

Performance Improvement of a Direction Finding System Antenna Using Method of Moment (MOM)

Ogonna F. Anaebo, Gloria N. Ezeh, Onyebuchi C. Nosiri, and Cosmas K. Agubor

Abstract—This paper focuses on the Performance Improvement of a Direction Finding System Antenna Using Method of Moment (MoM) Approach. The work is developed to provide an approximate current distribution for a direction finding system antenna by employing the use of Method of Moment on an array of Yagi-uda antenna. The parameters of the experimental antenna are derived and analyzed via Magnetic Vector Potential (MVP) operator. The accurate current flowing through the radiating elements of the direction finding system is analyzed using combination of Method of Moment technique and Magnetic Vector Potential (MVP) operator. This helps to avoid the detection of false alarms and inability of the system to detect remote targets. A typical direction finding system Yagi antenna is designed and operated at a frequency range of 0.6- 0.8 GHz. The antenna has a single reflector, an active (driven) element and three (3) parasitic directors. The antenna parameters are simulated using MatLab R2010a software tool. The average pointing vector of the designed Yagi antenna was obtained as 3.73watt per square metre, and Radiation Intensity value of about 9.400 coulomb per kilogram. The simulation results indicate an appreciable increase in directivity of 9.03dBi, an enhanced directive gain compared to that of the equivalent dipole antenna of 1.76dBi, signifying 7.27dBi enhancement.

Index Terms—Yagi Antenna, Moment Method, Wire Antennas, Magnetic Vector Potential.

I. INTRODUCTION

The high spate of security attacks and indiscriminate use of communication frequencies by hoodlums have no doubt had a distressing effect on every country's economy. These prompted the need for the detection of the direction and location of these enemies using direction finding system. Development of a comparatively miniature but enhanced broadband direction finding system to be deployed with airborne or ground crafts is of concern in both military and civilian applications [1]. The surreptitious tracking of these opponent fighters through their wireless communications is a main concern in the combat on terror both now and in the future time.

According to [2], for accurate performance of such surveillance and reconnaissance mission using direction finding system, directive and improved broadband antennas were required. Hence, the development of an antenna system that will proffer broad frequency ranges and ensure accurate direction finding capabilities is of great importance to these applications. Various antenna designers have contributed towards the advancement of this course via deployment of arrays of antennas of varying dimensions and configurations. These principles were helpful to the advancement of direction finding system but lacked precision required for detection of target positions.

The recent use of narrow band antennas, and the practice of using constant current and sinusoidal current sources in analyzing the performance of the antennas in direction finding system results in the development of a system that lacks precision [3]. These result in high detection of false alarms and inability of the system to detect remote targets.

Also, it is observed that huge amount of money is usually spent in applying corrective measures trying to detect faults in direction finding system which ordinarily could have been averted if proper measures were taken before the antenna deployment.

In [4], opined the apparent need for advanced analysis and design apparatus for forecasting the performance and optimizing the parameters of such antennas prior to costly prototype development and deployment. In order to ensure high precision in antenna performance, there is great need to analyze the antenna parameters using an exact or approximate value of current flowing through the radiating elements.

This paper presented an improvement on the performance of the direction finding system via deploying Yagi-Uda array antenna and generating a close approximate current distribution using the Method of Moment (MoM) approach.

II. RELATED WORKS

The author of [5], worked on "A Direction Finding System Using Log Periodic Dipole Antennas in a Sparsely Sampled Linear Array". The author explored the use of Wide Band Log Periodic Dipole Array (LPDA) antennas in direction finding systems. A novel approach was introduced, utilizing non-uniform spacing in a linear array to improve the spatial resolution of the direction finding system. The linear arrays were referred to as minimum redundancy or non-redundant linear arrays. The author came up with results for the various sparse array configurations which demonstrated good increase in the overall angular resolution of a phased array direction finding system. The author

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however assumed constant current sources in its analysis which were not practically obtainable.

