Optimizing Log Periodic Dipole Array for Fractal Multiband Antenna Designs

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Abstract - *Recently, Genetic Algorithm/ Method of Moments (GA/MoM) technique is used as an efficient optimization tool for many antenna design problems. In this paper, a GA/MoM code is developed and used for compressing the size of the wideband Log-Periodic Dipole Array (LPDA). The numerical simulations prove that the optimized LPDA with compressed dimensions has nearly the same characteristics of the previously published designs. The optimized LPDA is then applied to a Cantor fractal array design and a multiband behavior is obtained successfully.*

I. INTRODUCTION

Log-periodic antenna (LP) is a wideband antenna that is not affected by the change in frequencies within the operation band. One of the widely used LP antennas in modern communication systems is the Log-Periodic Dipole Antenna (LPDA) [1]. Its characteristics remain nearly constant and it radiates with high gain at frequencies within the operating band. LPDA consists of an array of dipoles in which there lengths and spacings are arranged in a log-periodic manner. The antenna is fed by a balanced two-phase reversal transmission lines that are transposed between each adjacent pair of dipoles. LPDA has been used in many applications. Recently, it has been introduced as elements for multiband cantor array [2]. It has the advantage of radiating at different frequency bands with the same SLR, in addition to providing a very high gain reaches 16.5dB. These radiation properties allow this type of antennas to be used for the multiband wireless applications. The drawback that may be considered in this antenna is its large size [2]. Also, the mutual coupling and the complex electromagnetics interactions between the LPDA elements are not included in the traditional design equations in most books. Thus a proper optimization technique should be applied for designing a realistic design of LPDA that consider these effects along with compressing the size of the antenna at the same time.

Genetic Algorithm (GA) previously used in conjunction with Numerical Electromagnetic Code (NEC) to search in a very large design space of the LPDA design parameters and can find unexpected solutions to linear antenna array design problems [3]. In this paper, an efficient genetic algorithm optimization code combined with the well-known Method of moments NEC code is developed to fit compressed LPDA antenna design. Previously GA/MoM program implemented in [4] uses MATLAB routines for the GA optimization part, which is believed to extent the run time for the iterations. However, the present implementation uses FORTRAN code for both GA and NEC parts that makes the code more efficient with reduced run time. For the developed optimization technique the fitness function is calculated for each GA population numerically using the results obtained from the compiled NEC code. The objective of this paper is to obtain the optimum design of LPDA elements with minimum number of elements and compressed boom length using GA/MoM. These designs are optimized for the average gain and VSWR values over operating band frequencies. The LPDA is initially designed using the traditional LPDA designing procedures [1] within the desired frequency band. Then, GA/MoM is used to optimize this initial design for the average gain and VSWR with compressed dimensions. This optimized design is compared with previously published results for verification purposes [4]. Finally, new designs are introduced to fit the multiband cantor array [2]. he organization of the paper is as follows: An overview of the GA concepts and terminologies are discussed in section II. In section III, the computer model of GA/MoM is introduced. In section IV, the two LPDA case studies are presented and the numerical results for the compressed antennas and the fractal cantor array field patterns are illustrated. Finally, conclusions are derived in section V.

II. NUMERICAL OPTIMIZATION APPROACH

In this paper the used optimization technique (GA/MoM) is written in Fortran, where GA is coupled with a compiled version of the NEC code. The optimizing parameters (genes) are the LPDA elements lengths, radii, and spacings between them. These variable parameters of the LPDA are placed in the chromosome vector. The fitness function of GA linked with NEC to evaluate the gain and VSWR in terms of the optimization parameters is given in (1)

$$\text{Fitness} = \frac{A \times \sum_{f=fs}^{fd} \text{gain}(f)}{N} + \frac{N \times B}{\sum_{f=fs}^{fd} \text{VSWR}(f)} \qquad (1)$$

where A and B are constants chosen by user, N is the number of frequency steps, f_s is the initial frequency, while f_d is the final frequency. This fitness Function is used with two constrains. The two constrains states that the VSWR (f) lies between 1 and 2.5 and the higher order LPDA element length must be greater than lower order ones. If any of these constrains is not satisfied the fitness function resets to zero and the population is discarded.

