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On the Performance Analysis of Yagi-Uda at Wide Range Operational Frequencies

Akeem Abimbola RAJI

Department of Electrical/Electronic Engineering, D.S. Adegbenro I.C.T. Polytechnic, Itori-Ewekoro, Ogun State, Nigeria
abimbolaraji2012@yahoo.com

Corresponding Author: abimbolaraji2012@yahoo.com

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Abstract: *This paper evaluated the performance of Yagi-Uda antenna at High Frequency (HF), Very High Frequency (VHF) and Ultra High Frequency (UHF) communications. By employing popular method of moments algorithm for transforming electric field integral equation into a matrix equation, the current amplitude on the antenna emerged after matrix inversion of impedance matrix and multiplication by the voltage. The far zone field expression was developed by taking an integral of known current amplitude and green's function. Using radiation far zone pattern as the performance metric, it was found that, the antenna was characterized by significant main lobe radiation along the axis of the antenna with small minor lobe radiation. This characteristic remained unchanged over all frequencies utilized as candidates for investigation. It was revealed through the study that varying operational frequency has negligible effect on the radiation characteristics exhibited by Yagi-Uda antenna and this lends credence to its usage for a number of applications over a wide frequency range.*

Keywords: *End fire radiation, High frequency, Very high frequency, Ultra-high frequency, radiation pattern.*

1. INTRODUCTION

Yagi antennas have been widely employed for radar, Radio and Television services in the Very High Frequency (30-300MHz) and Ultra high Frequency (0.3-3GHz) bands. It is a travelling wave entity which radiates end-fire beam, directing most electromagnetic energy along the axis of the antenna. Its high gain characteristics, lower cost of fabrication have given impetus to considerable attention it has received from the research community over the years. For example, [1] examined the characteristic behaviours of Yagi-Uda antenna to variation in the number of elements and analytical results obtained suggested that the beam-widths, front to back ratio and electric field patterns were affected by the number of elements in the array. The veracity of using sinusoidal current distribution as an excitation function on Yagi-Uda antenna and investigation on the analytical performance behaviours of Yagi-Uda antenna at 200MHz for television broadcasting was carried elsewhere [2]. Adekola and Raji [3] designed novel Yagi-Uda array with parabolic spacings between elements of the antenna with a view to reducing undesirable backlobe radiation produced by the antenna.

Numerical electromagnetic code which is an offshoot of method of moment procedure was utilized by [4] and [5] for obtaining gain, front to back ratio of the antenna while [6-9] focused on other aspects of radiation problem of the antenna also using NEC. However, high directivity Yagi antenna was developed by [10] and [11].

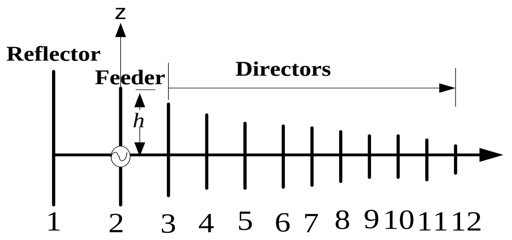
Cheong et al [12] designed Yagi-Uda antenna for multi-band radar applications. Computational and experimental results presented at millimetre wave frequencies indicated among other things that, gain, directivity and front-to-back ratio of the antenna may be improved by configuring directors in branch line form, reflector with stepped impedance design and employing L-shaped driven element. A three –element Yagi-Uda antenna was designed using CADFEKO (software tool) at Ultra High frequency for Radio Frequency Identification (RFID) application [13]. In [14], Sharma and Nagpal optimized design parameters of Yagi-uda antenna using pattern search based optimization approach for improved gain, and directivity. Comparative experimental analysis of Yagi-Uda antennas constructed with square shaped iron rod and those constructed with spherical iron rod was carried out by [15]. It was shown that Yagi-Uda arrays constructed with spherical rods performed better than those constructed with square shaped metals and the choice of metals used for developing the antenna plays significant role in its performance characteristics.

