Size-Reduced Printed Log Periodic Dipole Antenna with Single First Order Semi-Circle Iteration and Feed Point Patches

Mehmet Can Özgönül[1] and Mustafa Seçmen[2]

[1]Department of Electronics and Communication Engineering, Izmir Institute of Technology, Gulbahce Campus, Urla, 35430, Izmir, Turkey
mc.ozgonul@gmail.com
[2]Department of Electrical and Electronics Engineering, Yasar University, Selcuk Yasar Campus, Bornova, 35100, Izmir, Turkey
mustafa.secmen@yasar.edu.tr

Abstract

This paper presents the miniaturization and improvement of a printed log periodic dipole antenna (LPDA) by using patches at the feeding point and single first order semi-circles. After the design of a conventional printed LPDA on FR4 substrate to cover L-band is performed, patches having 12 mm × 5 mm dimensions are placed to the feed point of the antenna. Although this modification gives same antenna size, it brings considerable increase in the return-loss bandwidth up to 2.25 GHz and higher gain values up to 2 GHz at the expense of decrease in gain at about 2.4 GHz. Afterwards, in order to reduce the total size of the antenna, single semi-circles are substituted into the dipole arms, which results in 14% lateral size reduction. Besides, the bandwidth is further improved between 0.9 GHz and 2.4 GHz with better return loss performance, higher gain at 2.4 GHz and lower gain variation.

1. Introduction

Log periodic antenna can be considered as a kind of antenna, which is suitable for broadband applications. The antenna structure is mainly based on the design related with the frequency independent concept [1]. Straight dipole elements on dipole array are commonly used for well-known log periodic antenna structure. Log periodic dipole antennas (LPDAs) have admissible gain during wide operating frequency bandwidth; therefore, they are very attractive antennas for many broadband applications with moderate antenna gain requirement. LPDAs are generally known as moderate gain antenna with typically 5 dBi gain on the average. On the other hand, the main advantage of these antennas is to have low gain variation over the wide bandwidth such that gain variation of a few dBi can be observed over wide bandwidth or even decade bandwidth [2-4]. Therefore, in order to be suitable for the applications with almost constant gain, the gain variation should be low. LPDAs have also the other advantage of being used either in receiving or transmitting mode [1, 5].

In addition gain performance, the performance of many other antenna parameters such as return loss and radiation characteristics should be satisfied with appropriate dimensions of the antenna in many applications. For many applications, the printed (planar) versions of log periodic dipole antennas are more convenient option than standard LPDAs due to having many advantages of printed antennas such as low weight and volume, ease of installation, low fabrication cost [6-8].

If the overall space of the antenna is not sufficient for traditional printed LPDA, it is needed to carry out smaller designs to miniaturize the antenna with desired antenna parameters. The lateral (transverse) size of the printed log periodic dipole antenna is generally proportional to the minimum frequency of operation bandwidth and dielectric constant of the substrate used in the antenna. On the other hand, the longitudinal length is usually determined by the desired gain within the considered bandwidth such that the longer LPDAs have reasonably higher gain by keeping the minimum and maximum frequencies of the bandwidth constant.

