Design and Modelling of Printed Log Periodic Dipole Array Antenna with Different Feeding Methods

Abdulghafor A. Abdulhameed
Department of Electronics and Information Technology
Faculty of Electrical Engineering
University of West Bohemia
Pilsen, Czech Republic
ORCID: 0000-0003-0027-2607
abdalhme@fel.zcu.cz

Zdeněk Kubík
Department of Electronics and Information Technology
Faculty of Electrical Engineering
University of West Bohemia
Pilsen, Czech Republic
ORCID: 0000-0002-3328-6741
zdekubik@fel.zcu.cz

2022 International Conference on Applied Electronics (AE) | 978-1-6654-9482-3/22/$31.00 ©2022 IEEE | DOI: 10.1109/AE54730.2022.9919886

***Abstract*—This paper presents the design and analysis of a traditional printed log-periodic dipole array antenna with two feeding methods: direct feeding and straight coaxial feeding. Ten linear dipoles have been arranged in logarithmic style to cover an operating frequency bandwidth from 0.7 GHz to 2.3 GHz with a direct feeding method. At the same time, the same structure offered impedance bandwidth from 0.7 GHz up to 8 GHz with a coaxial feeding method. Moreover, the results showed that the coaxial cable method has lower antenna gain than a direct feeding method. Two different insulator materials have been utilized in the simulation of the coaxial cable feeding method to present the reason for achieving lower gain; air (lossy-free) and epoxy FR-4 ($\varepsilon_r = 4.4$). The simulation results of both feeding methods are in line with the measurement results.**

Keywords*—*Coaxial feeding method, EMC measurement, PLPDA, Radiation pattern, Realized gain, Wideband

I. INTRODUCTION

Recently, the massive developments in the telecommunication field stimulated the designers to increase demand for wideband antennae to handle a high-speed transmission with high gain and steady phase center [1]. The log-periodic dipole array antenna (LPDA) is a candidate antenna for the abovementioned purpose. It has many advantages like wideband since it is frequency-independent and consists of linear polarized dipoles with steady phase shift and end-fire radiation. It also has a considerable gain suitable for different applications [2]. The main problem with the LPDA antenna is that its large size makes it impossible to utilize in some applications that require a compact antenna. Therefore, printed log-periodic dipole array antenna (PLPDA) got more flexibility with the help of printed circuit board technology (PCB) features like low cost, low profile, and miniaturization techniques that can perform for size reduction and bandwidth enhancement [3].

Even with miniaturization techniques, the PLPDA antenna is still inconvenient to be integrated into the microwave circuits, especially those working at low-frequency bands. On the other hand, it would be an excellent candidate to use in other applications like reference antenna in electromagnetic compatibility (EMC) measurements [4], ultra-wideband (UWB) reception antenna [5], etc. In the last decade, several structures of PLPDA antenna operating from 700 MHz up to 2.4 GHz have been proposed with different feeding methods to serve many applications like Global Mobile System (GSM), Global Position System (GPS), Wireless fidelity (Wi-fi), etc. [6]. In [3], the authors presented step-by-step design procedures of a PLPDA antenna with 12 elements operating from 800 MHz to 2.5 GHz. The 50 Ω SMA direct port that feeds the structure reflects a slight deviation between the simulation and measurement results. The size of the PLPDA antenna presented in [3] has been optimized using Trusted Region Framework (TRF) algorithm in CST Microwave Studio in [7], which also uses a direct feeding method of 50 Ω SMA port.

On the other hand, the coaxial cable feeding method has been utilized in several articles. A balance coaxial cable method has been used to get wideband impedance bandwidth (0.5 GHz to 3 GHz) [8]. In [9], a dual-band dipole element technique was used instead of the classical dipole to reduce the size of the boom axial of the antenna. The exciting thing here is that the measured gain is lower than the simulated one due to the feeding method. A PLPDA antenna with size reduction and bandwidth enhancement has been presented in [10]. The compact size has been achieved using hat-shaped and T-shape loading techniques on the first six elements, while using the trapezoidal stub and meandered line techniques helped the author get wideband from 0.55 up to 9 GHz. [10] has the same problem between the simulated and measured gain as in [9]. Coplanar waveguide feeding method has been employed for PLPDA antenna in [11], this feeding method will make its balun using microstrip line to achieve wide bandwidth.