III. RESULTS

GA/MoM is used to reduce the antenna number of elements nearly to the half in addition to compressing its overall length. The GA and the integral equation numerical method are employed to determine all geometrical variables required for the LPDA antenna design. Two designs of LPDAs are optimized; first, a 3-elements LPDA covering the range from 300 to 400 MHz with a reduced boom length to be compared with the results of 5-elements LPDA in [4] for verification purpose. Next, an initial design of broadband 10-elements LPDA covering the range from 400-1800MHz is optimized and compressed to 5-elements array with reduced overall length. This optimized 5-elements LPDA is then applied to a cantor fractal array design to have a multiband behavior with high gain and compressed size.

A.300-400MHz LPDA REDUCTION

A 5-elements LPDA is designed to operate at the 300-400MHz-frequency band using the designing equations [1]. An average gain of 7.4561dB and VSWR of 1.9 are obtained. The total length of the array from the first to the last element (S_{total}) is found to be 0.5937m. This total length for reduced number of parallel elements was our optimization objectives. Having constrains of maximum gain and minimum VSWR over the whole operating band. GA / MoM runs were carried out to find an optimum design using only 3-elements. The chromosome has 3 genes representing the elements lengths, 3 genes representing the elements radii and two genes for spacing distances between elements. This gives a total of 8 parameters that is encoded into 64 bits. The gain and VSWR are sampled every 10MHz. The total antenna length S_{total}, mean of the gain and VSWR over the frequency range are shown in table (1). By comparing the initial design results and the 5 elements LPDA results obtained in [4] using different optimization techniques with the 3 elements LPDA design obtained using the developed GA/MoM. It is found that the average gain reduced by 1.25dB only. The VSWR improved as it decreased by around 0.6. Also the S_{total} reduced to 0.02m i.e. the antenna size reduced by about 0.5737m. Therefore, the same performance is nearly obtained using less number of elements and a reduced total antenna length. Figure 1a and 1b shows the gain and the VSWR of the initial 5-elements LPDA and the GA designed 3-elements LPDA are similar all over the band. That verifies that both the initial and the compressed LPDAs have the same performance.

TABLE I Initial LPDA and GA designed LPDA configurations

Frequency Range	300-400 Initial design	300-400 GA design
Number of elements	5	3
S_{total}	0.5937	0.02
GAIN	7.4561	6.2
VSWR	1.9	1.268788

B. 400-1800MHz LPDA REDUCTION

Next, A broadband 10-elements LPDA operating at 400-1800MHZ is optimized. This LPDA element is previously used to construct a multiband fractal cantor array [2]. This LPDA provides an average gain of 7.24dB and VSWR of 1.9 over the range from 400 to 1800 MHz. The antenna configuration details [2] are shown in table 2 (first column). L_n and R_n are the length and the radius of the LPDA n^{th} element respectively. The objective is to compress the antenna total length S_{total}= 0.39m with reduced number of elements using the developed GA/MoM. Therefore, the 10-elements LPDA is optimized to cover the same range using only 5-elements. The program uses 14 genes or optimization parameters. These parameters are for 5 elements lengths, 5 elements radii, and 4 spacings distances between the elements. Each gene is encoded by 6-bits, the chromosome length is 84 bits, number of populations per generation is 4, and number of generations is 2000. The gain and VSWR are sampled every 50MHz. The resultant elements lengths, spacings, total antenna length S_{total}, radii, mean of the gain and VSWR over the frequency range are also shown in table 2 (second column). By comparing the initial design results and the GA/MoM design, an average gain is produced given by 6.4dB. The average gain decreased by only 0.84dB. Therefore, both LPDA's nearly have the same average gain. The reduction in the number of elements led to compressing the antenna size as the total boom length (S_{total}) is reduced to 0.21m i.e. the antenna size reduced by about 46%. Figure 2a and 2b show the gain and the VSWR of the initial 10-elements LPDA and the GA designed 5-elements LPDA. This indicates that the compressed 5- elements LPDA performs the same as the initial design within the operating band. It should be noticed that, designing LPDA using the developed GA/MoM is also much easier that traditional designing procedures [1], as the designer does not have to worry about choosing the designing parameters such as τ (the scale factor of antenna elements lengths) and σ (spacing factor between elements).

