and the axial plane, d is the spacing between the antennas and λ is the wavelength. If the analysis is restricted to the angles near the axial plane of the interferometer, these equations may be simplified to

A(ɵ)[1±cos{(2 n d ɵ/λ)]

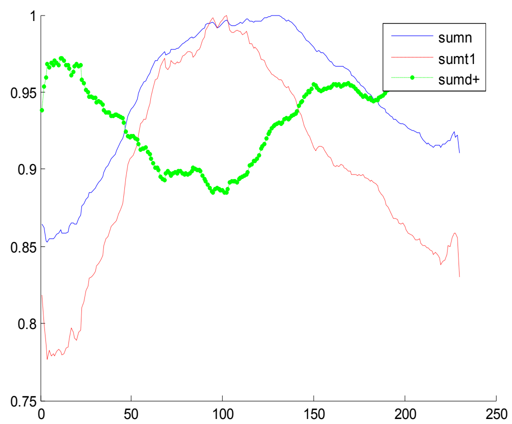
Suppose now that a point source of radiation (in case of MST radar: VIRGO-A), which produces a power flux p at the antenna, is situated in a direction ɵ, the powers intercepted by the antenna system in the two conditioned are given by P A(ɵ)[1+cos{(2nd/λ) sinɵ}] and

P A(ɵ)[1-cos{(2nd/λ) sinɵ}]

The antenna power whose magnitude is the difference is given by

p A(ɵ) cos (2ndɵ/λ)

IV. Results:



V. Conclusions

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