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Design and Development of Dual-Polarized Orthogonal Cross Yagi antenna for the frequency range of 50MHz to 500MHz

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Abstract--- **A dual-polarized orthogonal cross Yagi-Uda antenna with the end-fire transmission is designed, for astronomical observations, radio communication, and many more, in the frequency spectrum of 50MHz to 500MHz. Due to cross yagi directors, maximum directivity and linear polarity (vertical and horizontal) is achieved. Using much different software like Matlab, MMANA and CST Studio, all the parameters and plots are simulated. This antenna has a versatile design, ideal to make a wide array network to receive radio signals. For dual-polarity, the reflector at the back gives a balloon-shaped radiation pattern. The whole design fits within the one m². The peculiarity of the antenna is that it is portable, thus, convenient to set up. A lightweight tripod is designed with ABS+Aluminium alloy to handle wind resistance. This material makes the antenna cost-effective. A motorized mount of Altitude-Azimuth is mounted on the tripod also the antenna achieved an overall gain of around 12dB.**

***Index Terms*— Yagi-Uda, Matlab, MMANA, CST, Tripod, Altitude-Azimuth mount**

I. INTRODUCTION

A dual-polarized orthogonal cross Yagi-Uda antenna design with end-fire radiation is approached with the intention of a thorough analysis. This antenna works for astronomical researches the lies within the 50MHz to 500MHz band frequency. To design a Cross Yagi-Uda with dual-polarized orthogonality, after careful consideration of the benefits and limitations of various antennas. The central frequency of the antenna used in the design is 275MHz. All the parameters provided are fulfilled and shown further with plotted simulations. Considering the array of antennas, the Yagi-Uda is compact and yields good results.

Design of Yagi-Uda is done by initially developing the reflector mesh followed by the dipoles and two directors. Here, the directors designed in crossed orientation for dual polarity. The whole design is fitted within 1 x 1 m².

For low-frequency observations, size of the parabolic dish becomes impractically large in radio astronomy. Thus, a dipole-based antenna is a more suitable option for the given VHF range. The optimum antenna choice for the dual-polarization unit is a Yagi-Uda antenna. This antenna is lightweight and cost-efficient than other antennas available. Due to low frequency, it is a wired antenna and not patched. Initially, the antenna was designed with a single plane, as portrayed in fig. 1(a), fig. 1(b). For horizontal Yagi antenna, the Gain is 9.5 dB and, for vertical Yagi, the Gain is 9.53 dB individually. As per the proposed Yagi antenna setup with two Yagi subunits gain achieved is 13.61 dB. Thus, cross-polarization increased the Gain.

For further optimization, there is a reflector added to suppress the back and side lobes.

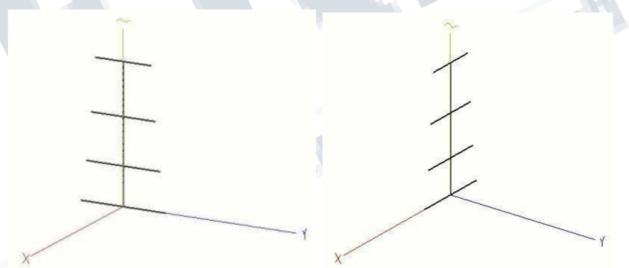


Fig. 1(a) fig. 1(b)

Linear polarized Yagi-Uda

In any antenna designed based industry, the basic need of the design should have reliability, working efficiency, purchase, and a band of the frequency range. This paper overall aims to design the dual-polarized Yagi-Uda antenna for astronomical application. Its effective antenna properties measure from 50MHz to 500MHz.

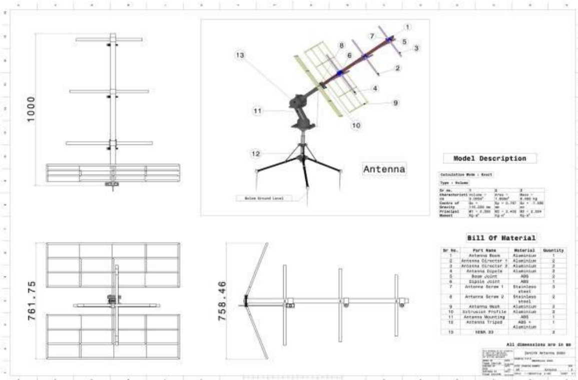


Fig. 2: Antenna components

The antenna composes dipoles, directors, reactors, and various non-conducting elements such as dipole and director mountings. As the methodology of antenna has shown earlier, assembly consists of an antenna boom made of Aluminium which is the holding element of the antenna. Next are antenna directors, which compose Aluminium, boom joint, dipole joint comprising ABS material, and antenna mesh of Aluminium. The sketched antenna is 1.2 to meters above ground level. Software to design antenna is CATIA, MMANA, MATLAB and CST. The above figure explains the Bill of the material, costing, specification and related data like material and quantity of components.

