Designing a Compact-Optimized Planar Dipole Array Antenna

Seyed Mohammad Hashemi, *Student Member, IEEE*, Vahid Nayyeri, *Student Member, IEEE*, Mohammad Soleimani, and Ali-Reza Mallahzadeh

***Abstract*—The design of an optimized planar dipole array (OPDA) antenna is presented using particle swarm optimization (PSO), a well-known global optimization method. The planar dipole array (PDA) elements' lengths and widths and the spacing between them were the optimization parameters, and the antenna input's VSWR and gain were optimization goals. In the optimization procedure, the fitness functions were evaluated by FEKO, which is commercial momentum-based software. A significant size reduction was achieved by exerting constraints on the optimization parameters. At the same time, the antenna characteristics, such as gain, bandwidth, and cross-polarization ratio, were not sacrificed in the compact-optimized antenna.**

***Index Terms*—Optimization methods, planar log-periodic dipole array antennas, size reduction.**

I. Introduction

LOG-PERIODIC dipole array (LPDA) antennas are extensively used in different applications due to their broadband characteristics, high gain, and low cross-polarization ratio. The LPDA consists of a number of dipole elements. Their performance depends on the choice of the proper elements' lengths and the proper spacing between them. Several studies were devoted to the wire-type LPDA at Illinois University during the 1960s [1], until finally, Carrel presented a method for its design in [2]. The advantages of planar antenna such as low weight, ease of manufacture, and integration with widely used planar microwave circuitry have led to the implementation of planar LPDA (PLPDA) antennas. Thus, different methods have been used for implementing PLPDA antennas [3]–[6] and, recently, several attempts have been made to reduce their sizes [7]–[11].

One way to make PLDPA dimensions smaller is to use meander dipoles [10]. This method, presented by Gheethan, decreases the PLPDA dimensions in both directions of the antenna boom length and dipoles' length. However, it decreases antenna gain [10] and increases the cross-polarized field components because of the dipoles' bends and the currents that are vertical to dipoles' axes [11].

Another technique to reduce the size of a PLDPA is to use Koch-dipoles, first introduced by Anagnostou [9]. By applying this method, the dipoles' length decreases, but the length of the antenna boom does not. However, it leads to lower gain and front-to-back ratio and also limits the antenna bandwidth. In addition, folding dipoles increases the currents that are vertical to the dipoles' axes and, consequently, increases the cross-polarized component of the field. In this method, fractalization also causes higher detrimental effects on the gain, front-to-back ratio, bandwidth, and cross polarization [9].

Another method to decrease the width of a PLPDA antenna in the direction of dipoles' length is to use a fractal tree, which was offered by Qui [7] and improved by Baixiao [8]. Decreasing antenna size was achieved at the expense of reducing antenna gain [7], [8]. The cross polarization and front-to-back ratio are not reported, but the detrimental effects are likely due to current elements, vertical to dipole trees.

In this letter, the size of a planar dipole array (PDA) antenna is reduced without sacrificing gain, bandwidth, and cross-polarization ratio by applying a global optimizing method to its structure. Achieving the desired values of gain and bandwidth are the optimization goals. Moreover, the size reduction is successfully achieved by limiting the optimization parameters in the procedure.

In the conventional method of designing PLPDAs based on the wire-type LPDA design [2], variables are the lengths of the first and last dipoles defined by the upper and lower frequencies of the desired band, respectively [5], and also the parameters σ and τ are chosen using the diagram shown in [2]. The lengths of other dipoles and the spacing between them are given in [2] and [5].

However, in this letter, the lengths and widths of all dipoles and the spacing between them are chosen as the optimizing parameter in order to reach a compact-optimized PDA structure. Because of the huge number of variables, the dimensions of the optimization-space will be increased, which makes it very time-consuming. In this letter, particle swarm optimization (PSO) [12], an easily implementable and effective global optimization method, is used to optimize the PDA antenna. In Section II, the difficulties of the optimization problem are explained, and then proper solutions are suggested. In Section III, this optimization method is implemented in an S-band PDA, and the results are presented in a size-reduced antenna with good performance. The compact-optimized PDA is manufactured, and a good agreement is demonstrated between the measured and simulated results.

