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Parametric evaluation of microstrip log periodic dipole array antenna using transmission line equivalent circuit

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ABSTRACT

This paper presents the design of a Microstrip Log Periodic Dipole Array (MLPDA) antenna for wireless communication in C band. A simplest structure of the edge fed Microstrip Log Periodic Dipole Array is chosen as base design. The parameters of proposed antenna are identified by investigating the effect of variation in geometrical structure on gain and bandwidth. A scale factor (τ) and a spacing factor (σ) are defined accordingly and imposed, in order to create the variations in these parameters. Complexity of parametric variations involved has been observed through change in bandwidth and realized gain of proposed MPLDA. A transmission line equivalent circuit of the proposed MLPDA is developed to give physical insight of the structure and validation. Log periodic nature of the proposed antenna array is verified by plotting input impedance with logarithm of frequency over the specified range. To validate the results, prototype of proposed antenna is realized in the high frequency laboratory and results are verified with few experimentally measured values.

1. Introduction

The conventional Log Periodic Dipole Array antenna design was proposed by R.H. Du Hamel and D.E Isbell in 1957 for broadband applications [1–4]. The Printed Log Periodic Dipole Array (PLPDA) antenna was presented by Campbell et al. in 1977 [5]. A microstrip based structure of log periodic dipole array was introduced first time using modified Carell's method [3]. Later on the basic geometry of a strip line Log periodic dipole antenna introduced by Campbell et al. has been modified sequentially by several researchers to achieve better antenna performance in terms of large bandwidth, reduced size, improved front to back ratio, low cross polarization level and better gain [6–8].

A wide variety of techniques have been proposed for size reduction, bandwidth enhancement, gain improvement, feeding techniques and cross polarization of PLPDA [9–22]. Gheethan et al. in [9] and Anagnostou et al. in [10] has reduced the size of PLPDA by using Meander shaped and Koch shaped dipoles respectively. A reconfigurable PLPDA with switching elements which operates in two modes to cover two bandwidths has been presented in [11]. Self-similarity property of fractals is used by authors in [12] by using tree dipole structure. An improved front to back ratio design of PLPDA for RFID application has been achieved in 2002 [13]. Casula et al. have proposed UWB PLPDA, in C, X and Ku bands with improved feeding structure of mirror coaxial cable to obtain stable phase center [14]. This structure was not easily realizable. Hence same authors have suggested CPW (Co planer waveguide) fed PLPDA with wide working band of 3–6 GHz with relatively large axial dimension [15]. An UWB low cross polarization PLPDA with a stable gain around 8 dB for 0.8–7 GHz range using FR4 substrate is given in [16]. A multiband antenna in S-C band for whether a radar application is proposed in [17]. Zhai et al. have designed a super high gain PLPDA antenna Using SIW (Substrate Integrated Waveguide) technology in Ka band (25–40 GHz) [18]. A non-cross feeding structure for PLPDA to avoid complexity in feeding with long coaxial line was suggested by Kang et al. [19]. But this antenna design is less efficient along with lagging of 180° additional phase shift in conventional cross feed structure, which eventually results in less bandwidth. A compact wideband Printed LPDA antenna for WLAN applications in 5 GHz band have been proposed in [20].

The research is comparatively limited in parametric analysis of PLPDA to understand its basic phenomenon of working. Pantoja et al. have given deep insight of feeding technique and effect of dielectric substrate in the basic design of PLPDA [7]. It explains the basic feeding mechanism by using a balun (balance to unbalance transformer) analysis that relies on a quasi static model of

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the transmission lines involved [7]. Abri et al. have proposed the transmission line model of a series fed log periodic antennas array over a band of frequencies for satellite communications [21]. A 14 element monolayer multi octave log periodic microstrip antenna have suggested by Lei et al. [22]. A series fed structure is analyzed using an equivalent circuit of patch antenna elements, for gap feed and direct feed of patches [22].

The performance of Microstrip Log Periodic Dipole Array (MLPDA) mainly determined by length, width and spacing between dipoles, interleave factor σ, and geometry constant τ. Antenna bandwidth, gain and radiation pattern are governed by these parameters. In this work, an effort is made to analyze the effect of parameters on reflection coefficient (S_{11}), realized gain and radiation pattern of MLPDA. An equivalent circuit model has also been presented to give more physical insight of the resonance behavior of antenna. Present analysis shows complexity of parametric variations in the design of MLPDA and can be helpful in design of optimized antenna in terms of size, bandwidth and gain.

In rest of the paper, Section 2 gives the design of proposed MLPDA antenna followed by its detailed analysis in Section 3. In Section 4, experimental outcomes of realized antenna are presented. Finally conclusions are made in Section 5.