The main aim of this study is to design and present a size-reduced printed log periodic dipole antenna. The proposed antenna also improves the performances of the return loss and gain variation within a wider bandwidth with respect to the conventional planar LPDA. For this purpose, although the main aim in this study is to reach an operating frequency bandwidth of the antenna between 0.9 GHz and about 2.4 GHz in order to cover GSM, GPS, 3G, Bluetooth and Wi-Fi 2.4 GHz bands; first, a traditional planar LPDA is designed for the frequency bandwidth between about 0.9 GHz and 2 GHz giving return loss greater than 10 dB. This antenna has arranged to give about 5 dBi realized gain within the frequency band of 0.9 GHz and 2 GHz; however, when the upper frequency of 2.4 GHz, which is the upper frequency of the stated size-reduced LPDA, is considered, the gain variation within 0.9-2.4 GHz is found to be more than 3.5 dBi. Therefore, when the given standard LPDA is considered, the performances of both return loss and gain variation for the frequency band between 0.9 GHz and 2.4 GHz are found to be not adequate. Then, the rectangular patches at the feed point of the antenna are added in order to increase the frequency bandwidth of the antenna. The insertion of these patches, which may be also called as feed point patches, are very wise technique to increase the bandwidth of not only planar log periodic antenna [3, 6] but also other microstrip based antennas [9]. Although this modification keeps total size of the antenna same, the expected increase in the return-loss bandwidth is verified by the simulations and measurements performed on the fabricated structure. The corresponding results reveal that the upper frequency of the bandwidth for return loss > 10 dB is increased to about 2.25 GHz. Moreover, the gain values up to 2 GHz frequency band are obtained to be higher for this LPDA than the one without feed point patches. However, the gain variation is evaluated to be about 0.5 dBi higher than that of standard LPDA in addition to slight drop in the gain at about 2.4 GHz. Then, as the final part (step) of the proposed study, the size-reduction of the LPDA with feed point patches is employed. Here, the average gain performance of the size-reduced LPDA is aimed to be similar to that of standard LPDA; consequently, no size change (reduction) in the longitudinal direction is realized that the longitudinal dimension of the miniaturized antenna is kept constant. The size-reduction of the miniaturized antenna is carried out in lateral (transverse) direction by making the length of the dipole arms on log-periodic structure shorter. Many size-reduced LPDAs can be found in the literature [10-13], and the lateral size-reduction in these studies are satisfied by decreasing the edge-to-edge distances of the dipole antennas on LPDA; but; keeping total path length over which current flows the dipole arms constant, in general. Therefore, same resonant length values can be obtained with smaller sizes. In this study, single semi-circular metallic structures are substituted on the middle part of the dipole arms at the both sides of the substrate, which results in about 14 percent size reduction in lateral direction. The final (proposed) antenna, which has smallest size among three antennas in consideration (standard LPDA, standard LPDA with feed patches and size-reduced LPDA with patches), is also verified to give the widest frequency bandwidth between 0.9 GHz and 2.4 GHz for return loss at worst 10 dB with simulation and measurement results. The performance of gain variation within 0.9 GHz and 2.4 GHz for LPDA is progressed with a gain variation lower than 3 dBi in the frequency band for the miniaturized antenna. In addition, the drawback of low gain value at 2.4 GHz for LPDA with feed patches is solved such that the gain of size-reduced antenna at 2.4 GHz is calculated to be even 1 dBi higher than the one in standard LPDA. Therefore, the size-reduced LPDA with feed point patches is stated to have smallest size, widest frequency bandwidth, lowest gain variation within the band and highest gain at upper edge frequencies.

The rest of the paper can be summarized as follows. Section 2 describes the design, realization and corresponding results of conventional LPDA and LPDA with feed point patches. Section 3 includes the size-reduced LPDA with the details of reduction technique mentioned in the above paragraph. Section 4 gives an overall comparison of the results of three antennas considered in this study, and Section 5 concludes the study.

2. The Designs of Conventional LPDA and LPDA with Feed Point Patches

As the initial part of the study, a standard planar log-periodic dipole antenna is aimed to be designed in L-band on a dielectric substrate of FR4 with the following substrate parameters: dielectric constant of $\varepsilon_r = 4.3$, loss tangent of $\tan\delta = 0.02$ and height of $h = 1.52$ mm. The frequency bandwidth of the antenna is chosen between 0.9 GHz and approximately 2 GHz with a moderate directivity. The log periodic dipole antenna can be designed by the help of well-known formulation of log periodic antenna in [1, 14, 15]. There are some crucial design parameters of the antenna; τ is scaling factor, which gives periodicity relationship of the antenna dimensions, σ is spacing factor, α is the half of the aperture angle, and N is the number of dipoles used in LPDA. In order to design LPDA, α and τ are generally selected as $10° \leq \alpha \leq 45°$ and $0.7 \leq \tau \leq 0.95$; and there is an inverse relation between α and τ [1]. Since the designed antenna has a double-sided (bi-faced) topology on a dielectric substrate as shown in Fig. 1, τ is chosen as 0.88 to be consistent with the one in [16].

