COMPARATIVE ANALYSIS OF BROADSIDE AND END-FIRE LINEAR ARRAYS OF DIPOLES FOR RADIO BROADCASTING IN NIGERIA

[1]Erinosho T., [1,2]Adekola S., and [1]Amusa K.

[1]Dept. of Electrical and Electronic Engineering, Federal University of Agriculture, Abeokuta, Nigeria

[2]Dept. of Electrical and Electronic Engineering, Niger Delta University, Wilberforce Island,

Yenagoa, Nigeria

Corresponding Authors: toluerinosho@gmail.com, adekola_sulaiman@yahoo.com,amusaakinwale@yahoo.com

ABSTRACT

This paper investigates the performance characteristics of broadside and end-fire linear arrays of half-wave dipole antennas for radio broadcasting. Six FM radio stations from the six geo-political zones of Nigeria are selected as candidates for the analysis, each at their operating frequencies. The results of the array factor algorithm used for the analysis of all the FM radio stations show that, for the best directivity and minimum relative side lobe levels, the maximum inter-element separation for end-fire configuration is 0.42λ and 0.45λ for a broadside arrangement of dipoles. This amounts to a reduction of 46.7% in the size of the antenna structure for an 8-elements linear array of dipoles arranged in end-fire configuration.

***Keywords**: Dipole antenna, Broadside configuration (BRC), End-fire configuration (EFC), array factor (AF)*

I. INTRODUCTION

Since its invention by Heinrich Hertz in 1886, dipole, a type of thin wire antennas, has gained the attention of many investigators. It has been widely used in several applications especially in the area of wireless communication engineering (Abdelhakim et al., 2013; Fathi et al., 2015; Parminder et al., 2012; Son et al., 2015; Yu-Xiang, 2017; Govardhani et al., 2018; Diri, 2008; Agubor et al., 2013; Yu-Xiang et al., 2017). It can be used as a standalone antenna, a feed antenna or used in its array form. For an antenna to be suitable for radio broadcasting which operates on medium and shortwave frequency range, it must be of high directivity or gain and highly efficient in power radiation, especially for long distance communications. Depending on the desired application, antenna array could be used for point-to-point communications, directional broadcast applications or omni-directional coverage. In radio broadcasting, the omni-directional property of dipole antenna is of great importance for uniform radiation. In modern radio broadcasting, because of its less susceptibility to signal interference, better sound quality and high power transmission characteristics, Frequency Modulated (FM) radio stations are becoming more popular than their Amplitude Modulated (AM) counterparts.

However, in a recent work, the performance of a single element dipole and linear array of dipoles was investigated for some TV stations in Nigeria at their operating frequencies (Adewuyi et al., 2017). The result shows that using an assembly of radiating elements arranged in a proper electrical and geometrical configuration called an antenna array give a better directivity than a single element dipole antenna. The result also shows that the high degradation in the relative sidelobe strength of a single element dipole when used for TV broadcasting can be reduced to a minimal level if a broadside array of dipole is used. This can only be achieved if the inter-element separation between the elements of the broadside linear array antenna is not greater than 0.45λ (Erinosho and Adekola, 2017). Such an antenna can be installed and directed towards areas where weak radio signals are being experienced without necessarily increasing the power of the transmitter.

The main thrust of this work is to compare the performance characteristics of broadside and end-fire linear arrays of dipole for selected FM radio stations from the six geo-political zones in Nigeria. The effects of change in inter-element separation on the directivity and the relative side lobe level of the radiation patterns are also examined for each of the FM radio stations. The stations employed for this analysis at their respective operating frequencies are (Wikipedia):

1. South West Region, Premier FM, Dugbe, Ibadan, Oyo State at 93.5MHz
2. North Central, Karama FM, Kaduna State at 92.1MHz.
3. South South, Bronze FM, Aduwawa, Edo state at 101.5MHz.
4. South East, Voice FM, Nsukka, Enugu State at 96.7MHz.
5. North East, Peace FM, Maiduguri, Borno state at 102.5MHz
6. North West. Freedom FM, Sokoto at 99.5MHz.

