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Design and Construction of a Folded Dipole Log-Periodic Stack Array Antenna at UHF/L Band

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Abstract: In this study, design and construction of a folded dipole log-periodic stack array antenna operating at UHF/L band (900-2000 MHz) for GSM base stations applications are presented. Two major parameters, namely the gain and radiation patterns were measured and used to evaluate the performance characteristics of the proposed antenna. The results obtained show that the antenna's measured gain varies between 8.8 and 13.2 dBi over the impedance bandwidth of 900-2000 MHz. Also, the measured radiation patterns of the antenna show omnidirectional patterns with the beamwidth >90° for all resonant frequencies within the band.

Key words: Performance, stack array, folded dipole, base station antenna, UHF and l bands, Nigeria

INTRODUCTION

The increasing demand for efficient wireless communication services in recent time has necessitated the need for high gain omnidirectional antennas capable of operating at a broad band frequency range. Since, it is necessary to transmit and receive over a wide band using a typical antenna system be it transmitting or receiving antennas then the importance of a broadband antenna or bandwidth compensation antenna such as folded dipole antenna in communication cannot be overemphasized. Despite the various researches embark on by antenna engineers worldwide, antennas that can deliver high gain over wide bandwidth are still big challenge (Jaleel, 2008; Alade and Akande, 2010; Perevalov *et al*., 2007; Krzysztof, 2002; Kim *et al*., 2000).

The characteristics of folded dipole antenna reported in the literatures show that it is best choice for wide bandwidth compensation required for the modern wireless communication applications. A major set back of the folded dipole is the high input impedance (288 Ω) which is four times that of a straight dipole (Kenedy and Davis, 2005; Balanis, 2005).

However with the assistance of the balun, good match of the antenna with the transmission line is possible. This study presents the design, implementation and performance analysis of high gain, light weight and low cost folded dipole log-periodic stack array antenna operating at UHF/L band (900-2000 MHz) for Global System Mobile communication (GSM) applications. The existing log-periodic design equations are employed (Kenedy and Davis, 2005; Balanis, 2005). K7MEM online feeder simulator by Martins (Balanis, 2005) is employed to determine the length of the cable required to form a λ/2 U-shape coaxial cable balun for the appropriate impedance match of the antenna with the transmission line.

MATERIALS AND METHODS

Antenna design analysis

Step 1: The initial boundary conditions for the design of the antenna are as follows; the maximum frequency (F_{max}) and the minimum frequency (F_{min}) frequency for the design are 900 and 2000 MHz. The Bandwidth ratio (B) is obtained using the equation (Krzysztof, 2002; Kim *et al*., 2000):

$$B = \frac{F_{max}}{F_{min}} = \frac{2000}{900} = 2.00 \quad (1)$$

The center frequency:

$$F_c = \frac{F_{max} + F_{min}}{2} = \frac{2000+900}{2} = 1450 \text{ MHz} \quad (2)$$

Step 2: To determine the antenna's design parameters, the steps is as follow: the initial guess for the antenna parameters: gain G and design constant is determined using the chart in the Fig. 1 (Balanis, 2005; Kraus *et al*., 2002). G is chosen to be 10.5 dBi (6≤G≤10.5). From the LPDA design parameters curve above, the values of design constant τ and relative spacing σ corresponding to the 10.5 dBi gain are 0.968 and 0.184.

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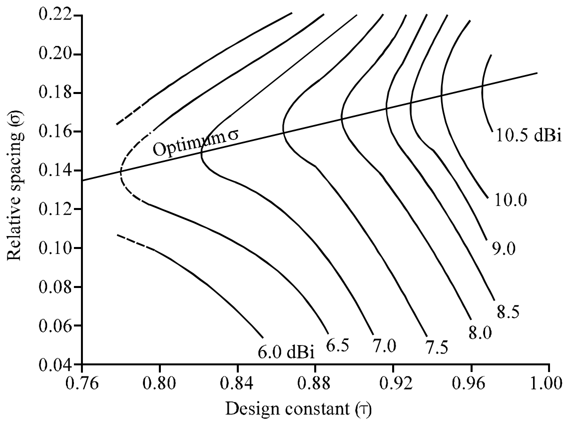

