A New Design of Log-Periodic Dipole Array (LPDA) Antenna

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***Abstract*- This paper presents a new approach for design of the log-periodic dipole array antenna (LPDA) based on using of different design parameters in the LPDA elements to control the antenna behavior. In the proposed procedure, the design parameters can control the value of forward gain over the operating frequency range, and also adjust the gain flatness. Furthermore, this design procedure can decrease the LPDA dimensions in comparison to the conventional design. Based on the proposed design method, several LPDA antennas are designed and simulated numerically by the method of moment. The simulation results show that this LPDA design procedure can be a good candidate for design of optimized antenna in different frequency bands.**

***Index Terms*-** Gain control, gain flatness, log-periodic dipole array, miniaturized LPDA

I. INTRODUCTION

Antenna design is a challenging topic among the communication experts for wideband communication systems [1]. The Log-periodic dipole array (LPDA) which can be used in these systems is a wideband directional antenna and consists of parallel dipoles with different lengths [2]. Its concept has made a huge impact on both commercial and military application, since it operates over a broad band of frequencies. The conventional design method of LPDA is proposed by Carrel [3] and modified by Butson and Thompson [4]. In this method, all the dipoles are inside the same angular sector, and the dipole lengths and distance between them can be calculated if the two design parameters, defined as scale and space factors (τ , σ), are known. The τ and σ are found from the constant directivity contour curves given by Carrel [3] and corrected by Butson and Thompson [4]. With this conventional method, it will be easy to design a LPDA. However, the size of the antenna based on this method is usually so large in the VHF band [5]. In addition, the conventional method has not any control on value of forward gain over the operating frequency range so that in

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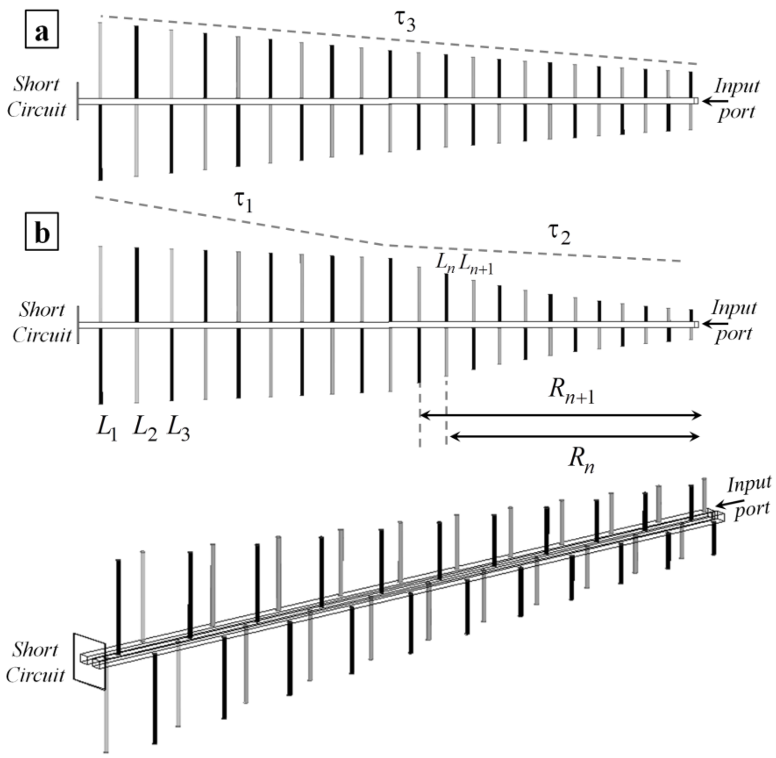

Fig. 1. The LPDA Antenna configuration (a) conventional design, (b) proposed design.

conventional design the gain is usually decreased by increasing the frequency [6].The abovementioned issues have been addressed by a multitude of works [7, 8]. In all of these works, a numerical optimization technique such as Genetic Algorithm (GA) or Particle Swarm Optimization (PSO) is used for improvement of conventional LPDA response. However, these techniques cannot show the direct effect of design parameters on optimized results.