II. SCOPE OF THE PROJECT

Presently, wireless communication, satellite communication, and astronomical observations use element-based Yagi-Uda antennas [11]. Design and simulation of the antenna specification and salient features were accomplished using MMANA, CATIA, and MATLAB [5]. Applications of the designed antenna are Telecommunication, bridge antennas, ham radios, and connecting several areas through wireless communication. The optimized design with the model, transient analysis, results in a safe radiation pattern. The cluster of Yagi-Uda antennas acts like an array with the optimum selection of material, cost reduction, and effective gain results.

III. MATH

1. Dipoles and Directors:

The length of dipoles and directors is calculated with the consideration of design aspects, as shown below. The complete design is tried and embedded in the area of the one-meter square.

The formula for calculating the wavelength is [11]:

$\lambda = c / f$

$= (3 \times 10^8) / (275 \times 10^6)$

$= 1.09m$

-Where,

λ is the wavelength, c is the speed of light and f is the range of frequency (selected for antenna)

Lr - Signifies the length of the reflector.

La - Signifies the length of the generator dipole. Ld1 - Signifies the length of dipole one.

Ld2 - Signifies the length of dipole two.

By considering the calculated wavelength length of the dipoles and directors are,

Lr=0.6=0.61.09= 0.654m (2)

La=0.5= 0.51.09=0.545m (3)

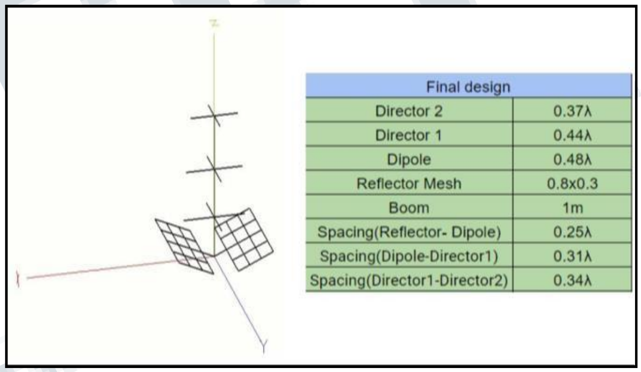
Ld1=0.46=0.461.09= 0.5014m (4)

Ld2=0.45=0.451.09=0.4905m (5)

Dra=0.25= 0.2725m (7)

Dad=0.31 = 0.3379m (8)

The wavelength gained after the calculation is 1.09m.



Final design	
Director 2	0.37λ
Director 1	0.44λ
Dipole	0.48λ
Reflector Mesh	0.8x0.3
Boom	1m
Spacing(Reflector- Dipole)	0.25λ
Spacing(Dipole-Director1)	0.31λ
Spacing(Director1-Director2)	0.34λ

Fig. 3: Scaled drawing

After numerical analysis of mutual coupling (amount) between two close elements, the antenna needs modification. All the antenna parameters for a single component and an array of 2*2 and 3*2 antennas are measured. The gain is more than 10 dB of the designed antenna, with the radiation efficiency value between 60-70%.

IV. SCALED DRAWING, STRUCTURE:

The structure design of the Yagi-Uda antenna composes a series of several thin rod elements parallel and mostly half-wave long and typically placed on a crossbar/ boom perpendicular, along the center. A driven element (single) connects to the receiver/ transmitter (having two rods attached to both sides of the transmission path) that follows a (feed depending) [4] shifting figure of parasitic elements, consecutively on both side, with a single reflector and one or more directors (optional). In contrast, this model has two Directors and a single Reflector, as

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stated. These passive radiators are not in connection with the transmitter and receiver. For modification of the radiation pattern, these elements redirect the radio waves. Compared to the driven elements, the directors are slightly shorter, while the reflectors are longer.