Virtually in the foregoing studies, results presented for performance behaviours of Yagi-Uda antenna either address the effects of number of elements, choice of design parameters or type of metal used in constructing the antenna. There is little information to the best of our knowledge on the consequences of varying operating frequency on the performance metrics of Yagi-Uda antenna. What is needed therefore for completeness is analysis of the effect of frequency on the characteristic behaviour of Yagi-Uda antenna. It is in this regard that we focus attention here on the quantitative investigation of effect of frequency on the performance characteristics of Yagi-Uda antenna. In order to carry out the investigation, we employ popular method of moment algorithm to determine current flow on the antenna and radiation far field. Computations of resulting equations emanated from method of moments implementation in Matlab environment produces graphical illustrations of current excitations and radiation electric field patterns over a number of operating frequencies (f) in the range $200 \le f \le 900MHz$.

There are three subsequent sections after this introductory remark. Section 2 describes Yagi-Uda model and equations used in the computation of results presented in this work with section 3 bothering on discussion of those results. Section 4 on the other hand is the concluding remark.

2. SYSTEM MODEL

Figure 1 describes the geometry of Yagi-Uda array of perfectly conducting thin wires of interest in this work, in which L_1, L_2, L_3 denote the lengths of reflector, driven element, and the first director, respectively. The length of second, third, fourth, fifth, and sixth director are represented by L_4, L_5, L_6, L_7 and L_8 while $L_9, L_{10}, L_{11}, L_{12}$ represent the length of seventh, eighth, ninth and tenth director. S_1 represents spacing between the reflector and driven element, S_2 symbolizes spacing between the driven element and the first director while S_3 is the spacing between the rest of the directors



$L_1 = 0.49\lambda$ $L_2 = 0.47\lambda$ $L_3 = L_4 = 0.41\lambda$ $L_5 = 0.406\lambda$
$L_6 = 0.405\lambda$ $L_7 = 0.403\lambda$ $L_8 = 0.402\lambda$ $L_9 = 0.401\lambda$
$L_{10} = 0.401\lambda$ $L_{11} = L_{12} = 0.40\lambda$ $S_1 = 0.25\lambda$ $S_2 = 0.325\lambda$ $S_3 = 0.325\lambda$

Fig. 1: Geometry of Yagi-Uda Array

By invoking thin wire approximation and retarded potential theory, impressed field on the antenna due to voltage applied at the feeder admits expression of the form given by [1] as:

$$E^{in} = \frac{i\eta_0}{\beta_0} \int_{-h}^{h} I_n(z_n')\left[\left(1 + jk_0 R_n\right)\left(2R_n^2 - 3a^2\right) + k_0^2 R_n^2 a^2\right] \frac{e^{-ik_0 R_n}}{4\pi R_n^5}\, dz_n' \qquad (1)$$

where (E^i, I_n, R_n) respectively is the impressed field, unknown excitation current and distance from source point, a is the radius of the wires. $i = \sqrt{-1}$, is an imaginary number, η_0 is the intrinsic impedance while β_0 is the propagation constant.
Upon applying method of moments in equation (1) and as presented in our papers [1] and [2], the unknown current emerges from Ohms circuit law expression of the form

$$[I] = [Z]^{-1}[V] \qquad (2)$$

in which $[I]$ is the generalized current matrix which is determined and whose values represent the excitation current on the antenna, $[V]$ is the generalized voltage matrix which contains entries that describe delta gap excitation while $[Z]$ is the generalized impedance matrix of the array.
However, electric field radiated obtained by using vector magnetic potential approach and far field approximation is expressible in a form given by [1] as:

$$E_\theta(\theta,\varphi) = \frac{i\beta_0 \eta_0 e^{-i\beta_0 r}\sin\theta}{4\pi r} \sum_{n=1}^{N} \left\{ exp\left[i\beta_0\left(x_n \sin\theta\cos\varphi + y_n \sin\theta\sin\varphi\right)\right] \sum_{p=1}^{P} I_{np} \left[\frac{\sin\left(\frac{(2p-1)\pi}{2h_n} + \beta_0\cos\theta\right)h_n}{\left(\frac{(2p-1)\pi}{2h_n} + \beta_0\cos\theta\right)h_n} + \frac{\sin\left(\frac{(2p-1)\pi}{2h_n} - \beta_0\cos\theta\right)h_n}{\left(\frac{(2p-1)\pi}{2h_n} - \beta_0\cos\theta\right)h_n} \right] \right\} h_n \qquad (3)$$