Compared to the conventional method, in this paper we propose a new approach for design of LPDA where the scale factor is not a constant value and changes in different regions of the antenna elements. Using the simulation results, we show that the main advantage of the proposed approach is the possibility to control the forward gain on operation frequency range by changing the scaling factor in different region of antenna elements. Based on the application, the gain control can be applied under specific requirements such as the minimum forward gain at the beginning frequencies, the minimum forward gain at the end frequencies and the gain flatness over the operating frequency range. As another advantage, the proposed design method can be used for miniaturizing of conventional one.

The paper is organized as follows. Section II outlines the operation principle of the proposed design method of LPDA. The effect of the design parameters values on forward gain is also considered in this section by using of some full-wave simulations. Compared to the conventional LPDA, the ability of miniaturization in the proposed LPDA is investigated in section III where the results verify that the classical LPDA can be miniaturized by smoothing the antenna gain in the bandwidth.

II. OPERATION PRINCIPLES

Fig. 1(a) shows the conventional LPDA configuration where the antenna boom is composed of two separated parallel which are shorted in the end by a metal plate. The scale and space factors in the conventional design are given as follows [3-4]:

$$\tau = \frac{d_{n+1}}{R_n} < 1 \tag{1}$$

$$\frac{L_1}{R_1} = \ldots = \frac{L_n}{R_n} = \frac{L_{n+1}}{R_{n+1}} = \ldots = \frac{L_N}{R_N} \tag{2}$$

$$\tau = \frac{d_{n+1}}{d_n} = \frac{L_{n+1}}{L_n} \tag{3}$$

$$\sigma = \frac{d_n}{2L_n} \tag{4}$$

Where L_n is the length of the *n*th element, R_n is the distance of *n*th element from the input port and d_n is the space between two adjacent elements.

In conventional design method, the first element length L_1 is determined by the lowest frequency and then the other element lengths are specified by (3) where τ is a constant value. As it shown in Carrel design curves [3], the maximum antenna gain in its bandwidth is increased by choosing of higher τ which results in long antenna boom length in a specified bandwidth. Clearly, if we chose a lower τ, the antenna boom length is decreased as well as the maximum gain. In this conventional method, there is not any control on the antenna gain versus frequency and the antenna gain is usually decreased by increasing the frequency.

In the new proposed LPDA, we use a non constant τ versus elements to control the antenna gain in its frequency band. In more details, we know that the longer elements contribute in the radiation in lower frequencies while the shorter ones contribute in the higher frequencies. Therefore, the antenna gain can be controlled with changing τ in different region of antenna elements by non constant functions versus the element positions. If we want to decrease the gain in a specified frequency range, we can decrease τ in the corresponding elements in the antenna configuration. This fact is depicted in Fig. 1(b). As it can be seen, two different τ are selected in this new proposed antenna compared with the conventional one with single τ. In fact, the values of τ_1 and τ_2 control the frequency band of maximum gain.

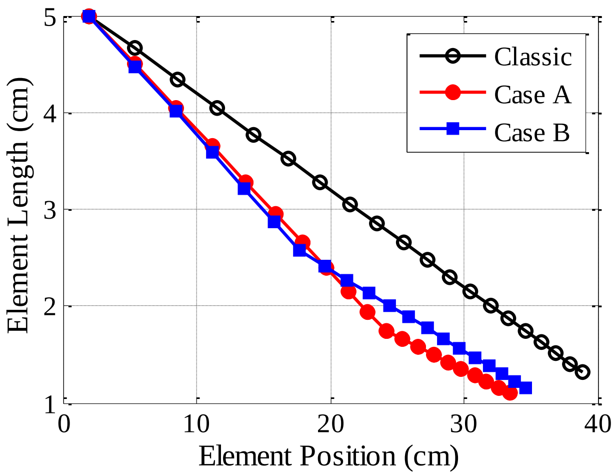

Fig. 2. Antenna elements length versus elements position in three cases, classic, Case A and Case B

