Microstrip Log-periodic Dipole Array Antenna

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1. Introduction

It is required to develop a broadband antenna which can provide ultra wide band operations in the wireless communications systems. The log-periodic dipole array (LPDA) antenna has been proposed as one of the broad band antennas. Although it has an infinite range of bandwidth theoretically, its bandwidth is restricted by both of the high frequency and the low frequency limits; the high frequency limit is determined by the manufacturing precision of the smallest dipole element near feed point and the low frequency limit is also determined by the physical dimension of the largest dipole element. Many researches have been devoted to make a small size LPDA antenna by reducing its low frequency cutoff so that the lower frequency is available with the same physical length of the largest element; the trials of helical elements [1], various forms of capacitive loading and element folding [2], and double ridged waveguide shaped dipole elements [3] have been studied. Those size reduction techniques, however, affect the performance of the antenna such as the gain and the VSWR as compared to a full size structure. Also the design method of LPDA antenna has been studied by many researchers [4], [5], [6].

On the other hand, the microstrip antenna has some advantages of low profile, light weight, small size and easiness of printed-circuit construction while it has the narrow bandwidth problem. In this paper, the microstrip LPDA (MS-LPDA) antenna using the dielectric substrate is designed and the impedance and VSWR of the MS-LPDA antenna are measured and analyzed. The MS-LPDA antenna is basically designed by following the design procedure of Carrel [4], but the size reduction is realized by using the effective dielectric constant ϵ_{eff} [7]. In addition the feeding technique by using a semi-rigid coaxial cable is studied.

2. Design of MS-LPDA Antenna

In general, there are three parameters in designing the LPDA antenna; the geometric ratio τ, the spacing factor σ, and the angle α, which are derived from the structure of the LPDA antenna. The design procedure of the LPDA antenna has been proposed by Carrel [4], which took into account the mutual coupling between dipole elements and presented a step-by-step procedure. However, later studies and experimental results have shown that Carrel's method has considerable discrepancies between designed antenna and manufactured one [5], [6]. Although some corrections have been added to Carrel's method, the basic procedure is valid for the LPDA antenna in free space condition. In the case of the MS-LPDA antenna, the dielectric substrate makes it difficult to maintain proper tapered-spacing between the feed lines and to determine the characteristic impedance of the feed lines as well as the characteristic impedance of the dipole elements. Therefore the design procedure of the MS-LPDA antenna with the dielectric substrate should be different from that of the LPDA antenna in free space. However, some procedures of the LPDA antenna design can be used for the MS-LPDA antenna because the basic design concept is the same. First, the design parameters of τ and σ are selected by following Carrel's curves of constant free-space directivity [4], because the gain curves of the MS-LPDA antenna, considering the dielectric substrate, may have the same tendency as those of the LPDA antenna in free space even though the gain degradations are expected. The concept of active region bandwidth B_{ar} is also used from [8]. The length of feed line or the length L is determined by

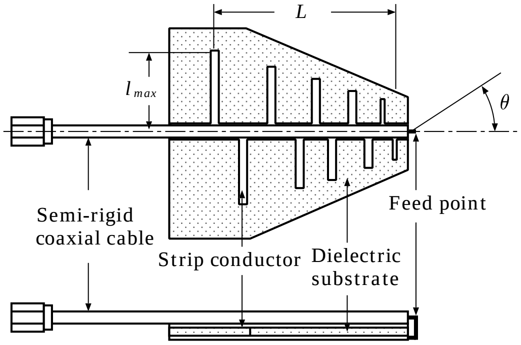


Figure 1: The MS-LPDA antenna.

Table 1: The MS-LPDA antenna parameters.

