Performance Optimization and Comparison Analysis of Different Conventional Array Antennas at UHF Band

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ABSTRACT

Due to increase need for higher communication capacity in wireless and mobile communication system, high-gain, directional and omnidirectional antennas have become more attractive for wireless communication applications. This paper presents the results of the performance optimization and comparison analysis of three different conventional antennas namely: log-periodic dipole array (LDPA), folded dipole array (FDA), and star array (SA) antennas designed and fabricated at the ultrahigh frequency (UHF) band of 900MHz to 1880MHz. Some antenna characteristics such as half-power beam width (HPBW), directivity, gain, and efficiency were used as performance metrics. The results show that each of the three conventional array antennas shows good performance and unique characteristics. The (SA) antenna has the best performance with an optimized gain of 9.2 dB compared to the designed gain of 8.0 dB, which suggests that it is best of the three antennas for high-gain and omnidirectional antenna applications.

KEYWORDS: *conventional, array, antenna, gain, directivity, efficiency, optimization*

How to cite this paper: Adewumi Adebayo Segun | Àlàgbé George Atilade | Eleyele Dolapo | Ikubanni Stephen "Performance Optimization and Comparison Analysis of Different Conventional Array Antennas at UHF Band" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-5, August 2022, pp.2108-2113, URL: www.ijtsrd.com/papers/ijtsrd50333.pdf

IJTSRD50333

I. INTRODUCTION

Conventional antennas are typically the ones that can be constructed manually with handheld tools [1]. For the array types, performance can be enhanced by optimizing the antenna input gain via the optimization of the elements' lengths, widths, and the spacing between them, but with miniaturization uneasiness [2]. Several of the array types of conventional antenna have seen wide applicability. For example, log-periodic dipole array (LPDA) antennas, whose performance depends on the choice of the elements' lengths and the proper spacing between them, have been extensively used in different applications due to their broadband characteristics [2]. LPDA antennas are widely used in the modern wireless communication system because of their advantages of fixed peak radiation, stable radiation pattern, wideband and moderate gain, and they are also good candidates for wideband antennas with their logarithmically -scaled geometric dimensions to enhance the range in ultra wideband communication [2], [3], [13]. Another conventional antenna, folded dipole antenna (FDA) is made up of two conductors connected on both sides and folded to form a cylindrical closed shape where the length of the dipole is determine to be half of the wavelength. The advantage of a half-wave folded dipole antenna is the reception of undistorted signals while the disadvantage is the difficulty in outdoor management when the size increases due to displacement and readjustment of the antenna. The folded dipole is mainly used as feeder elements in other conventional antennas and is generally used in radio receivers [4]. With the rapid development of mobile communication technology, wideband antennas with moderated-gain are required to cover multiple communication bands [5]. Antennas having an omnidirectional radiation pattern in the azimuthal plane can cover a large service area and are very attractive for applications in wireless communications such as in the mobile and wireless local area network

(WLAN) systems [2]. Star Antenna (SA) has shown futuristic application in multiple input, multiple output (MIMO) and as part of the edges that can be used for simultaneous transmitting and receiving of signals. It has been used to facilitate spectrum access by increasing the number of users within a given frequency band [6]. The performance of a non-uniform star array antenna mounted on a vehicle for UHF signal reception has been reported [14]. The omnidirectional antenna isolation performance confirms that the star antenna is effective [6], [7]. Many antenna applications require radiation characteristics that may not be achievable by a single element, it may be possible that an aggregate of radiating elements (an array) will result in the desired radiation characteristics [8]. With the rapid development being witness in modern wireless communications, dual-polarized base station antennas with impedance, bandwidth, stable 3-dB beam width in the horizontal plane, high-gain, and high cross-polarization discrimination are in urgent need to meet the market requirements [9]. Hence, this work is focused on developing three different conventional array antennas with a view to improving the characteristics. It is expected that the antennas will deliver higher gain, good broadband, low cross-polarization ratio, fixed peak radiation pattern, and good omnidirectional and directional radiation characteristics.