Fig. 1: LPDA gain as a function of λ and σ

Step 3: Determination of the active bandwidth, structural bandwidth and number of elements corresponding to the 10.5 dBi gain: By successive application of Eq. 3-5, the active region bandwidth B_{ar}, structural bandwidth B_s and the number of elements N required for the design are calculated as follow (Kennedy and Davis, 2005; Balanis, 2005; Kraus *et al*., 2002):

$$\beta_{ar} = 1.1 + 7.7(1-\tau)^2 \frac{4\sigma}{1-\tau}$$
$$\beta_{ar} = 1.1 + 7.7(1-0.968)^2 \frac{4(0.184)}{1-0.968} \quad (3)$$
$$\beta_{ar} = 1.281$$

$$\beta_s = \beta.\beta_{ar} = \frac{F_{max}}{F_{min}} B_{ar} \quad (4)$$
$$\beta_s = 2.222 \times 1.281 = 2.846$$

$$N = 1 + \frac{\log \beta_s}{\log \frac{1}{\tau}},\ N = 1 + \frac{\log 2.846}{\log \frac{1}{0.968}} \quad (5)$$
$$N = 1 + \frac{0.4542}{0.0141} = 1 + 32.2$$

Therefore, the number of elements required for the design is approximately 33 elements.

Step 4: Determination of the apex angle corresponding to the 10.5 dBi gain: To determine the apex angle α corresponding to these design parameters, the equation is as follow (Kennedy and Davis, 2005; Balanis, 2005; Kraus *et al*., 2002):

$$\alpha = \tan^{-1}\left(\frac{1-\tau}{4\sigma}\right) \quad (6)$$

Where, τ = 0.968 and τ = 0.184

$$\alpha = \tan^{-1}\left(\frac{1-0.968}{4(0.184)}\right)$$
$$\alpha = \tan^{-1} 0.04347826$$
$$\alpha = \tan^{-1} 2.489^0$$

Step 5: Determination of the antenna boom length: To determine the boom Length (L) of the antenna, the equation is as follow (Kennedy and Davis, 2005; Balanis, 2005; Kraus *et al*., 2002):

$$L = \left[\frac{1}{4}\left(1-\frac{1}{B}\right)\cot\alpha\right]\lambda \max$$
$$L = \left[\frac{1}{4}\left(1-\frac{1}{2.846}\right)\cot\alpha\right]\lambda \max \quad (7)$$

Where, λ max L is the longest free space wavelength:

$$\lambda \max = \frac{C}{f_L} = \frac{3\times10^8}{900\times10^6} = 0.333 \text{ m}$$

Therefore:

$$L = \left[\frac{1}{4}\left(1-\frac{1}{2.846}\right)23\right]0.333$$
$$L = \left[0.25\,(1-0.35137)23\right]0.333$$
$$L = \left[0.25(0.64863)23\right]0.333$$
$$L = 1.24 \text{ m} = 124 \text{ cm}$$

Therefore, the boom length of the antenna is 124 cm.

Step 6: Determination of the longest length element: The longest element length L_1 is determined as follows:

$$\lambda = \frac{C}{f_L} = \frac{3\times10^8}{900\times10^6} = \frac{300}{900} = 0.333 \text{ m}$$
$$\lambda = 33.33 \text{ m}$$

Therefore:

$$L_1 = \frac{\lambda}{2} = \frac{33.33}{2} = 16.67 \text{cm}$$

Step 7: Determination of the remaining element length: The remaining elements lengths are determined using the Eq. 8 (Kennedy and Davis, 2005; Balanis, 2005; Kraus *et al*., 2002) and shown in Table 1:

$$L_{i+1} = \lambda L_i\ 1 \le i \le 32 \quad (8)$$

Step 8: Determination of the spacing between the elements: The spacing between the first two elements is