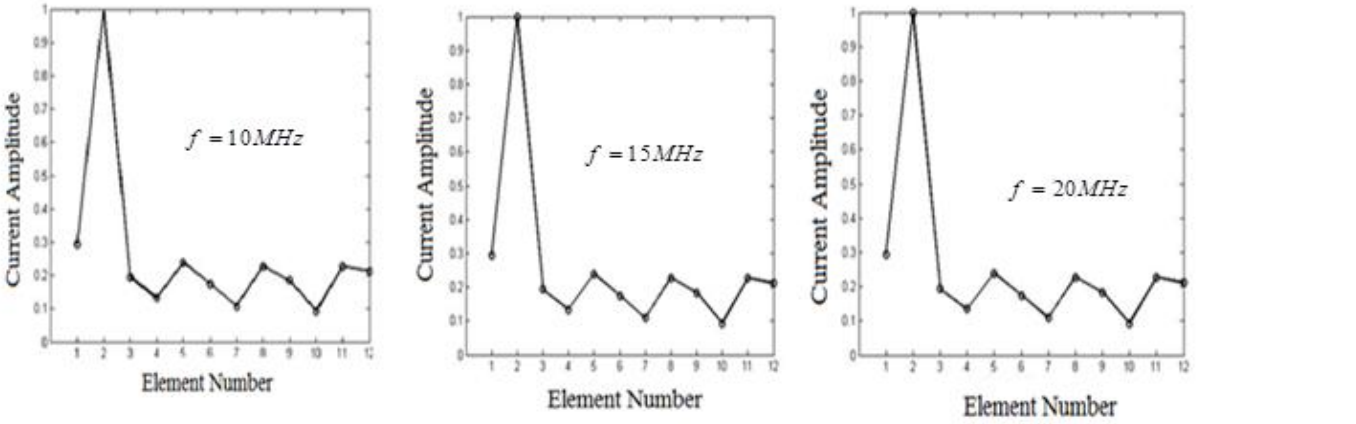
Here $\left(E_{\theta}(\theta,\varphi),\beta_0,\eta_0\right)$, respectively, symbolize electric field radiated by n-th element Yagi-Uda antenna, free space propagation constant and free space intrinsic impedance. x_n, y_n, represent positions on the nth element Yagi-uda antenna, p is the number of basis modes while i is an imaginary number. I_{np} is the unknown complex coefficient which is determined from expression of eqn. (1), h_n is the half of length of successive dipole elements, and the free space green's function is denoted by $e^{-i\beta_0 r}/r$.

3. RESULTS AND DISCUSSION

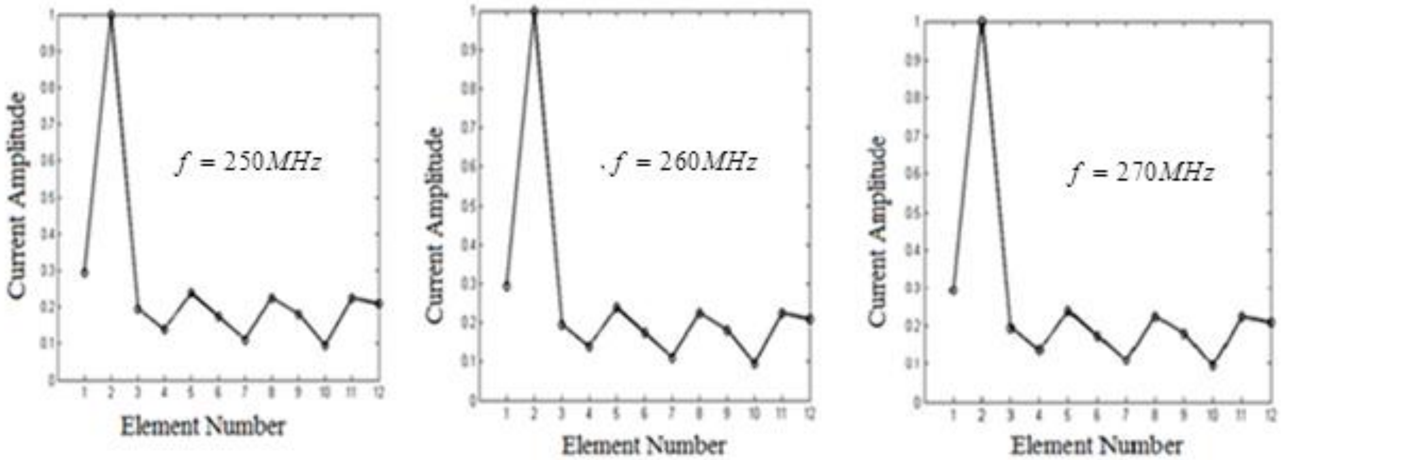
Here, we carry out simulations for the excitation current and electric fields generated at large distance from the Yagi-Uda antenna using operating frequencies within HF, VHF and UHF bands. These are discussed in what follows.