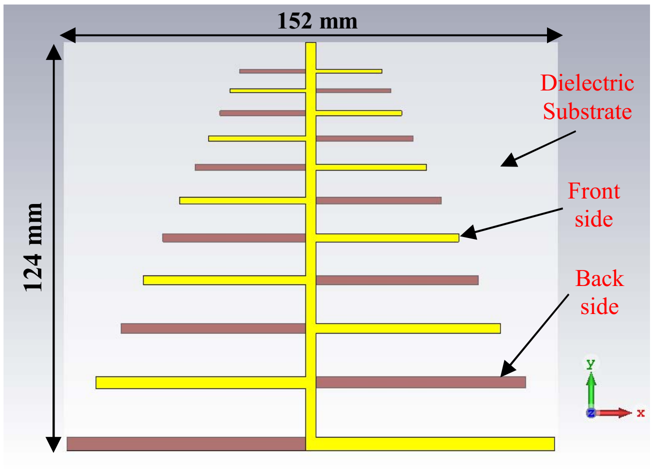

Fig. 1. Simulation view of the conventional LPDA antenna designed in this study.

The longitudinal dimension of the antenna (the dimension along *y* axis in Fig. 1) is related with σ parameter of the LPDA design. In this study, in order to make the antenna as compact as possible, σ parameter is selected to be small but by still taking moderate directivity specification into account. With the selected value of $\tau = 0.88$, the spacing factor is chosen to be $\sigma = 0.06$, which gives a directivity value slightly lower than 7 dBi (approximately 6.8 dBi) obtained from the directivity graphs in [1, 14]. Then, the other relevant design parameters of log-periodic antenna are calculated as $\alpha = 26.6°$ and N = 11 (the number of dipoles used in the design as shown in Fig. 1). The corresponding length (l_n), width (w_n) and spacing/distance (d_n) values of these dipoles are given in Table 1, where the longest dipole with 150 mm length value almost determines the transverse (lateral) dimension of the designed standard LPDA, which is given as 152 mm in Fig. 1. All of these dipoles are fed by identical microstrip lines on the both sides of the substrate having 3 mm width.

Table 1. The dimensions of dipole antennas used in standard printed LPDA. The dimensions are in mm.

n	l_n	w_n	d_n
1	150	4	18.7
2	132.36	3.52	16.5
3	116.84	3.1	14.6
4	103.18	2.73	12.9
5	91.16	2.4	11.4
6	80.58	2.11	10
7	71.26	1.86	8.8
8	63.06	1.64	7.7
9	55.86	1.44	6.8
10	49.52	1.27	6
11	43.94	1.12	-

Since the main interested antennas in this study are the modified antennas (the LPDA with feed point patches and the size-reduced LPDA), only simulation results of the traditional antenna, whose dimensions are described above, are acquired by using CST Microwave Studio 2016. The corresponding results for the performances of return loss and antenna gain are given in Fig. 2 and Table 2.

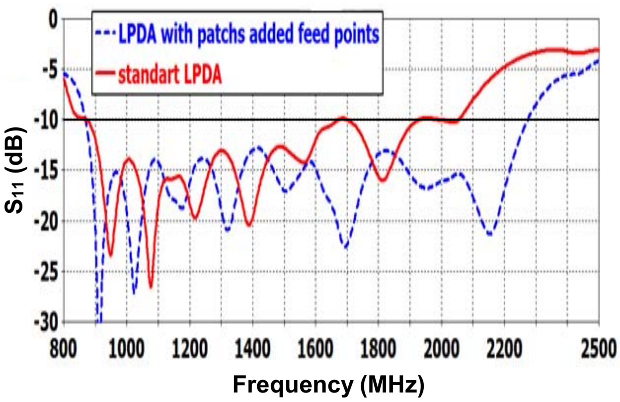

Fig. 2. The simulation results for reflection coefficients of the standard LPDA and LPDA with patches added at feed point.

Table 2. The realized gain values at certain frequencies for the standard LPDA and LPDA with patches added at feed point.

Frequency (GHz)	Standard LPDA	Standard LPDA with patches
0.9	5.25 dBi	5.57 dBi
1	5.18 dBi	5.42 dBi
1.5	5.20 dBi	5.41 dBi
2	4.67 dBi	5.04 dBi
2.25	1.86 dBi	3.29 dBi
2.4	1.60 dBi	1.45 dBi

As observed in Fig. 2, the return loss of the standard LPDA is better than 10 dB for the frequency band between 0.9 GHz and 2.05 GHz. So, the antenna is said to have the operating frequency band of 0.9-2.05 GHz by considering minimum 10 dB return loss constraint. The standard LPDA has an average realized gain of almost 5 dBi within the frequency band up to 2 GHz. Then, the gain value sharply drops to a level of 1.6 dBi at 2.4 GHz due to high mismatch loss at the frequencies higher than 2 GHz. Therefore, although the variation of gain values between 0.9 and 2 GHz is fair, it is more than 3.5 dBi when the frequency band of 0.9 and 2.4 GHz is considered.