2. Proposed microstrip log periodic dipole array (MLPDA) antenna

This work presents a detailed analysis of eight element MLPDA antenna using FR4 substrate (ε_r = 4.4 and width h = 1.6 mm) [20]. The structure is very close to a standard (wire) LPDA and therefore the standard strategy of designing LPDA can be used [3], along with some modifications (Fig. 1). The property of antenna is mainly determined by 3 parameters; the scale factor τ, spacing factor σ and number of diploes N. All the adjacent dipoles elements are printed on two sides of micro strip substrate, in an alternate way and are fed with coaxial cable at lower end using 50 Ω SMA connector.

All the elements of antenna are fed by a paired microstrip to match the resistance of 50 Ω. Fig. 1 completely describe the geometry of MLPDA, where L_1, L_2...L_8 are half lengths of dipole element, W_1, W_2,.....W_8 are widths of dipole element, S_1, S_2......S_8 are center to center spacing between dipoles, W_s is width of strip line and K is feed length. For proper analysis of the antenna layout, microstrip dipole elements of upper layer are denoted by odd numbers 1, 3, 5, 7...0.15, while the lower layer dipole elements are denoted by even numbers 2, 4, 6...16.One complete dipole is formed by considering upper and lower dipole elements as one unit, which is distributed asymmetrically over the strip length. For calculating the width of parallel strip feed line to match the required impedance of 50 Ω, a 25 Ω standard micro strip with substrate height of $h/2$ is designed using calculations given in [14]. The resulting width of parallel strip obtained is 4.185 mm (=W_s). The effective dielectric constant is calculated by using relation;

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \frac{1}{\sqrt{1 + \frac{10 \times h}{W_s}}} \quad (1)$$

The calculated value of ε_{eff} = 3.6962, from Eq. (1). Now, starting with required bandwidth of $(f_u - f_l)$ GHz, where f_u is upper cut off frequency and f_l is lower cutoff frequency and following the rules given in [23], the length of largest dipole L_{max} is determined as:

$$L_{max} = K_1 \lambda_{max} \quad (2)$$

where $\lambda_{\max}$ is the largest effective wavelength at the lowest operating frequency f_l, and is given as;

$$\lambda_{max} = \frac{c}{\sqrt{\varepsilon_{eff}} \times f_l} \quad (3)$$

K_1 is upper truncation constant that depends on scaling factor τ and is calculated using Eq. (4) [23],

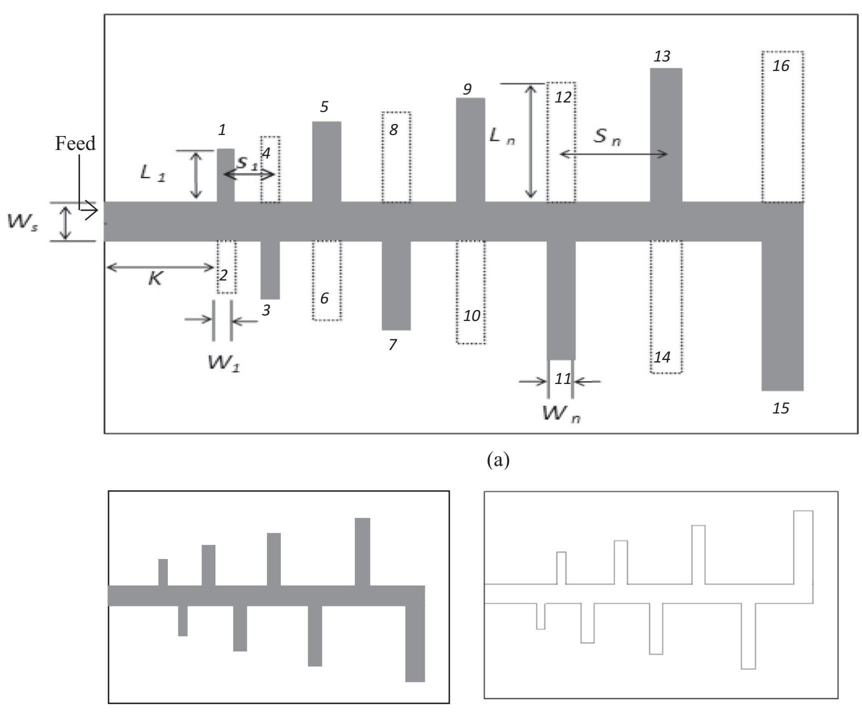

Fig. 1. Geometry of 8 element printed log periodic dipole array antenna (a) Complete schematic layout, (b) upper layer (solid lines), (c) Lower layer (blanked lines).

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