Depicted in figure 1.1 below are the geographical locations of the FM radio stations on the Nigeria map as earlier identified.

Figure 1: Locations of FM Radio stations used as case studies, on the Nigerian Map

The organization of this work will be as follows: Section I is the introduction which deals with the background information of this study. Section II concerns itself with the formulation giving insight to the mathematical equations governing the behavior of dipoles with frequency variation. Section III presents the results obtained from our computations and MATLAB simulations with corresponding discussions given. Highlighted in Section IV are the conclusions drawn from the results and the practical applications of the work.

II MATERIALS AND METHODS

A Field Radiated by a Dipole Antenna

Figure 2.1 below is a geometrical representation of a vertically polarized dipole antenna. The dipole is modeled in a way such that the axial component of the associated Magnetic Vector Potential, A_z is expressed as (Erinosho and Adekola, 2017):

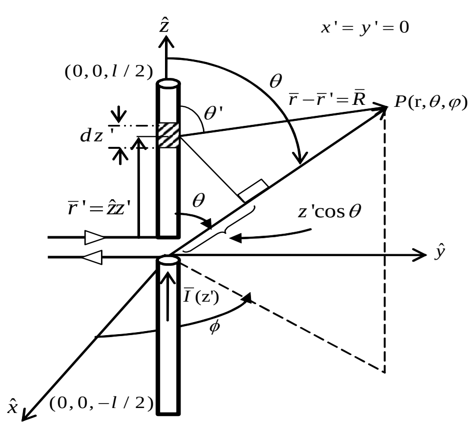

Figure 2: Geometrical representation of a dipole antenna: with the far-field coordinates

$$\bar{A}_z = \frac{\mu_0}{4\pi}\int_{-l/2}^{l/2} \bar{I}(z')\frac{e^{-jk_0R}}{R}dz' \quad (1)$$

Provided $\bar{I}(z')$ is the filamentary current flowing in the wire and z' is the corresponding running variable. μ is the permeability of free space, k_0 is the wave number, R is the distance from the source point to the field point as portrayed in figure 2.1, $j=\sqrt{-1}$ and an $e^{j\omega t}$ time variation assumed, has been suppressed here and henceforth. The wire is assumed to be perfectly conducting with necessary boundary conditions enforced.

Applying the corresponding far-field approximations in (1) and converting the field from rectangular to spherical co-ordinate system, the radiated field by the dipole is obtained in (Erinosho and Adekola, 2017) as:

$$E_\theta = -\frac{j\omega\mu\sin\theta}{4\pi r}e^{-jkr}\sum_{m=1}^{M} I_m\left\{\left[\frac{\sin(A)}{A}\right]+\left[\frac{\sin(B)}{B}\right]l/2\right\} \quad (2)$$

where

$$A=\left(\frac{(2\mathrm{m}-1)\pi}{l}+k\cos\theta\right)\frac{l}{2} \quad (2a)$$

and

$$B=\left(\frac{(2\mathrm{m}-1)\pi}{l}-k\cos\theta\right)\frac{l}{2} \quad (2b)$$

Normalizing, renders (2) to a form given as

$$\bar{\mathrm{E}}_0(\theta)=\sin\theta \quad (3)$$

The corresponding far zone magnetic field H_ϕ is readily obtained from (2) as

$$H_\phi = -\frac{j\omega\mu\sin\theta}{4\pi r\eta_0}e^{-jkr}\sum_{m=1}^{M} I_m\left\{\left[\frac{\sin(A)}{A}\right]+\left[\frac{\sin(B)}{B}\right]l/2\right\}$$

(4)

Where η_o is the intrinsic impedance of free space.