This paper presents the design of a conventional PLPDA antenna for EMC measurements, operating from 0.7 GHz up to 2.3 GHz with two different feeding methods to show their impact on impedance matching, gain, and radiation pattern. The antenna design is described in Section II, Section III presents the feeding methods with the simulation and measurement results, and finally, a brief conclusion is summarized in Section IV.

II. ANTENNA DESIGN

Design a traditional printed log-periodic dipole array antenna follows standard steps start with estimating the scaling factor and spacing factor from carrel diagram based on the desired directivity [6]. The number of dipole elements N can be evaluated using the following equations:

$$N = 1 + \frac{\log B_S}{\log\frac{1}{\tau}}, \tag{1}$$

$$B_S = B.B_{ar} = \frac{f_{upper}}{f_{lower}} \times B_{ar}, \tag{2}$$

$$B_{ar} = 1.1 + 7.7(1-\tau)^2\frac{4\sigma}{1-\tau}. \tag{3}$$

where, B_S and B_{ar} are the structure bandwidth and the active region bandwidth, respectively. τ represents the scaling factor and σ is the spacing factor.

The standard dipole equation (4) computes the length of the most extended dipole L_1 from the minimum frequency. At the same time, the spacing between the successive dipoles is calculated by comparing lengths of consecutive dipoles with the help of the spacing factor σ and scaling factor τ, as shown in equation (5).

$$L_1 = \frac{1}{2} \times \frac{3\times10^8}{f_{lower}}. \tag{4}$$

$$R_1 - R_2 = \frac{L_1 - L_2}{2} \times \frac{4\sigma}{1-\tau}. \tag{5}$$

The width of the first dipole can be evaluated using equations (6, 7).

$$Z_0 = \frac{377}{\pi}\left(\ln\left(\frac{L_n}{a_n}\right) - 2.25\right), \tag{6}$$

$$W_n = \pi \times a_n, \tag{7}$$

where Z_0 represents the characteristic impedance (50 Ω). Since we deal with the PCB technology, the whole dimensions must be divided by the square root of effective relative permittivity [9]. The effective dielectric constant is described by equation (8).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}}. \tag{8}$$

Figure 1 presents the geometrical shape of this antenna, while Table I. illustrates the optimum dimensions of this structure.

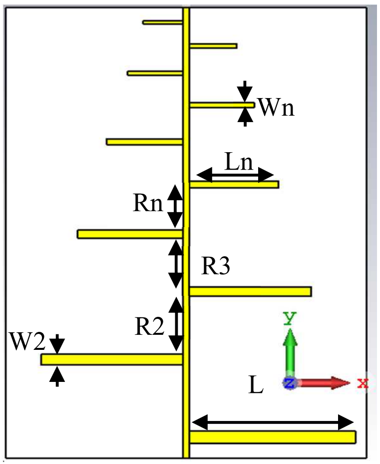


Fig. 1: Geometrical shape of the proposed antenna

TABLE I. THE OPTIMUM DIMENSIONS OF THE PROPOSED ANTENNA

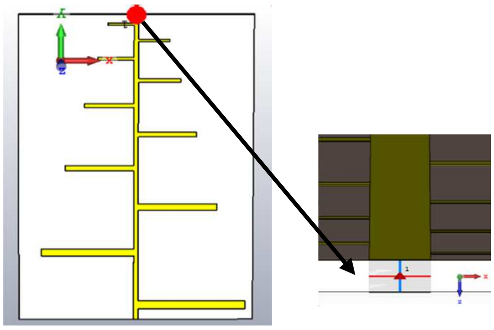
No.	*L* (mm)	*W* (mm)	*R* (mm)
1	150	6	38.6
2	129	5.16	33.2
3	111	4.44	28.5
4	96.4	3.28	24.5
5	82	2.28	21.1
6	70.5	2.43	18.15
7	60.7	2.09	15.6
8	52.2	1.54	13.42
9	44.9	1.33	11.54
10	38.6	1.14	-------

III. FEEDING METHOD

The feeding technique of PLPDA considers one of the critical issues in the design because it affects other antenna parameters like impedance bandwidth, radiation pattern, and gain. The logarithmic arrangement of the dipole set and its connection to the top and bottom layers of the microstrip will give a 50 Ω input impedance at a point of the narrow tip of the structure. The width of the microstrip line w_f connecting the top and bottom layers can be calculated using equation (9)[12].