Table I. Studied LPDA cases

Case	**Region of High gain**	τ_1	τ_2
Classic	Start of Band	0.932	0.932
Case A	Middle of Band	0.895	0.94
Case B	End of Band	0.9	0.95

To validate the proposed design, we design and simulate three kind of LPDAs in frequency range of 1.5 GHz to 4.5 GHz (See Table 1) with two different τ values instead of a constant one which is used in the classical design. The first one is a conventional LPDA (Classic Case) which has high gain in the start of the band. The second one with high gain in the middle of the band is named as case A, and finally, the third case with the high gain in end of the band is case B.

As tabulated in Table. I, the classic antenna has one constant τ value versus the antenna elements. In all cases the number of antenna elements, N, is chosen as 20 and the spacing factor for d_1 is determined by using Carrel design curves to achieve the optimal value for gain. The other spaces between each two adjacent elements (d_2, d_3, …) are determined by (3) based on using corresponding τ. Notice that, the τ values are chosen by doing some simulations to know the antenna behavior with these coefficient variations. The length of antenna elements versus position of the elements is depicted in Fig. 2 for these three cases. Notice that based on the design formulas, the scaling factor is related to the inverse slope of the lines.

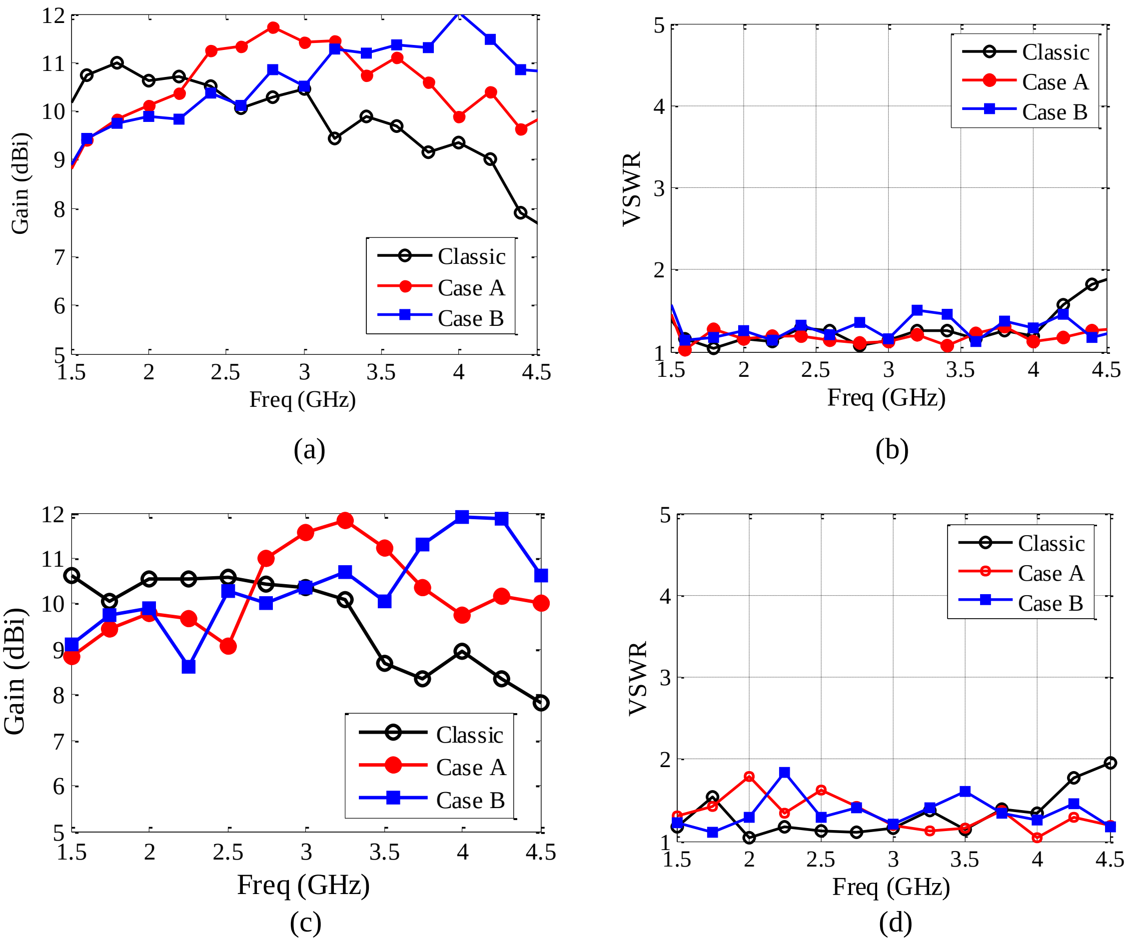

Fig. 3. Comparison of three designed LPDA given in Table I (a) Gain versus frequency by FEKO (b) VSWR versus Frequency by FEKO (c) Gain versus frequency by HFSS (d) VSWR versus Frequency by HFSS.

As shown in Fig. 2 in the classical structure, the scaling factor is a constant value and the line slope is not changed. For cases (A and B) based on the new proposed design method, we use two different values for τ and it can be seen that the line slope is changed in the middle for A and in the end for the B. In case A, we increase the τ in the middle elements of the antenna and decrease the τ in the first elements which results in high gain in the middle frequency band of the antenna. But in case B, we decrease τ in start and middle elements while it is increased in the last ones which causes gain enhancement in the end of antenna bandwidth.

The commercial full wave simulation software, FEKO is used to simulate the proposed antennas. The simulation results of |S11| and gain in the whole antenna bandwidth for these three cases are shown in Fig. 3. As it can be seen, by changing the scale factor coefficient, we can set the gain behavior in the frequency range of operation. Moreover the radiation patterns of the designed antenna are demonstrated in Fig. 4 at three different frequencies, start of bandwidth (1.6 GHz), middle of bandwidth (3 GHz) and end of bandwidth (4.3 GHz). To validate the simualtion resutls, the