The directivity values of the standard LPDA has actually found to be 6.5 dBi on the average, which is close to the one described in the design procedure in Section 1. However, since the used substrate of FR4, whose main usage in the design is due to its low cost and being easily supplied from the market, has high dielectric losses especially at RF frequencies; approximately 1.5 dB loss in radiation efficiency is observed, which drops directivity values about 6.5 dBi to realized gain values of almost 5 dBi. Therefore, when another dielectric substrate, which has less dielectric losses at the mentioned frequencies, is used instead of FR4 in the stated design, realized gain values of almost 6 dBi can be achieved.

After the design of the standard LPDA is carried out, the first modification on the mentioned antenna is employed by adding rectangular patches on the feed point of the antenna. In this modification, all the dimensions described in the design of the conventional LPDA are kept same, and rectangular patches with 12 mm × 5 mm length and width dimensions are added at the feed point (the uppermost point of the antenna in Fig. 1 and Fig. 3) on both sides. The corresponding simulation results are again demonstrated in Fig. 2 and Table 2 such that the return-loss bandwidth is improved up to 2.28 GHz. The LPDA with inserted patches has higher gain values than the standard LPDA up to 2.25 GHz. Nevertheless, the drop in the gain after 2.25 GHz is more severe that the gain at 2.4 GHz is lower than that of standard LPDA. Therefore, the variation in the gain between 0.9 GHz and 2.4 GHz is even higher than that of standard LPDA. After the handling of the simulation results modified LPDA, it is fabricated as depicted in Fig. 3.

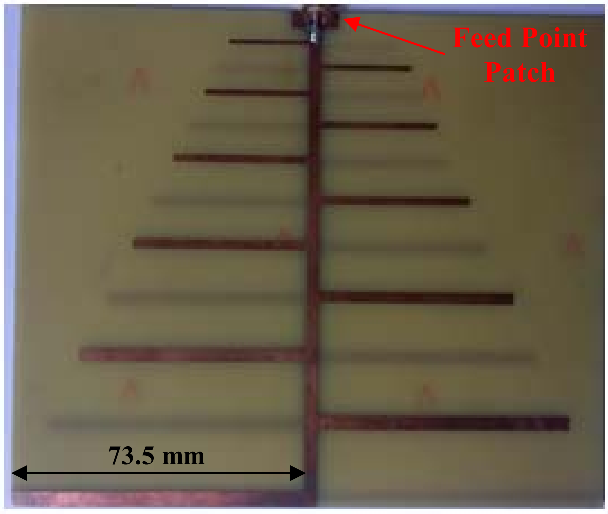

Fig. 3. The photograph of the fabricated LPDA with patches added at feed point.

The reflection coefficient values of the fabricated structure in Fig. 3 are measured, and the corresponding graphs are given in Fig. 4 along with simulation results of the modified LPDA. The corresponding results are quite in agreement especially at the frequency regions close to lower and upper boundaries, where the differences in other frequency regions may arise from manufacturing errors and the deviation of dielectric constant and tangent loss of the substrate used in simulation and production.

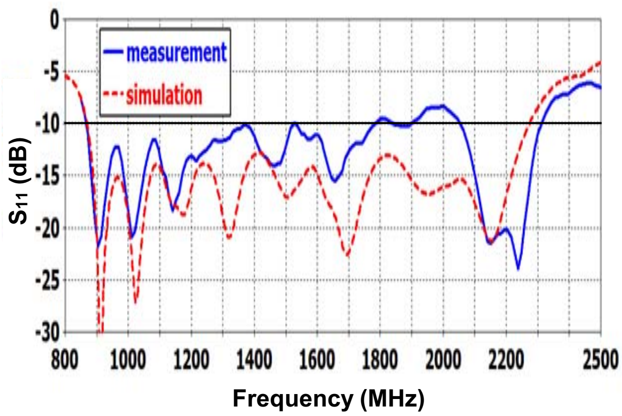

Fig. 4. The simulation and measurement results for reflection coefficients of LPDA with patches added at feed point.