The Design and Numerical Analysis of a Single Half-Wave Dipole Antenna using Method of Moment by [6], dealt with the design and numerical analysis of a single Half-wave dipole antenna suitable for transmitting UHF television signals at a frequency of 235MHz. The authors employed the radiating field and the electric field strength equations to determine the variations in the electric field strength and free space loss with distance in kilometers. The radiation patterns obtained indicated that the antenna radiated well while the variations in electric field strength and free space loss with distance showed the distance covered and the rate of loss of the signal transmitted at this particular frequency using half –wave dipole antenna. It was noted that the design was not basically for direction finding antenna system, though Method of Moment approach was used. In [7], entitled “Direction Finding Performance of Antenna Arrays on Complex Platforms Using Numerical Electromagnetic Simulation Tools”, presented a method for both modeling and simulation in a numeric electromagnetic simulation tool “FEKO” (This is derived from the German acronym: **F**ELdberechnung für **K**örper mit beliebiger **O**berfläche). The method depended on the data generated by FEKO. The data

was processed by correlative interferometer algorithm; and implemented in a MATLAB environment. The author used different types of antenna arrays and evaluated the direction finding performance for different scenarios. This approach was effective for understanding the direction finding characteristic of antenna arrays but undermine the importance of antenna current accuracy on the system performance.

III. METHODOLOGY

In analyzing the current as well as the parameters of Yagi array antenna used for a direction finding system, the Magnetic Vector Potential operator and the Moment Method techniques were employed. The Moment Method technique helped to derive the approximate current flowing through the antenna elements while the Magnetic Vector Potential model was introduced as it contained an auxiliary function that eased the analytical procedures. A conventional diagram for the analysis of the Yagi antenna current and parameters is shown in Fig. 1. The elements of the Yagi array were positioned along the Z-axis on the Cartesian plane.

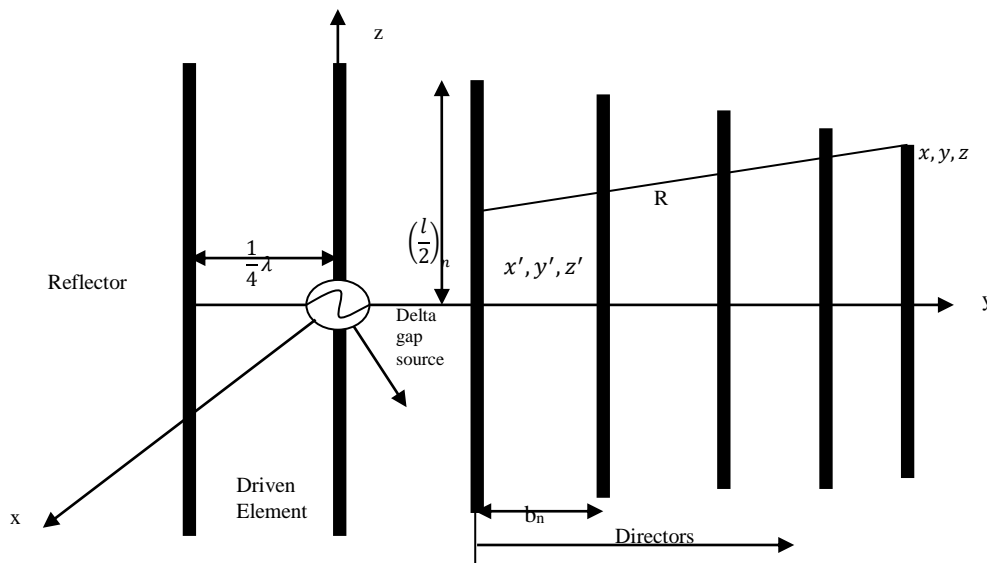


Fig. 1: Diagram of the Yagi array along the Z-axis on the Cartesian plane

Hence, the conventional Magnetic Vector Potential operator was generally expressed as [8].

$$\bar{A} = \iiint \bar{J}(r') \left[\frac{\exp(-jk_0 R)}{R} \right] dv' \quad (1)$$

And the Lorentz gauge equation is expressed as [9]

$$\varphi = \frac{-\bar{\nabla} \cdot \bar{A}}{j\omega\mu_0\epsilon_0} \quad (2)$$

where,

ϵ_0 represents free space permittivity,

μ_0 is the free space permeability,

k_0 represents the free-space propagation constant,

R is the distance from source to field point,

\bar{J} is the electric current density,

dv' is the elemental volume of the radiating wire,

$\frac{e^{-jk_0 R}}{R}$ is the free space Green's function,

j is the imaginary number and

ω is the angular frequency in radians per second.