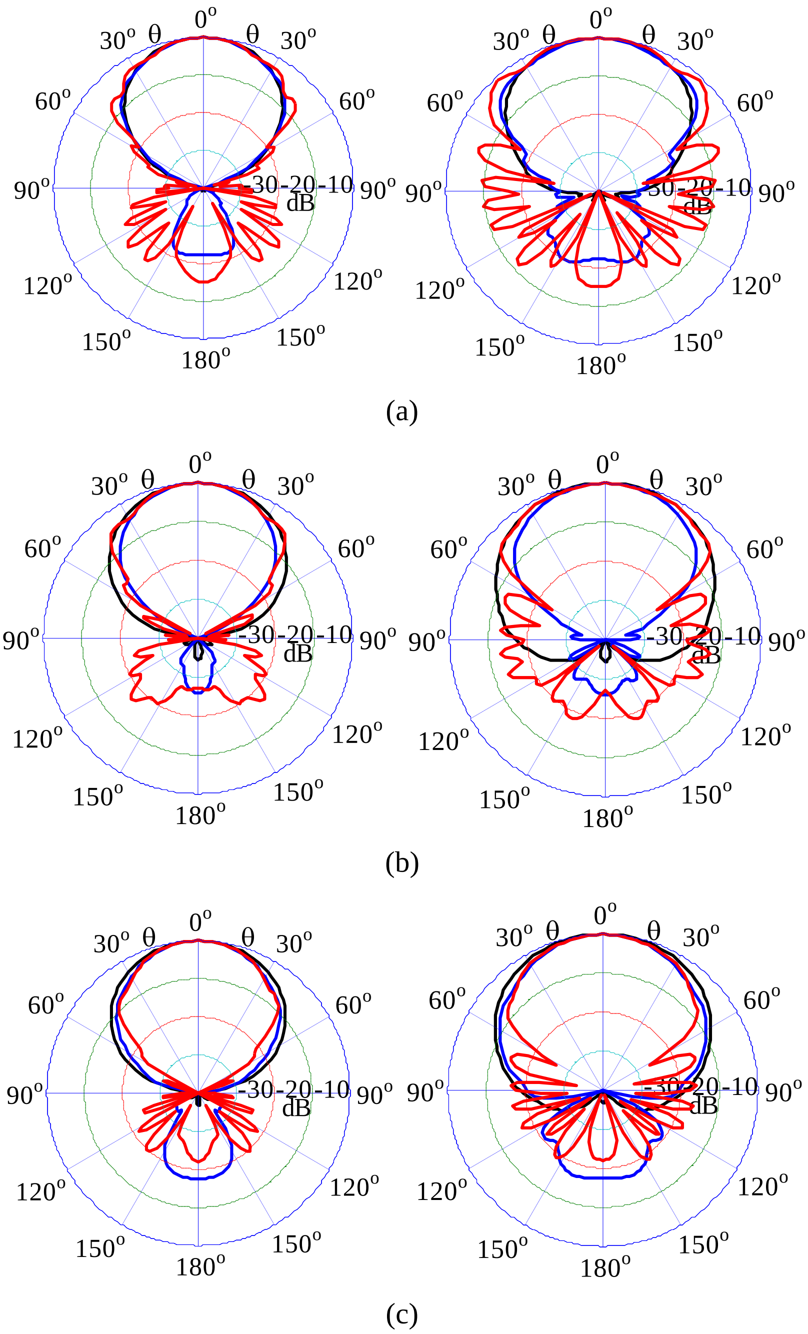

Fig. 4. E-Plane (right column) and H-plane (left column) radiation pattern of three designed LPDA given in Table I at 1.6 GHz (black), 3 GHz (blue) and 4.4 GHz (red). (a) Classic (b) Case A (c) Case B

simualtions are done by Ansoft HFSS software also which are shown good agreements with the FEKO ones.

III. Compact LPDA Design

By the new proposed method in LPDA design, we can design a compact LPDA. For this purpose, we

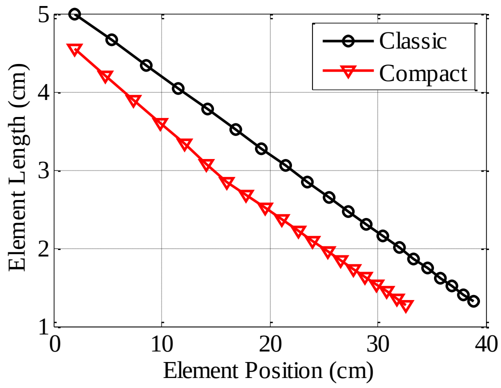

Fig. 5. Antenna element lengths versus elements position.