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r + 1.41}} ln\left(\frac{5.98 \times h}{0.8 \times w_f}\right). \tag{9}$$

where h is the height of the substrate and ε_r is the relative permittivity. The feeding of this point will transfer maximum power to the different array dipole elements antenna. The dipoles are arranged in a style that has a phase difference between every two successive dipoles. The phase difference guarantees that the other dipoles will not participate in radiation while the energy will be emitted from the resonance dipole only.


(a)

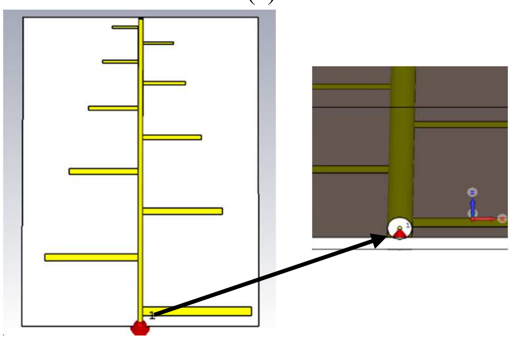

(b)

Fig. 2: Geometrical shape of feeding methods of the proposed antenna, (a) direct feeding method and (b) coaxial feeding method

The active region will move through the whole structure according to the resonance frequency, where at any particular frequency, the dipoles with larger wavelengths will act as reflectors. In contrast, the dipoles with smaller wavelengths would act as directives dipoles. With the help of the phase difference and the electromagnetic waves' group delay, this process will push the radiation toward the narrow end, producing end-fire radiation. The main problem of that radiation is now has a direction opposite to feeding. Two feeding methods have been employed; a direct way which can be modeled in CST Microwave studio by a 50 Ω discrete port, and a coaxial cable method which can be modeled in CST Microwave studio by a coaxial cable with discrete port. Figure 2 presents the geometrical shape of both direct and coaxial cable methods. Both inner and outer diameters of 50 Ω coaxial cable are calculated analytically with the help of the

CST Microwave Studio feature. Table II. illustrates the inner and outer diameters for different materials for substrates like FR-4, Rogger 5880, and lossy-free (air).

TABLE II. LISTS THE RELATIVE PERMITTIVITY OF DIFFERENT STRUCTURES WITH THEIR INNER AND OUTER DIMENSIONS TO GET 50 Ω INPUT IMPEDANCE

Material	Fr-4	Roger 5880	air
ε_r	4.4	2.2	1
d	0.52	0.52	0.52
D	3	1.8	1.2

Figure 3 shows the simulated reflection coefficient for the direct feeding and the coaxial cable with FR-4 substrate. It seems that coaxial feeding offers wide bandwidth (0.7 - 8 GHz) rather than the direct feeding method (0.7 - 2.3 GHz) because the coaxial cable makes its balun and hence enhances the impedance bandwidth [8]. The big question here is whether the reflection coefficient is a conclusive factor in finding out the antenna operating range. Another factor that can help us get a comprehensive idea is the gain, as shown in Figure 4. The antenna can work up to 5 GHz with the coaxial feeding method since the gain value is more than 0 dBi. It was evident that the gain with coaxial cable has values lower than that of the direct feeding method for the whole observing frequencies, as demonstrated in Figure 4. The authors hypothesized that the gain degradation with coaxial cable is because of the lossy material of the coaxial cable and the direction of the energy is counterclockwise to the typical radiation pattern. Different materials (lossy and lossy-free) for coaxial cable have been utilized to validate this hypothesis.