II. Procedure for Designing an Optimized Planar Dipole Array

General optimization of a problem can be achieved by implementing each of the global optimization techniques such as

Manuscript received February 06, 2011; accepted March 07, 2011. Date of publication March 17, 2011; date of current version April 11, 2011.

S. M. Hashemi, V. Nayyeri, and M. Soleimani are with the Department of Electrical Engineering, Iran University of Science and Technology, Tehran 1684613114, Iran (e-mail: hashemy@iust.ac.ir; nayyeri@iust.ac.ir; Soleimani@iust.ac.ir).

A.-R. Mallahzadeh is with the Electrical Engineering Department, Shahed University, Tehran 1598774811, Iran (e-mail: mallahzadeh@shahed.ac.ir).

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LAWP.2011.2129550

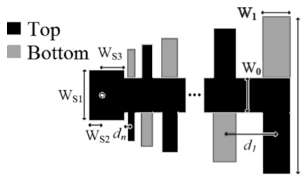

Fig. 1. Considered PDA antenna structure with its parameters contributing to the optimization.

genetic algorithm (GA), PSO, etc. Here, the PSO method was applied because of its easy implementation and effectiveness. Each technique needs to define an optimization space and a fitness function, both of which have significant effects on the optimization results. Therefore, their definitions in this letter are explained as follows.

A. Optimization Space

Different ways for planar implementation of the LPDA antenna were used in [3]–[6]. Although optimization can be implemented on each of them, in this letter, the differential feeding [6] and conventional feeding were considered. Generally in differential feeding, a rectangular patch will be placed on the input of the antenna and improve antenna matching [6] and also the SMA connector placed on the input patch.

A typical graph of the considered PDA structure along with its parameters is shown in Fig. 1. The optimization parameters are the dipoles' lengths and widths, the space between them, and the parameters of feeding patch.

The bounding value of the shortest dipole length was defined as $\lambda_{\rm h}/2\sqrt{\varepsilon_{\rm r}}$, where $\varepsilon_{\rm r}$ is the permittivity of the substrate and $\lambda_{\rm h}$ is the free-space wavelength relating to the highest frequency of the desired antenna bandwidth. Each following dipole length should be greater than the precedent. The bounding value of the shortest width of the dipole was defined as the value needed for the desired characteristic impedance [5]. Since the impedance is determined by the length-to-width ratio, each following dipole width also should be greater than the precedent. The shortest dipole spacing is shown in Fig. 1, the bounding value of which was determined as $2\sigma L$ [2], where L is dipole's element length and σ is computed from the diagram in [2]. Thus, each of the following dipole spacings should be greater than the precedent. According to the description, optimization parameters are defined as follows:

$$L_n = L_{n+1} + \Delta L_n \quad (1)$$

$$d_n = d_{n+1} + \Delta d_n \quad (2)$$

$$W_n = W_{n+1} + \Delta W_n \quad (3)$$

where $n = N-1, \ldots, 2, 1$, N is the index of shortest dipole element, and L_n, W_n, and d_n are the length, width, and spacing of other dipoles. ΔL_n, ΔW_n, and Δd_n are the added values to each of the previous shorter dipoles. All of these variables—L_N, W_N, d_N, ΔL_n, ΔW_n, and Δd_n—are optimization variables. For controlling the total size of the PDA after optimization, some limitations should be considered on the upper bounds of optimization variables.

Finally, the bounding of the feed-line width was defined as the desired value needed for the impedance of 50 Ω. The parameters relating to the input feed patch were also considered as the optimization variables.

