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A printed LPDA antenna with improved low frequency response

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Abstract

This paper presents a design of a printed log-periodic dipole array (PLPDA) antenna with large operating frequency range from 0.4 GHz to 8 GHz. The proposed antenna design employs a triangular shaped longest dipole element. The triangular shape of the longest dipole element and optimization of the last four dipole element lengths, thicknesses and spacings between them significantly improves the low frequency response. The proposed antenna design provides low return loss demonstrating excellent matching of the antenna. The antenna also provides a reasonable gain of around 5.5 dBi and highly directional characteristics.

1 Introduction

During the last decades, wireless systems have evolved significantly and are being used for several industrial as well as military applications. Several of these wireless systems utilize an ultra-wideband frequency (UWB) range for communication. The Federal Communication Commission (FCC) has legislated a UWB frequency range from 3.1 GHz to 10.6 GHz for the use of wireless communication systems [1]-[2]. Thus, several wireless systems require antennas with large bandwidth. Another such application where antennas with large bandwidth are used is for direction finding (DF) techniques for military purposes. These techniques involve use of antennas that can determine the angle of the originating signal source in the azimuth plane and also have the ability to receive the signal over a wide frequency range to track and locate targets [3]. In case of fixed surveillance systems, DF antennas are required to be in the form of an array, that consists of multiple antenna elements arranged in a circular formation. The elements can be dipole antennas, monopole antennas, bi-conical antennas, log-periodic dipole arrays (LPDAs) and Vivaldi antennas. Another application for DF antennas is in the drone market, where these antennas are deployed on drones. For all such DF applications, LPDAs are extensively used as they provide a highly directive radiation pattern and can also operate at wide frequency ranges with high front-to-back ratio in their operating bandwidth. However, the size of these antennas can be large depending on the lowest frequency of operation. Therefore, an alternative solution is required where similar performance can be achieved at a reduced antenna size. One such solution involves using printed log-periodic dipole array (PLPDA) antennas. The PLPDA follows the same design procedure as conventional LPDAs, in addition to, considering the effective dielectric constant of the substrate. Some compact DF antennas are proposed in [4], and [5].

Furthermore, antennas with wide bandwidth are also required for Electromagnetic Compatibility (EMC) measurements in anechoic and reverberation chambers. In several cases, the size of reverberation chamber is relatively small for the lowest frequencies to be measured in UHF bands [6]. Mostly, LPDAs are used as reference antennas for EMC measurements as they provide flat gain and highly directive characteristics in a wide frequency range. However, for the measurements in the UHF range, the size of an LPDA can be very large depending on the lowest operating frequency. Therefore, for such cases, in order to reduce the size of antennas, PLPDAs are also considered as a good alternative. A PLPDA design for EMC measurements is presented in [7] that operates from 800 MHz to 2.3 GHz. To reduce the PLPDA size even further, several miniaturization techniques are used. The most commonly used miniaturization technique for PLPDAs is top-loading, where different shaped elements like T-shaped [8]-[9], double-T shaped, hat-shaped [8], arc-shaped [10], C-shaped [11] or any other shapes are added at the termination of dipole elements. Adding different dipole shapes at the termination of the dipole element ensures that the overall dipole length is unchanged while the overall antenna size is reduced.

This paper proposes a design of a PLPDA where the longest dipole is replaced by a triangular shaped one in order to increase the bandwidth of the antenna in the lower frequency band. The proposed antenna design operates from 400 MHz to 8 GHz providing a gain of approximately 5.5 dBi.

2 A conventional LPDA design

The idea of frequency independent antennas with wideband frequency range was initially proposed by Rumsey [12]. This study provided a foundation for the development of LPDAs as shown in [13]-[14]. Based on the study, the conventional LPDA design guidelines were proposed by Carrel [15]. A schematic diagram showing the geometry of an LPDA is shown in Figure 1. The dipole elements of the LPDA, usually cylindrical in shape, are embedded to the two tubular longitudinal parallel supports (booms), in an angular sector of 2α. The dipoles are arranged in a crisscross fashion such that first half-dipole is attached to the upper boom and the other half-dipole is attached to the lower boom. The dipole lengths and the spacing between the two consecutive dipoles increases from the front part of the antenna to the rear part of the antenna. The crisscross arrangement of dipoles with an appropriate spacing between two consecutive dipoles ensures that a phase reversal of 180 degrees is achieved between two consecutive dipoles[16]. The gain of LPDAs depend on the number of dipoles used [17].

