Progress In Electromagnetics Research C, Vol. 38, 15–26, 2013

DESIGN OF A PRINTED LOG-PERIODIC DIPOLE ARRAY FOR ULTRA-WIDEBAND APPLICATIONS

Giovanni A. Casula*, **Paolo Maxia, Giuseppe Mazzarella, and Giorgio Montisci**

Dipartimento di Ingegneria Elettrica ed Elettronica, Universita' di Cagliari, Piazza D'Armi, Cagliari 09123, Italy

Abstract—A printed Log-periodic dipole array (LPDA) is presented, operating over the C, X and Ku bands. The antenna feeding structure consists of two coaxial cables, in order to realize an infinite balun which provides the required broadband input matching. The second coaxial cable mirrors the first one, connected to the antenna input, and is capable of both stabilizing the antenna phase center and improving the radiation pattern. The antenna has been designed using CST Microwave Studio, with an useful frequency range of 4–18 GHz. Moreover, both simulated and measured results show that the proposed LPDA can be successfully used as an Ultra Wideband Antenna in the range 4.25–13.25 GHz, in which its phase center remains stable.

1. INTRODUCTION

Log-periodic dipole arrays (LPDA) of cylindrical wire dipoles are well known since the 50's, and their design rules are mainly based on the works of Isbel and Carrel [1–3]. Their very large bandwidth (up to a decade), with a reasonable gain, makes them excellent candidates for UWB transmitting and receiving systems [4]. Thanks to these desirable features, log-periodic antennas have been used with different implementations and technologies, aiming to compact realization, low production cost, and broadband applications.

Printed antennas are a common choice for microwave antennas, both for their small weight and size, low cost, and ease of fabrication and integration. Their main drawbacks are the low efficiency, the narrow frequency bandwidth, the relatively high cross-polar

---

Received 27 January 2013, Accepted 4 March 2013, Scheduled 6 March 2013

* Corresponding author: Giovanni Andrea Casula (a.casula@diee.unica.it).

component of the radiated field, and the propagation of the surface wave in the dielectric substrate. The narrow bandwidth, due to the high quality factor of the printed antennas, is a strong limitation for a number of applications, such as radar and wireless communication systems. This limitation can be overcome by using the concept of log-periodic arrays for the design of wideband printed antennas [5].

In the last years, a number of printed LPDAs have been proposed. The design and optimization of these antennas can be easily implemented by tailored numerical techniques [5–8], or general purpose electromagnetic commercial tools [4, 9–14].

To the best of our knowledge, only a few works dealing with printed LPDA antennas operating both in the C, X and Ku bands can be found in the open literature (see, e.g., [8]). Actually, it is difficult to obtain a wideband input matching and a stable phase center over the required bandwidth. Moreover, in [8] the broadband behavior is questionable since the VSWR is greater than 2 for a large part of the required frequency range. As a matter of fact, most of the works deal with antennas operating in the C band, or at lower frequencies [6, 7, 12, 13, 15, 16], and are focused on the study of the best configuration of the dipoles able to reduce the antenna size.

In this work, we propose an implementation of a wideband LP printed array, operating in the C, X and Ku bands (4–18 GHz), showing very good performances, not only among standard LP antennas, but also as an UWB antenna [4]. Actually, in the range 4.25–10.75 GHz, both its gain and phase-center are remarkably stable with respect to the frequency.

