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Phased array of 619-element Yagi-Uda antenna for Wind Profiler Radar at Cochin University of Science and Technology

Titu K Samson(1), Binoy Babu(1), V. K. Anandan(2), Rakesh V(1),Rejoy Rebello(1),K Mohanakumar(1), and P Mohanan(1)
(1) Advanced Aenter for Atmospheric Radar Research, Cochin University of Science and Technology,Cochin-22,Kerala India, http://acarr.cusat.ac.in
(2) Indian Space Research Organization (ISTRAC), Bangalore, India

Abstract

During the last 3 to 4 decades radar technology has grown into an indispensable technology for weather phenomenon detection , prediction and tracking. There are mainly two types of atmospheric radar, Doppler weather radar to detect clouds, thunder storms, cyclone etc and Wind Profiler Radars (WPR) used to detect the speed and direction of wind above the radar. In this paper we are discussing the design of 619 element Yagi-Uda antenna array for Stratosphere Troposphere Wind profiler radar(ST Radar) operating at 205MHz. Frequency was selected considering the objective of height coverage of 500m to 20Km above earth. Design is done based on the volume reflectivity and refractive index structure coefficient of atmosphere. Minimum detectable signal(MDS -150dBm) of the system is considered as design criteria.

1 Introduction

During World War II military radar operators noticed noise in the returned echoes due to weather elements like rain , snow and sleet. These observation give rise to the development of atmospheric radars to study the storm, cyclone, rain and wind. The basic working principle of WPR is the back scattering of electromagnetic wave from the variation in the atmospheric refractive index. If an EM wave propagate through a dielectric medium with different refractive index the wave will get scattered depending on the medium properties. A portion of energy will be scattered in all direction, these scattered signal can be analyzed to find out the properties of scattering medium. The typical operating wavelength of WPR are from L-band to VHF. Jicamarca radar was built on 1961 which is a incoherent scatter radar for ionospheric studies operating at 50MHz [4]. R F Woodman detected echos from mesosphere, stratosphere and troposphere. An active phased array system located in Shigraki, Japan was developed in 1984 was the first of its kind. MU radar is considered as the milstone in the history of atmospheric Radars [5]. Colorado WPR [6] network was one of the first WPR network established for operational and meteorological research. This network has got 4 VHF and 1 UHF WPR systems. The main objective of the network program was to provide vertical profiles of horizontal wind through out the troposphere in all weather conditions. Colorado WPR network has given confidence to the meteorologist to use WPR as a tool for operational forecast. Department of Science and Technology, Govt. of India has sanctioned a project to Cochin University of Science and Technology to establish a Stratosphere Troposphere wind profiler radar operating at 205MHz for wind profiling application from 500m to 20Km above earth [1, 2, 3].

2 Yagi-Uda antenna Theory and operation

Yagi-Uda antennas are suitable for these kind of application because of its high gain, moderate front to back (F/B) ratio, mechanically sturdy and good radiation characteristics [7]. A three element Yagi-Uda antenna is selected for this application. Typical construction of Yagi-Uda antenna is shown in the figure 1. All elements are arranged parallely in a boom as shown in the figure 1. The driven elements are $\lambda/2$ dipole or folded dipole antenna. Directors are smaller and reflectors are larger when compared to driven element. The length of the director varies from 0.4λ to 0.45λ and the spacing between the directors varies from 0.3λ to 0.4λ. The spacing between the driven element and reflector is generally 0.25λ. Yagi-Uda antenna is designed by considering gain, front to back lobe ratio and voltage standing wave ratio. 3 element Yagi-Uda antenna is simulated using CST microwave studio and the optimized

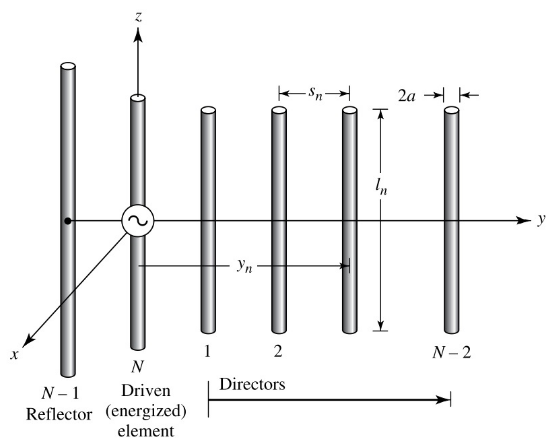

Figure 1. Yagi-Uda antenna.

antenna parameters are shown in the table 1.