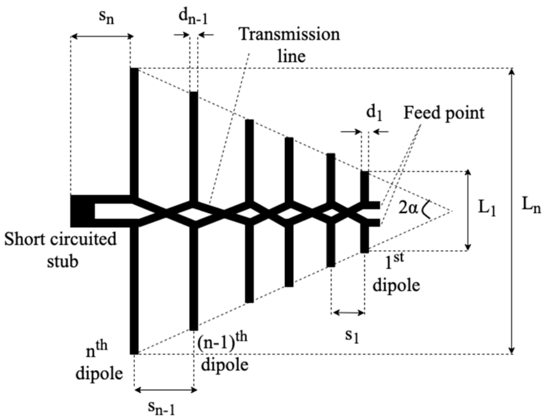

Figure 1. A conventional LPDA geometry.

LPDAs are frequency independent antennas because their geometry and physical dimensions are completely dependent on a scaling factor (τ) and spacing factor (σ) [15]. The half-angular sector α of the LPDA depends on the scaling factor as well as the spacing factor of the antenna design, and can be mathematically expressed as:

$$\alpha = \tan^{-1}\left[\frac{1-\tau}{4\sigma}\right] \qquad (1)$$

The scaling factor is calculated by determining the ratio of the lengths or the diameters of the two consecutive dipoles, and is mathematically expressed as:

$$\tau = \frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n} \qquad (2)$$

where, L_n and d_n are respectively the length and the diameter of the nth dipole. The spacing factor defines the spatial arrangement of the dipoles, and is mathematically written as:

$$\sigma = \frac{s_n}{2L_n} \qquad (3)$$

where s_n is the spacing between the nth dipole and its consecutive $(n+1)^{th}$ dipole and L_n is the length of the n^{th} dipole.

3 Proposed PLPDA antenna design

Initially, a conventional 25-dipole LPDA was designed to operate from 700 MHz to 8 GHz to obtain a gain of approximately 6.5 dBi. The scaling factor τ = 0.90 and spacing factor σ = 0.16 are chosen to obtain the dimensions using design guidelines proposed by Carrel [15]. The size of this conventional LPDA antenna, was then reduced by designing a similar LPDA on a dielectric substrate. In order to transform the conventional LPDA design to a PLPDA design, the effective dielectric constant ε_{eff} of the substrate should be considered. The lengths of the dipoles, the dipole diameters and the spacings between the dipoles are modified by calculating $(l_n/\sqrt{\varepsilon_{eff}})$, $(d_n/\sqrt{\varepsilon_{eff}})$ and $(s_n/\sqrt{\varepsilon_{eff}})$ respectively. The PLPDA antenna designed using these dimensions has a reduced size compared to a conventional LPDA but can still operate from 0.7 GHz to 8GHz. In this case, an FR4 substrate with dielectric constant of 4.3 and 1mm thickness was used to design the PLPDA. The studies presented in [18], validate that the longer dipoles at the rear part of the LPDA are responsible for antenna performance at the lower frequencies and the smaller dipoles at the front part of the antenna are responsible for antenna behaviour at the higher frequencies. Therefore, in order to extend the operating frequency range of the antenna at lower frequencies, the longest dipole element of the transformed PLPDA design was first replaced by a triangular dipole. Then, the lengths and the thickness of the last four dipoles (including the triangular dipole) were optimised to extend the bandwidth of the antenna. The optimization of these parameters in this case, was performed using the Trusted Region Framework (TRF) algorithm in CST Studio Suite. However, several other optimization algorithms can be used for optimization. A comparison of evolutionary algorithms used for LPDA optimization is presented in [19]. The optimization of the PLPDA with triangular longest dipole resulted in an increased operating frequency range from 400 MHz to 8 GHz. A CST model of the optimized PLPDA with the triangular longest dipole is shown in Figure 2.