A critical point in the design of printed log-periodic arrays is the modeling of the feeding network [11]. The feeding network can be *divided* into two parts: the printed dipoles feeding line, and the external feeding structure. In the antenna simulation, the LPDAs external feeding is modeled as a differential port placed at the narrow end of the antenna, providing the necessary wideband matching. However, this is an *ideal* device because it does not physically incorporate the actual external feeding line and the geometry of the SMA connector. In practice, the wideband matching of a LPDA can be obtained with an infinite balun [17]. In the wire LPDA antennas employed for TV receivers, this infinite balun is realized with a coaxial cable passed through one of the antenna booms and connected to the narrow side of the antenna. In the printed LPDA this infinite balun has been obtained soldering the outer conductor of a coaxial cable to the bottom layer of the LPDA, and connecting the inner conductor to the top layer of the antenna using a via-hole inside the substrate [11]. This allows an antenna with a reasonably large matching and gain bandwidth, but destroys the antenna symmetry. We will show here that the insertion of an additional mirror coaxial cable, soldered in the top layer of the array, allows to obtain not only an excellent input matching and a very good radiation pattern over the whole frequency band, but also the stabilization of the antenna phase center.

The LPDA array has been designed using CST Microwave Studio 2012, a general purpose software for the 3D electromagnetic simulation of microwave components, and the designed antenna has been manufactured with the mirror coaxial cable. Since printed LPDAs at operating frequencies up to the Ku Band are very small, the described feeding technique using coaxial cables presents some realization difficulties, and the soldering of both the feeding and the mirror coaxial cables over the antenna layout could be tricky, and must be adequately implemented, since a careless realization will compromise the antenna matching and behavior.

The comparison between simulated and measured results shows that the proposed LPDA can be used as an Ultra Wideband Antenna in the range 4.25–13.25 GHz, and as a wideband end-fire antenna in the whole operating bandwidth (4–18 GHz).

2. ANTENNA DESIGN

The concept of log-periodic wire-antennas is applied to microstrip printed technology, to get the antenna layout shown in Figure 1. The array dipoles are fed (in an alternate way) with two microstrip lines printed on the opposite sides of a dielectric slab (as in Figure 2(a)).

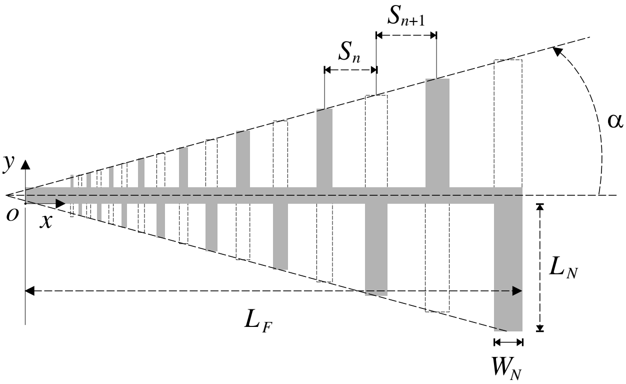


Figure 1. Antenna layout: dark lines on the upper side of the dielectric slab, transparent ones on the bottom. $L_F = 56.92\,\text{mm}$.

As a consequence, the standard approach for the design of LPDAs proposed by Carrel [1] can be used, but with some modifications. Starting from the required bandwidth (4–18 GHz), and following the design rules given in [1], we get the following antenna parameters: Number of dipoles $N = 15$, aperture angle $2\alpha = 30°$, log-period $\tau = 0.85$ for an average directivity of 8.5 dB. The wideband matching of the printed LPDA is obtained with an infinite balun, realized with a coaxial cable. The outer conductor of the coaxial cable is soldered to the bottom layer of the LPDA, and the inner conductor is connected to the top layer of the antenna using a via-hole inside the substrate. In order to improve the antenna performances, an additional mirror coaxial cable, soldered in the top layer of the array, can be used. We have selected the characteristic impedance of the feeding line equal to $50\,\Omega$, so as to obtain an easy matching with the coaxial cable. Since the feeding line (Figure 2(a)) has an anti-symmetric field configuration, its corresponding width can be computed by inserting a dummy ground plane in the middle of the substrate (Figure 2(b)) [18, 19]. As a consequence, we can simply design a $25\,\Omega$ standard microstrip (with $h/2$ slab thickness) and evaluate its corresponding width W by assuming a quasi-static propagation.