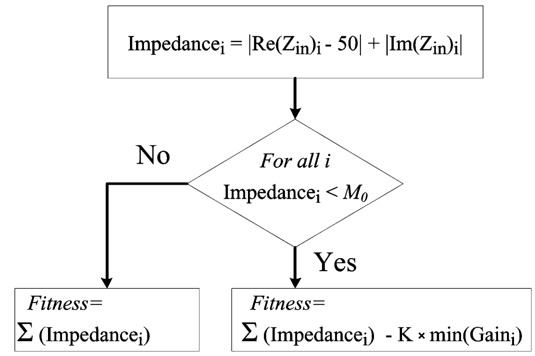

Fig. 2. Fitness function calculation.

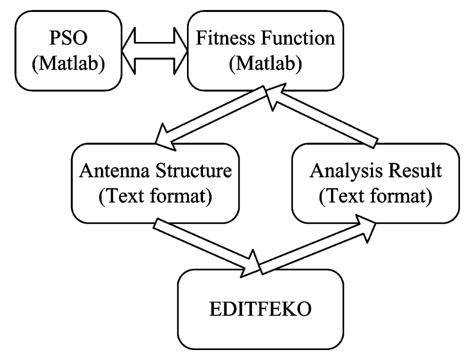

Fig. 3. FEKO and MATLAB correlate with each other.

B. Fitness Function Definition

First, the concept of antenna fitness will be explained. Between two antennas with suitable VSWR, the one with a better VSWR but lower gain is not preferred. Therefore, the antenna fitness will conditionally be defined. In this manner, the antenna VSWR, which is indicative of the antenna bandwidth, should be a specified value in the whole of the desired bandwidth. Then, between the cases that are meeting this requirement, the one that has the best gain is preferred. The fitness-function definition of this letter is demonstrated in Fig. 2. In this figure, $\mathrm{Impedance}_i$, having a positive real value, is a criterion for matching the antenna in the ith frequency sample, i.e., the less $\mathrm{Impidance}_i$, the less antenna VSWR in the ith frequency sample. The fitness function is defined as the sum of the $\mathrm{Impedance}_i$ in all frequency samples. To increase the gain of well-matched antennas and decrease the fitness function, a weighted (K is the weighting factor) least antenna gain in all frequency samples will be subtracted from the sum of $\mathrm{Impedance}_i$ if $\mathrm{Impedance}_i$ is less than the specified value of M_0 for every frequency sample. Because of this fitness definition, the optimization goal decreases the fitness function.

Inside the PSO code that is written in MATLAB, any particle is an antenna candidate, which is written in a text file and run by FEKO. Additionally, the output of simulation in FEKO is a text file that is read by MATLAB. These software can correlate with each other (Fig. 3).

Because the fitness function is calculated repeatedly, the time of antenna analysis should be decreased. A feature of FEKO

TABLE I
PARAMETER OF PDA AFTER OPTIMIZATION

Branch Num.	$\sigma = \frac{d_n}{2L_n}$	$\tau = \frac{L_{n+1}}{L_n}$	$\tau = \frac{d_{n+1}}{d_n}$
1	0.185	0.929	0.944
2	0.188	0.937	0.881
3	0.177	0.900	0.886
4	0.174	0.929	0.861
5	0.162	0.905	0.895
6	0.160	0.849	0.728
7	0.137	0.856	0.603
8	0.097	0.896	0.686
9	0.074	0.901	0.429
10	0.035	—	—

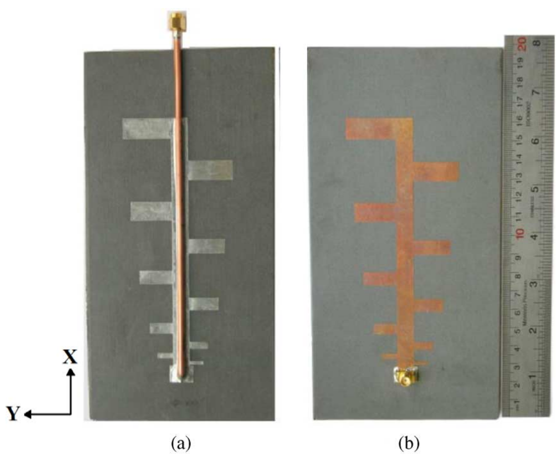

Fig. 4. Printed circuit board (PCB) of compact-optimized PDA. (a) Conventional feeding. (b) Differential feeding.

software is its use of the green function for the multilayer dielectrics in order to increase the analyzing speed. Also, the population fitness was calculated in parallel.