Note: Lorentz gauge condition offers the relationship between the current and charge distributions by the equation of continuity.

If the antenna is electrically thin, that is, its radius (a) is much smaller than wire length (l) and wavelength (λ), the usual thin-wire approximations can be used with the wire antenna lying along the z axis. Equation (1) then becomes:

$$A_z = \frac{\mu_0}{4\pi} \int_{-\frac{l}{2}}^{+\frac{l}{2}} I(z') \frac{e^{-jk_0 R}}{R} dz' \quad (3)$$

and

$$\varphi = \frac{-1}{j\omega\mu_0\epsilon_0} \cdot \frac{\partial A_z}{\partial z} \quad (4)$$

$I(z')$ is the filamentary source current on the radiating wire.

Thus, the procedure followed in the operation of the Magnetic Vector Potential (MVP) on the Lorentz gauge equation to generate the incident Electric Field of equation (5) is shown in Fig. 2.

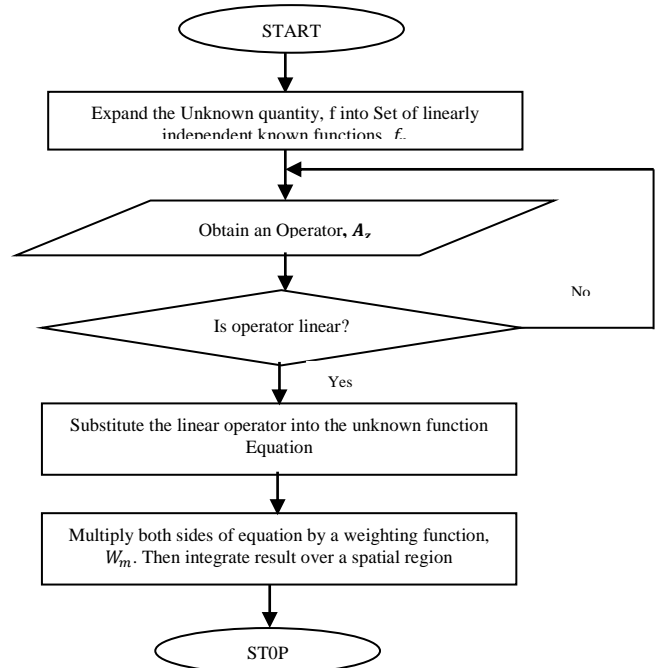


Fig. 2. Flowchart for the MoM Technique

$$\int_{-\frac{l}{2}}^{+\frac{l}{2}} W_p E^i(z) dz = \frac{j\eta_0}{k_0} \sum_{n=1}^N \sum_{m=1}^M I_{nm} \int_{-\frac{l_n}{2}}^{+\frac{l_n}{2}} \cos\left[\frac{(2m-1)\pi z'_n}{2\frac{l_n}{2}}\right] \left[(1 + jk_0 R_{np})(2R_{np}^2 - 3a^2) + k_0^2 R_{np}^2 a^2 \right] \frac{e^{-jk_0 R_n}}{4\pi R_{np}^3} dz'_n \quad (5)$$

Also, the matlab program for the analysis of the current flow through the antenna element is implemented in (5) using the flowchart of Fig. 3.