Table 1. Optimized design for Yagi-Uda antenna

Parameters	Lengthλ	Length (mm)
Dipole Length	0.438 x lambda	642
Director Length	0.427 x lambda	626
Reflector Length	0.488 x lambda	715
Director Spacing	0.203 x lambda	298
Reflector Spacing	0.137 x lambda	200
Element Radius	0.0048 x lambda	7
Lambda	1465mm	

Table 2. Simulation result of optimized Yagi-Uda antenna

Frequency of Operation	205 MHz
Gain	$8.8dBi$
Front to Back lob ratio	$-17dB$
Bandwidth of Operation	$5.56MHz$

3 Array design

ST Radar wind profiler consists of array of Yagi-Uda antennas arranged as triangular grid in circular aperture to achive better side lobe level. The system should capture back scattered signals from an altitude of 20 Km and capable of tilting the beam upto 30^0 off-Zenith. The half power beam width should be approximately 3^0. The MDS of the system is fixed as -150dBm ie. the received power better than this can be detected. For the wind profiler radar the received power P_r can be calculated as equation 1

$$P_r = \frac{\pi P_t A_e \Delta r \eta_r}{64r^2} \tag{1}$$

With the MDS of -150dBm the power aperture product(PAP) as per the equation 1 is $1.6 \times 10^8 Wm^2$ with a range resolution Δr 150m and η_r is the volume reflectively which is a function of refractive index structure co-efficientC_n^2 of the atmosphere is calculated by equation 2

$$\eta_r = 0.38 C_n^2 \lambda^{\frac{-1}{3}} \tag{2}$$

from the previous radiosonde observations C_n^2 varies from $10^{-12} to 10^{-18}$, the value of η_r is calculated as 3.3478×10^{-19}.

In a phased array system the grating lobes are controlled by the inter element spacing. A system with inter element spacing greater than $\lambda/2$ will generate multiple beams with almost similar magnitude which is not a desired condition. To avoid this the system should satisfy the condition in equation 3,where θ is the maximum tilt angle. To satisfy this condition the inter element spacing(D) is approximated as 0.7λ.

$$\frac{D}{\lambda} \leq \frac{1}{1+sin\theta} \tag{3}$$

The HPBW directly depends on the no of elements in the array, as the number increases the radiation pattern will be more directive. The relation between aperture diameter and HPBW is given by equation 4

$$HPBW = 58.92\frac{\lambda}{L} \tag{4}$$

Where L is the diameter of the circular aperture. The approximated length for a 3.2^0 HPBW is calculated as 27 meters. The total number of elements required to fill a circular aperture of 27 meters diameter with an inter element spacing of 0.7λ is approximately 619. From the equation 1 the power input to the individual elements is calculated as approximately 500 Watts.

4 Simulation study

619 element Yagi-Uda antenna is simulated using CST software. The array is arranged in a triangular grid of 0.7λ spacing. Basic calculation of array are done by considering a rectangular grid. A triangular grid can be made by carefully giving the alternative element amplitude of excitement to zero. Figure 2 shows the arrangement of 619 element in a circular array with an inter element spacing of 0.7λ

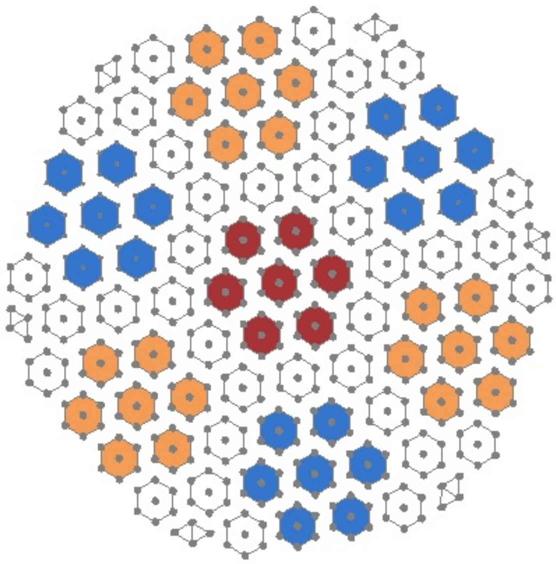

Figure 2. 619 elements arranged in a circular array, each dot represents a Yagi-Uda antenna

Seven elements are grouped to form a basic cluster . Simulation is done with progressive phase difference with 0^0, so that the excited beam pattern will be towards zenith. The simulation results of 619 element array shows that the HPBW is 3^0 with a gain of 35dBi. Figure 3 and 4 shows the 3-Dimensional and polar diagram of radiation pattern