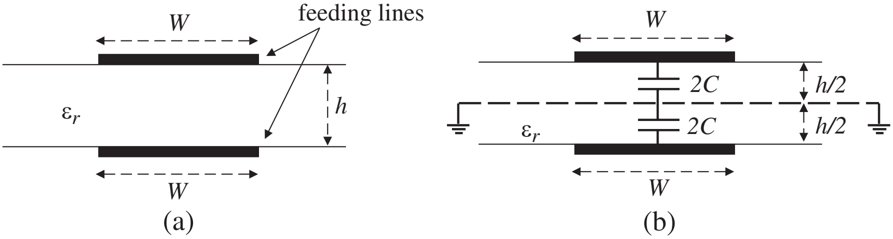


Figure 2. (a) Section of the antenna feeding line. (b) Equivalent circuit for the computation of the line parameters.

Since the printed LPDA lies on a dielectric substrate, the geometric parameters of this antenna cannot be computed as in the case of a standard wire-LPDA [1], which radiates in free space. In our prototype we have used a Arlon AD 250 substrate (with $\epsilon_r = 2.5$ and $h = 0.51\,\mathrm{mm}$), for which the width of the $50\,\Omega$ feeding lines is $W = 1.91\,\mathrm{mm}$. For this specific substrate, the resonant length $2L_N$ of the largest dipole (see Figure 1) at the lowest operating frequency (4 GHz) is computed by using CST Microwave Studio, and is equal to 14.665 mm. The length of the other dipoles is computed according to:

$$\frac{L_{n+1}}{L_n} = \frac{1}{\tau} \qquad n = 15, \ldots, 1 \tag{1}$$

Now, we must compute the width W_N of the largest dipole. Let us consider the following expression:

$$Z_n = \frac{\eta_0}{\pi}\left[ln\left(\frac{L_n}{a_n}\right) - 2.25\right] \tag{2}$$

which was derived by Carrel [3] as the average characteristic impedance of a cylindrical dipole, wherein a_n is the radius of the dipole, and L_n its half-length. We select the radius a_N of the largest dipole in order to give a $50\,\Omega$ average characteristic impedance. Then, we compute W_N by the requirement of equivalent perimeter [10]:

$$W_N = \pi a_N \tag{3}$$

The width of the other dipoles can be computed by using the well know expression for LPDAs [5]:

$$\frac{W_{n+1}}{W_n} = \frac{1}{\tau} \quad n = 15, \ldots, 1 \tag{4}$$

The lengths and widths of the dipoles (see Figure 1) are summarized in Table 1, and their spacings are computed accordingly to [1].

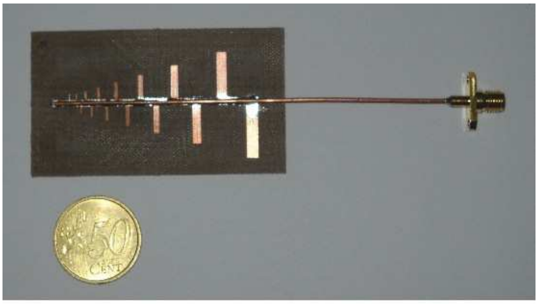
Table 1. Geometry of the designed printed LPDA.

Dipole	L_n [mm]	W_n [mm]	S_n [mm]
1	1.507	0.33	
2	1.773	0.39	0.99
3	2.086	0.45	1.17
4	2.454	0.54	1.38
5	2.887	0.63	1.62
6	3.397	0.74	1.90
7	3.996	0.88	2.24
8	4.701	1.03	2.63
9	5.531	1.21	3.10
10	6.507	1.42	3.64
11	7.655	1.67	4.28
12	9.006	1.97	5.04
13	10.595	2.32	5.93
14	12.465	2.72	6.98
15	14.665	3.20	8.21