Table 1: Antenna parts and material

Sr No.	Antenna Part name	Material	Quantity
1	Antenna Boom	Aluminium	1
2	Antenna Director 1	Aluminium	2
3	Antenna Director 2	Aluminium	2
4	Antenna Dipole	Aluminium	2
5	Antenna Boom Joint	ABS	2
6	Antenna Dipole Joint	ABS	1
7	Antenna Screw 1	Stainless Steel	3
8	Antenna Screw 2	Stainless Steel	2
9	Antenna Mesh	Aluminium	2
10	Extrusion Profile	Aluminium	2
11	Antenna Mounting	ABS	1
12	Antenna Tripod	Aluminium	1
13	Antenna NEMA 23	-	2

Table 2: Antenna material properties

Material	Density (g/cm³)	Melting Point (°F)	Tensile Strength (Mpa)
Aluminium	2.7 g/cm³	1220.54 °F	90 MPa
ABS (Acrylonitrile Butadiene Styrene)	1.05 g/cm³	374 to 518 °F	22.1 - 59.3 MPa
Stainless Steel	8.00 g/cm³	2642 °F	505 MPa

The parasitic dipole elements are fit to the central support boom. At the middle is the driven element, so its halves are insulated. Mesh attached at an angle helps the passive radiators receive radio waves and guide them.

V. PERFORMANCE DESCRIPTION

Simulation of the stated antenna is done using three different software viz. MATLAB, CST Studio Suite, and MMANA. Various parameters such as Return Loss, VSWR, etc., are observed.

a. Return Loss:

[6] Return loss denotes the ratio of rejected radio waves arriving at the antenna input to accepted radio waves.

$$\text{Return Loss} = 10\log\frac{P_r}{Pi}$$

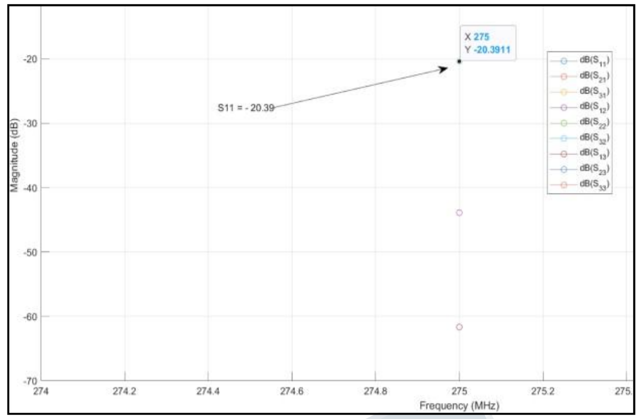

Fig. 4: Return loss output

Fig 5.1 displays the return loss at a frequency of 275 MHz The graph of magnitude vs. frequency is plotted, which results in the S11 or Z parameter as -20.39.

b. VSWR:

The power reflected by the antenna is the function of the reflector factor known as VSWR. It is the real number for the antennas. The antenna gets matched to the power line, which in turn delivers more power.

The following formula defines the VSWR:

$$VSWR = \frac{1+\Gamma}{1-\Gamma}$$

Where Γ = Reflection Coefficient

Fig. 5: VSWR simulated output

Here the cross Yagi-Uda antenna results are depicted in fig. 5 come from MMANA software. Hence SWR is 2.4 for 275MHz, keeping impedance Z as 50 Ω.

c. Radiation efficiency:

The antenna efficiency relates to total waves radiated to the waves accepted. A highly efficient antenna has most of

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its waves present at the input, emit away. In a low-efficient antenna, it mostly gets absorbed as losses get reflected.

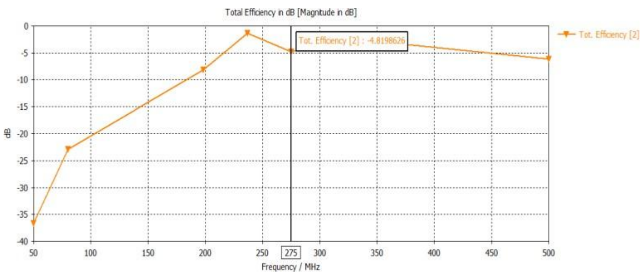

Fig. 6: Radiation Efficiency output

Fig. 5-3 displays a graph with radiation efficiency for a frequency band ranging from 50MHz to 500MHz [9]. The maximum radiation efficiency lies in frequencies ranging from 200MHz to 500MHz. For the frequency 275MHz, the observed efficiency is -4.8198dB.

d. Impedance:

One of the essential parts of the antenna result is the impedance. Impedance applies the voltage to the input current to the antenna.