3. The Design of Size-Reduced LPDA

After the realization of first modification on the traditional LPDA, the second modification, which is also main modification stated in this study, is applied on the antenna as the reduction of the lateral dimension of the LPDA. In this proposed design, all width dimensions including width of the feed line, spacing values and patch dimensions are taken as same values in the antennas given in Section 2. Therefore, total longitudinal dimension of the size-reduced antenna becomes same with the previous antenna designs; therefore, the average gain of the size-reduced antenna is intended to be also 5 dBi roughly. The reduction in size is performed at the lateral (transverse) dimension of the antenna by optimizing the edge-to-edge distances of dipole arms in array. As explained in Section 2, the lateral dimension is mainly determined by edge-to-edge distance of longest dipole (150 mm). Thus, although the other dipole arms are also trimmed, the main contribution for the size reduction arises from the shortening the longest dipole. The key point in the size reduction of the dipoles is the decrease of edge-to-edge distance by keeping the length of metallic part (path length) same with the original structure in order not to alter the desired frequency bandwidth significantly. In the proposed structure of this study, this reduction is provided by inserting a single semi-circle at the middle part of each dipole arms on both sides of the substrate. A typical example for this structure is depicted in Fig. 5 such that the dipole arm structure in Fig. 5 is substituted in the straight structure of 73.5 mm shown in Fig. 3.

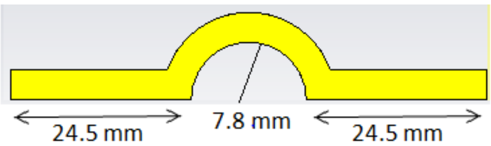

Fig. 5. The size-reduced structure for the dipole arm of the longest dipole on the front side of the substrate.

When the fractal theory is considered [10, 12], single semi-circle put at each dipole arm as shown in Fig. 5 can be regarded as first order iteration where second order iteration contains additional semi-circles (with radii smaller than 7.8 mm) inserted on both straight and semi-circular parts of the structure in Fig. 5.

In Fig 5, the radius of circle is optimized to 7.8 mm, which results in the total path length in Fig. 5 as 2×24.5 mm $+ \pi \times 7.8$ mm ≈ 73.5 mm, which is almost equal to the straight length given in Fig. 3. Consequently, the resonance frequency corresponding to this half-length of 73.5 mm, which is probably the lowest frequency of the band as 0.9 GHz, does not change in the miniaturized structure. On the other hand, edge-to-edge distance from leftmost to rightmost point is 2×24.5 mm $+ 2 \times 7.8$ mm $= 64.6$ mm. Therefore, in the size-reduced antenna, the edge-edge distance of the longest dipole becomes 2×64.6 mm $+ 3$ mm (width of the feeding line), which is equal to 132.2 mm. Therefore, a considerable shortening is achieved in the longest dipole, accordingly, lateral dimension of the overall antenna. The other dipole arms in the array are also miniaturized in the same way as Fig. 5 that the radii of the circles and other dimensions on these dipoles are scaled down properly with the appropriate ratio values given in Table 1.

After the given procedure, the size-reduced LPDA antenna is manufactured whose photograph is shown in Fig. 6. As given in Fig. 6, the lateral (transverse) dimension of the modified LPDA is reduced to 133.5 mm from 152 mm (the lateral dimension of original LPDA), which brings about 14% overall size reduction.

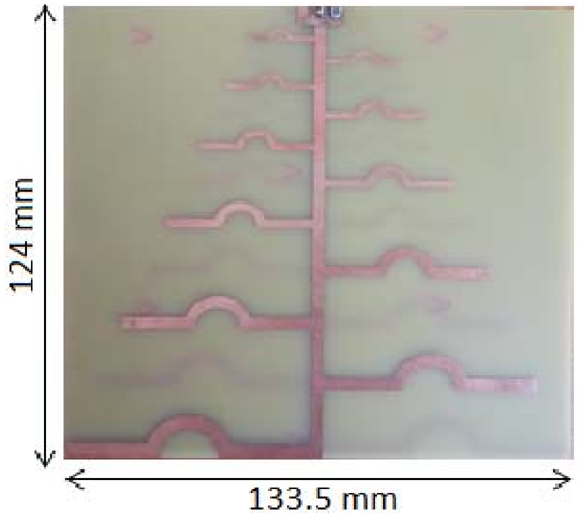

Fig. 6. The photograph of the prototype of size-reduced LPDA.

