RADIATION BEHAVIOURS OF YAGI-UDA ANTENNA DESIGNS

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Abstract: *This paper examined the radiation behaviour of Yagi-Uda antenna designs consisting of 3, 4, 5, 6, 7, 8, 9 and 11 elements. A point matching method of moment procedure was utilized as an analytical tool to obtain the current distribution on the antennas, where an excitation voltage of 1V was applied at the driven element of the antennas. This facilitated the computation of radiated far fields. Computational results for the current distribution depicted non- linearity in the amplitude and it was seen that the driven element has the highest current amplitude. However, it was found that the radiated fields due to corresponding current were propagated in an end-fire mode where the direction of propagation of the fields was in the same direction as the orientation of the antennas. It was seen that larger percentage of electromagnetic energy was focused in the main lobe with minimal side and back lobe radiations.*

1. INTRODUCTION

Yagi-Uda antenna has been widely used for receiving and transmitting electromagnetic waves because of its low cost, light weight and simplicity in construction. A simple Yagi-Uda array usually consists of reflector, driven element and director with each element performing different role. To ensure that the antenna transmits little power backwards, the reflector produces wave which cancels backward wave from the dipole. The driven element (dipole) provides means of powering the antenna [1] or intercepting radiated electromagnetic wave from the environment. Director is used to achieve good directivity by radiating or receiving electromagnetic wave more effectively in some directions than the other. Typically, the reflector is usually 5 to 10% longer than the driven element. The length of the driven element varies from 0.45λ to 0.49λ while directors are shorter, typically 10 to 20% smaller than the driven element, and may not necessarily be of the same length [2]. Over the years, quite a number of analytical and experimental investigations has been reported on Yagi antenna. A few representative examples of experimental research findings of Yagi antenna include [3], which designed a procedure for obtaining maximum gain from Yagi antenna of uniform length of directors. A Yagi antenna of 50dB gain was developed in [4] which was deployed in remote location for receiving television signal from distant transmitting station. The advent of digital computer has culminated in the introduction of a number of numerical techniques such as method of moment [5] and finite element method for simulating performance characteristics of Yagi- Uda antenna. Method of moment reduces an electric field integral equation that arises after enforcing boundary condition on the surface of an antenna into matrix form, solution of which is the current distribution on the antenna. With the numerical solution to the current distribution, parameters of engineering interest such as far-field pattern is easily determined. Quite a number of works on method of moment treatment of problem of Yagi Uda antennas have been reported in the literature. Examples include but not limited to publications of [6], which adopted Galerkin's method of moment procedure for the analysis of Yagi-Uda array of circular loop elements and that of [7] which employed similar method in computing the radiation pattern of Yagi-Uda array of linear elements. Authors in [8-9] utilized numerical electromagnetic code (NEC), a simulation software designed using method of moment algorithm, to compute numerical results for Yagi antenna's gain, current distribution and front-to-back ratio. Other investigations of problem of Yagi- Uda antenna using NEC have been reported by [10-11]. The performance characteristics of Yagi-Uda antenna with uniformly and non-uniformly spaced directors was considered in [12]. It was suggested in the work that Yagi-Uda antenna with non-uniformly spaced directors had better performance than Yagi-Uda antenna with uniform spacing of the directors. On using method of moments, [13] examined the type of Yagi-Uda array suitable for television broadcasting. The performance of Yagi-Uda antenna over a wide range of broadband frequencies was considered in [14]. It was shown that the performance of Yagi-Uda antenna was unchanged over a number of frequencies considered. The authors suggested that Yagi-Uda antenna is a good candidate for wide band applications. [15] presented method of moment evaluation of electric field and magnetic fields of Yagi-Uda antenna suitable for direction finding. It was shown that though both the electric and magnetic fields of this antenna exhibited the same radiation pattern, electric field possessed higher magnitude than the magnetic field. A Galerkin's method of moment procedure where expansion and weighting functions were the same was employed to analyze the performance of Yagi-Uda antenna of linear wires. It was shown that the elements radii and relative positions played a role in the performance characteristics of the antenna [16].

This paper employs method of moments to examine radiation fields of Yagi-Uda antenna designs consisting of 3, 4, 5, 6, 7, 8, 9 and 11 elements using point matching technique which to the best of our knowledge have not been considered in this manner before in the literature. Numerical results are compiled for the approximate current distribution as well as field strengths in the far region which are utilized to analyze the performance of these antenna designs. The rest of the paper is organized in such a way that section 2 presents materials and methods, section 3 is the results and discussion and section 4 is the conclusion.