Substrate material	Teflon
Freq. range (GHz)	4∼14
Substrate ϵ_r	2.6
Geometric ratio τ	0.8
Spacing factor σ	0.14
Angle α (°)	20
Element no.	10
Feed line length L (mm)	36.98
Feed line width (mm)	1
l_{max} (mm)	12.5
Width of l_{max} (mm)	3

$$L = \frac{\lambda_{max}}{4}\left(1 - \frac{1}{B_s}\right)\cot\alpha, \tag{1}$$

where λ_{max} is the wavelength of the lowest frequency and B_s is the designed bandwidth. The length of the largest dipole element l_{max} is determined by

$$\lambda_{max} = 2l_{max} = \frac{v}{f_{min}}, \qquad v \simeq \frac{c}{\sqrt{\epsilon_{eff}}}. \tag{2}$$

The overall size of the MS-LPDA antenna is reduced by the dielectric substrate with the effective dielectric constant ϵ_{eff} [7]. The number of dipole elements is determined by

$$N = 1 - \frac{\ln B_s}{\ln\tau}. \tag{3}$$

It is very difficult to determine the width of the conductors, both the feed line and the dipole elements. For simplicity, it was determined from the characteristic impedance of the parallel strip lines separated by a dielectric substrate [9]; the width of conductor is determined so that the characteristic impedance of the strip line is to be 50 Ω. For the frequency range of 4–14 GHz, the length of the smallest dipole element determines the width of the feed line.

As to the feed of the microstrip antennas using log-periodic structure two different types of the feeding structure have been reported; a corporate feed using coplanar line [10] and a series feed [11]. To achieve a wide bandwidth, the series feed is used rather than the corporate feed because the latter has significant loss. On the other hand, the series feed uses basically the electromagnetic coupling to the antenna elements, and it requires additional dielectric layers. In this paper, an asymmetrically soldered semi-rigid coaxial cable is used to feed the MS-LPDA antenna as shown in Fig. 1. Although the symmetric structure of the feed lines is desirable, the asymmetrical structure is used for the simplicity of manufacturing because the VSWR of both the symmetrical and asymmetrical structures is found to be almost the same through many experiments. The desired bandwidth is 4–14GHz and the design parameters are given in Table 1. The effective dielectric constant ϵ_{eff} is 2.29 from [7].

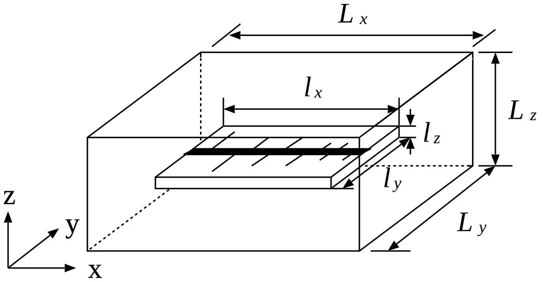


Figure 2: The FDTD analysis model.

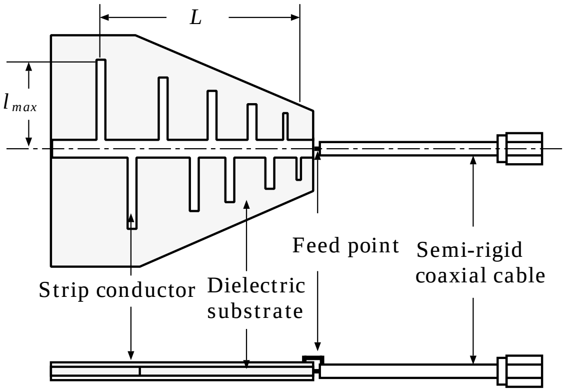


Figure 3: The MS-LPDA model without coaxial cable.