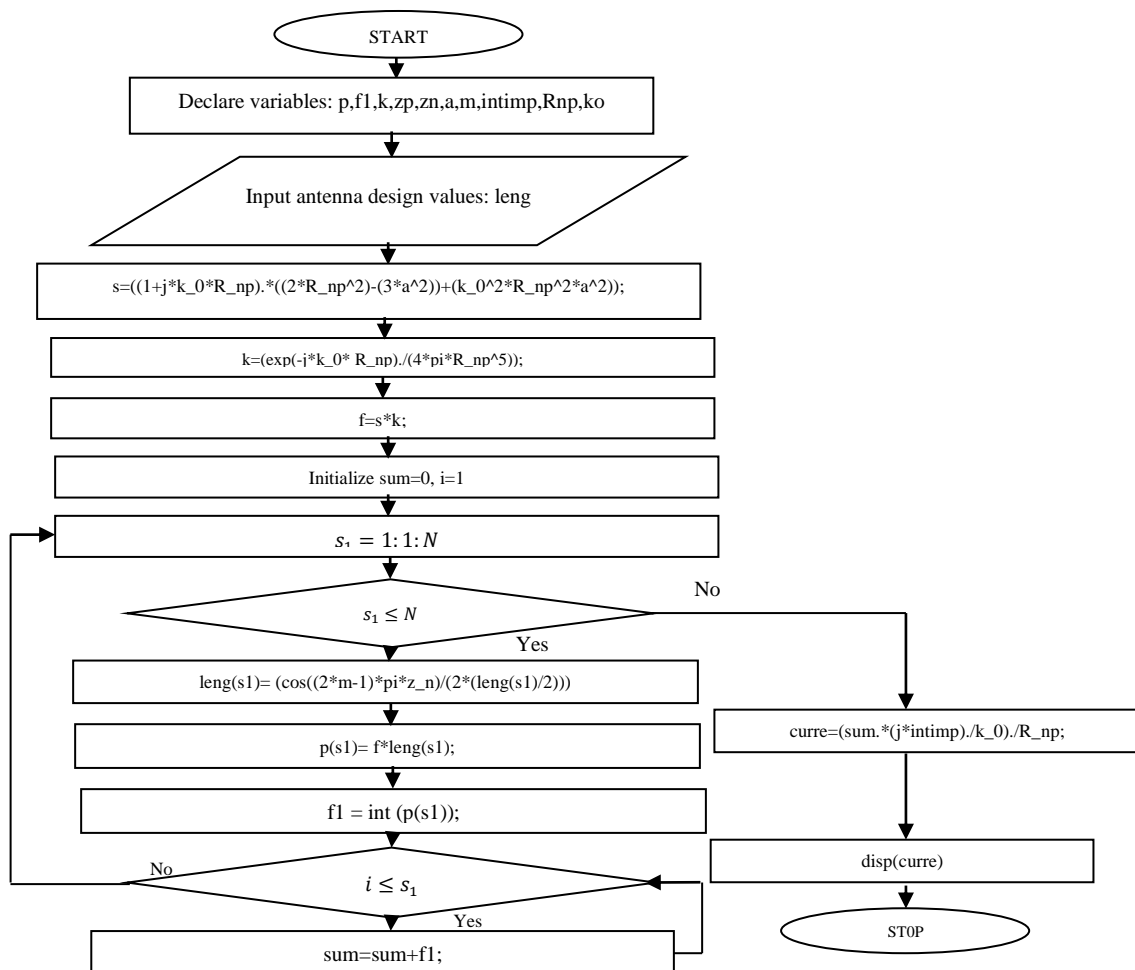


Fig. 3. Flowchart for the antenna current generation

A. Electric and Magnetic Fields Radiated by the Yagi Antenna

In the Matlab implementation, *SINTEG* function was used to analyze integration. Thus, since integration was very difficult to be analyzed here, the weighted method (Gaussian method) was applied in the study. Therefore, the Electric and Magnetic fields of the Yagi Antenna array radiated at the far fields of five element Yagi array antenna in free space was obtained by summing the fields from each of the elements in the array. The far field generated by the experimental five element Yagi antenna was obtained as

$$E_{\theta} = \sum_{n=1}^5 E_{\theta n} = -j\omega A_{\theta} \quad (6)$$

Where,

$$A_{\theta} = \sum_{n=1}^5 A_{\theta n} = \frac{\mu e^{-jk_r r} \sin\theta}{4\pi r} \sum_{n=1}^5 \left\{ e^{jk(x_n \sin\theta \cos\varphi + y_n \sin\theta \sin\varphi)} \sum_{m=1}^M I_{nm} \left[\frac{\sin(Z^+)}{Z^+} \right] \left[\frac{\sin(Z^-)}{Z^-} \right] \right\} \frac{I_n}{2} \quad (7)$$