The diagram shown below plots the impedance graph of the Yagi antenna.

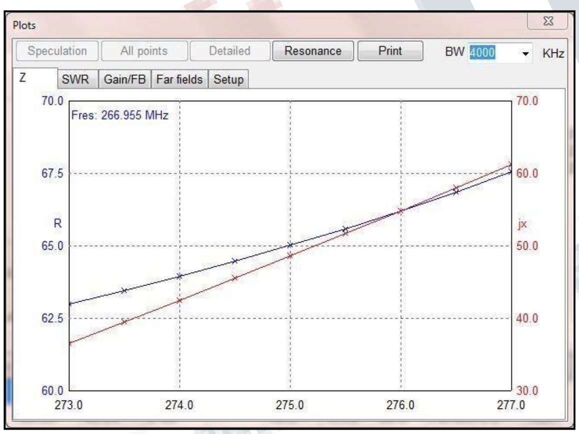

Fig. 7: Impedance output

The Yagi-Uda antenna's observed input impedance at the near to centre frequency of 266.955 MHz is (65.03+j48.64) in real and imaginary terms.

e. E- plane and H- plane plots

The radiation pattern relates to the directional dependence on the RF wave antenna source. MATLAB software calculates the far-field radiation pattern [7][10]. The below diagrams display the results of the E-plane & the H-plane directivity concerning the frequency 275MHz. The following plot represents the 2D plus 3D radiation pattern obtained from a polarized Yagi-Uda antenna.

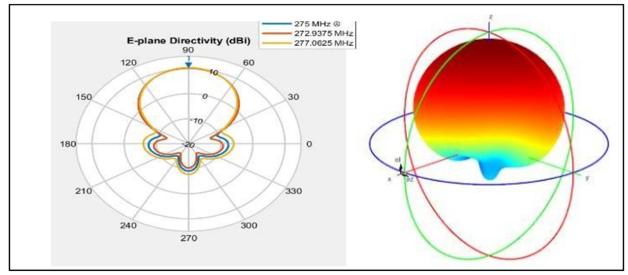

Fig. 8(a): E-Plane Directivity

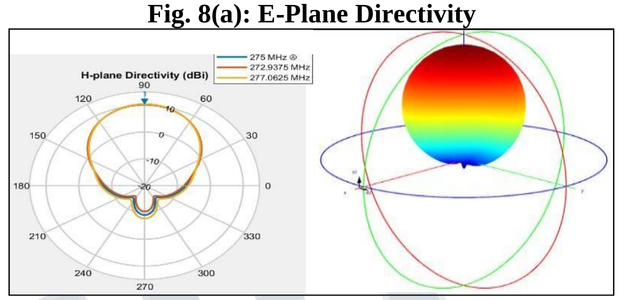

Fig. 8(b): H-Plane Directivity

f. Directivity

The above diagram shows the directivity, S11 and Z11 parameters for the degrees adjusted according to the view. As per the above results, the E- Field for 0 degrees, H-field for 0 degrees, E-Field for 50 degrees, H=Field for 50 degrees is shown above in fig. 8 (a) & 8 (b). Table no 3 represents the directivity that is consistent throughout its entire band of operation.

Table 3: Simulation for degree variation

Degree	Directivity	S1,1	Z1,1
10	6.688	-0.0188	358.8391
20	4.698	-0.0016	562.0351
30	6.431	-0.0015	783.878
40	6.048	-0.0039	717.3171
50	6.582	-0.0227	434.484
60	5.163	-0.04	767.6368
70	3.775	-0.0103	804.8163
80	4.82	-0.0195	703.8941
90	4.619	-0.0722	415.4505

Radiation Pattern:

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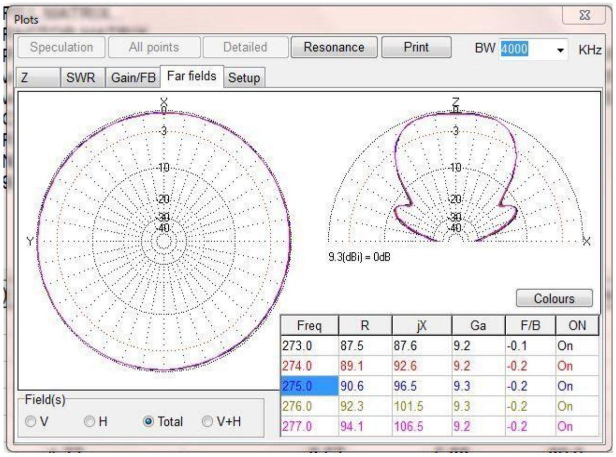

Fig. 9: Simulated Radiation Pattern

After analyzing various frequencies in the order of 50MHz, 80MHz, 198MHz, 275 MHz, 320MHz, and 500MHz as well as by varying the number of elements in the array,[4], the optimum radiation pattern was observed at 198MHz frequency for a four-element Yagi-Uda antenna (2 directors) which perfectly fits under the given frequency bandwidth of 80-320MHz. The gain obtained for this frequency is about 8 dB.

Table 4: Antenna Parameter Results

Gain	**13.61 dB**
Z	**84.04 + j126.6**
SWR	**2.44**
S11	**-20.39 dB**
Radiation efficiency	**66% (-4.8dB)**

Table 4 represents the Antenna parameters results after designing the Yagi-Uda receptor. The designed antenna receives RF waves from space. The wide square array of the antenna covers a large area in the sky. The portability of the antenna makes it convenient to set up the arrangement for space observations.

The antenna gain is 13.61dB with the 3x2 array antennas—the Gain increases as the antenna number in the array increases. SWR of the antenna is 2.44dB at the central frequency of 275MHz with Z as 50ohm.

VI. MATERIALS AND PROPERTIES

Basic Materials used in antenna designing are Aluminium, ABS, and Stainless Steel [2]. The initial purpose behind selecting these materials is their mechanical properties. Aluminium is a lightweight material also solid, extraordinarily flexible, and corrosion-resistant. The ABS material is impact-resistant thermoplastic, and its Acrylonitrile component contributes to change in resistance and stabilization of heat transfer. The styrene component provides rigidity and process ability. Overall, ABS has strong resistance to corrosion-based chemicals and physical impact. It has a low melting temperature which is effortless to the machine. Stainless steel has many desirable properties that contribute significantly to its wider use. These Steel-based alloys persist properties like High tensile strength, Temperature Resistance, Corrosion Resistance, and cost-effectiveness.

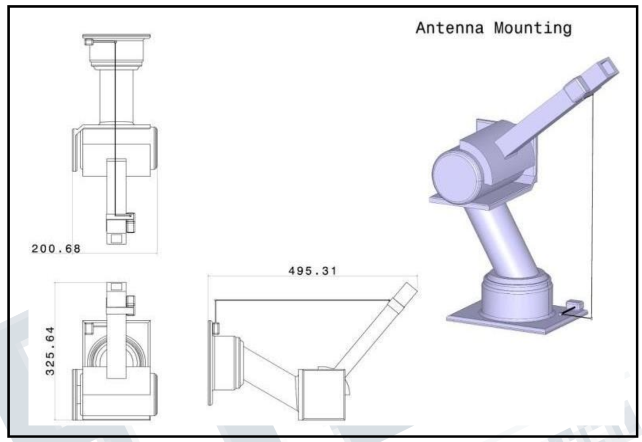

Fig. 10: Antenna Mount

The Yagi-Uda antenna has an [8] altitude-azimuth mounting system powered by a 2.8A/phase current-driven NEMA 23 stepper motor [12]. The altitude-azimuth mount has two orthogonal axes. The circle traversed along the horizon, concerning ground, is known as azimuth. The rotation about the vertical axis is called the angle of elevation, which helps to determine the accurate position of a celestial radio source. The NEMA 23 motor drives the gears in a 200 steps/revolution, thereby offering an accuracy of 1.8-degree tracking. The complete setup including driving and driven gears and NEMA 23 stepper motor is enclosed with a casing of Acrylonitrile Butadiene Styrene. This casing protects the internal setup from external mechanical and environmental stresses. This casing protects the internal setup from mechanical and external stresses. The NEMA 23 stepper
motor has a holding torque of 10.1 kg/cm, which is sufficient to hold the antenna structure at any specified elevation angles. The mount has an overall weight of 3.0039 kg.