III. Implementing Optimized Planar Dipole Array and the Results

An antenna in the S-band is designed with the reduced size and 9 dBi gain in order to show the advantages of the procedure explained in Section II. Following the conventional method of designing an LPDA antenna for 9 dBi gain led to a scale factor (τ) and spacing factor (σ) values of 0.9 and 0.18, respectively [2]. In this method, 10 dipoles are required for a 2–4-GHz bandwidth. The final dimensions of an antenna can be controlled by limiting the value of the upper bounds of the optimization variables. It is worth mentioning that very small values can cause inaccessibility to the optimization objectives.

The RT/duroid 5880 board with 3.175 mm thickness, $\varepsilon_r = 2.2$, and $\tan\delta = 0.001$ was used. After implementing the optimization, the parameters defining the elements' structure were obtained (Table I). The W_0, W_{s1}, W_{s2}, and W_{s3} achieved 9.0, 13, 3.25, and 5.6 mm, respectively.

The position of the antenna toward the coordinate axes is depicted in Fig. 4, where it is evident that the main beam was set toward the $-x$-direction. The total width of the optimized antenna is 61 mm, and its total length is 142 mm. The area of the trapezoid-like shape of our antenna is 5254 mm^2.

TABLE II
CALCULATION OF σ AND τ FOR COMPACT OPTIMIZED PDA

Dipole Spacing	(mm)	Dipole Length	Include W_0 (mm)	Dipole Width	(mm)
d_1	22.6	L_1	61.0	W_1	11.0
d_2	21.4	L_2	56.7	W_2	10.2
d_3	18.8	L_3	53.2	W_3	10.0
d_4	16.7	L_4	47.8	W_4	7.7
d_5	14.4	L_5	44.4	W_5	7.1
d_6	12.8	L_6	40.2	W_6	6.9
d_7	9.4	L_7	34.1	W_7	5.7
d_8	5.6	L_8	29.2	W_8	4.0
d_9	3.9	L_9	26.2	W_9	2.9
d_{10}	1.7	L_{10}	23.6	W_{10}	1.8