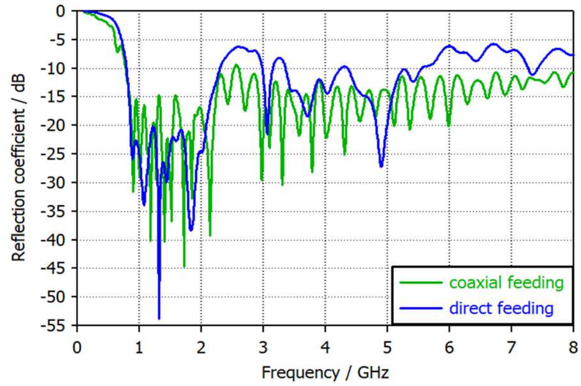


Fig. 3: S11-parameters of the proposed structure versus frequency

Figure 5 shows the simulated realized gain with two different materials, FR-4 and air (lossy-free with ε_r =1). It is turned out that achieved realized antenna gain of coaxial cable with lossy-free material has almost the same values as the direct feeding gain. Hence, the gain degradation has come from the lossy material of the coaxial cable. Despite that, lossy free coaxial cable is not available in reality, so the right choice here is to use coaxial cable with small relative permittivity material close to the air, like using Rogers 5880 with ε_r =2.2.

If the direct feeding has better gain values than coaxial cable, why are different research articles prefer the coaxial cable as in [8-10]?. The coaxial cable indeed degrades the gain. Still, at the same time, it has no degradation radiation pattern due to the feeding point and the radiation direction in different places and it offers wide impedance bandwidth. On the other hand, direct feeding provides good antenna gain with sometimes degradation in the radiation pattern due to the feeding point. It will be demonstrated clearly in practical results.

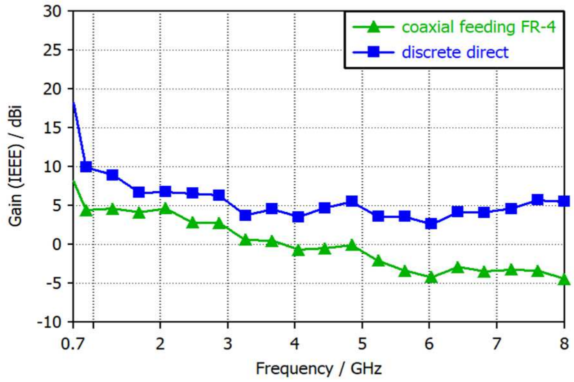


Fig. 4: Gain in dBi of the proposed structure versus frequency

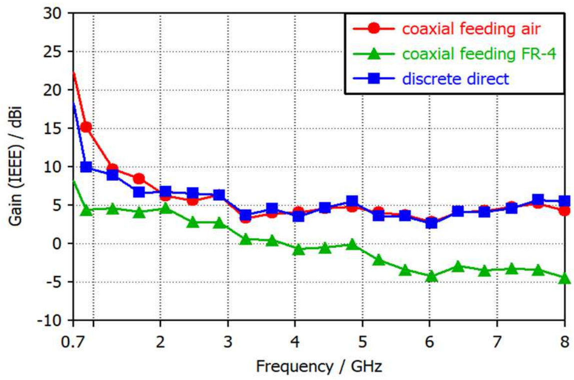


Fig. 5: Realized gain in dBi versus frequency for different materials.

This structure has been fabricated and tested in the EMC laboratory at the University of West Bohemia and it is based on an FR-4 substrate with relative permittivity of 4.4 and loss tangent of 0.025. Figure 6 demonstrates the reflection coefficient measurements setup of the structure with both feeding methods.