4. Overall Results

After the production of the size-reduced antenna, the corresponding simulation results with CST Microwave Studio 2016 and measurement results are obtained for return-loss and gain values, and compared with those of other LPDA antennas in Section 2. As the first demonstrated result, the return-loss performances of three antennas mentioned in this study are figured out and compared in Fig. 7.

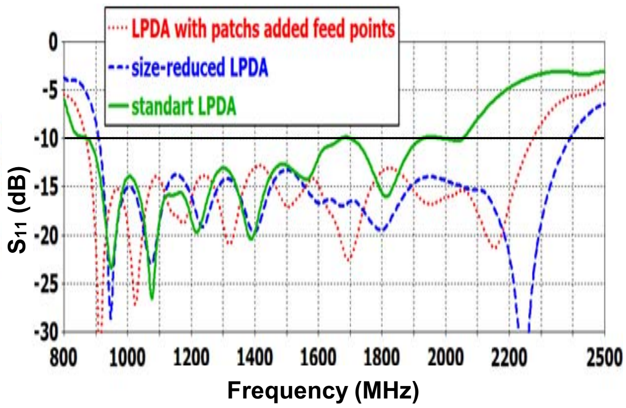

Fig. 7. The simulation results for the reflection coefficients of three LPDA antennas described in this study.

The results revealed in Fig. 7 demonstrate that the size-reduced antenna does not only provide more compact structure but has also improved upper band of the frequency bandwidth for $|S_{11}| \leq -10$ dB up to about 2.4 GHz. So, the frequency bandwidth for return-loss of the size-reduced becomes between 0.9 GHz and 2.4 GHz, which is the widest among three antennas in consideration. The wideband characteristics described here is also verified by the measurement results, which are given in Fig. 8. According to the measured values, the bandwidth is extended to even approximately 2.45 GHz.

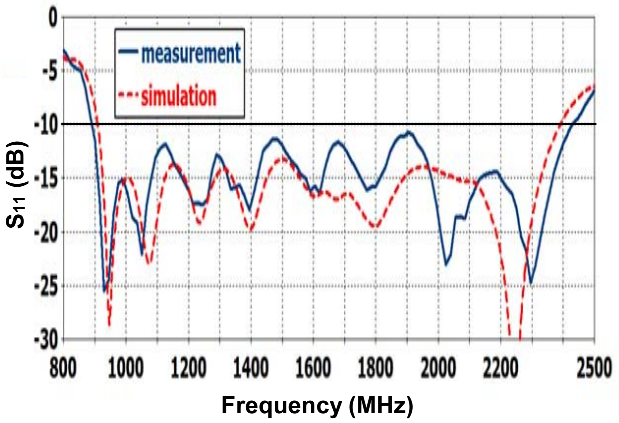

Fig. 8. The simulation and measurement results for reflection coefficients of size-reduced LPDA.

As the comparison of other performance parameter, realized gain values throughout 0.9-2.4 GHz frequency band are presented in Table 3.

Table 3. The realized gain values at certain frequencies for three LPDA antennas.

Frequency (GHz)	Standard LPDA	Standard LPDA with patches	Size-Reduced LPDA with patches
0.9	5.25 dBi	5.57 dBi	3.93 dBi
1	5.18 dBi	5.42 dBi	5.28 dBi
1.5	5.20 dBi	5.41 dBi	5.55 dBi
2	4.67 dBi	5.04 dBi	5.41 dBi
2.25	1.86 dBi	3.29 dBi	4.33 dBi
2.4	1.60 dBi	1.45 dBi	2.64 dBi

The gain values given in Table 3 show that although the gain of the size-reduced LPDA is smaller at the lower edge of the frequency band of 0.9-2.4 GHz, the gain variation as being lower than 3 dBi within the whole band is the lowest of three antennas. Therefore, the size-reduced LPDA is also more suitable for the applications with constant gain throughout the desired frequency band. Besides, the gain values at the upper edge of 0.9-2.4 GHz is the highest such that the drawback of low gain at 2.4 GHz for the antenna just with feed point patches in Section 2 is overcome with a gain value of size-reduced LPDA at 2.4 GHz being even greater than that of standard LPDA. Thus, the proposed size-reduced LPDA has the smallest size, the widest frequency bandwidth and the lowest gain variation for the frequency band of 0.9-2.4 GHz.