B. Field Radiated by Linear Array of Dipole Antenna

For the N-element linear array of dipole shown in figure 3, it is assumed that the elements of the array are identically equal in all respects and arranged along the z-axis of the rectangular co-ordinate system and the current distribution of each element symbolized as $I_n(z')$, be approximately the same for all the elements of the array.

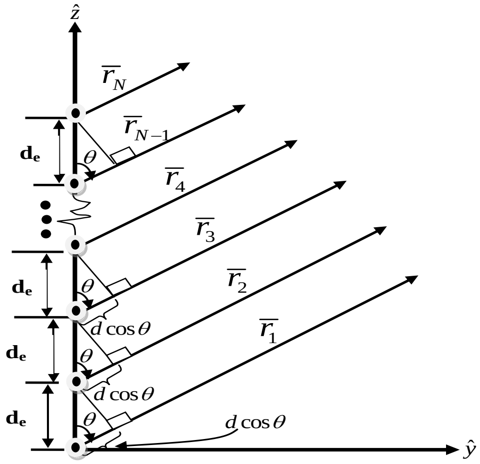

Figure 3: Geometry of an N-Element Linear Array of Dipoles

By pattern multiplication theorem, the total field radiated by the N-element linear array assumes a form expressed as (Kraus, 1997; Balanis, 1997)

$$\bar{E}^t(\theta) = [\text{Field of a single element}(\bar{E}_\theta)] \text{ x } [\text{Array factor(AF)}] \quad (5)$$

The array factor, AF, is a function of the geometrical configuration of the array and their respective excitation phase β and expressed in its normalized form as (Adewuyi et al., 2017)

$$AF_n(\varphi) = \left| \frac{\sin\left(\frac{N\varphi}{2}\right)}{N\sin\left(\frac{\varphi}{2}\right)} \right| \quad (6)$$

provided $\varphi = kd_e \cos\theta + \beta$ (6b)

N = Number of elements in the array

β= Progressive phase shift of an element with respect to another element

θ = elevation angle

k = wave number = $\frac{2\pi}{\lambda}$

d = inter-element spacing between the elements

For a broadside array of dipoles, the direction of propagation of the electromagnetic waves is perpendicular to the axis of the antenna. That is, the array has its maximum direction, $\theta_{\max} = 90^0$.

Since the array factor is maximum at $\varphi = 0$, it then follows that for a broadside linear array of dipoles, $\beta = 0$ and the corresponding normalized array factor is,

$$(AF)_n(\varphi)_{\theta=90^0} = \left| \frac{\sin\left(\frac{N\varphi}{2}\right)}{N\sin\left(\frac{\varphi}{2}\right)} \right| \quad (7)$$

With the total field for the broadside case given as

$$(\bar{E}^t)_n(\theta) = \sin\theta \quad \text{x} \quad \left| \frac{\sin\left(\frac{N\varphi}{2}\right)}{N\sin\left(\frac{\varphi}{2}\right)} \right| \quad (8)$$

where θ *and* φ have been defined in (6b).

However, for an end-fire linear array, it has its maximum radiation along the axis of the array. That is for z-oriented linear array elements of this type, the direction of maximum radiation is steered towards $\theta = 0^0 \ or \ 180^0$. Invoking this condition in (6b), when

$$\theta_{\max} = 0^0, \quad \beta = -kd_e \ and \ \varphi = kd_e(\cos\theta - 1)$$

(9a)

$$\theta_{\max} = 180^0, \quad \beta = +kd_e \ and \ \varphi = kd_e(\cos\theta + 1)$$

(9b)

The corresponding normalized array factor for the end-fire linear array is thus expressed as

$$(AF)_n(\varphi)_{\theta=0^0 \ or 180^0} = \left| \frac{\frac{1}{N}\sin\left(\frac{Nkd_e}{2}(\cos\theta \mp 1)\right)}{\sin\left(\frac{kd_e}{2}(\cos\theta \mp 1)\right)} \right| \quad (10)$$