2. MATERIALS AND METHODS

2.1 Modelling of current distribution on Yagi-Uda antenna design

Figure 1 illustrates Yagi-Uda antenna consisting of a reflector, driven element and three directors. The scattered electric field represented by E^s due to axial current and charges on the surface of a driven element can be expressed by equation (1) as

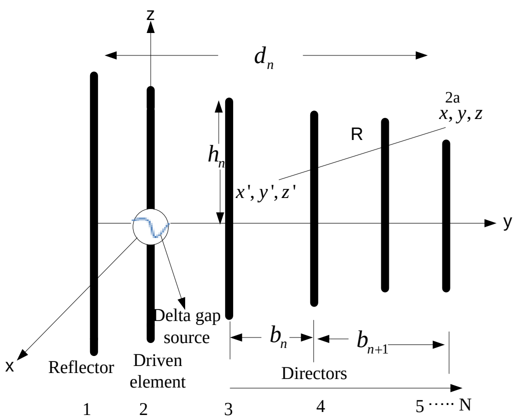

Fig. 1. Yagi-Uda antenna design

$$E^s(z) = -j\omega A_z - \frac{\partial \varphi_z}{\partial z} \quad (1)$$

in which A_z and φ_z are the magnetic vector potential and the electric scalar potential, respectively, j is the imaginary number and ω is the angular frequency in radians per second. It is assumed in equation (1) that dipole as well as other elements of Yagi-Uda antenna are thin such that $l/a >> 1$ and $a << \lambda$ are satisfied, where a is the radius of the wires, l is the length of antenna elements and λ is the wavelength. In this connection, the current flow can be assumed to be restricted to the axis of each wire with current and charge densities being represented by its filamentary forms. Hence, A_z and φ_z in equation (1) can be expressed by:

$$A_z = \mu_0 \int_{-h}^{+h} I(z') \frac{e^{-jk_0R}}{4\pi R} dz' \quad (2a)$$

$$\varphi_z = \frac{-1}{j\omega\varepsilon_0} \cdot \frac{\partial}{\partial z} \int_{-h}^{+h} I(z') \frac{e^{-jk_0R}}{4\pi R} dz' \quad (2b)$$

in which 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 point, denoted by r' to the field point, symbolized by r while $\frac{e^{-jk_0R}}{R}$ is the free space Green's function. $I(z')$ is the filamentary current element and z' is the filamentary running variable.

Substituting equations (2a) and (2b) in equation (1) leads to Pocklington's integral equation given as:

$$E^s(z) = \frac{\eta_0}{jk_0} \int_{-h}^{h} I(z') \begin{bmatrix} (1 + jk_0R) \\ (2R^2 - 3a^2) \\ +k_0^2R^2a^2 \end{bmatrix} \frac{e^{-jk_0R}}{4\pi R^5} dz' \quad (3)$$

where η_0 is the free space intrinsic impedance.

By invoking boundary condition involving perfectly conducting wire leads to equation (4) described as:

$$E^i(z) = \frac{j\eta_0}{k_0} \int_{-h}^{h} I(z') \begin{bmatrix} (1 + jk_0R) \\ (2R^2 - 3a^2) + \\ k_0^2R^2a^2 \end{bmatrix} \frac{e^{-jk_0R}}{4\pi R^5} dz' \quad (4)$$

For which $E^i(z)$ represents the tangential impressed electric field.

Adapting equation (4) to Yagi Uda antenna consisting of n number of elements leads to an expression of the form:

$$E^i(z) = \frac{j\eta_0}{k_0} \sum_{n=1}^{N} \int_{-h_n}^{h_n} I_n(z_n') \begin{bmatrix} (1 + jk_0R_n) \\ (2R_n^2 - 3a^2) + \\ k_0^2R_n^2a^2 \end{bmatrix} \frac{e^{-jk_0R_n}}{4\pi R_n^5} dz_n' \quad (5)$$

$I_n(z'_n)$ is the excitation current on elements of Yagi-Uda antenna which is the only unknown in equation (5) and whose approximate solution is obtained via moment of moment. And to obtain approimate value of the current, $I_n(z'_n)$ is cast in the form of expansion or basis function and unknown complex current coefficient. In this regard, the unknown current admits an expression in the form given by thiele [17] as:

$$I_n(z_n') = \sum_{p=1}^{P} I_{np} \cos\left[\frac{(2p-1)\pi z_n'}{2h_n}\right], \ p = 1, 2....\text{P} \quad (6)$$

in which, I_{np} represents the complex current coefficient of on element n and P is the number of mode on n^{th} wire and $h = \lambda/2$