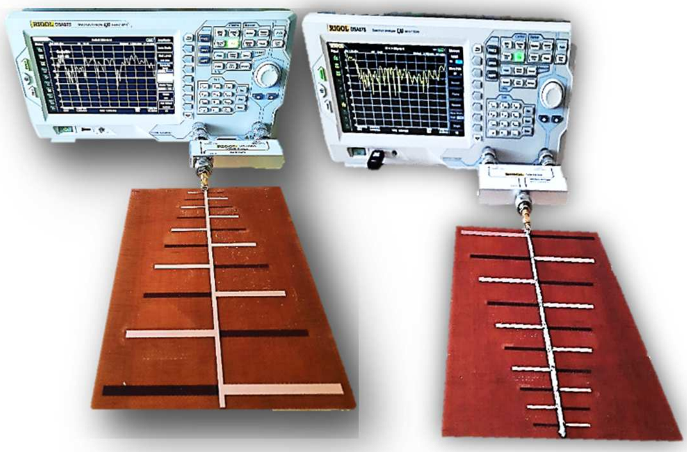


Fig. 6: Illustrates the testing and measurement setup for both feeding methods – reflection coefficient measurements using Network Analyzer.

The measured return losses in Figure 7 are in line with the simulated result shown in Figure 3. Furthermore, the measured realized gain in dBi for both direct and coaxial feeding methods is depicted in Figure 8. As expected, a direct feeding method has achieved a higher realized gain in dBi than the coaxial feeding method. Moreover, the measured gain results agree with the simulated results presented in Figure 4.

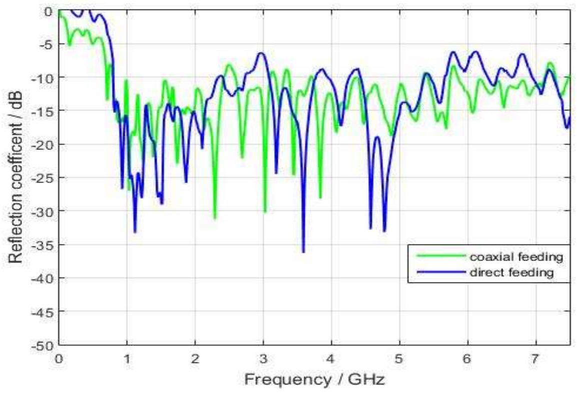


Fig. 7: Testing and measurement results for both feeding methods – measured return losses versus frequency

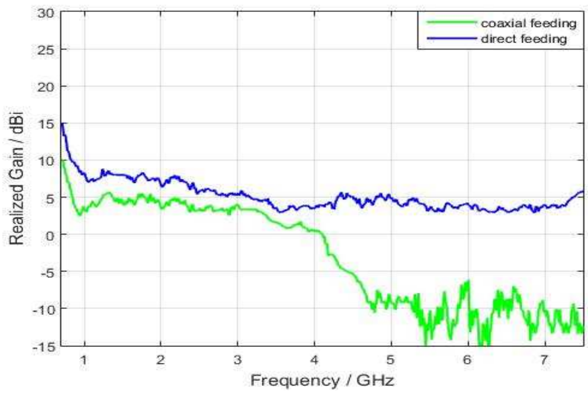
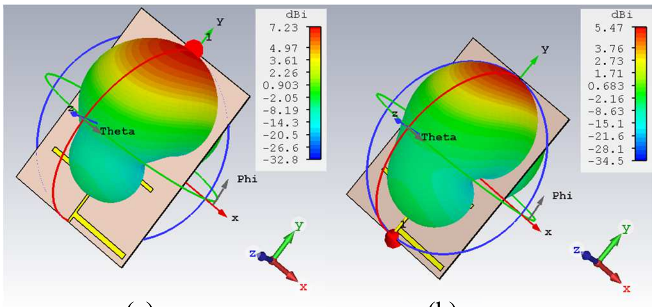


Fig. 8: Measurement results of realized gain in dBi versus frequency for both feeding methods

Figure 9 presents the radiation pattern for both feeding methods at 0.85 GHz. The maximum point of the radiation pattern that shows the maximum gain at his frequency gives 7.23 dBi for the direct feeding method compared with 5.47 dBi for the coaxial method and that's due to the distribution of the radiation pattern difference between these two methods.