II. Log-Periodic Dipole Array, Folded Dipole Array and Star Array Design Procedures

The maximum frequency (F_{max}) and minimum frequency (F_{min}) for the design of the antennas at UHF frequency are 1880MHz and 900MHz respectively. The bandwidth ratio (β) of each antenna is deduced as [10]

$$\beta = F_{max}/F_{min} \quad (1)$$

The center frequency F_c is deduced as [10]

$$F_C = (F_{max} + F_{min})/2 \quad (2)$$

The design constant (τ) and the gain (G) were chosen from the Carrel graph [11] as follows; An optimized gain value of 8.0 dB was chosen from the Carrel graph to have an optimum relative spacing of 0.166 and an optimum design constant of 0.912. The active region bandwidth (β_{ar}), structural bandwidth (β_s) and the number of elements (N) needed for each antenna design were calculated as provided by [4], [10]

$$\beta_{ar} = 1.1 + 7.7(1-\tau)^2 \times {}^{4\sigma}/_{1-\tau} \quad (3)$$

$$\beta_s = \beta\beta_{ar} = (F_{max}/F_{min})\beta_{ar} \quad (4)$$

$$N = 1 + \left({}^{\log\beta_s}/_{\log(1/\tau)} \right) \quad (5)$$

The apex angle (α) relative to design parameters, the boom length (L) of each antenna, the maximum wavelength (λ_{max}) and the longest length (L) are obtained as provided by [11]

$$\alpha = \tan^{-1}[1 - {}^{\tau}/_{4\sigma}] \quad (6)$$

$$L = \left[{}^{1}/_{4}\left(1 - {}^{1}/_{\beta}\right)\cot\alpha\right]\lambda_{max} \quad (7)$$

$$\lambda_{max} = {}^{c}/_{F_L} \quad (8)$$

$$L_1 = {}^{\lambda}/_{2} \quad (9)$$

c is the speed of light, λ_{max} is the longest free-space wavelength, F_L is the lowest Frequency, and L_1 is the longest element's length. The first and second elements' spacing and remaining elements' spacing are obtained as provided by [11], [12]

$$S_1 \leftrightarrow S_2 = {}^{1}/_{2}\,(L1 - L2)\cot \propto \quad (10)$$

$$S_{i+1} = \tau S_1 \quad 1 \le i \le 14 \quad (11)$$

$S_1 \leftrightarrow S_2$ is the spacing between the first and second elements, L_1 & L_2 are the longest and the next to the longest element lengths.

III. Materials and Methods

Aluminium pipes and sheet were used to fabricate three different types of conventional antennas: the Log-Periodic Dipole Array (LPDA) Antenna, the Folded Dipole Array (FDA) Antenna and the Star Array (SA) Antenna. The Aluminium pipes were cut into appropriate dimensions and arranged as a non-uniform dipole array as specified in equations 5,7, 9, 10, and 11 and sketched as shown in Figure 1. While similar elements length as in the case of LPDA were folded to form folded dipole shapes and arraigned to form an array of folded dipole as sketched in Figure 2. The Star antenna elements were designed as hexagonal shapes by cutting out six (6) smaller hexagonal from aluminium sheet edges. The vertical length was deduced using equations (7) and (9), the width and vertex dimensions were deduced as a fraction of the vertical length, and the number of elements and the spacing was deduced and arranged to form an array using equations 5, 10 and 11, the sketch is shown in Figure 3. The same aluminium material was used as antenna boom length on which the elements were suspended, however, the elements were insulated from the boom by placing a rubber between them as shown in Figure 4. Aluminium was employed for both the elements and the boom due to its lightweight, low cost, and corrosion resistance. The antennas were installed in an open space for signal reception as shown in Figure 5. A Spectrum Analyzer (Figure 6) was used for measuring some characteristics of the three conventional antennas. The measured parameter obtained from the radiation patterns mainly HPBW were substituted to equations (12), (13) and (14) to determine the directivity, gain and efficiency, and the results obtained (Table 1) were used for performance evaluation and comparison analysis. The directivity (Do) and the Gain (G) of the three conventional arrays were estimated from the radiation pattern as provided by[11];