Substituting equation (6) in equation (5) results to:

$$E^i(z) = \frac{j\eta_0}{k_0} \sum_{n=1}^{N} \sum_{p=1}^{P} I_{np} \int_{-h_n}^{h_n} \cos\left[\frac{(2p-1)\pi z_n'}{2h_n}\right] \begin{bmatrix} (1 + jk_0R_n)(2R_n^2 - 3a^2) \\ +k_0^2R_n^2a^2 \end{bmatrix} \frac{e^{-jk_0R_n}}{4\pi R_n^5} dz_n' \quad (7)$$

By taking inner product of equation (7) with Dirac delta weighting function symbolized by w_{nm} leads to:

$$<W_{nm}E^i>=\frac{j\eta_0}{k_0}\sum_{n=1}^{N}\sum_{p=1}^{P}I_{np}\int W_{nm}(z_n)\int_{-h_n}^{h_n}\cos\left[\frac{(2p-1)\pi z_n'}{2h_n}\right]\times \left[\begin{array}{l}(1+jk_0R_n)(2R_n^2-3a^2)\\ +k_0^2R_n^2a^2\end{array}\right]\frac{e^{-jk_0R_n}}{4\pi R_n^5}dz_n'dz_n \quad (8)$$

where $< >$ is the notation for inner product.

Equation (8) is recast in the form of geometric circuit parameters as

$$[V]=[I][Z] \quad (9)$$

where [V] is the voltage matrix whose entries account for antenna's excitation due to an impressed field, Z is the impedance matrix and I is the unknown complex current coefficient, which can be obtained by the inversion of impedance matrix and multiplication by voltage matrix as written in the form of equation (10) as:

$$[\mathrm{I}]=[\mathrm{Z}]^{-1}[V] \quad (10)$$

A delta –gap feed voltage model with 1Volt is used to model the excitation on the driven element of Yagi-Uda antenna.

2.2 Modelling of radiated electric field of Yagi-Uda antenna design

The radiated electric field due to corresponding current distribution on a single wire admits expression of the form:

$$E_\theta=-jwA_\theta \quad (11)$$

where E_θ is the $\hat{\theta}$ -component of the electric field and A_θ is the magnetic vector potential which is expressed as:

$$A_\theta=-\frac{\mu_0\sin\theta e^{-jk_0r}}{4\pi r}\times \int_{-h}^{+h}I(z')e^{jk_0(x'\sin\theta\cos\varphi+y'\sin\theta\sin\varphi+z'\cos\theta)}dz \quad (12)$$

Substition of equation (12) in equation (11) leads to:

$$E_\theta=\frac{j\omega\mu_0\sin\theta e^{-jk_0r}}{4\pi r}\times \int_{-h}^{+h}I(z')e^{jk_0(x'\sin\theta\cos\varphi+y'\sin\theta\sin\varphi+z'\cos\theta)}dz' \quad (13)$$

The far zone electric field of Yagi-Uda array of n elements may therefore be written as:

$$E_\theta=\frac{j\omega\mu_0\sin\theta e^{-jk_0r}}{4\pi r}\times \sum_{n=1}^{N}e^{jk_0(x_n'\sin\theta\cos\varphi+y_n'\sin\theta\sin\varphi)}\int_{-h_n}^{+h_n}I_n(z_n')e^{jk_0z_n'\cos\theta}dz_n' \quad (14)$$

Substitution of equation (6) in equation (14) produces:

$$E_\theta=\frac{j\omega\mu_0\sin\theta e^{-jk_0r}}{4\pi r}\sum_{n=1}^{N}e^{jk_0(x_n'\sin\theta\cos\varphi+y_n'\sin\theta\sin\varphi)}\times\sum_{p=1}^{P}I_{np}\cos\left[\frac{(2p-1)\pi z_n'}{2h_n}\right]e^{jk_0z_n'\cos\theta} \quad (15)$$

It is of interest to point out that equation (15) is the electric filed radiated by Yagi-Uda antenna of n elements

3. RESULTS AND DISCUSSION

Results that characterize the current distribution and radiated fields of Yagi-Uda antenna designs consisting of 3, 4, 5, 6, 7,8, 9 and 11 elements are presented. Simulaton codes written with MATLAB R2016a software and implemented on Intel ® Pentium ® CPUB960 @ 2.20GHz with 64 bit operating system are used to generate the results. The design parameters of Yagi-Uda antenna designs are given as:

Length of reflector $= 0.495\lambda$, length of driven element $= 0.47\lambda$, length of directors $= 0.41\lambda$, spacing between reflector and driven Element $= 0.25\lambda$, spacing between driven element and director 1 $= 0.325\lambda$, spacing between directors $= 0.325\lambda$ and radius of the conductors = 0.033λ. By employing equation (10), Figs. 2-9 depict current distribution on Yagi-Uda antenna designs considered as candidates for numerical exposition, where the current amplitude is plotted against element number such that the value of the current amplitude is indicated on each element of Yagi-Uda antennas. It is observed in all the current profiles that the amplitude of the current is highest on the driven element. A close look at these figures reveals that the current amplitude varies non-uniformly across all elements of Yagi-Uda antenna.

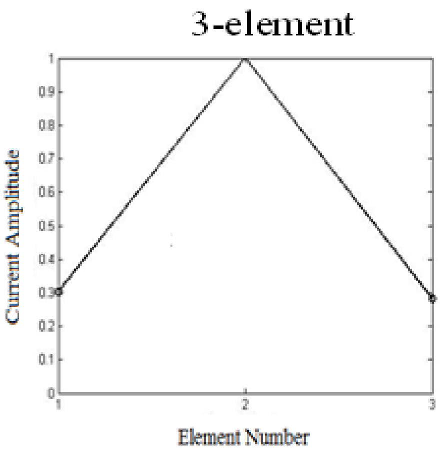

Fig.2. Distribution of curent on 3-element Yagi-Uda antenna

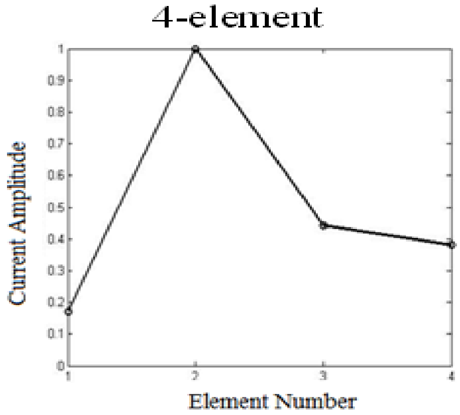

Fig.3. Distribution of curent on 4-element Yagi –Uda antenna .

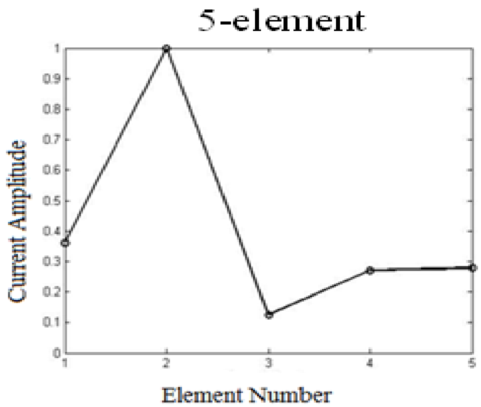

Fig.4. Distribution of curent on 5-element Yagi-Uda antenna.