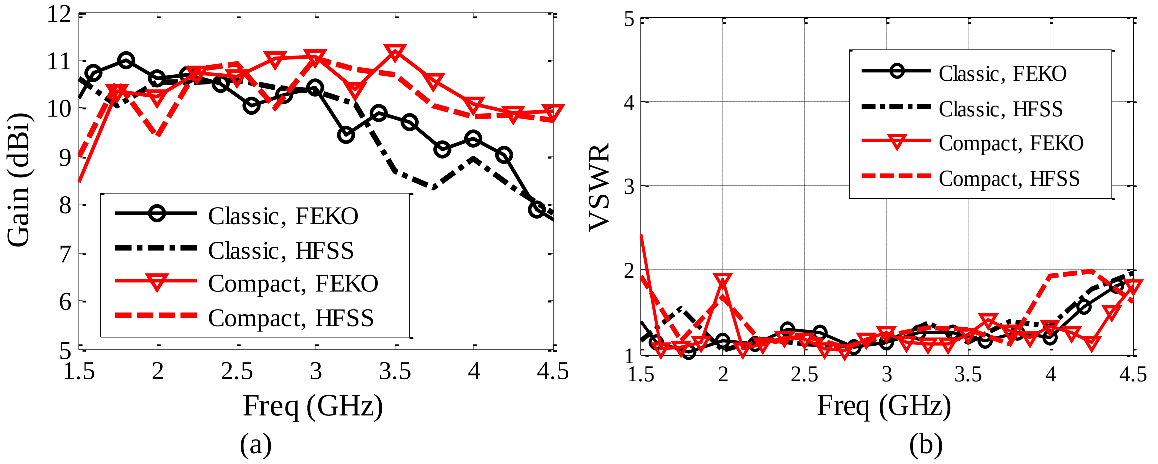

Fig. 6. Comparison of the designed compact LPDA and conventional one (a) Gain versus frequency (b) VSWR versus Frequency.

Table II. Miniaturized and Conventional LPDAs Comparison

Case	Total Length, cm	τ_1	τ_2
Classic	39.8	0.932	0.932
Compact	33.5	0.925	0.94

should try to decrease the first element length to achieve a more compact structure. Therefore, we chose this element length as short as possible only to satisfy the VSWR condition of the antenna design (VSWR < 2). Then we use two different values for τ as it tabulated in Table. 2. Notice that the total number of elements is 20 and the antenna works between 1.5 GHz to 4.5 GHz same as the previous cases discussed in section II. The antenna element lengths versus element positions are depicted in Fig. 5 beside the classical one.It is clear that the antenna elements lengths and positions follow two different τ. The first element length in the compacted LPDA has about 10% compactness rather than the classical one. Also, the proposed LPDA boom length is 32.59 cm which shown about 17% compactness compared with the classical LPDA boom length. In other words, the proposed

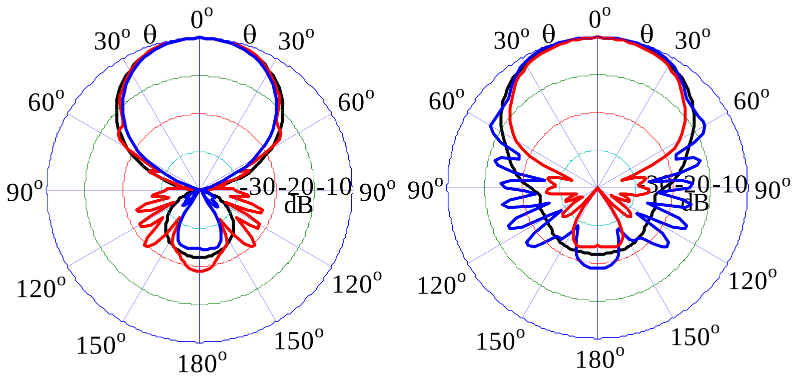

Fig. 7. E-Plane (right columb) and H-plane (left columb) radiation patterns of the designed compacted LPDA given in Table II at 1.6 GHz (black), 3 GHz (blue) 4.4 GHz (red).

design procedure compacts the LPDA in two dimension; first elements and boom length. The simulation results of VSWR and gain reported in Fig. 6 show that the proposed antenna has a good performance compared with the conventional one. These results show that the proposed method can be used to compact the conventional LPDA. Notice that the HFSS simulation results shown in Fig. 6 validate the FEKO ones, also. Moreover, this compact antenna shows a smooth gain variation versus frequency. The radiation patterns of this compact LPDA are demonstrated in Fig. 7 at three different frequencies, start of bandwidth (1.6 GHz), middle of bandwidth (3 GHz) and end of bandwidth (4.3 GHz).

IV. CONCLUSION

The gain control and size reduction of LPDA was demonstrated in this work based on optimization of scale design factor. For these purposes, the scale factor was not chosen as a constant value and was changed in different regions of antenna elements. Moreover, by tapering the scale factor, a smoothly varied gain is achievable. Three kinds of the proposed LPDAs have been designed and simulated with two different scale values. The simulation results verified the proposed method ability to gain control of LPDA in the operation bandwidth as well as size reduction.

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