$$D_o(dimensionless) \cong {}^{32{,}400}/_{\Theta_{1d}\Theta_{2d}} \quad (12)$$

and

$$G_o(dimensionless) \cong {}^{30{,}000}/_{\Theta_{1d}\Theta_{2d}} \quad (13)$$

where Θ_{1d} = half-power beamwidth in one plane (degrees) and Θ_{2d} = half- power beamwidth in a plane at right angle to the other (degrees). The D_o and G_o values obtained were converted to decibel (dB). The radiation efficiency (e_R) of the three conventional array antennas were deduced from the ratio of the gain to the directivity as provided by[11]

$$e_R = {}^{G_{dB}}/_{D_{dB}} \quad (14)$$

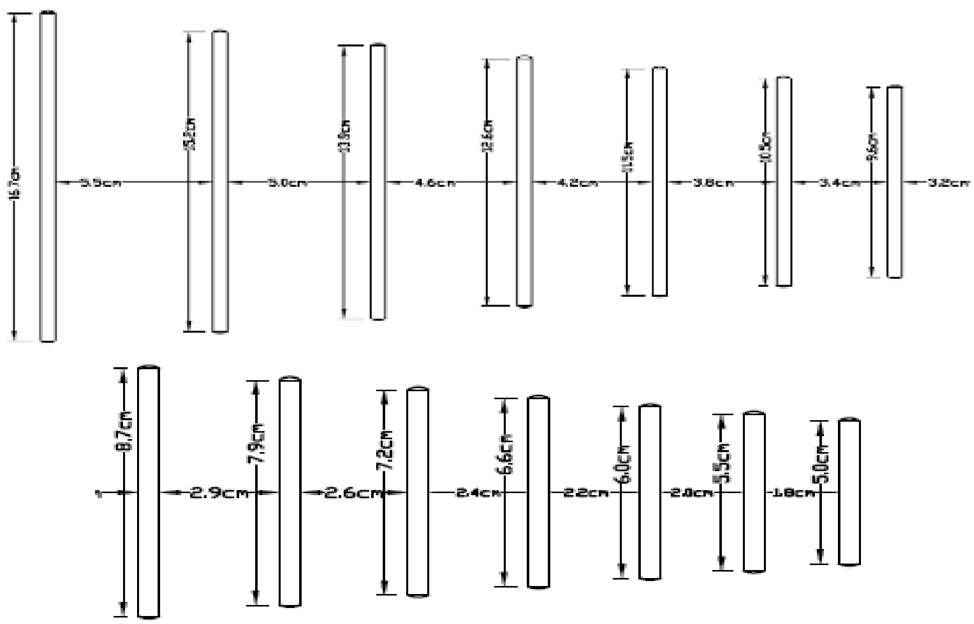


Figure 1: Sketch and geometrical specifications of the designed 14 elements Log-periodic dipole array antenna

