Design and Analysis of 3-Element yagi-uda Antenna for Wind Profiling Radar

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Abstract

VHF/UHF Radars use yagi-uda antenna in an array configuration for various applications including phased Doppler radars to probe atmosphere. Wind profiler system is used to find the wind profiles in the layers of the atmosphere. The main aim of this paper is to design a 3-element yagi-uda antenna for wind profiler radar system. The simulations of yagi-uda antenna are carried out using windows based 4NEC2 antenna modeler. The radiation characteristics that are usually of interest in the yagi-uda antenna are forward and backward Gain, Input impedance, bandwidth, beamwidth front to back ratio, VSWR, and magnitude of major lobes and minor lobes of a typical 3-element yagi-uda antenna operating at VHF-Band used in wind profiler radar systems.

Keywords

VHF, Wind Profiling Radar, Yagi-uda antenna, NEC.

1. INTRODUCTION

The term “RADAR” is the abbreviation for Radio Detection And Ranging, defined as the art of detecting the presence of target, determining their direction and range, recognizing their character by means of radio waves. The principle involved in the atmospheric Radar is to transmit the modulated waveform of electromagnetic energy using antenna array into the atmosphere and processing the backscattered echoes through suitable means by utilizing a chain of signal processors to determine vertical wind components with a high degree of temporal and spatial resolutions and other vital parameters required for studying the structures and dynamics of atmosphere [1]. Wind profilers provide three dimensional atmospheric wind data on a continuous basis with good spatial and temporal resolution [2]. This continuous high resolution wind data is very useful for studying the development of wind shears in near real time; especially over the rocket launch sites as wind shears affects the performance of the rockets for that Wind profilers are found to be an effective solution. Wind profiler system is used to find the wind profiles in the layers of the atmosphere. Like any radar, Backscattering of the energy from the atmospheric irregularities is the basic principle behind the wind profiler operation. Energy reflection occurs preferentially from irregularities of a size on the order of one half wavelength of the incident wave. These irregularities are primarily due to the variations in the temperature and humidity of the air, which are carried out with the wind in the form of turbulent eddies. These irregularities exist in a size range of a few centimeters to meters. A small portion of the scattered beam is returned to the radar site where it is received and analyzed.

Wind Profiler

The principle of operation of WPR is Electromagnetic pulse waves radiated by the radar antenna and propagate toward the sky. During the propagation, the electromagnetic pulse waves experience random refractivity fluctuations caused by atmospheric turbulence and are scattered. Parts of the scattered pulse waves (echoes) then return to the radar with time delays proportional to the height where the scattering had occurred, making it possible to relate the scattering intensity to the height by sampling them with proper time intervals. Since turbulence moves with the flow of the wind, the echoes are subjected to the frequency shifts (Doppler shifts) proportional to the wind velocity (V) at the height where the scattering took place.[2]

The wind profiler is a vertically oriented, Doppler radar that utilizes scattering from irregularities in the radio refractive index or precipitation to measure the horizontal and vertical components of wind velocity. A linearly polarized, phased array antenna is sequentially steered in three directions. Data are collected from the three or five beams and processed at the profiler site.[3]

The major subsystems of the Wind Profiler are as follows [3]

1. Antenna subsystem
2. Feeder network
3. Transmit Receive (TR) modules
4. Data Acquisition System
5. Radar Controller.

An antenna array is a multiple of active antennas coupled to a common source or load to produce a directive radiation. The phased array antenna is the one of the most important subsystem in phased array radar. A phased array antenna is a group of antennas or group of antenna arrays that, we connected together, function as a single antenna, whose beam width and direction can be changed electronically without having to physically move within the array. The primary
The advantage of phased array antennas is that they eliminate the need for mechanically rotating antenna elements. In essence, a phased array is an antenna whose radiation pattern can be electronically adjusted or changed. The primary application of phased arrays is in "RADAR". When radiation pattern must be capable of being rapidly changed to follow a moving object.[7]

The main antenna Parameters which controls the design of phased array for wind profiler are:
- Gain
- Beamwidth
- First side lobe level
- Beam scanning

2. YAGI-UDA ANTENNA

A Yagi-Uda array, commonly known simply as a Yagi antenna, its Configuration normally consists of a number of directors and reflectors that enhance radiation in one direction when properly arranged on a supporting structure. Yagi-uda antenna is a directional antenna system consisting of an array of dipoles and additional closely coupled parasitic elements usually a reflector and one or more directors.[5-7]

![Figure 1: 3-Element yagi-uda beam antenna](image)

The yagi antenna's basic design is a "resonant" fed dipole with one or more parasitic elements. These parasitic elements are called the "reflector" and the "director." A dipole will be "resonant" when its electrical length is 1/2 of the wavelength of the frequency applied to its feedpoint.

The yagi-uda array can be summerised by its performance considering in three parts:
- Reflector
- Feeder or dipole
- Director

The length and spacing of the reflector do affect the forward gain but have large effects on the backward gain (F/B ratio) and input impedance (Zin). Thus they can be used to control or optimize antenna parameters.