5. Conclusions

In this paper, a size reduction technique on a printed log periodic dipole antenna (LPDA) is presented by using first order iteration semi circles on dipole arms. By combining with rectangular small patches at feed point, the proposed antenna increases the upper edge of the frequency bandwidth by about 20% as compared to standard LPDA from 2 GHz to 2.45 GHz while the lower edge remains almost same as 0.9 GHz. Besides, the proposed structure has the reduction in size about 14%, average gain of 5 dBi and lower gain variation within 0.9-2.45 GHz, which is convenient for the applications demanding constant gain in the band. Therefore, the proposed antenna can be used in GSM, GPS, 3G, Bluetooth and Wi-Fi 2.4 applications with its compact structure, moderately wideband characteristics and sufficient gain performance including deviation in the gain.

6. References

[1] C. A. Balanis, “Antenna Theory: Analysis and Design”, 4th ed., John Wiley & Sons, New York, United States, 2016.

[2] G. A. Casula, P. Maxia, G. Mazzarella, and G. Montisci, “Design of a printed log-Periodic dipole array for ultra-wideband applications”, *Progress in Electromagnetics Research C*, vol. *38*, pp. *15-26*, 2013.

[3] G. Bozdag and A. Kustepeli, “Subsectional tapered fed printed LPDA antenna with a feeding point patch”, *IEEE Antennas and Wireless Propagation Letters,* vol. *15,* pp. *437-440*, 2016.

[4] M. Secmen, “Scattering method for resonance region target recognition: Application to small-scale airplane targets with measured data”, in *European Conference on Antennas and Propagation (EUCAP),* Lisbon, Portugal, 2015, pp. *1-5*.

[5] W. L. Stutzman and G. A. Thiele, “Antenna Theory and Design”, 3rd ed., John Wiley & Sons, New York, United States, 2013.

[6] G. Bozdağ, “Novel microstrip antennas for multiband and wideband applications”, M.S. thesis, Electronics and Communication Engineering, Izmir Institute of Technology, Izmir, Turkey, 2014.

[7] G. A. Casula, P. Maxia, G. Mazzarella, “A printed LPDA with UWB capability”, in *International Workshop on Antenna Technology*, Lisbon, Portugal, 2010, pp. *1-4*.

[8] M. C. Özgönül, “Wide-band antenna design and implementation for small-size RF anechoic chambers”, M.S. thesis, Electrical and Electronics Engineering, Dokuz Eylul University, Izmir, Turkey, 2016.

[9] G. Bozdag and M. Secmen, “Eğimli Beslemeli Geniş Bantlı Basılı Papyon Anten Tasarımı”, in *URSI-TÜRKİYE’2016 VIII. Bilimsel Kongresi,* Ankara, Turkey, 2016, pp. *1-3*.

[10] M. N. A. Karim, M. K. A. Rahim, H. A. Majid, O. Ayop, M. Abu, and F. Zubir, “Log periodic fractal koch antenna for UHF band applications”, *Progress in Electromagnetics Research,* vol. *100*, pp. *201-218*, 2010.

[11] Y. Zhengguang, S. Donglin, and L. Shanwei, “A size-reduced Log Periodic Dipole Antenna”, *Journal of Electronics (China)*, vol. *23*, no. *6*, pp. *913-914*, Nov. 2006.

[12] D. F. Chairunnisa, D.F. Sihaloho, and A. Munir, “Size reduction of printed log-periodic dipole array antenna using fractal koch geometry”, *International Journal on Electrical Engineering and Informatics*, vol. *7*, pp. *226-236*, 2015.

[13] V. R. Lakshmi and G. S. N. Raju, “A novel miniaturized log periodic antenna,” *International Journal of Scientific & Engineering Research*, vol. *3*, no. *2*, pp. *64-68*, Feb. 2012.

[14] R. Carrel, “The deisgn of log-periodic dipole antennas” in *1958 IRE International Conventional Record*, New York, USA, 1966, pp. *61-75*.

[15] D. M. Pozar, “*Microwave Engineering”*, 3rd ed., John Wiley & Sons, United States, 2005.

[16] E. Ávila-Navarro, J. M. Blanes, J. A. Carrasco, J. Reig, and E. A. Navarro, “A New Bi-Faced Log Periodic Printed Antenna,” *Microwave and Optical Technology Letters*, vol. *48*, no. *2*, pp. *402-405*, Feb. 2006.