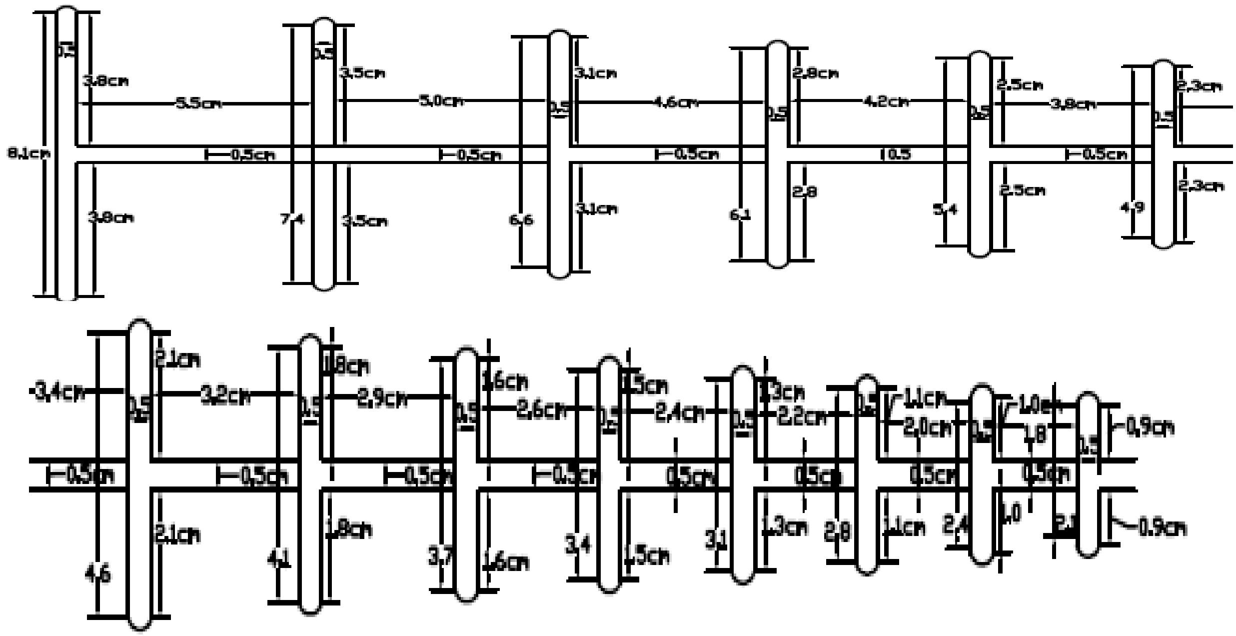


Figure 2: Sketch and dimensional specifications of the designed 14 elements Folded Dipole array antenna

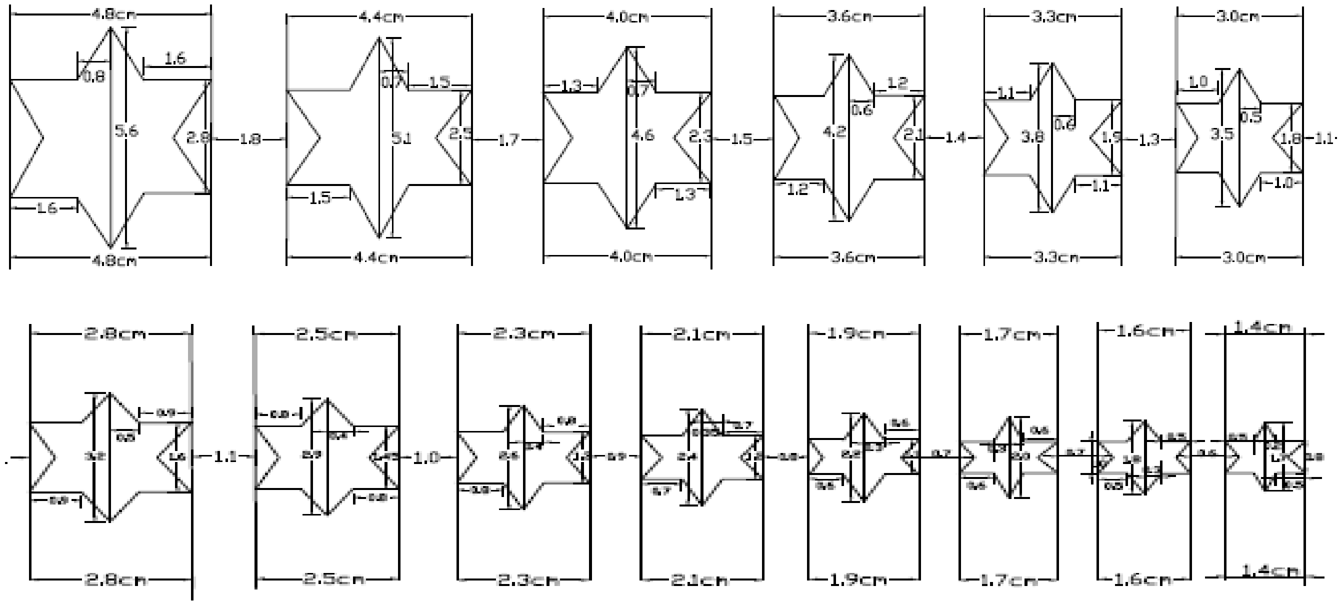


Figure 3: Sketch and geometrical specifications of the designed 14 elements star array antenna