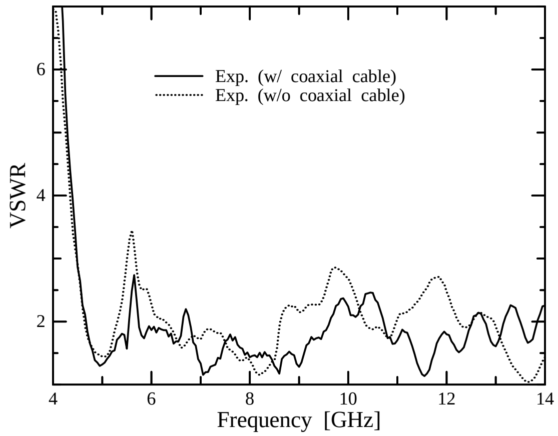
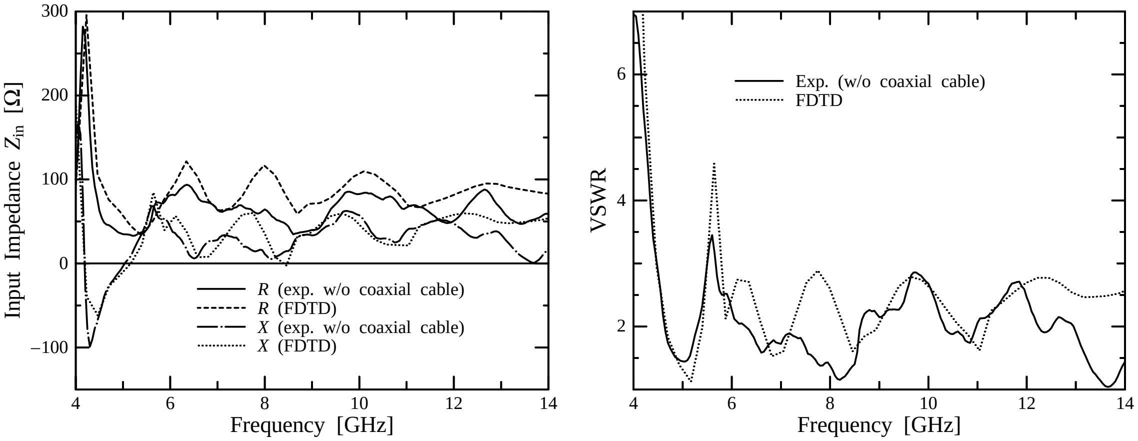


Figure 4: The Comparison of the VSWR.



(a) (b)

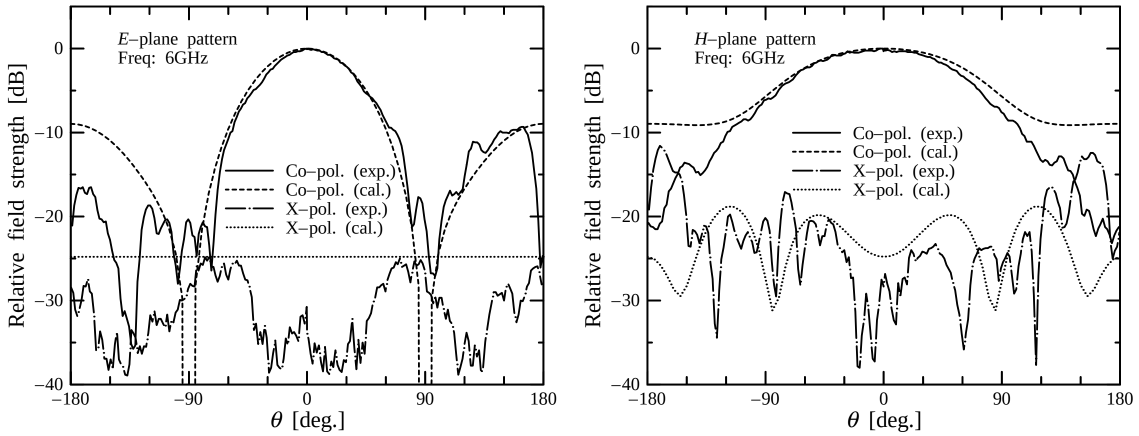
Figure 5: (a)The input impedance and (b) the VSWR of the MS-LPDA antenna.