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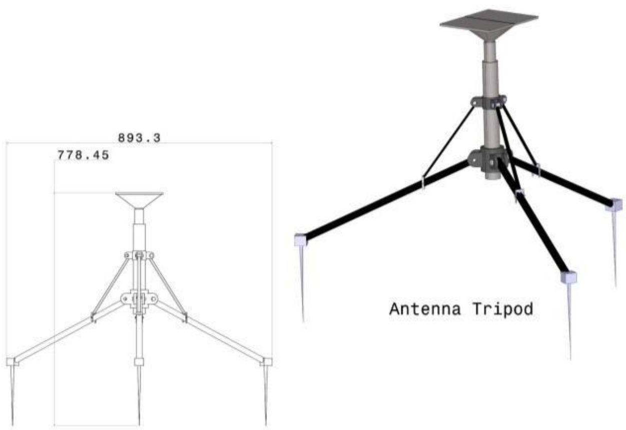

Fig. 11: Antenna Tripod

Fig. 11 shows the tripod extension used to maintain the spirit level of the antenna. The antenna tripod is the non-conducting component of the Yagi made of acrylonitrile-butadiene-styrene + Aluminium. The tripod has a three-legged frame with a needle-shaped heel block right in the median of the tripod; this will be pierced into the ground to give the antenna more stability. It provides a sharp reading as the material has a very low density and can be disturbed in extreme climatic conditions. The tripod legs are adjustable. In addition, the tripod length can be re-oriented in radius.

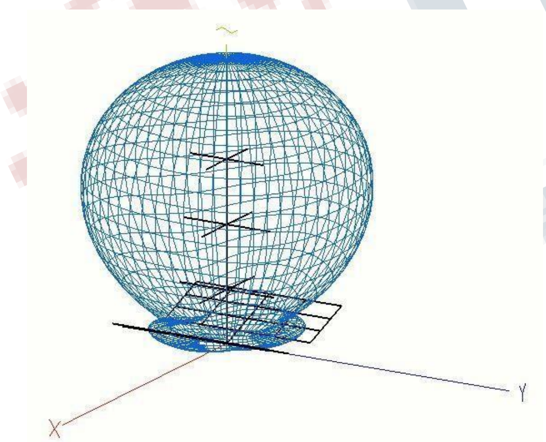

Fig. 14: Radiation Pattern for single antenna

The tripod's material makes this tripod very light in weight as the material is less dense. Another advantage of using this material ABS and aluminum is that it makes the tripod cost-effective. As the material requires is a low amount, cheap, and should be easily obtainable. This tripod is transportable and can be installed conveniently.

Two variations of the array are simulated to check their gain as well as the other parameters.

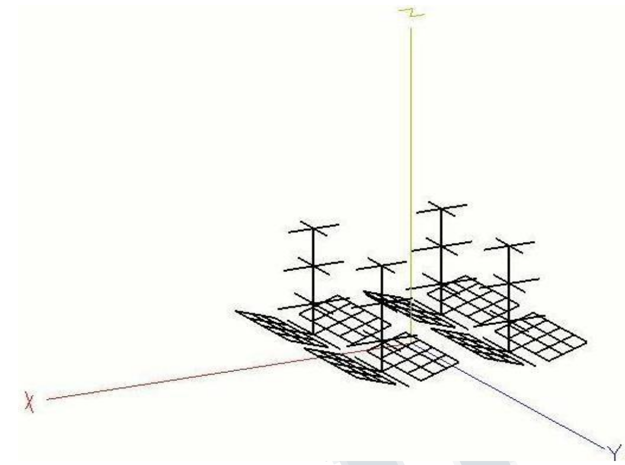

Fig. 12: 2x2 Antenna array

A 2*2 element VHF Yagi cross-polarized (horizontal and vertical) increases the Gain to 12.01dB from 9.5dB for a single antenna at 275MHz. The 3*2 array receives a Gain of 13.61dB and a front-to-back ratio of -3.82 dB at an elevation angle of 89.7 degrees for the central frequency of 275MHz.