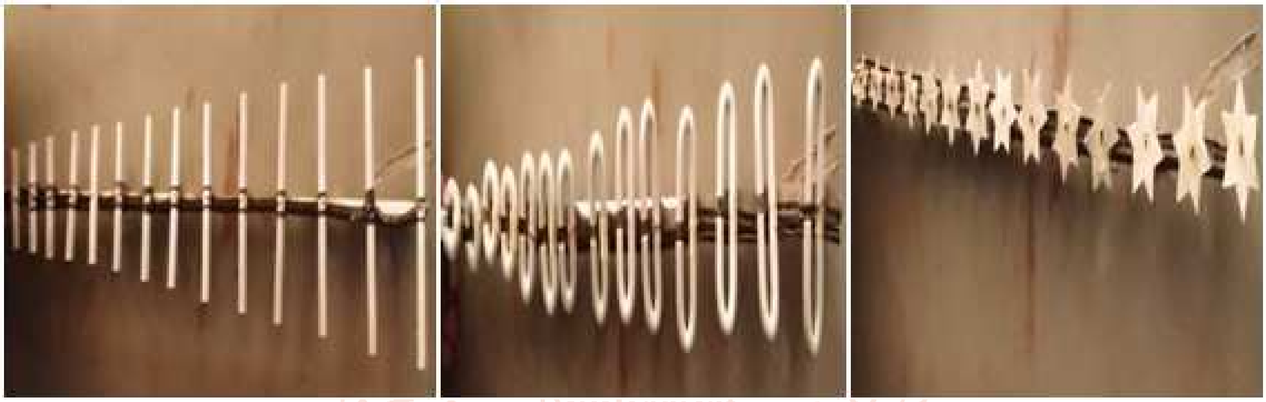
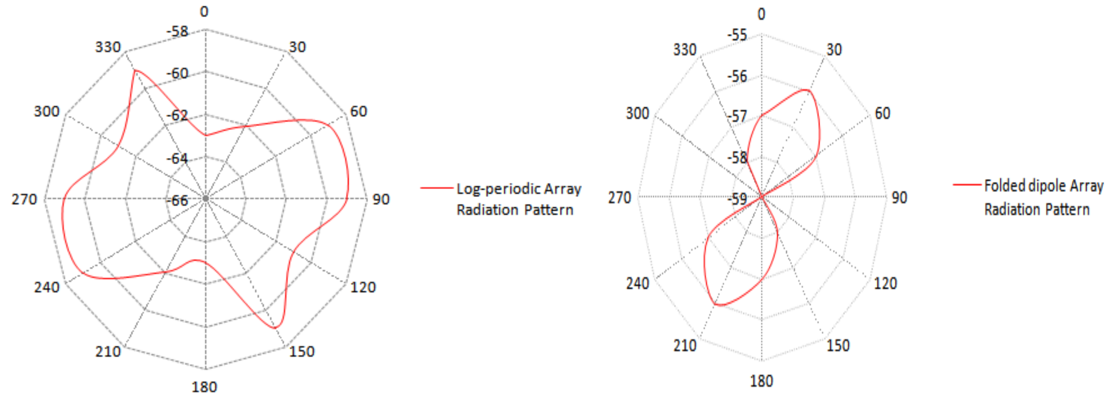


Figure 4: The fabricated log-periodic dipole array (left panel), Folded dipole array (centre panel) and Star array Antennas (right panel)

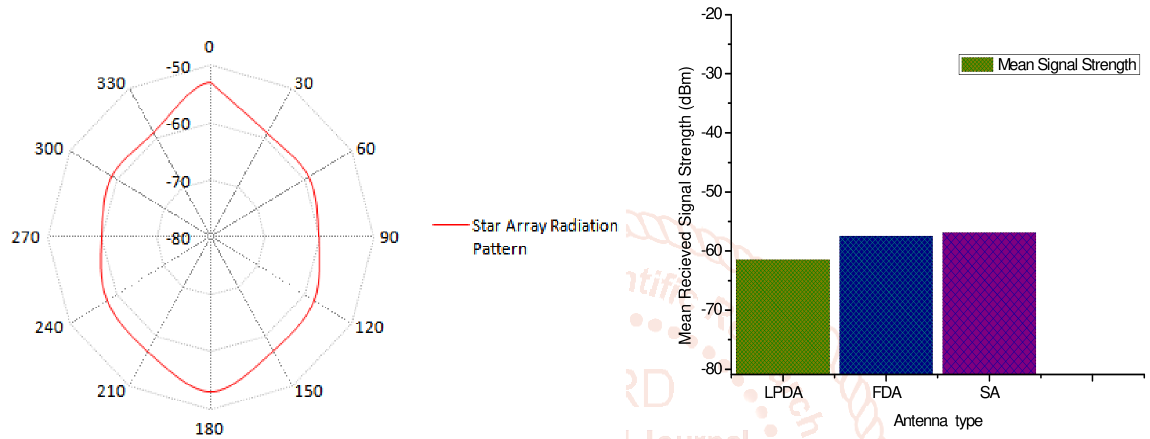
Figure 5: Experimental setup of the three fabricated conventional antennas