Table 1: The structural dimensions of the proposed antenna

Measurement (cm)	Structural dimensions												
L	16.670	16.140	15.620	15.120	14.640	14.170	13.720	13.280	12.850	12.440	12.040	11.660	11.290
S	6.095	5.900	5.711	5.528	5.351	5.180	5.014	4.854	4.698	4.548	4.402	4.261	4.125
L	10.930	10.580	10.240	9.910	9.600	9.290	8.990	8.700	8.420	8.150	7.890	7.640	7.390
S	3.993	3.865	3.741	3.621	3.505	3.393	3.284	3.179	3.077	2.979	2.884	2.792	2.703
L	7.160	6.930	6.710	6.500	6.090	5.900	-	-	-	-	-	-	-
S	2.617	2.533	2.452	2.374	2.298	2.224	-	-	-	-	-	-	-

determined using Eq. 9 (Kennedy and Davis, 2005; Balanis, 2005; Kraus *et al*., 2002):

$$S_1 \leftrightarrow S_2 = \frac{1}{2}(l_1 - l_2)\cot\alpha \tag{9}$$

Where l_1 and l_2 are the first and second longest element lengths:

$$S_1 \leftrightarrow S_2 = \frac{1}{2}(16.67 - 16.14)23$$

$$= \frac{1}{2}(12.19) = 6.095 \text{ cm}$$

Step 9: Determination of the remaining elements spacing: The remaining elements spacing are determined using the Eq. 10 (Kennedy and Davis, 2005; Balanis, 2005; Kraus *et al*., 2002) and shown in Table 1:

$$S_{i+1} = \tau S_1 1 \le i \le 31 \tag{10}$$

Step 10: Determination of feeder impedance: The feeder characteristic impedance that provide good matching impedance (VSWR~1:1) with the 75 Ω coaxial cable transmission line was determined by using K7MEM online feeder simulator which automatically determines the length of the cable required to form a λ/2 U-shape coaxial cable balun for the antenna.

RESULTS AND DISCUSSION

Figure 2a, b show the pictures of the proposed folded dipole log-periodic stack array antenna and the experimental measurement setup. Light weight rigid aluminium metal of diameter 6 mm was cut and folded according to different lengths and spacing shown in Table 1. A wooden plank is used for the boom on which the folded dipole elements were fixed at appropriate positions with accurate spacing.

The folded dipole elements are coupled together inductively on the wooden plank using 900/215 MHzEPD-12 model frequency splitters and 75 Ω coaxial cable transmission wire which was connected to λ/2 U-shape balun to achieve voltage standing wave ratio (1:1) before connecting it to GSP10 spectrum analyzer with the aid of

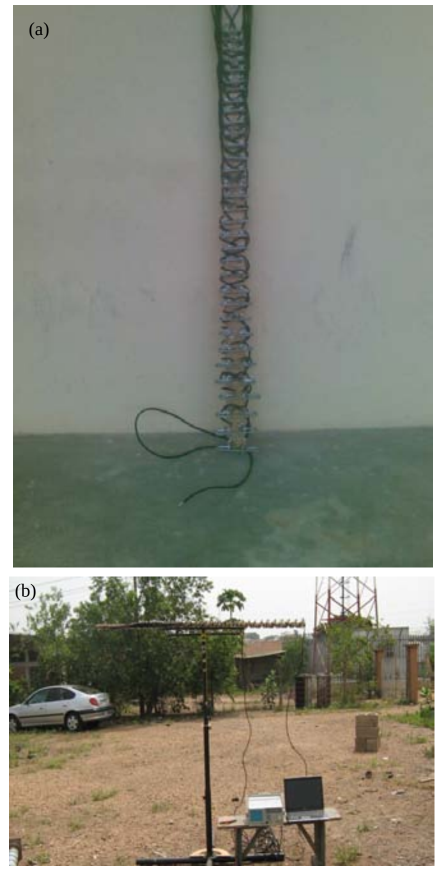

Fig. 2: The pictures of; a) the proposed folded dipole log-periodic stack array antenna and b) the experimental measurement setup

frequency multiplier for the antenna gain and field pattern characteristics measurements. The performance characteristics of the proposed antenna were investigated for 96 h in the open air far field measurements. The signal strengths (E in dBm) of the signals received by the antenna suspended on a mast 4 m above the ground level were measured over a rising time of 2-5 min in the wide frequency range of 900-2000 MHz at a frequency interval of 5 MHz while varying the azimuth angle Q about the horizontal plane from 0-360°.