TABLE 2 Initial LPDA and GA Designed LPDA Configurations

Configuration	Initial design	GA design
Number of elements	10	5
L10/2, R10	0.0252, 0.0017	0.06127, 0.001762
L9/2, R9	0.0315, 0.0022	0.064286, 0.012048
L8/2, R8	0.0393, 0.0027	0.085397, 0.012048
L7/2, R7	0.0492, 0.0034	0.142698, 0.012048
L6/2, R6	0.0614, 0.0042	0.178889, 0.011667
L5/2, R5	0.0768, 0.0053	-
L4/2, R4	0.0960, 0.0066	-
L3/2, R3	0.1200, 0.0083	-
L2/2, R2	0.1500, 0.0103	-
L1/2, R1	0.1875, 0.0129	-
S_{total}	0.39	0.21
GAIN	7.24	6.4
VSWR	1.9	1.8

Finally, the compressed LPDA is used as the elements of the cantor array. So a compressed multiband fractal Cantor LPDA array is obtained providing the same performance as the uncompressed one. Figure 3 shows the far field patterns at 870 MHz and 1800MHz for both compressed and uncompressed Fractal LPDA Cantor Array. By comparing the patterns, it can be concluded that the GA/MoM developed tool provided a compressed LPDA Cantor Array elements that have the same performance as uncompressed one. As shown in the figure, the multiband behavior is achieved with reduced number of elements and also has a compact size.

IV. CONCLUSION

Genetic algorithm in conjunction with numerical electromagnetic code technique is successfully employed to compress the overall size of the LPDA antenna. Several LPDA designs using both the traditional analytical designing methods and the optimization GA/MoM technique are investigated in this paper. It has been shown that GA/MoM technique provides optimum LPDA designs with less number of elements and total length. These antennas operate in the same frequency band as the analytically designed LPDAs nearly with the same average gain and average VSWR. The optimum LPDA design is then applied to construct a practical multiband cantor array. With the efficient GA/MoM optimization tool LPDA overall length could be compressed to high values relative to its initially analytical design with reduced number of elements. For example, 300-400 MHz LPDA design that has 5 elements and 59 cm boom length [4] is successfully compressed to 3 elements and 20 cm boom length having nearly the same average gain and VSWR values. Results also show that 400-1800 MHz broadband LPDA that has 10 elements is compressed to 5 elements LPDA with 46% reduction of its original size. Finally, it has been shown that this optimum 5-elements LPDA operating at 400-1800 MHz performs well if it is used as to construct a realistic multiband cantor array. The array multiband behavior with high gain is obtained and it is illustrated.

It can be also concluded that designing LPDA using the developed GA/MoM produce superior antenna designs to traditional analytical approaches. As the designer does not have to worry about the designing parameters like in the traditional designing procedures.

REFERENCES

[1] C. Peixeiro, "Design of Log Periodic Dipole Array," IEEE proceeding, Vol. 135, Pt. H, No. 2, pp. 98-102, April 1988.

[2] S. Elkhamy et.al., "Design of Multiband Fractal Antenna Arrays with Wideband LPDA elements" International Conference on Computer Theory and Applications, 13th ICCTA, Alexandria, Egypt, Aug. 2003.

[3] E. A. Jones and W. T. Joines "Genetic algorithm for linear antenna array" IEEE antennas and Propagation Magazine, Vol 42, No. 3, pp. 92-100, June 2000.

[4] Y. C. Chung, and Randy L. Haupt, "Log-periodic dipole array optimization," Journal of Electromagnetic Waves and Application, vol. 15, no. 9, pp. 1269-1280, 2001.

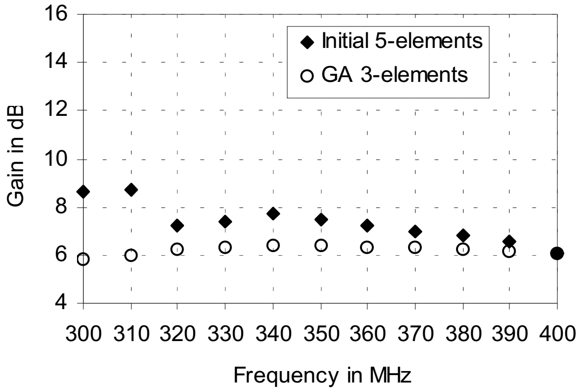

Fig. 1a Gain of the initial 5-elements LPDA and the GA designed 3-elements LPDA (300-400 MHz)