3. Experimental and Numerical Results

The FDTD (Finite Difference Time Domain) method is used to analyze the designed MS-LPDA antenna. The semi-rigid coaxial cable is not included in the model of analysis. The geometry of the model is illustrated in Fig. 2, where each cell size is $\Delta x = \Delta y = \Delta z = 0.1$ mm, and the dimensions of computing space are $L_x = 492$ cells, $L_y = 420$ cells and $L_z = 128$ cells. The dimensions of the antenna are $l_x = 372$ cells, $l_y = 300$ cells and $l_z = 8$ cells, so that there are 60 extra cells between the absorbing boundary and the antenna.

Since the semi-rigid coaxial cable is excluded from the analysis model, both the input impedance and VSWR of the MS-LPDA antenna without the semi-rigid cable, as illustrated in Fig. 3, are measured for the comparison. Fig. 4 shows the VSWR of the MS-LPDA antenna with and without the semi-rigid cable; the semi-rigid cable is considered to influence the VSWR. The VSWR is less than 2.5 for almost all the frequency range in the experimental results of the semi-rigid cable; for large part of the frequency range the VSWR is less than 2.

The comparisons of the experimental and numerical results, in both the input impedance and the VSWR, are shown in Fig. 5 (a) and (b), respectively. The numerical results agree to the experimental results. The measured and calculated radiation pattern of the MS-LPDA are shown in Fig. 6 (a) and (b), which are the E-plane pattern and the H-plane pattern, respectively. There is a reasonable agreement between experimental and calculated results, especially in the co-polarization, for both the E- and H-planes.



(a) (b)

Figure 6: (a) The E-plane and (b) the H-plane pattern of the MS-LPDA antenna.

4. Conclusions

The Teflon based broadband MS-LPDA antenna has been designed and analyzed. Size reduction of the antenna is achieved by down-scaling of $1/\sqrt{\epsilon_{eff}}$. Experimental results show that VSWR of the MS-LPDA with the semi-rigid coaxial is less than 2.5 for almost 4–14GHz frequency range and that the experimental and numerical results agree well in the input impedance, the VSWR and the patterns of E- and H-planes.

References

[1] J. S. Chatterjee and M. N. Roy, “Helical log-periodic array,” *IEEE Trans. Antennas Propagat.*, vol. AP-16, pp. 592–593, December 1964.

[2] D. F. DiFonzo, “Reduced size log-periodic dipole antennas,” *Microwave J.*, vol. 7, pp. 37–43, December 1964..

[3] S. C. Kuo, “Size-reduced log-periodic dipole array antennas,” *Microwave J.*, vol. 15, pp. 27–33, December 1972.

[4] R. L. Carrel, “The design of log-periodic dipole antennas,” in *1961 IRE Int. Conv. Rec.*, vol. I, pp. 61–75.

[5] G. D. Vito and G. B. Stracca, “Comments on the design of log-periodic dipole antennas,” *IEEE Trans. Antennas Propagat.*, vol. AP-21, pp. 303–308, May 1973.

[6] G. D. Vito and G. B. Stracca, “Further comments on the design of log-periodic dipole antennas,” *IEEE Trans. Antennas Propagat.*, vol. AP-22, pp. 714–718, September 1974.

[7] I. J. Bahl and Ramesh Garg, “Simple and accurate formulas for a microstrip with finite strip thickness,” *Proc. IEEE*, vol. 65, pp. 1611–1612, November 1977.

[8] C. A. Balanis, *Antenna Theory*, John Wiley & Sons, New York, 1982, pp. 427–439.

[9] H. A. Wheeler, “Transmission-line properties of parallel strips separated by a dielectric sheet,” vol. MTT-12, pp. 172–185, 1965.

[10] Pues, H., Vandesande, J., and Van De Capelle, A., “Broadband microstrip resonator antennas,” in *IEEE APS Int. Symp.* , pp. 268–271, Washington DC, May 1978.

[11] Hall, P. S., “Log periodic microstrip patch array,” UK Patent Application 7940382, 22nd November 1979.