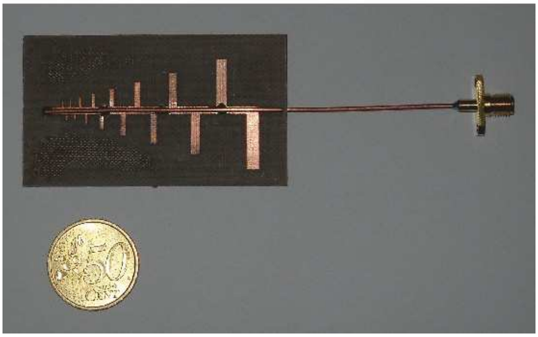
The coupling between the coaxial feeding network and the radiating dipoles degrades the antenna matching, especially in the upper frequency band, where the dipoles are very small. In order to improve the antenna performances at high frequencies, a further dipole is inserted immediately before the dipole 1, with the same width and length, and with a spacing equal to the one between dipole 1 and dipole 2. The inclusion of this further dipole does not imply any change in the overall size of the antenna, but is able to lower the return loss below $-10\,\mathrm{dB}$ in the whole operating bandwidth, as we will show in the following section.

3. RESULTS

The LPDA antenna, designed in Section 2, has been fed by a coaxial cable in order to implement the infinite balun providing the required wideband matching. The outer conductor of the coaxial cable has been soldered to the bottom layer of the LPDA, while the inner conductor



(a)



(b)

Figure 3. Photo of the LPDA antenna. (a) Front. (b) Back.

has been connected to the top layer by a via-hole drilled inside the substrate. Actually, this asymmetric configuration shows a significant drift of the phase center with the frequency. Therefore, the insertion of an additional mirror coaxial cable, soldered in the top layer of the array, has been investigated. The simulations have shown that the latter has significantly better radiation performances, and therefore the designed antenna has been manufactured with the mirror coaxial cable (see Figure 3).

Figure 4 shows both the simulated and measured frequency responses of the input reflection coefficient. We have found that the additional mirror coaxial cable does not modify the antenna input matching, therefore this case is not reported in Figure 4. As apparent, the broadband specification between 4 and 18 GHz is fulfilled with a good agreement between simulation and measurement. In Figure 5, the antenna gain (evaluated by CST) as a function of the frequency is

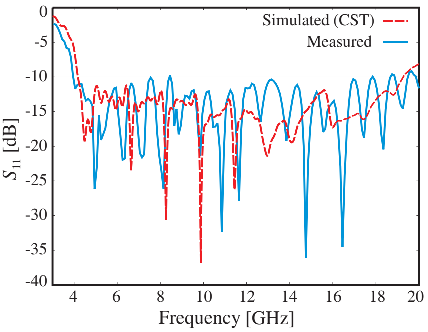


Figure 4. Reflection coefficient of the designed antenna.

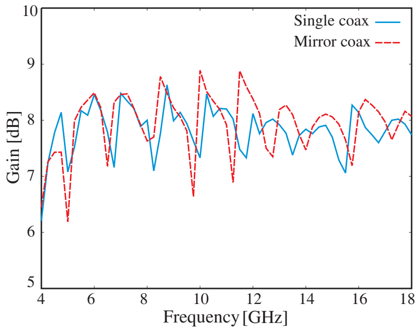


Figure 5. Gain of the designed LPDA antenna.

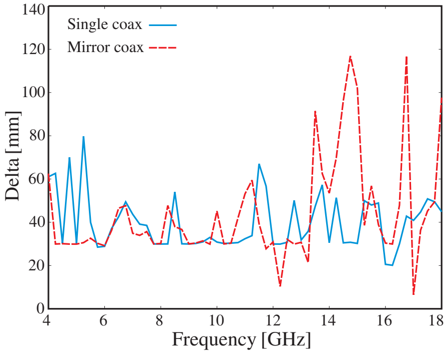


Figure 6. Phase center variation of the designed LPDA antenna.

reported, both for the configuration with and without mirror coaxial cable. The antenna gain is quite stable over the required bandwidth.