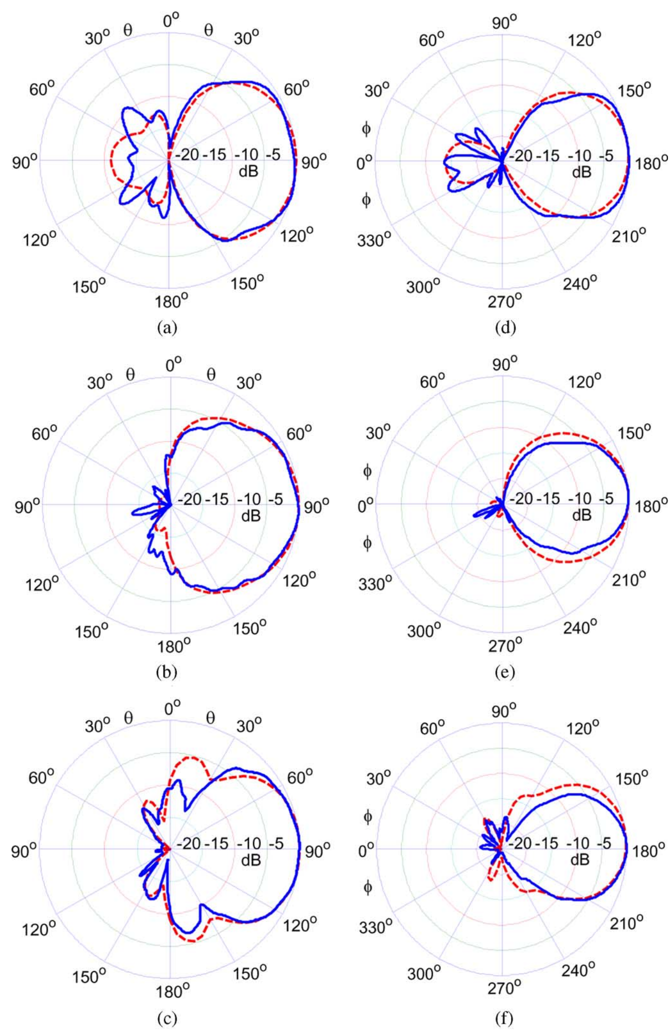

Fig. 5. Measurement (–) and FEKO result (- -) for E-plane and H-plane of compact-optimized PDA. (a) H-plane, 2 GHz. (b) H-plane, 3 GHz. (c) H-plane, 4 GHz. (d) E-plane, 2 GHz. (e) E-plane, 3 GHz. (f) E-plane, 4 GHz.

To compare the results obtained for optimized planar dipole array (OPDA) using the PSO method with the ones obtained by the classical method of designing PLPDA antennas, which is based on designing wire-type LPDA [2], the coefficients of

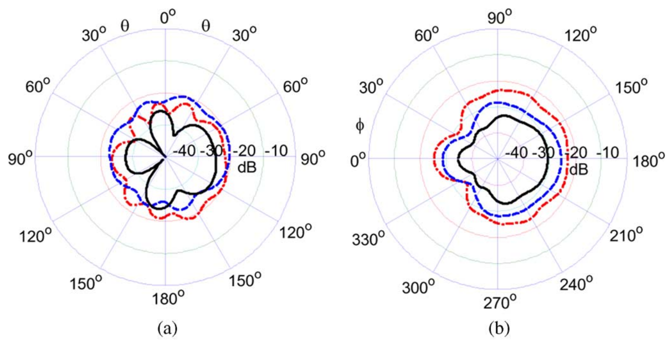

Fig. 6. Cross-polarization component for E-plane and H-plane of compact-optimized PDA. (a) H-plane, 2 GHz (–), 3 GHz (- -), 4 GHz (- · · -). (b) E-plane, 2 GHz (–), 3 GHz (- -), 4 GHz (- · · -).

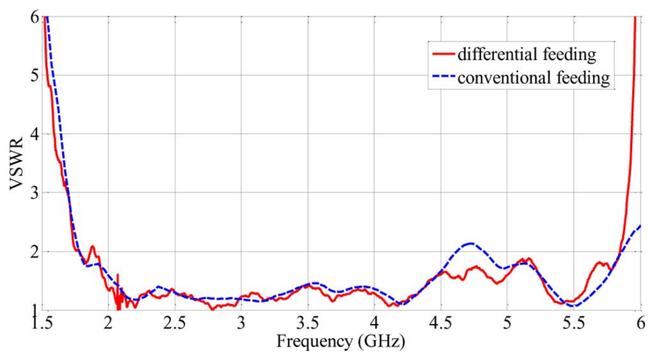

Fig. 7. The measurement of VSWR of the compact-optimized PDA, differential feeding (–), conventional feeding (- -).

τ and σ can be calculated for the OPDA using the parameters summarized in Table I. These values are shown in Table II.

As can be seen in Table II, σ does not have a constant value and decreases from 0.185 to 0.035, which means that the value of σ is smaller for the smaller branches (larger n). When τ is calculated based on the spacing ratios, these values will be variable and decrease from 0.944 to 0.429. In the classical design, the obtained amount of τ is 0.9. Thus, smaller branches have more compressed spacing in comparison to the conventional design (with the constant value of σ and τ). These explanations specify the way the dimensions of this OPDA antenna decrease. The results of simulation and measurement of the OPDA are depicted in Figs. 5–7.