Therefore, the normalized total field for the end-fire linear array takes the form given as

$$(\bar{E}^t)_n(\varphi) = \sin\theta \text{ x } \left| \frac{\frac{1}{N}\sin\left(\frac{Nkd_e}{2}(\cos\theta \mp 1)\right)}{\sin\left(\frac{kd}{2}(\cos\theta \mp 1)\right)} \right| \quad (11)$$

C. The Relative Side Lobe Level

In the design of any communication antenna, the relative sidelobe level of such an antenna must be reduced to the minimal level to avoid spurious signals from interfering with desired signals. The side lobe is the maximum value of smaller beams apart from the main beam which radiates in an undesired direction. It is usually rated in dB, and expressible in the form given as:

$$SLL(dB) = 20\log\left[\frac{Magnitude\ of\ the\ maximum\ sidelobe}{Magnitude\ of\ the\ mainlobe}\right] \quad (12)$$

We therefore examine the radiation characteristics of the linear array when $\beta = 0$ (broadside case $\theta_{\max} = 90^0$) and $\beta = -kd_e$ (end-fire case, $\theta_{\max} = 0^0$) in what follows at varying inter-element separation, d_e.

III. RESULTS AND DISCUSSION

The computational results of the radiation patterns for both broadside and end-fire configurations for an 8-elements linear array for each of the six FM radio stations under review at their operating frequencies are presented here. For clarity, the discussion of the results are presented in two sections: Section IIIA discusses results of Table I and Fig. 4, the results computed from (8) and (12) for a broadside case while section IIIB deals with that of end-fire counterpart, which results are given in Table II and Fig. 5, as computed from (11) and (12). To avoid unnecessary repetitions, graphical profiles of E_θ and H_φ fields for Premier FM Ibadan at operating frequency of 93.5MHz are displayed since all the six FM stations have similar responses to variations in the inter-element spacing, d_e . In figs. 4 and 5, for each value of inter-element separation d_e, the results are presented in two formats. First is the 2D polar plot and second is the isometric plot viewed in free space.

Table I: Relative Sidelobe Level (Broadside configuration) for 8-element half-wave Dipole Antenna Array at

S/N	Name of Stations	Frequency (MHz)	Side-lobe Level (dB)					
			Inter-element spacing, d					
			0.35λ	0.4λ	0.42λ	0.45λ	0.46λ	0.5λ
1	Premier FM, Ibadan	93.5	-13.35	-12.76	-22.5	-15.4	-13.98	-9.63
2	Karama FM, Kaduna	92.1	-13.26	-12.67	-21.94	-15.28	-13.89	-9.37
3	Bronze FM, Adamawa	101.5	-14.04	-13.65	-24.01	-16.72	-14.92	-10.66
4	Voice FM, Nsukka	96.7	-13.64	-13.28	-23.57	-16.02	-14.28	-10.19
5	Peace FM, Maiduguri	102.5	-14.18	-13.87	-24.15	-16.76	-15.11	-10.79
6	Freedom FM, Sokoto	99.5	-13.82	-13.48	-23.83	-16.22	-14.45	-10.43