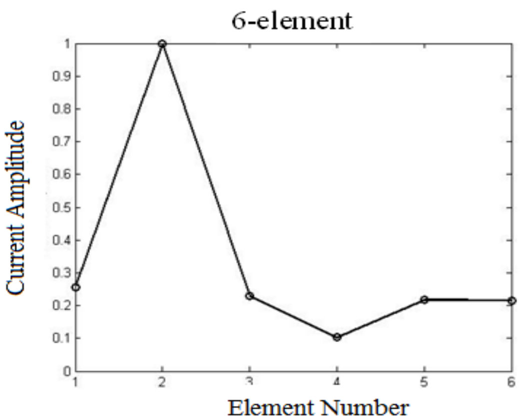

Fig.5. Distribution of curent on 6-element Yagi –Uda antenna

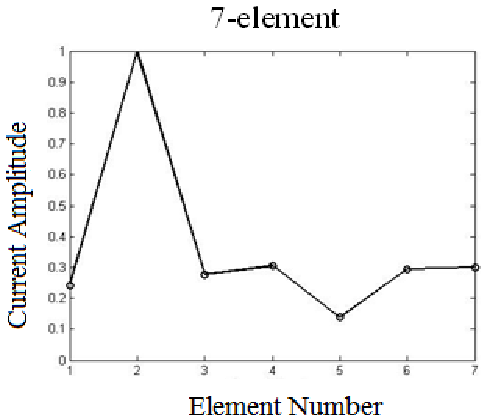

Fig.6. Distribution of curent on 7-element Yagi –Uda antenna

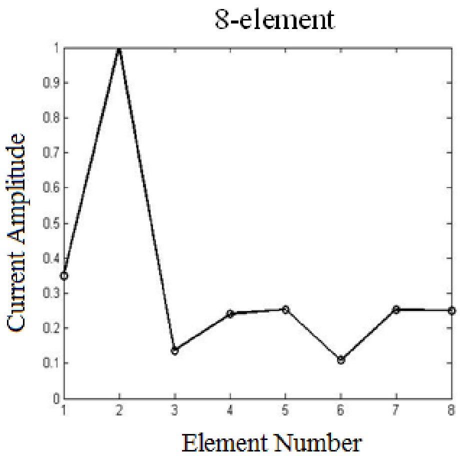

Fig.7. Distribution of curent on 8-element Yagi –Uda antenna

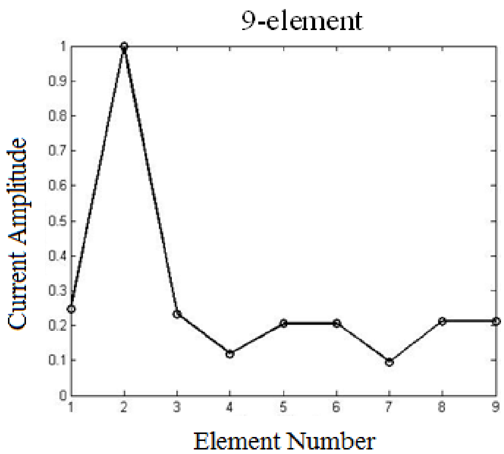

Fig.8. Distribution of curent on 9-element Yagi –Uda antenna

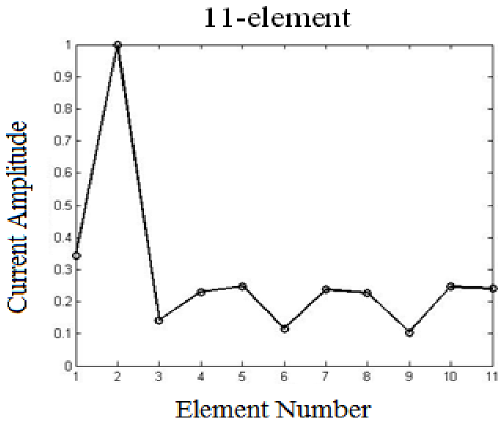

Fig.9. Distribution of curent on 11-element Yagi-Uda antenna.

On the other hand, Figs. 10-17 depict the radiated electric field in E-plane and H-plane due to corresponding currents in Figs. 2-9

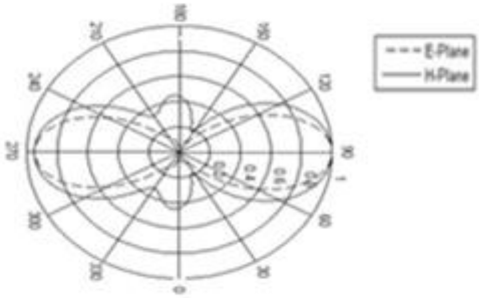

Fig. 10: Radiated electric field of 3-element Yagi-Uda antenna

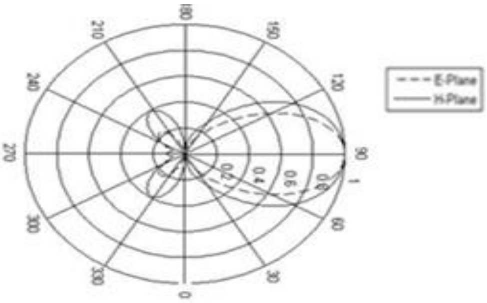

Fig. 11: Radiated electric field of 4-element Yagi –Uda antenna

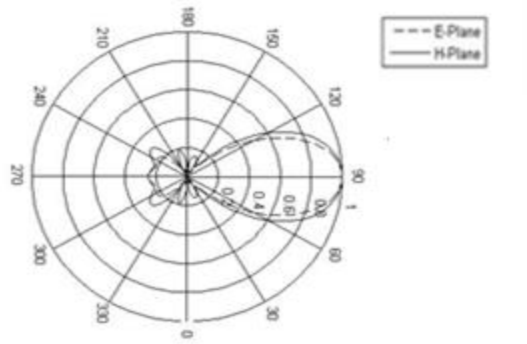

Fig. 12: Radiated electric field of 5-element Yagi-Uda antenna.