Thus,

$$E_{\theta} = \frac{jk_0 \eta_0 e^{-jk_r r} \sin\theta}{4\pi r} \sum_{n=1}^5 \left\{ e^{jk(x'_n \sin\theta \cos\varphi + y'_n \sin\theta \sin\varphi)} \sum_{m=1}^M I_{nm} \left[\frac{\sin(Z^+)}{Z^+} \right] + \left[\frac{\sin(Z^-)}{Z^-} \right] \right\} \frac{I_n}{2} \quad (8)$$

where

$$Z^+ = \left(\frac{(2m-1)\pi}{2h_n} + k_0 \cos\theta \right) h_n \quad (9)$$

and

$$Z^- = \left(\frac{(2m-1)\pi}{2h_n} - k_0 \cos\theta \right) h_n \quad (10)$$

where

$$h_n = \frac{l_n}{2} \quad (11)$$

Further analysis of the Electric field gave rise to (12) in as much as the total radiation electric field intensity pattern of the Yagi antenna was as a result of field superposition from all elements;

$$E_{\theta} = \frac{j\eta_0 e^{jk_r r}}{2\pi r} \sum_{n=1}^5 I_n \left(\frac{\cos(kl_n \cos\theta - \cos(kl_n))}{\sin\theta} \right) e^{jks_{n-1} \cos\theta} \quad (12)$$

The corresponding magnetic field was obtained thus,

$$H_{\varphi} = \frac{E_{\theta}}{\eta_0} \quad (13)$$

$$H_{\varphi} = \frac{j e^{jk_r r}}{2\pi r} \sum_{n=1}^5 I_n \left(\frac{\cos(kl_n \cos\theta - \cos(kl_n))}{\sin\theta} \right) e^{jks_{n-1} \cos\theta} \quad (14)$$

B. Power Density or Average Poynting Vector

The Power density or Average poynting vector of the Yagi array antenna was obtained from the relation in (15):

$$\rho_{ave} = \frac{1}{2} \text{Re}(E_{\theta} \times H_{\varphi}^*) \quad (15)$$

Substituting (12) and (14) into (15) resulted to (16)

$$\rho_{ave} = \frac{\eta_0}{8\pi^2 r^2} \left\{ \sum_{n=1}^5 I_n \left(\frac{\cos(kl_n \cos\theta - \cos(kl_n))}{\sin\theta} \right) e^{jks_{n-1} \cos\theta} \right\}^2 \bar{a}_r \quad (16)$$

To obtain total Power (P) radiated by the antenna, we integrate (16) $\rho_{ave} ds$ over a closed sphere of radius 'r' such that

$$\rho_{ave} = \frac{\eta_0}{8\pi^2 r^2} \int_0^{\pi} \int_0^{2\pi} \left\{ \sum_{n=1}^5 I_n \left(\frac{\cos(kl_n \cos\theta - \cos(kl_n))}{\sin\theta} \right) e^{jks_{n-1} \cos\theta} \right\}^2 \sin^3\theta d\theta d\varphi d\varphi \quad (17)$$

C. Radiation Intensity

Radiation intensity $U(\theta, \varphi)$ is represented as the product of square of the distance from origin to the far field point denoted by 'r' and the average poynting vector. This is shown in (18)

$$U(\theta, \varphi) = \rho_{ave} \times r^2 \quad (18)$$

Resolving (18) results to (19)

$$U(\theta, \varphi) = \frac{\eta_0}{8\pi^2 r^2} \left\{ \sum_{n=1}^5 I_n \left(\frac{\cos(kl_n \cos\theta - \cos(kl_n))}{\sin\theta} \right) e^{jks_{n-1} \cos\theta} \right\}^2 \bar{a}_r \times r^2 \quad (19)$$