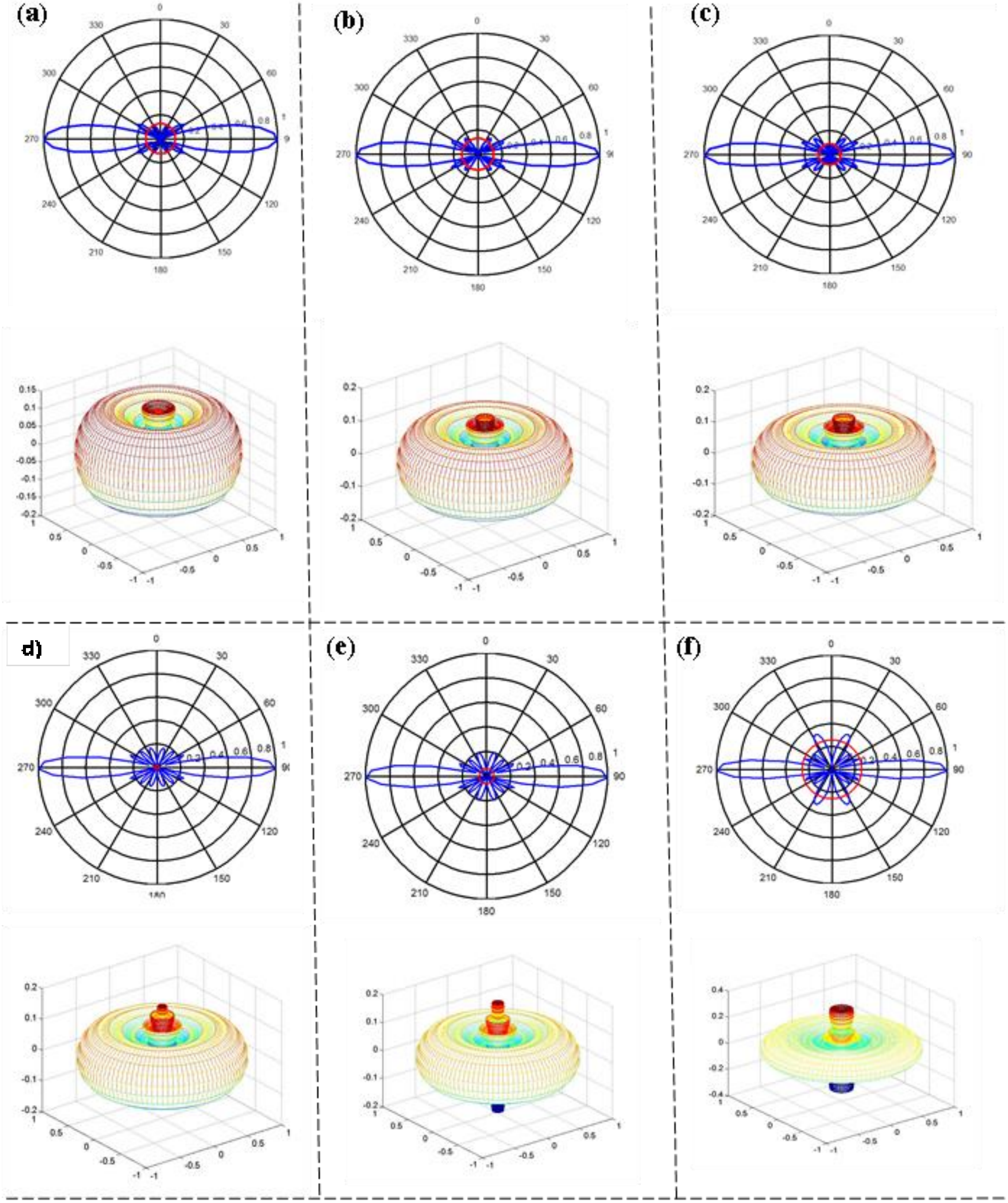

Figure 4: Radiation Patterns of Broadside Array of Dipole Antennas for Premier FM Ibadan 93.5MHz at (a) d_e=0.35λ (b) d_e =0.40λ (c) d_e =0.42λ (d) d_e =0.45λ (e) d_e =0.46λ (f) d_e =0.5λ

A. Broadside Case

Table I and fig. 4 show the response of each of the FM radio stations to varying inter-element separations as computed from (12). It can be seen that the relative sidelobe level and the directivity increases as the inter-element separation increases. However, when d_e > 0.4λ as depicted in fig. 4c, there is an evolution of the 11th and 12th sidelobes whose strength increases rapidly as d_e increases up to a point where it is radiating in opposite direction to the main lobe. This is presented in figs. 4e-4f. Hence, to avoid this type of false signals in a broadside configuration antenna array, the maximum inter-element separation, $d_{e_{\max}} = 0.45\lambda$

These results are consistent with what is obtained in the literature (Adewuyi et al., 2017; Yao et al., 2011).