Since UWB antennas are employed for pulse-based systems, the stability of the phase center with frequency is very important. Actually, all frequencies in the pulse spectrum should be radiated from the

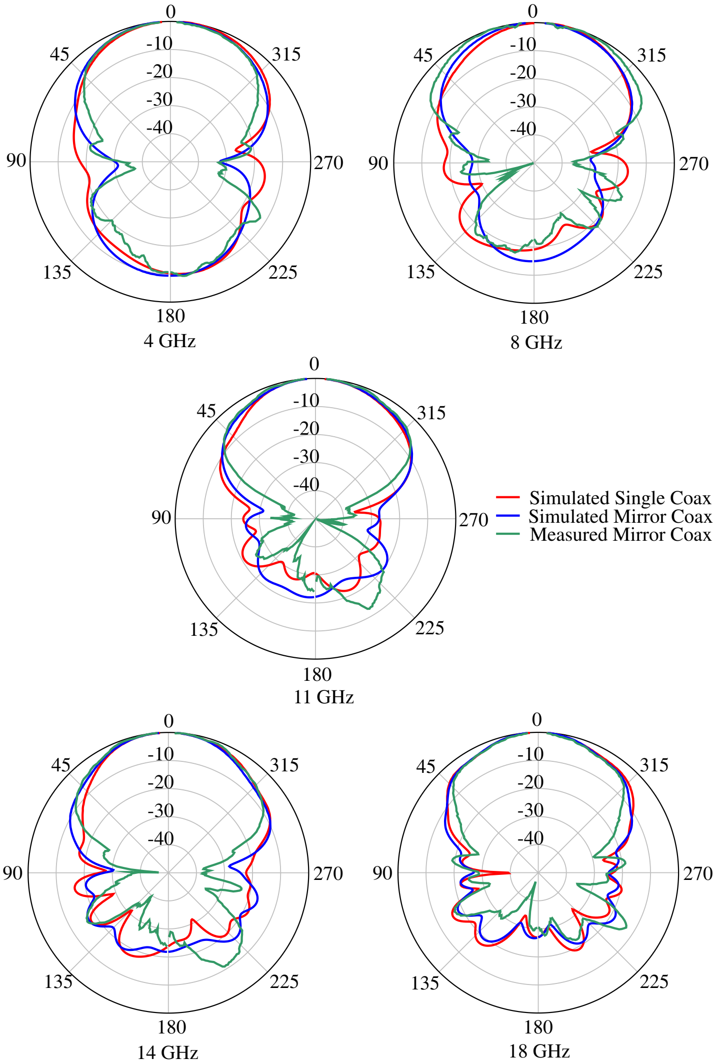


Figure 7. Simulated and measured *E*-Plane radiation pattern of the designed LPDA antenna.

same point (the antenna phase center) in order to avoid a distortion in the received pulse. The phase center variation as a function of the frequency is computed by using CST Microwave Studio and is reported in Figure 6, where Delta is the distance between the phase center and the origin O of the coordinate system in Figure 1. The