(a) (b)

Fig. 9: 3-D radiation pattern distribution for both direct and coaxial feeding methods at 0.85 GHz

IV. CONCLUSION

Different feeding methods for printed log-periodic dipole array antenna have been modeled and simulated in CST Microwave Studio. The coaxial feeding method has better impedance matching than the direct feeding method at the expense of achieved gain due to the losses of the core material inside the coaxial cable. The measurement results for both ways showed good agreement with the simulation results. It should be mentioned that the direct feeding method also has a disadvantage if used for radiation pattern measurements. It would cause a slight deviation between the simulation and measurement results, as noticed in many research papers, due to the direction feeding port against the end-fire direction.

ACKNOWLEDGMENT

This research has been supported by the Ministry of Education, Youth and Sports of the Czech Republic under the project OP VVV Electrical Engineering Technologies with High-Level of Embedded Intelligence CZ.02.1.01/0.0/0.0/18_069/0009855 and by the project SGS-2021-005: Research, development and implementation of modern electronic and information systems.

REFERENCES

[1] Alnahwi, F. M., Abdulhameed, A. A., Swadi, H. L., & Abdullah, A. S. (2020). A planar integrated UWB/reconfigurable antenna with continuous and wide frequency tuning range for interweave cognitive radio applications. *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, *44*(2), 729-739.

[2] Mistry, Keyur K., Pavlos I. Lazaridis, Zaharias D. Zaharis, and Tian H. Loh. 2021. "Design and Optimization of Compact Printed Log-Periodic Dipole Array Antennas with Extended Low-Frequency Response" *Electronics* 10, no. 17: 2044. https://doi.org/10.3390/electronics10172044

[3] Mistry, K.K.; Lazaridis, P.I.; Zaharis, Z.D.; Xenos, T.D.; Tziris, E.N.; Glover, I.A. An optimal design of printed log-periodic antenna for L-band EMC applications. In Proceedings of the 2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility (EMC/APEMC), Suntec City, Singapore, 14–18 May 2018; pp. 1150–1155.

[4] Abdulhameed, Abdulghafor A., and Zdeněk Kubík. 2021. "Investigation of Broadband Printed Biconical Antenna with Tapered Balun for EMC Measurements" *Energies* 14, no. 13: 4013. https://doi.org/10.3390/en14134013.

[5] Mistry, K. K., Lazaridis, P. I., Ahmed, Q., Zaharis, Z. D., Loh, T. H., & Chochliouros, I. P. (2020, October). A printed LPDA antenna with improved low frequency response. In *2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science* (pp. 1-4). IEEE.

[6] Limpiti, T., & Chantaveerod, A. Y. (2016, June). Design of a printed log-periodic dipole antenna (LPDA) for 0.8–2.5 GHz band applications. In *2016 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)* (pp. 1-4). IEEE.

[7] Studio, C.M. CST Computer Simulation Technology AG (2016).

[8] Yu, L., Chai, S., Huang, H., Ding, L., Xiao, K., & Zhao, F. (2016, August). A printed log-periodic dipole antenna with balanced feed structure. In *2016 Progress in Electromagnetic Research Symposium (PIERS)* (pp. 2035-2038). IEEE.

[9] Anim, K., & Jung, Y. B. (2018). Shortened log-periodic dipole antenna using printed dual-band dipole elements. *IEEE Transactions on Antennas and Propagation*, *66*(12), 6762-6771.

[10] Kyei, A., Sim, D. U., & Jung, Y. B. (2017). Compact log-periodic dipole array antenna with bandwidth-enhancement techniques for the low frequency band. *IET Microwaves, Antennas & Propagation*, *11*(5), 711-717.

[11] Casula, G. A., Maxia, P., Montisci, G., Mazzarella, G., & Gaudiomonte, F. (2013). A printed LPDA fed by a coplanar waveguide for broadband applications. *IEEE Antennas and Wireless Propagation Letters*, *12*, 1232-1235.

[12] Abdulhameed, A.A.; Kubik, Z. Design and Modeling of Spiral Circular Magnetic Probe for Near Field Measurements in CST Microwave Studio. In Proceedings of the 2021 International Conference on Applied Electronics (AE), 2021; pp. 1-4.