Figure 6: Interface of the Spectrum Analyzer for the measurements and performance study of the three conventional antennas

IV. Results



(a) (b)



(c) (d)

Figure 7: Radiation patterns for: (a) log-periodic dipole array (LPDA) antenna (b) folded dipole array (FDA) antenna (c) star array (SA) antenna and (d) plot of mean received signal strength (dBm) of the three designed and fabricated conventional array antennas.

Table 1: Measured Parameters of the three Designed and Fabricated Conventional Antennas

Operating Frequency Band (MHz)	Antenna	Axial Ratio (AR)	HPBW (3dB)	Directivity (dB)	Gain (dB)	Efficiency
900-1880	Log-periodic Array	AR>1	90 deg.	6.5	5.6	0.86
	Folded dipole Array	AR>1	75 deg.	7.6	7.3	0.96
	Star Array	AR=1	60 deg.	9.5	9.2	0.97

V. Discussion

Figures7a, b, and c show the radiation patterns of the designed and fabricated conventional array antennas. The (LPDA) in Figure 7a shows an radiation in all directions with its main lobe directions at 75 and 255 degrees, while the side lobe direction is at 150 and 330 degrees. The field pattern is elliptically polarized. The FDA depicted an elliptically directional pattern (Figure 7b) with its main lobe directions at 30 degrees and 210 degrees respectively. SA depicted omnidirectional and circularly polarized field patterns as shown in Figure 7c, with its main lobes at 0 and 180 degrees. Figure 7d depicts the comparison graph of the signal strength of the three conventional array antennas. Using a spectrum analyzer as the signal receiver, SA has the highest received signal strength closely followed by FDA. Table 1 shows the comparison results of the measured parameters of the three designed and fabricated conventional antennas. The performance metrics used were Axial ratio, Half Power Beamwidth (HPBW), Directivity, Gain, and efficiency. It was observed that SA has an Axial ratio of 1 with HPBW of 60 degrees. SA has the highest directivity of 9.5 dB, highest gain of 9.2 dB, and highest efficiency of 0.97, followed by the FDA with an Axial ratio greater than 1 and HPBW of 75 degrees, the directivity of 7.6 dB, a gain of 7.3 dB and efficiency of 0.96. LPDA has an Axial ratio greater than 1 and the highest HPBW of 90 degrees with the least directivity, gain, and efficiency of 6.5 dB, 5.6 dB, and 0.86 respectively.

VI. Conclusion

This paper has shown that different conventional array antennas can be designed, fabricated, and optimized to meet mobile communication network antenna performance expectations. All the three conventional array antennas have demonstrated good but different properties which will make them suitable for different wireless antenna applications. The fabricated SA array which is not very common has demonstrated an omnidirectional radiation pattern with an optimized gain of 9.2 dB compared to the designed gain of 8.0 dB, thus, this shows that SAA will be a good candidate for omnidirectional UHF antenna applications, particularly in scenarios where high gain is required. The designed and fabricated LPDAA and FDAA can be found useful in broadband wireless applications where moderate gain is required. The three fabricated conventional antenna array can be found useful for increasing channel capacity and spectrum efficiency as in case of the SAA and LPDAA, and tailoring beam shape to reduce multipath fading, and co-channel interferences as in the case of SAA and FDAA.

VII. Acknowledgement

We hereby acknowledge our undergraduate students for their support during experimental work.

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