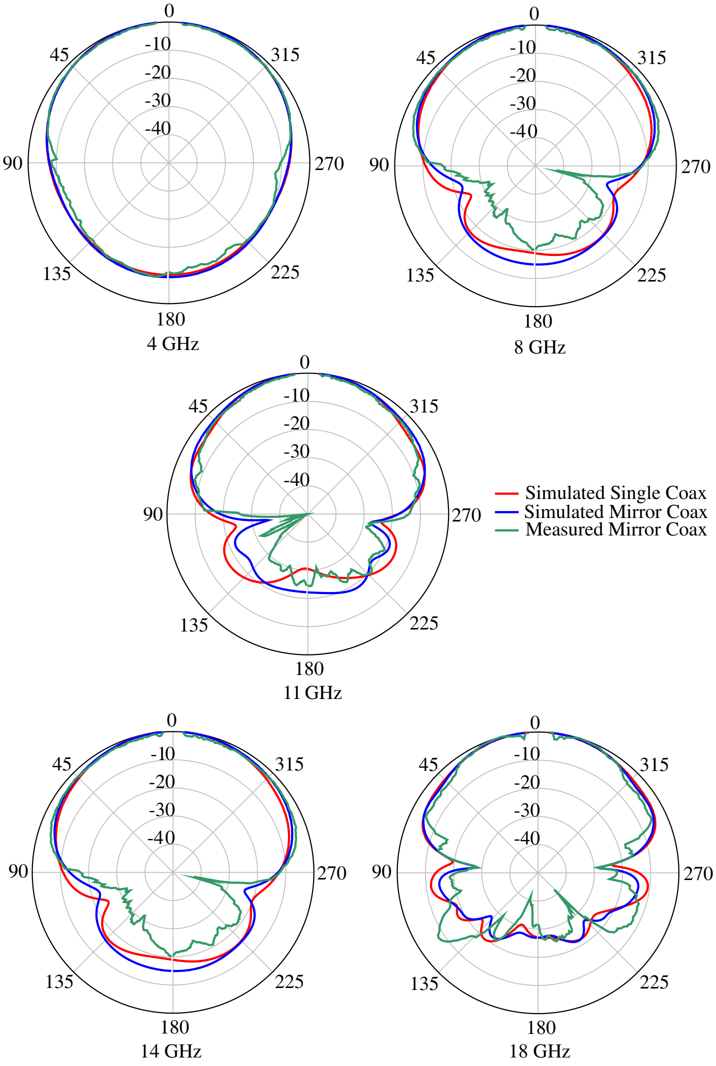


Figure 8. Simulated and measured H-Plane radiation pattern of the designed LPDA antenna.

comparison with the feeding configuration using a single coaxial cable is also shown. Using a single coaxial cable in the implementation of the feeding network, the phase center remains almost constant in the frequency band 5.5–11.25 GHz, wherein it varies from 30 mm to 50 mm (with a maximum variation equal to ±10 mm, i.e., $\pm 0.25\lambda_0$, being $\lambda_0 = 40$ mm the free-space wavelength at the center frequency of 8.375 GHz). From the results shown in Figure 6, it appears that the presence of the mirror coaxial cable allows to stabilize the phase center up to 13 GHz. As a matter of fact, in the configuration with the mirror coaxial cable the phase center is stable in the frequency band 4.25–13.25 GHz, with a relative bandwidth greater than 100%, with a maximum variation equal to 28 mm. It is worth noting that, if we limit ourselves to a 30% smaller frequency band, namely 4.25–10.75 GHz, the phase center variation halves to 15 mm.

In Figures 7 and 8, the simulated and measured E-Plane and H-Plane radiation patterns are reported, respectively. The comparison between the simulated far field of the configuration with and without the mirror coaxial cable shows that the last configuration allows a significant improvement on the radiated field, which is in this case more symmetrical and with a lower side lobe level. The measured far field pattern, reported only for the configuration with the mirror coaxial cable, is in very good agreement with the simulations.

4. CONCLUSION

A printed log-periodic dipole array (LPDA), operating over the C, X and Ku bands, has been designed and analyzed using CST. The antenna is fed using two coaxial cables, which provide the required broadband input matching, stabilize the antenna phase center, and improve the far field pattern when compared with an antenna fed with a single coaxial cable. The simulated and measured results show that the proposed LPDA can be successfully used as a wideband end-fire antenna in the whole operating bandwidth (4–18 GHz), and as an Ultra Wideband Antenna in the range 4.25–13.25 GHz, i.e., in a relative bandwidth greater than 100%.