3.1 Current Excitation

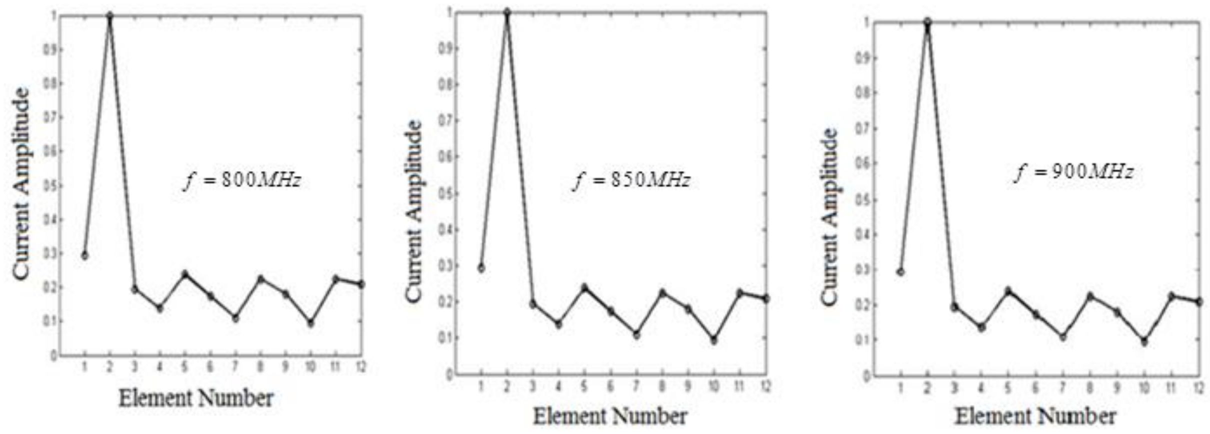
Figure 2(a) describes the characteristics patterns of current distribution on Yagi-Uda antenna operating within High frequency bands wherein the amplitudes of the current are plotted against element number. It is found that, the current amplitude surges to its peak on the driven element and thereafter assumes sinusoidal form as the number of elements in the array increases. This is similar to the resuls presented in [1] and [2]. However, figures 2 (b) and (c) describe current patterns on Yagi-Uda antenna when it is deployed at Very High frequency and Ultra High frequency. Those current patterns are largely similar to the one obtained at High frequency which indicate that current is unaffected or unperturbed by frequency increase.



(a)



(b)