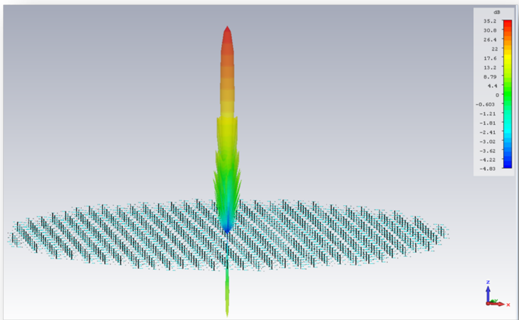

Figure 3. 3D array pattern for uniform excitation

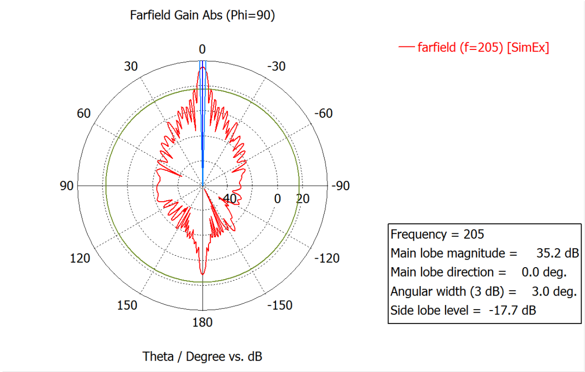

Figure 4. Polar array pattern

of the array. The side lobe level is -17.7 dB and F/B ratio is >30 dB. The main lobe can be tilted by applying phase shift to individual elements. The table 3 shows the result of beam tilt simulation. The result shows that there is an increase of 0.5^0 beam width when tilted to 30^0off-zenith.

Beam Direction		Beam Width	SLL(dB)
0^0	0^0	3.2^0	-17.4
15^0	0^0	3.3^0	-16.9dB
15^0	90^0	3.3^0	-17.3dB
15^0	270^0	3.3^0	-16.9dB
30^0	0^0	3.6^0	-14.1dB
30^0	90^0	3.7^0	-17.1dB
30^0	270^0	3.7^0	-17.1dB

Table 3. Simulation results of beam tilting

In a phased array system phase difference plays the important role in beam forming. Before applying progressive phase shift, individual elements has to be phase calibrated. In this system manual phase calibration is done with a magnetic current probe placed on the folded dipole using a network analyzer. One element is taken as a reference and all other elements phase are matched to the reference phase by applying delays using the 6-bit phase shifter in the Transmit/Receive module. Radiation pattern of large aperture system cannot be measured inside an anechoic chamber . For this we make use of radio star, which will emit radio frequencies in a wide frequency spectrum. In this measurement radar is configured in receive mode. The experiment was carried out on 15th Oct at 1000-1100LT.

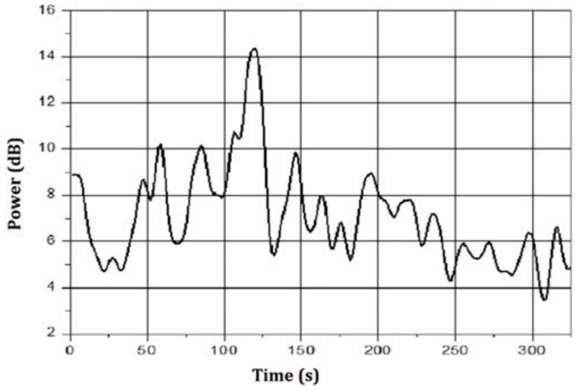

Figure 5. Received power from radio stat Virgo-A

Figure 6. 619 element antenna array installed in the roof top

The beam was tilted towards 2^0 north to track the movement of Virgo A. Observed received power is shown is the figure 5. From the observation there is an increase in the received power when the radio star is approaching the main lobe. Null-to-null beam width calculated from the figure is approximately 5.07^0 and the HPBW is 3.36^0 which is matching with the simulation results [1]. Generally the radar is operating in 5-beam configuration for wind observation. A sample spectrum for all beams are shown in the figure 7. The spectrum shows the frequency shift up to 20 Km altitude. As discussed on figure 7 the results are validated using radiosonde [1] and portable lower atmospheric wind profiler(LAWP) from NARL, Tirupati. This again confines the validity of the simulation results.

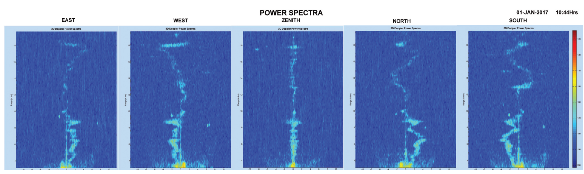

Figure 7. Power spectrum of East, West, Zenith, North and South beams.

5 Conclusion

619 element phased array system with 3 element Yagi-Uda antenna is designed, simulated, developed and installed on the roof top of a 3 storey building. Stratosphere Troposphere wind profiler phased array system was designed developed and installed at Cochin University of Science and Technology, which is giving very good performance throughout the year.

6 Acknowledgements

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