B. End-fire Case

Table II also shows a linear variation of the inter-element separation with relative side lobe intensity and directivity for the case of emd-fire linear array of dipoles.

Table II: Relative Sidelobe Level (End-fire configuration) for 8-element half-wave Dipole Antenna Array at varying inter-element separations of the selected FM Radio Stations in Nigeria at their Transmitting Frequencies

Name of Stations	Frequency (MHz)	Side-lobe Level (dB)					
		Inter-element spacing, d					
		0.35λ	0.4λ	0.41λ	0.42λ	0.45λ	0.5λ
Premier FM, Ibadan	93.5	-12.44	-10.46	-10.13	-2.22	2.56	3.78
Karama FM, Kaduna	92.1	-12.2	-10.35	-10.06	-2.11	2.61	3.85
Bronze FM, Aduwawa	101.5	-12.78	-10.88	-10.94	-2.57	2.26	3.2
Voice FM, Nsukka	96.7	-12.55	-10.63	-10.49	-2.38	2.46	3.59
Peace FM, Maiduguri	102.5	-12.85	-10.97	-11.08	-2.66	2.16	3.04
Freedom FM, Sokoto	99.5	-12.68	-10.79	-10.58	-2.48	2.37	3.32

Fig. 5 is computed from (11) which reveals that when d_e < 0.4λ, the radiation exists in both directions $(\theta = 0^0 \, and \, 180^0)$. In fact, at d_e =0.41λ, there exists a maximum in the broadside direction as depicted in fig. 6 below.

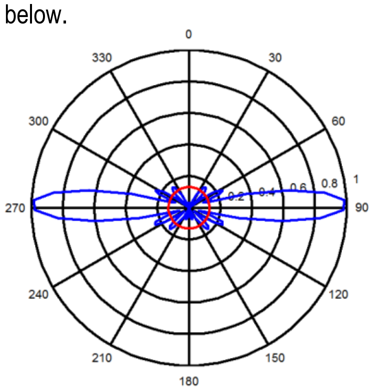

Figure 6: Radiation Pattern of End-fire Array of Dipole Antennas for Premier FM Ibadan 93.5MHz, when d_e =0.41λ

However, fig. 5c shows that once d_e > 0.41λ, there is an evolution of the 9th and 10th side lobes whose strength increases exponentially as d_e increases, even tapering the radiation amplitude of the main lobe. Of great interest is fig. 5e which shows that at d_e =0.45λ, the sidelobes have gained more strengths than the main lobe thereby parading itself as a true signal whereas it is a false signal. Therefore, for best performance characteristics of this antenna array if to be configured in end-fire arrangement, $d_{e_{\max}} = 0.42\lambda$.