Which then becomes,

$$U(\theta, \varphi) = \frac{\eta_0}{8\pi^2} \left\{ \sum_{n=1}^5 I_n \left(\frac{\cos(kl_n \cos\theta - \cos(kl_n))}{\sin\theta} \right) e^{jks_{n-1} \cos\theta} \right\}^2 \bar{a}_r \quad (20)$$

Implementing the experimental values realized as stated thus; the intrinsic impedance of 377Ω , the length of the reflector as 0.025m, dipole length of 0.022m, the length of the three directors as 0.0211m, 0.0202m and 0.0193m. The spacings of 0.0108m between reflector and dipole, 0.0086m between dipole and first director, 0.00034m between first director and second director, and 0.0001m between second director and third director, with dipole wavelength of 0.043m. The Electric and Magnetic fields, the average pointing vector and the radiation intensity of the Yagi antenna were actualized as plotted using MatLab tools, specifically shown in Fig. 4, 5 and 6 respectively.

IV. RESULTS AND DISCUSSION

The obtained data and the antenna parameters were analyzed and plotted using Matlab tools. Three (3) categories of results were presented, namely:

- the polar plots of the Electric/Magnetic Fields of the Yagi antenna;
- the polar plot of the Average Poynting Vector of the Yagi antenna;
- polar plot of the directivity of the antenna;

The experimental antenna structure comprised five (5) elements (a reflector, a dipole, and three (3) directors) as represented in Fig. 1. These results were plotted at an intrinsic impedance of 377Ω ; a far field distance of 50m (distance between the antenna source point to the far field point); and antenna wave number of 1. Fig. 4 demonstrated the polar plot of the Electric Field and the corresponding Magnetic Field of the Yagi antenna as epitomized in the experimental antenna.

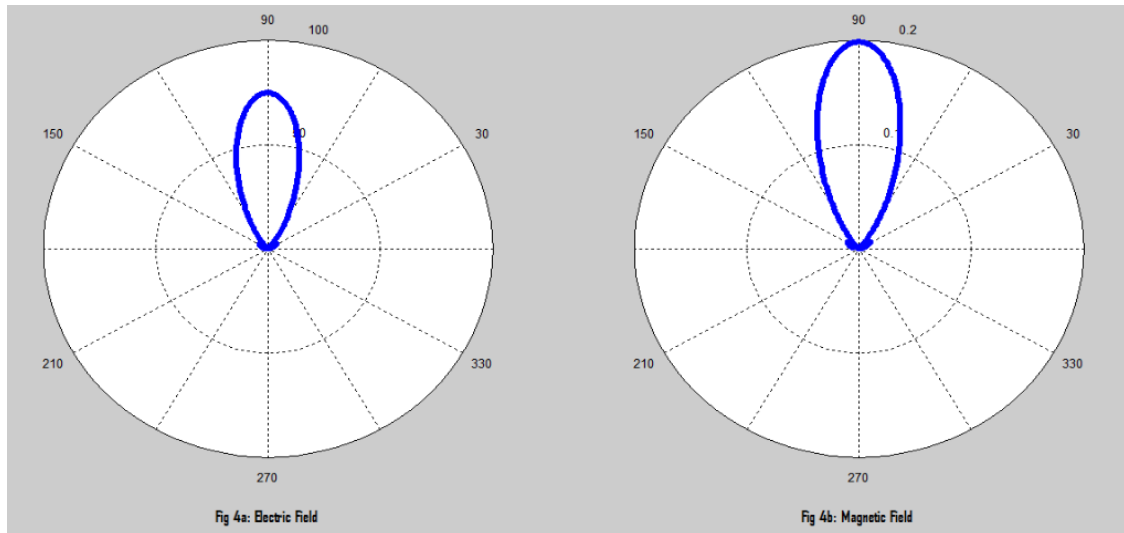


Fig. 4. Polar plot of Electric and Magnetic fields of the Yagi Antenna

It could be keenly observed that both field patterns are similar in shape except that the Electric field is of higher magnitude. The magnetic field as shown in (14) was obtained by dividing the electric field of equation (12) by the intrinsic impedance, 120π . Hence, the reduction in magnitude of the pattern of the magnetic field was decreased as witnessed in Fig. 4b. While the Electric field with a magnitude of about 75 Newtons/coulomb was obtained from the plot, also the magnetic field having a magnitude of 0.2 Tesla. These values were very appropriate when compared to other directional antennas like Log-periodic dipole array antenna. The polar plot of average Poynting vector of the Yagi antenna is represented in Fig. 5.