The driven element is typically a λ/2 dipole or folded dipole and is the only member of the structure that is directly excited -electrically connected to the feedline. All the other elements are considered parasitic.

The feeder length and radius has small effects on the forward gain but a large effect on the backward gain and input impedance. Its geometry is usually chosen to control the input impedance that most commonly is made real (resonant element).

The length and spacing of the directors have large effects on the forward gain, backward gain ratio and input impedance. They are considered to be the most critical elements of the array.[7]

3. DESIGN PROCESS OF 3-ELEMENT YAGI-UDA ANTENNA

The main requirements for the design of 3 element Yagi antenna are the following:
- Element gain
- Front to back ratio
- VSWR
- Impedance
- Design considerations

The dimensions of the elements are frequency dependent.

Here the general rules for length are:
- Reflector length -0.495* wavelength
- Dipole length -0.473* wavelength
- Director length -0.440* wavelength

Getting right length is the part of tuning. Spacing between the elements is the other part.

- Reflector to Dipole spacing -0.125*Wavelength
- Dipole to Director spacing -0.125*Wavelength

Design frequency around 200MHz
\( \lambda = \frac{c}{f} \)

\( \lambda \) - Wavelength in meters
\( c \) - Velocity of propagation in air(3*10^8 m/s)
\( f \) - Carrier frequency in MHz

Specifications of 3-element Yagi antenna
- Frequency of operation : 200MHz
- Gain : 7dBi
- F/B ratio : 15dB
- VSWR : 1.5:1

A three element Yagi antenna is designed and Simulated.

The design parameters are:
- Reflector length
- Dipole length
- Director length
- Reflector to dipole spacing
- Director to dipole spacing
- Radius of the elements

The feeding of RF power to the Yagi antenna is through a coaxial cable.

**Design Specifications**

For antenna gain of the order of 7dBi, it is decided to develop a three element Yagi-Uda array antennas.

**LR** = Reflector length = 0.7425m
**LE** = Driven element length = 0.7095m
**LD** = Director Length = 0.66m
**S1** = Spacing between reflector and driven element = 0.2m
**S2** = Spacing between Director and driven element = 0.2m

**SOFTWARE SELECTION FOR SIMULATION**

The software used to model and simulates the Yagi-Uda antenna was 4NEC2. It can be used to calculate and plot Gain, Front to back ratio, RL (Return Loss), VSWR (Voltage Standing Wave Ratio), Radiation pattern (Azimuth and Elevation), Smith chart and various other parameters.
Numerical Electromagnetic Code

The 'Numerical Electromagnetic Code', which is based on the Moment Method, is a user-oriented computer code for analysis of the electromagnetic response of antennas and other metal structures. It's a software program developed at Lawrence Livermore Lab for numerical electromagnetic antenna design, antenna modeling, and antenna analysis. [7] 4NEC-2 Software based on Method of Moments has been used to carry out the simulations in this present work. [8]

4. IMPLEMENTATION OF THE YAGI-UDA ANTENNA USING 4NEC2

Using the calculated dimensions, the design is simulated in 4NEC2 software. A 3-element Yagi composed of a driven element, reflector, and a director can achieve higher gain and front to back ratios. Geometrical view of 3-element yagi-uda antenna.

Figure 2: Geometry of 3-Element yagi-uda beam antenna

The radiation pattern of a 3-Dimensional antenna can be shown below, which consists of front lobe and back lobe, and are undesirable as they represent the energy that is wasted for transmitting antennas and noise sources at the receiving end. The pattern is below.

Figure 3: 3-D Radiation Pattern

The radiation pattern in 2-Dimensional of the antenna can be shown below, which consists of front lobe and back lobe.

Figure 4: 2-D Radiation Pattern

The simulated gain of the 3-element yagi-uda antenna is 7.14dBi at 200MHz.

Figure 5: Radiation pattern response

Figure 6: polar plot of total gain @200MHz
The most popular antenna specification is the front to back ratio. It is defined as the difference in dB between the maximum gain of the antenna—usually 0 degrees—and a point exactly 180 degrees behind the front. The simulated front to back ratio for a 3-element yagi-uda antenna is 17.78 dB at 200 MHz.

VSWR is a measure of the mismatch between the load and the transmission line. The VSWR of the antenna can be considered and desirable as if it is less than 2. In this below standing wave ratio vs frequency graph shows the VSWR is 1.62 at 200 MHz.

Conclusion
The yagi-uda antenna was designed and simulated for a single element. The proposed antenna at the frequency of 200 MHz, the peak antenna gain for a single element is 7 dBi. Similarly, the measured antenna efficiency for single element. Thus increasing the number of elements in linear enhances the performance of antenna. Method of Moment based Numerical Electromagnetic Code, windows based NEC-2/NEC-4 antenna modeler, available in public domain, has been used to design a 3-element Yagi-Uda antenna, which is 3 element cylindrical dipoles. The results obtained here shows that the designed antenna best suits for the Wind profiling Radar (or) Phased Array Radar applications.

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6. REFERENCES


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