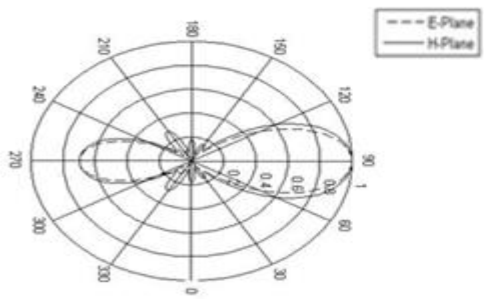

Fig. 13: Radiated electric field of 6-element Yagi –Uda antenna

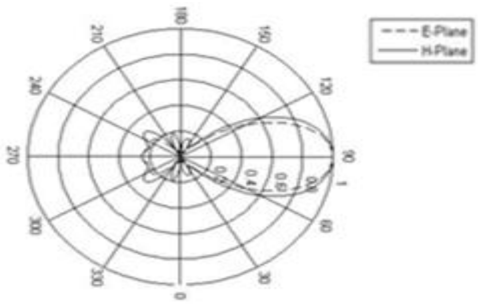

Fig. 14: Radiated electric field of 7-element Yagi-Uda antenna

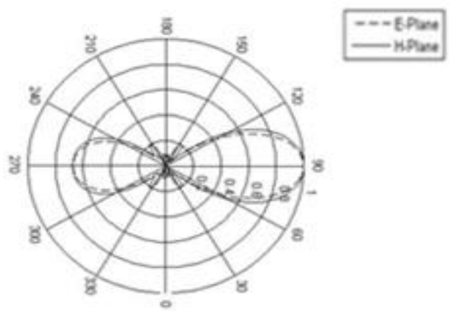

Fig. 15: Radiated electric field of 8-element Yagi-Uda antenna.

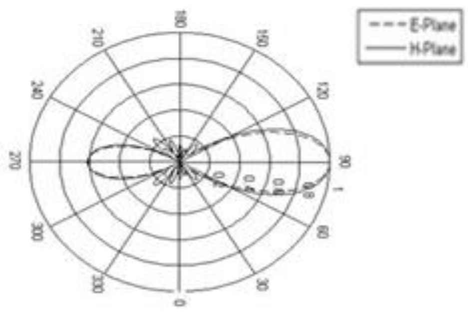

Fig. 16: Radiated electric field of 9-element Yagi-Uda antenna

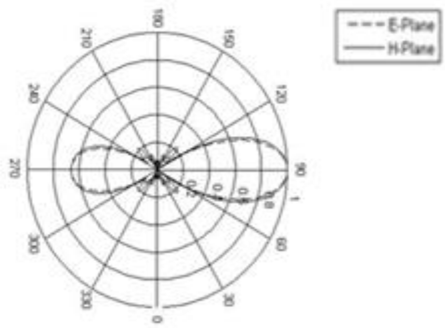

Fig. 17: Radiated electric field of 11-element Yagi-Uda antenna.

A close observation of Figs. 10-17 reveals that all the Yagi-Uda antenna designs radiate in an end fire mode, directing electromagnetic wave in the same direction as direction of orientation of the axis of the antennas. It is seen that maximum energy is concentrated in the main lobe with less radiation in the back lobe and side lobe. It is found that the beam width of the main lobe reduces as the number of element increases which is consistent with the expectation.

This implies that the directivity of the antenna improves with increasing number of elements. It is seen in Fig. 17 that Yagi-Uda antenna with 11 elements has the most directive beam. This is in agreement with what was reported in [7] which implies that Yagi-Uda antenna with the highest number of elements has the most directive beam. This attibute is common to most wire antenna arrays.

4. CONCLUSIONS

We have in this paper employed method of moments to examine the radiation characteristics of Yagi-Uda antenna consisting of several elements. A point matching method of moment procedure was adopted for evaluating approximate current distributions and corresponding far zone electric fields of 3, 4, 5, 6, 7, 8, 9 and 11- element Yagi-Uda antenna designs which were being considered in this manner here for the first time. The profiles for current distribution depicted the maximum current amplitude on the driven element. These profiles also showed non-uniformity in the amplitudes of the current distribution on all elements of Yagi Uda antenna designs. Patterns obtained for the radiated electric field clearly revealed that, the antennas concentrated much of its energy in the main lobe with tolerable side and back lobes. In addition, it was found that the beam width of the main lobe became smaller as the number of elements increased.

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