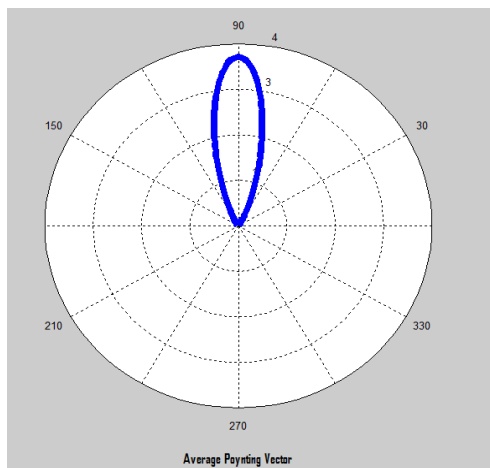


Fig. 5. Polar plot of Average poynting Vector of the Yagi Antenna

The Average poynting Vector of the Yagi Antenna was obtained from the average value of the vectorial product (of the real values) of the Electric and Magnetic fields of the Yagi Antenna. This was as denoted in (16). From the plot, the average pointing vector of the designed Yagi antenna was obtained as 3.73 watt per square metre. The polar plot of directivity of Yagi array Antenna is shown in Fig. 6.

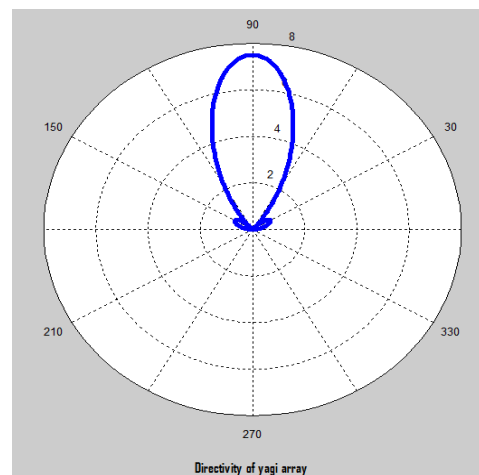


Fig. 6. Polar plot of Directivity of the Yagi Antenna

In Fig. 6, the directivity of the Yagi Antenna demonstrated a firm precision and of good magnitude. This is ideal as the directivity is obtained as the ratio of maximum radiation intensity from an antenna (power per unit solid angle) to the average radiation intensity. From Fig. 6, the directivity of the Yagi antenna was realized to be about 9.03 dBi. Thus, the Yagi array is said to have an average directivity of about 9 dBi which is far better than that of the dipole antenna.

V. CONCLUSION

The performance of direction finding system antenna was improved by generating the current distribution for a direction finding system antenna via Method of Moment approach. An experimental Yagi antenna was designed and analyzed for the study. The antenna had a single reflector, one active (driven) element and three parasitic directors. The parameters of the Yagi antenna of the direction finding system were numerically developed and analyzed at far field of the antenna using Magnetic Vector Potential (MVP) technique. This antenna was designed and operated at an Ultra High Frequency band of 0.6GHz – 0.8GHz, wave number of one (1), intrinsic impedance of 377Ω . The measurement was carried out at a distance of 50m from the

antenna source to the far field of the Yagi antenna. Afterwards, MatLabR2010a tool was used to simulate the antenna Electric and Magnetic fields, the Average poynting Vector and the directivity of the Yagi antenna. The results from the analyzed Yagi antenna indicated an appreciable and improved directivity of 9.03dBi compared to that of dipole antenna of 1.76dBi.

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