For showing the advantages of the mentioned technique, the OPDA was compared to the references ones [10], [11], which were designed by conventional methods. Their dimensions were decreased in both the length and width of PLPDA using the meander dipole technique. The dimension of the OPDA was the same as the dimension of the antenna compacted by the meander dipole. Furthermore, the VSWR bandwidth of the optimized antenna continued up to 5.75 GHz, which was more than the bandwidth of the antennas designed by the conventional and meander dipole methods [10], [11]. The gain measured for the OPDA antenna was between 8.5 and 10 dBi in 2–4 GHz, while the meander dipole antenna provided the maximum gain of 7.5 dBi. Beyond 4 GHz, the gain of the OPDA decreases rapidly and its cross polarization increases.

IV. Conclusion

The optimization method of a PDA antenna for decreasing its dimensions was discussed with the minimum detrimental effects on the pattern and bandwidth of the antenna. An antenna with the reduced size, high gain, and required bandwidth was elaborated. An S-band OPDA antenna was implemented in order to show the advantage of this method. This antenna had VSWR < 2 from 2 to 5.75 GHz. Its gain was 8.5–10 dBi, and a value of cross-polarization ratio less than -20 dB was obtained in the 2–4-GHz band.

Acknowledgment

The authors would like to gratefully acknowledge the constructive comments of reviewers.

References

[1] D. Isbell, "Log periodic dipole arrays," *IRE Trans. Antennas Propag.*, vol. AP-8, no. 3, pp. 260–267, May 1960.
[2] R. Carrel, "The design of log-periodic dipole antennas," in *IRE Int. Convention Rec.*, 1961, pp. 61–75.
[3] C. Campbell, I. Traboulay, M. Suthers, and H. Kneve, "Design of a stripline log-periodic dipole antenna," *IEEE Trans. Antennas Propag.*, vol. AP-25, no. 5, pp. 718–721, Sep. 1977.
[4] A. Paul and I. Gupta, "An analysis of log periodic antenna with printed dipoles," *IEEE Trans. Microw. Theory Tech.*, vol. MTT-29, no. 2, pp. 114–117, Feb. 1981.
[5] R. Pantoja, A. Sapienza, and F. M. Filho, "A microwave printed planar log-periodic dipole array antenna," *IEEE Trans. Antennas Propag.*, vol. AP-35, no. 10, pp. 1176–1178, Oct. 1987.
[6] M. M. Tajdini and M. Shahabadi, "Wideband planar log-periodic antenna," in *Proc. IWAT*, 2007, pp. 331–334.
[7] J. Qiu, S. Lin, C. Yang, and Q. You, "A novel printed fractal log-periodic dipole antenna," in *Proc. 5th MEMIA*, 2005, pp. 50–53.
[8] W. Baixiao, C. Aixin, and S. Donglin, "An improved fractal tree log-periodic dipole antenna," in *Proc. 19th APEMC*, 2008, pp. 831–834.
[9] D. E. Anagnostou, J. Papapolymerou, M. M. Tentzeris, and C. G. Christodoulou, "A printed log-periodic Koch-dipole array (LPKDA)," *IEEE Antennas Wireless Propag. Lett.*, vol. 7, pp. 456–460, 2008.
[10] A. A. Gheethan and D. E. Anagnostou, "Reduced size planar log-periodic dipole arrays (LPDAs) using rectangular meander line elements," in *Proc. Antennas Propag. Soc. Int. Symp.*, 2008, pp. 1–4.
[11] A. A. Gheethan and D. E. Anagnostou, "The design and optimization of planar LPDAs," *PIERS Online*, vol. 4, no. 6, pp. 811–814, 2008.
[12] J. Kennedy and R. Eberhart, "Particle swarm optimization," in *Proc. IEEE. Int. Conf. Neural Netw.*, 1995, vol. 4, pp. 1942–1948.