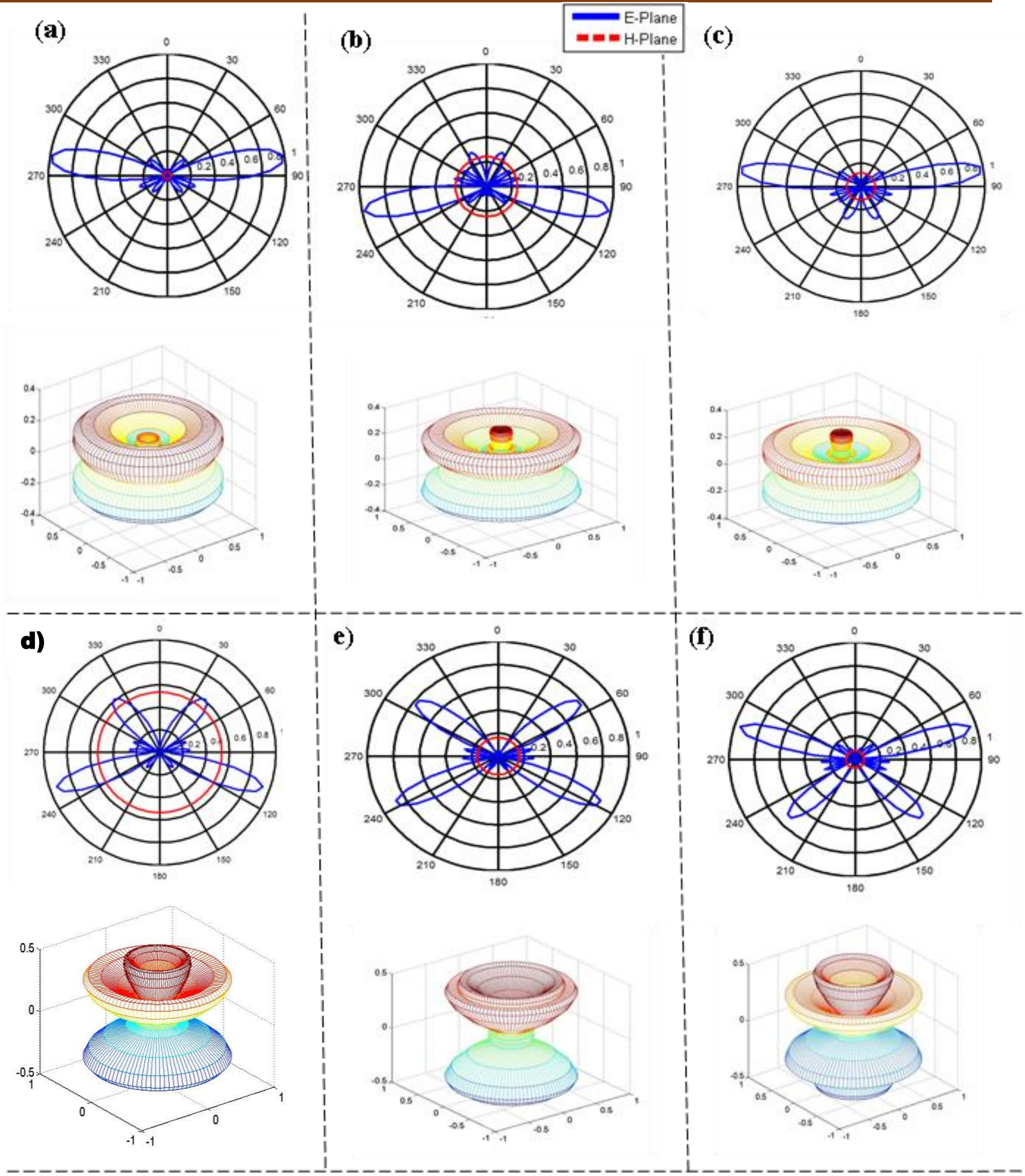

Figure 5: Radiation Patterns of End-fire Array of Dipole Antennas for Premier FM Ibadan 93.5MHz at (a) d_e=0.35λ (b) d_e =0.40λ (c) d_e =0.42λ (d) d_e =0.43λ (e) d_e =0.45λ (f) d_e =0.5λ

IV. CONCLUSION

Investigated in this paper is the comparative analysis of broadside and end-fire linear configurations of dipole antenna array suitable for radio broadcasting in Nigeria. The results for all the selected FM radio stations at their transmitting frequencies show that to avoid spurious signals from the visible range of the frequency spectrum of the antenna array, the maximum inter-element separation, $d_{e_{\max}}$ for broadside and end-fire configurations are 0.45λ and 0.42λ respectively. Thus, for an 8-element linear array of dipoles examined in this paper, there would be 46.7% reduction in antenna structure if arranged in end-fire type thereby reducing cost. This type of antenna could be installed as a directional antenna in areas where the reception is low instead of increasing the transmitting power of the base station. Also, adhering to these specifications in antenna design will help to reduce the back lobe radiations which are of hazardous to the people and personnel around our base stations.

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