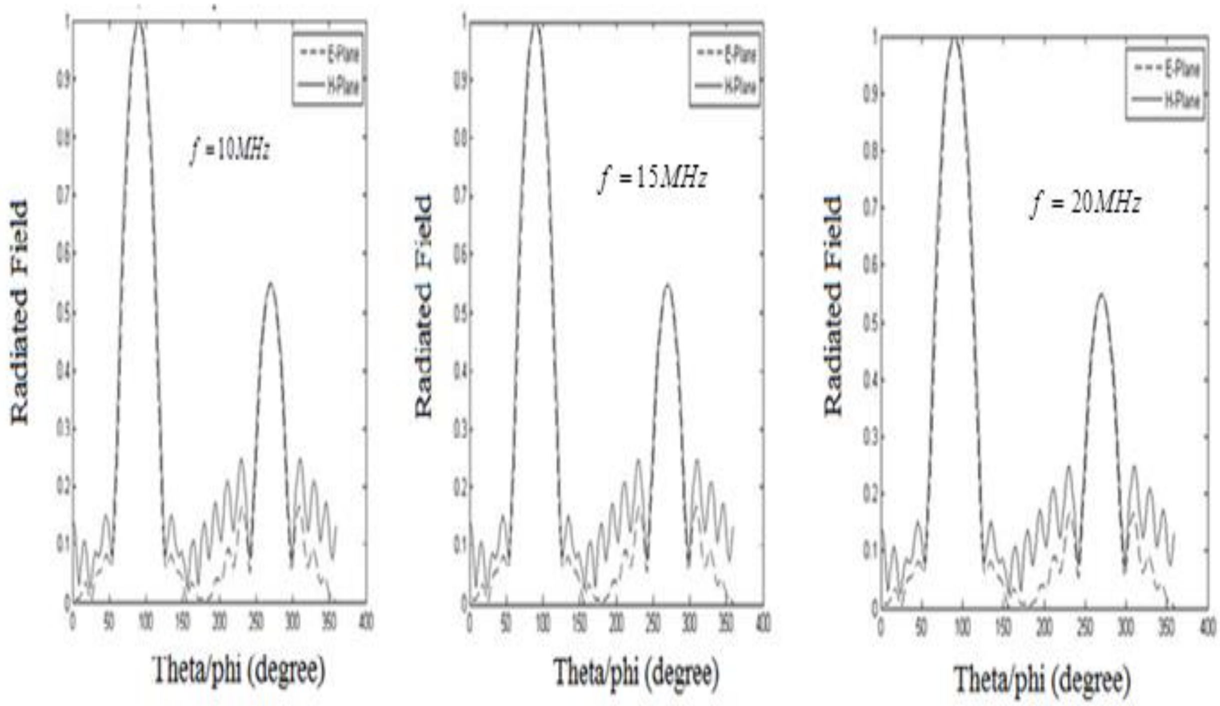


(c)

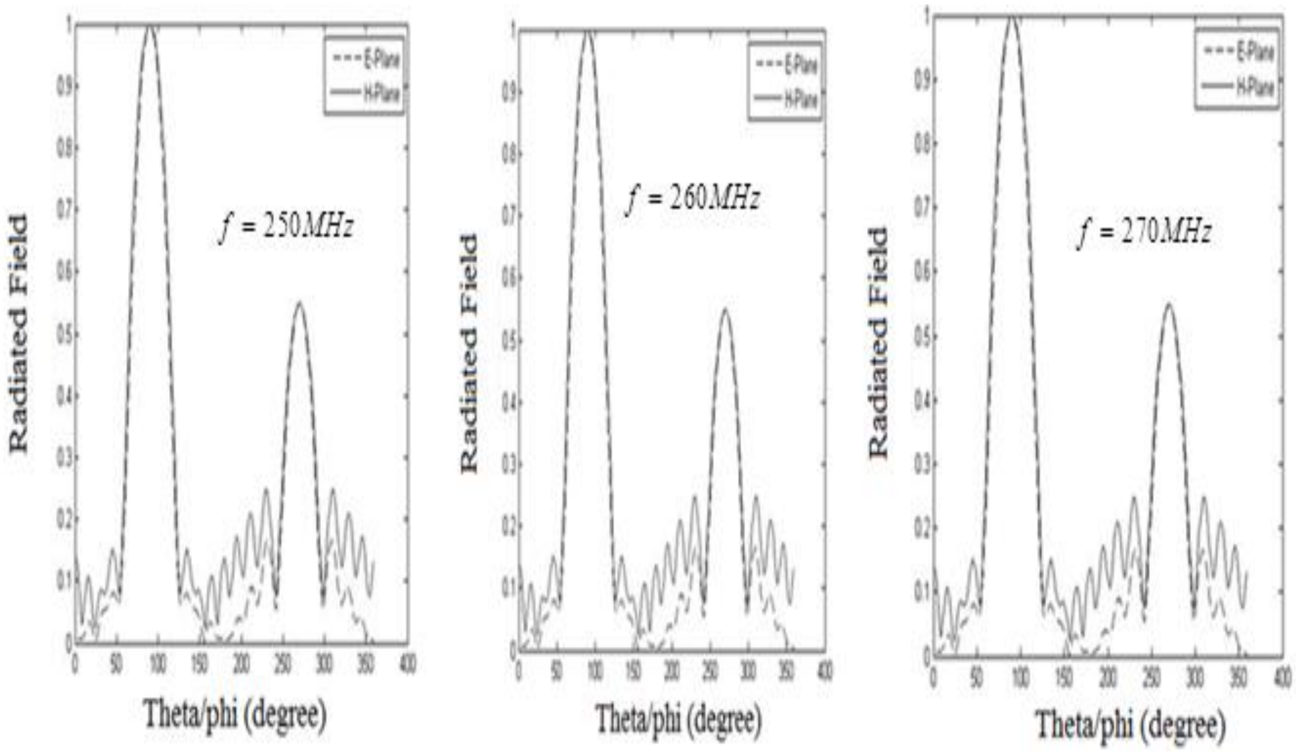
Figure 2: Current Profiles on Yagi-Uda antenna operating within (a) High Frequency, (b) Very High Frequency and (c) Ultra High Frequency bands