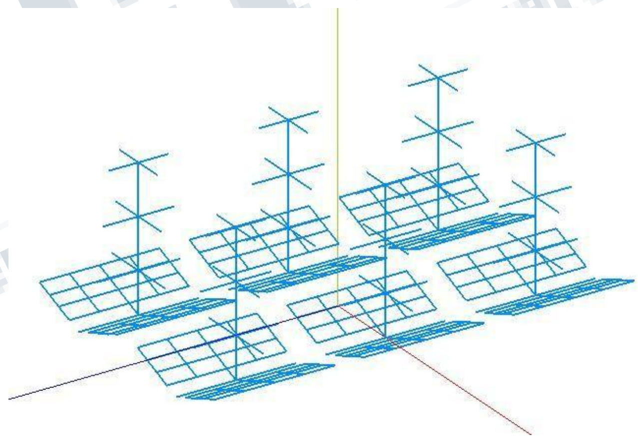

Fig. 13: 3 x 2 array antenna

The Yagi-Uda receptor has a higher degree of directiveness. The antenna's radiation pattern comprises of four lobes: a front lobe facing the directors, a back lobe facing the tip of reception, and two side lobes 180 degrees apart across the perpendicular axis to the directors.
The single Yagi-Uda antenna's radiation pattern [3] is as exhibited in figure 14. However, as displayed in the figure below, the observation tells that there is an increase in the gain. More than one antenna combination in the form of an array is the main reason for the same. The individual antennas in the form of the 3*2 or 2*2 Arrays enhance the front lobe by superimposing signals in the direction of directors, and the undesired noise from back and side lobes

gets canceled due to Negative interference. Thus it is inferred that an array of Yagi-Uda antennas is ideal for detecting narrowband and low-frequency radio signals from celestial bodies.

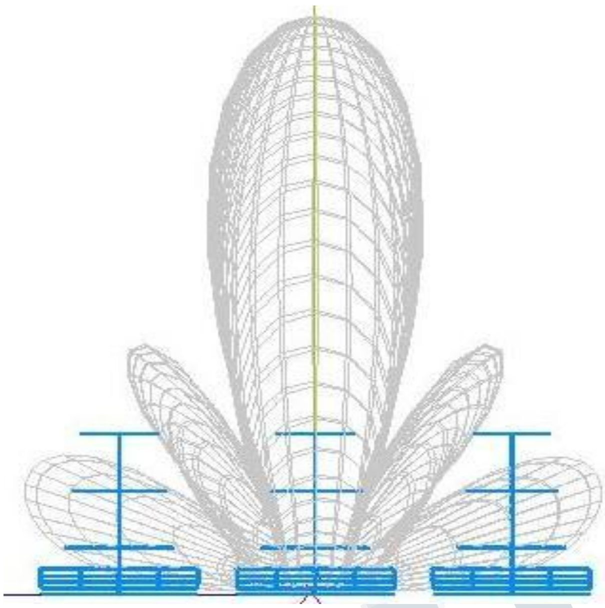

Fig. 15: Radiation Pattern for array

VII. FINAL DESIGN

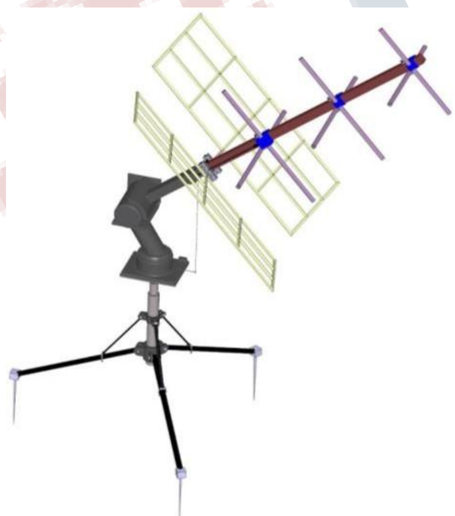

Fig. 16: Portable, mounted antenna

Fig 16 represents the antenna mounted on the alt-azimuth mount and the tripod with a total weight of 8.39kg. A portable antenna can be directed towards any particular point in the sky to receive a frequency between 50MHz to 500MHz. The antenna array forms the wide-area network.

VIII. CONCLUSION

A low-cost, portable Yagi-Uda antenna with a reflector mesh that avoids back lobes is developed and arranged in an array as generally. The receiver array antenna covers a wider sky area for astronomical purposes compared to a single Yagi-Uda antenna. The antenna array enhances the radiation pattern [10] in the source direction. All these aspects make this array of antennas a uniquely designed receiver for 50MHz to 500MHz frequency.

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