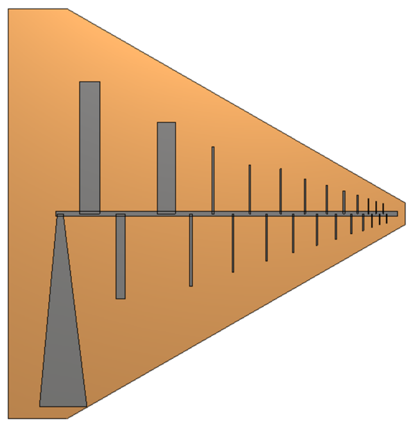

Figure 2. A CST model of the proposed PLPDA antenna.

The upper boom and the dipoles embedded to it are printed on the upper-side of the substrate whereas the lower boom and the dipoles embedded to it are printed on the lower-part of the substrate. The overall dimensions of the optimized PLPDA are: 270 mm x 279 mm x 1mm.

4 Results

Figure 1 shows the return loss of the optimized PLPDA design with the triangular dipole. This graph suggests that proposed antenna has low return loss below -10 dB in most of its operating bandwidth. This also suggests that the antenna has a good matching. However, the return loss from 650 MHz to 750 MHz needs further improvement. This can be further improved by replacing the 22^{nd} , 23^{rd} and 24^{th} dipole element of the proposed design with triangular dipoles. However, the modified design will again need to be optimized considering the physical dimensions of the last 4 dipoles as well as the spacing between them as parameters for optimization.

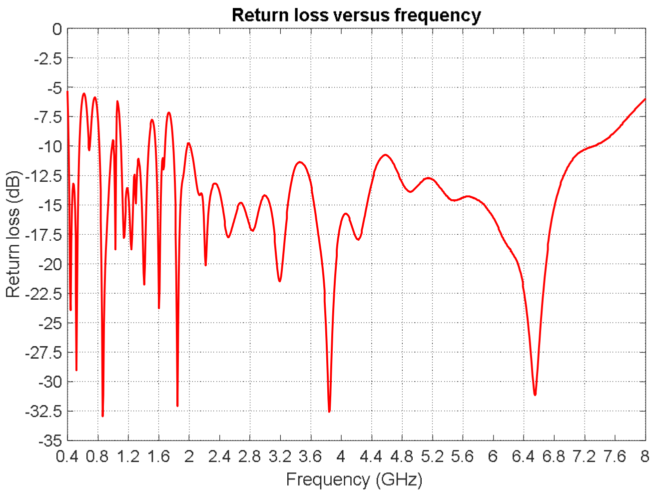

Figure 3. Simulated return loss of the proposed PLPDA antenna.

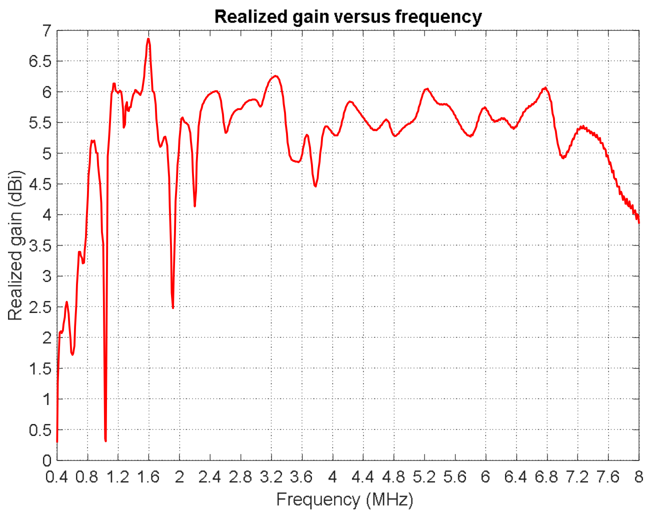

Figure 4. Simulated realized gain of the proposed PLPDA antenna.

Figure 4 presents the realized gain of the proposed antenna. The antenna achieves a realized gain of approximately 5.5 dBi. However, a lower gain is observed from 400 MHz to 800 MHz, and therefore, a further improvement of the antenna gain is required. This can be done by using several other bandwidth-enhancement techniques or by increasing the number of dipoles.

5 Conclusion

A PLPDA antenna design with a triangular longest dipole is proposed in this paper, that has an operating frequency range from 0.4 GHz to 8 GHz. The antenna provides a realized gain of approximately 5.5 dBi and above in most of its operating bandwidth. The proposed antenna has a reduced overall size compared to a conventional LPDA as well as a conventional PLPDA. The antenna is 270 mm long, 279 mm wide and 1 mm thick.

7 References

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