3.2 Far Zone Radiation Patterns

By using eqn. (3), far-zone patterns of Yagi-Uda antenna due to current distribution depicted in Fig. 2 are portrayed in Fig. (3) and (4), and which describe the far-zone electric field generated in the two principal planes (E-plane and H-plane). Figures 3(a)-(c) depict the rectangular plots of electric field radiated by the antenna at HF, VHF and UHF while Figures 4(a)-(c) on the other hand describe polar plots of far zone electric field intensity emanated from using 12-element Yagi-Uda antenna as a radiation source. It is observable from Figure (3) and (4) that the E and H plane fields are characterized by maximum radiation in the primary lobes (main lobes) in the forward end-fire direction with insignificant portion of radiation beam in the minor or secondary lobe



(a)



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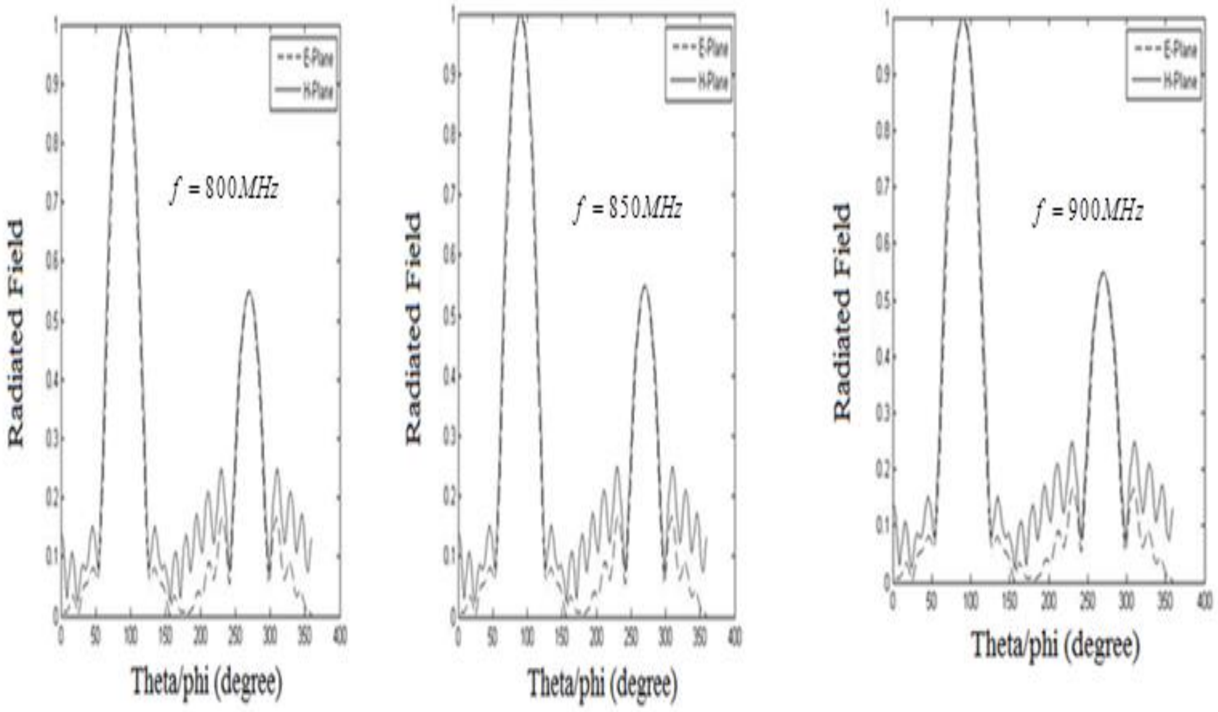
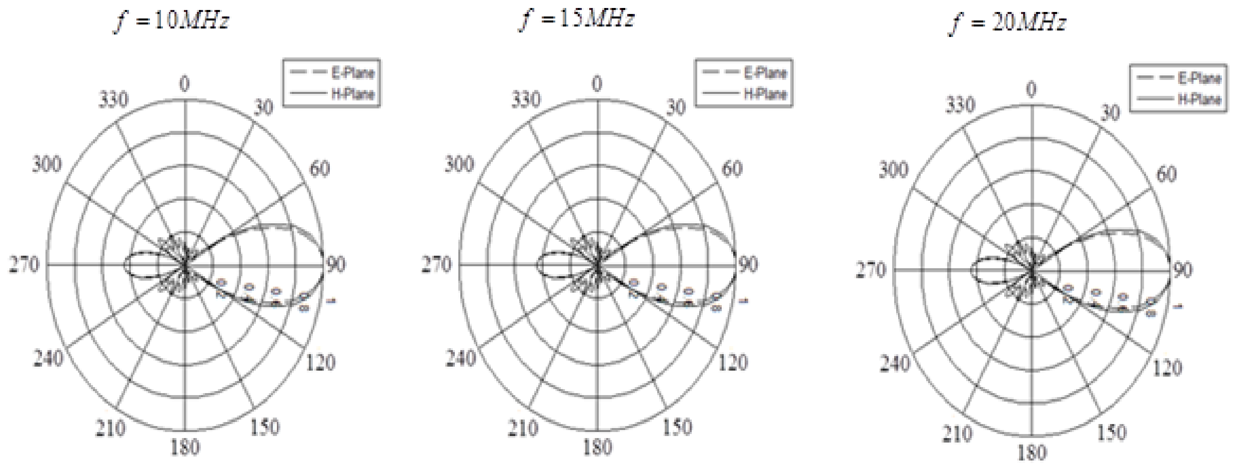