Figure 3 shows the plot of measured gain versus frequency at the direction of maximum radiation. It is observed that the measured gain varies between 8.8 and

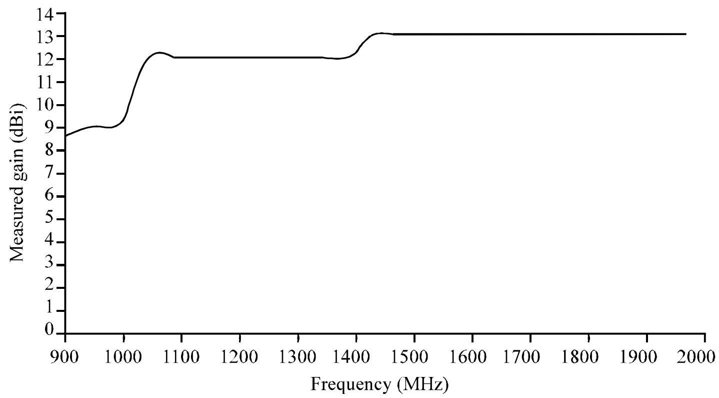

Fig. 3: The measured gain versus frequency of the proposed antenna

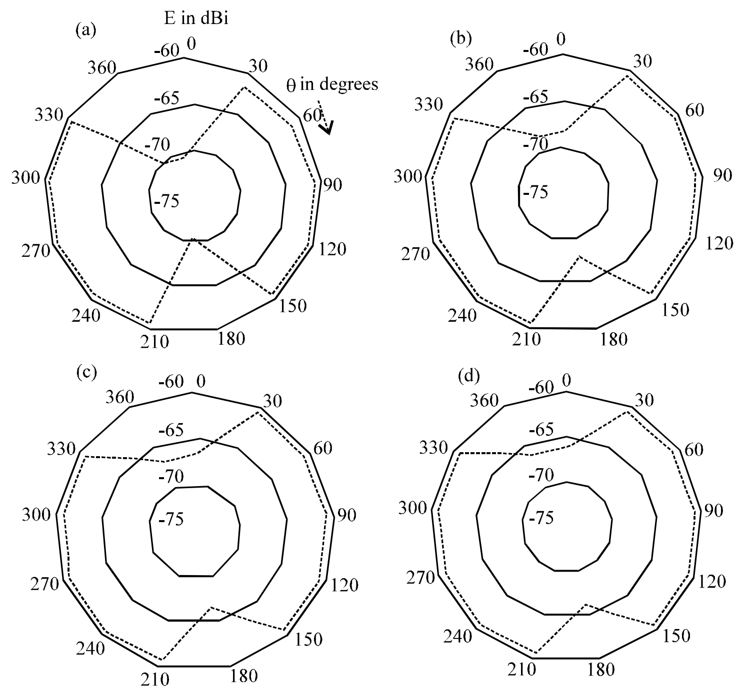

Fig. 4: Some measured radiation patterns of the proposed antenna; a) Frequency = 900 MHz, b) Frequency = 950 MHz, c) Frequency = 1000 MHz and d) Frequency = 2000 MHz

13.2 dBi over the impedance bandwidth of 900-2000 MHz. At resonant frequencies between 900 and 1000 MHz, the measured gain is about 1.5 dBi less than the designed gain of 10.5 dBi while at resonant frequencies >1000 MHz, the measured gain is about 2.7 dBi greater than the designed gain.

The proposed antenna demonstrates wide bandwidth characteristics. Figure 4a-d show some of the measured radiation patterns of the proposed antenna. The electric far-field radiation patterns obtained are omnidirectional (beamwidth>90°) for all the resonant frequencies withinthe desired band.

CONCLUSION

In this study, researchers designed and constructed a folded dipole log-periodic stack array antenna operating at UHF/L band (900-2000 MHz) for GSM base stations applications. The gain and radiation patterns characteristics of the proposed antenna were measured and used to evaluate its performance over the desired frequency band. The results obtained show that the proposed antenna has wide impedance bandwidth of 900-2000 MHz and broad beamwidth electric far-field radiation patterns at all resonant frequency within the band.

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