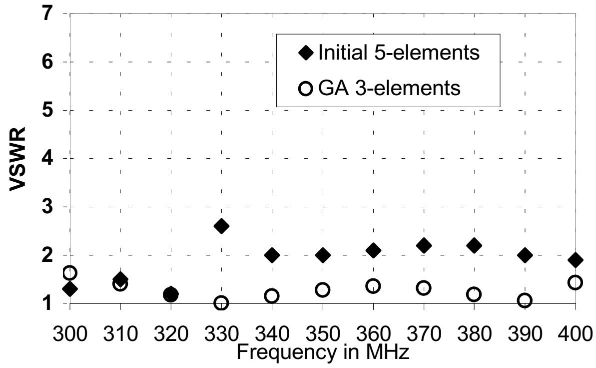

Fig. 1b VSWR of the initial 5-elements LPDA and the GA designed 3-elements LPDA (300-400 MHz)

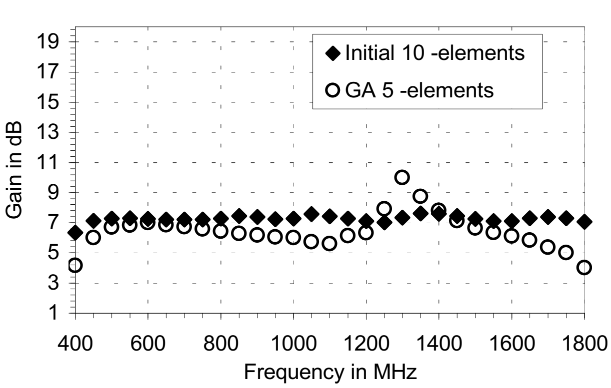

Figure 2a. Gain of the initial 10-elements LPDA and the GA designed 5-elements LPDA (400-1600 MHz)

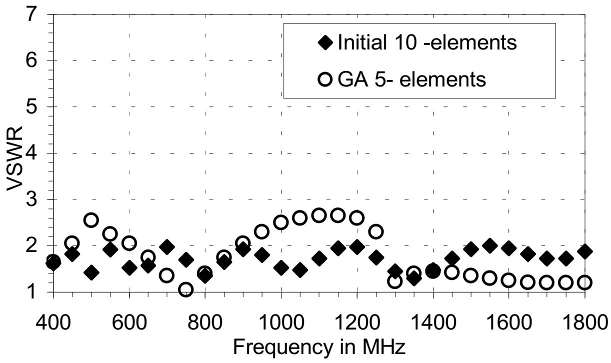

Figure 2b. VSWR of the initial 10-elements LPDA and the GA designed 5-elements LPDA (400-1600 MHz)

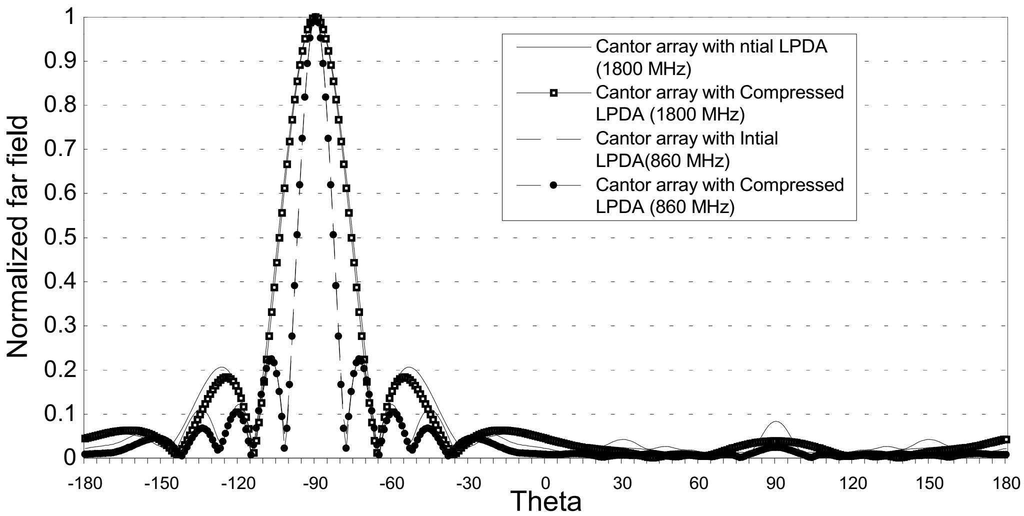

Fig. 5. Normalized copolar far field pattern versus theta