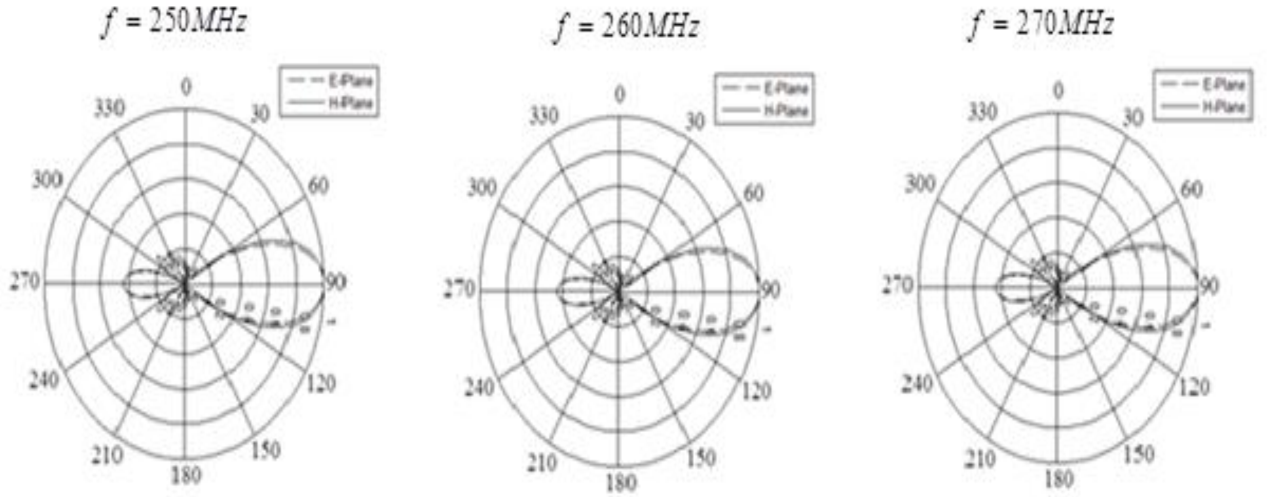
(c)