ACKNOWLEDGMENT

Paolo Maxia gratefully acknowledges Sardinia Regional Government for the financial support of her Ph.D. scholarship (P.O.R. Sardegna F.S.E. Operational Programme of the Autonomous Region of Sardinia, European Social Fund 2007–2013 — Axis IV Human Resources, Objective l.3, Line of Activity l.3.1.).

REFERENCES

1. Carrel, R., "The design of log-periodic dipole antennas," *IRE International Convention Record*, Vol. 9, 61–75, 1961.
2. Isbell, D. E., "Log periodic dipole arrays," *IEEE Transactions on Antennas and Propagation*, Vol. 8, 260–267, 1960.
3. Carrel, R., "Analysis and design of the log-periodic dipole antenna," Ph.D. Dissertation, University of Illinois, 1961.
4. Chao, Y., Y. Chen, H. Wei, Q. K. Zhen, and Q. Wei, "Band-notched UWB printed log-periodic dipole antenna fed by half mode substrate integrated waveguide," *International Symposium on Antennas and Propagation*, Bangkok, Thailand, 2009.
5. Avila Navarro, E., J. M. Blanes, J. A. Carrasco, and C. Reig, "A new bi-faced log periodic printed antenna," *Microwave and Optical Technology Letters*, Vol. 48, 2006.
6. Pantoja, R. R., A. R. Sapienza, and F. C. Medeiros Filho, "A microwave printed log-periodic dipole array antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 35, No. 10, 1987.
7. Navarro, E. A., J. A. Carrasco, and C. Reig, "Dual printed antenna for Wi-Fi applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 2009.
8. Kim, D., Q. Chen, and K. Sawaya, "Microstrip log-periodic dipole antenna array," *Proceedings of ISAP*, Fukuoka, Japan, 2000.
9. Gheethan, A. A. and D. E. Anagnostou, "The design of reconfigurable planar log-periodic dipole array using switching elements," *IEEE Antennas and Propagation Society International Symposium*, 1–4, 2009.
10. Gheethan, A. A. and D. E. Anagnostou, "Reduced size planar log-periodic dipole arrays using rectangular meander line elements," *IEEE Antennas and Propagation Society International Symposium*, 1–4, 2008.
11. Anagnostou, D. E., J. Papapolymerou, M. M. Tentzeris, and C. G. Christodoulou, "A printed log-periodic koch-dipole array (LPKDA)," *IEEE Antennas and Propagation Letters*, Vol. 7, 456–460, 2008.
12. Campbell, C. K., I. Traboulay, M. S. Suthers, and H. Kneve, "Design of a stripline log-periodic dipole antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 25, 718–721, 1977.
13. Mirkamali, A. and P. S. Hall, "Wideband frequency reconfiguration of a printed log-periodic dipole array," *Microwave and Optical*

Technology Letters, Vol. 52, 2010.

14. Hamid, M. R., P. S. Hall, and P. Gardner, "Wideband reconfigurable log periodic patch array," *Progress In Electromagnetics Research C*, Vol. 52, 123–138, 2013.
15. Lin, S., S. Luan, Y. Wang, X. Luo, X. Han, X. Q. Zhang, Y. Tian, and X. Y. Zhang, "A printed log-periodic tree-dipole antenna (PLPTDA)," *Progress In Electromagnetics Research M*, Vol. 21, 19–32, 2011.
16. Karim, M. N. A., M. K. Abd Rahim, H. A. Majid, O. B. Ayop, M. Abu, and F. Zubir, "Log periodic fractal koch antenna for UHF band applications," *Progress In Electromagnetics Research*, Vol. 100, 201–218, 2010.
17. Feng, C. and Q. Jian, "A novel infinite balun used in folded dipole," *IEEE Antennas and Propagation Society International Symposium*, Vol. 1, 547–548, 1990.
18. Pozar, D. M., *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*, IEEE Press, New York, USA, 1995.
19. Mazzarella, G., "CAD modeling of interdigitated structures," *IEEE Transactions on Education*, Vol. 42, No. 1, 81–87, 1999.