Figure 3: Rectangular Plots of Far Fields radiated by Yagi-Uda antenna at (a) High Frequency, (b) Very High Frequency and (c) Ultra High Frequency bands

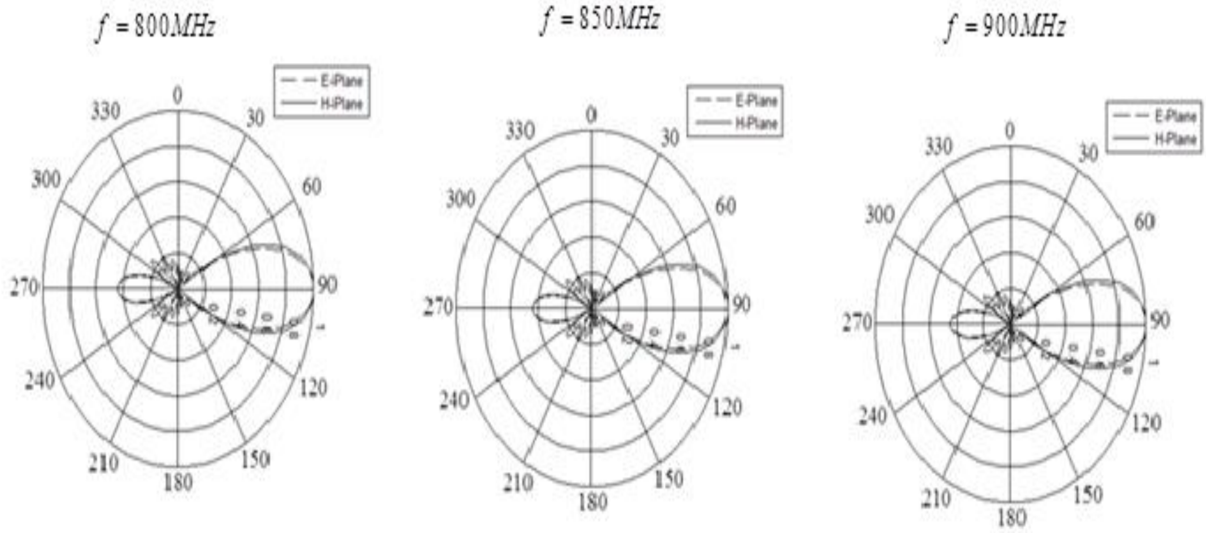
Of more significance is the far field plots of Figure (4) which depicts radiation along the structure and away from the feed point of the antenna which is the main reason why Yagi-Uda antenna is also known as End-Fire antenna. However, it is interesting to observe that the electric field patterns portrayed in Fig. (3) and (4) exhibit less or no frequency sensitiveness when operating frequency is increased as the figures are hardly differentiated from each other. This observation is consistent with characteristics of current distribution producing those field patterns.



(a)



(b)



(c)

Figure 4: Polar Plots of Far Fields radiated by Yagi-Uda antenna at (a) High Frequency, (b) Very High Frequency and (c) Ultra High Frequency bands

4. CONCLUSION

We have in this paper utilized method of moments to determine the excitation current as well as radiated electric field of Yagi-Uda array antenna in the E-plane and H-plane operating at HF/VHF/UHF communications. It is found that characteristic behaviour of current excitation on Yagi-Uda antenna is the same at all operating frequencies considered in this work. It is observed also that the angular distribution of electric field intensity in E-plane and H-plane over the same range of frequency displays feature that is consistent with the expectation wherein significant amount of radiated electromagnetic energy is directed at the main lobe and less radiation beam observed at the secondary lobes. This observation persists at all frequencies of operation of interest.

In conclusion, we find that though frequency of operation is useful in the design and construction of Yagi-Uda elements, varying operation frequency has negligible effect on excitation current and radiation electric field exhibited by Yagi-Uda antenna. It is however notable to remark here that number of elements in the array is one factor that influences behaviour of the antenna as reported by [1].

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