# Comparison of evolutionary algorithms for LPDA antenna optimization

Pavlos I. Lazaridis <sup>(1)</sup>, Emmanouil N. Tziris <sup>(2)</sup>, Zaharias D. Zaharis <sup>(3)</sup>, Thomas D. Xenos <sup>(3)</sup>, John P. Cosmas <sup>(2)</sup>, Philippe B. Gallion <sup>(4)</sup>, Violeta Holmes <sup>(1)</sup>, and Ian A. Glover <sup>(1)</sup>

(1) University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK.

(2) Brunel University, London, UB8 3PH, UK.

(3) Aristotle University of Thessaloniki, GR-54124 Thessaloniki, Greece.

(4) ENST Telecom ParisTech, CNRS, LTCI, 46, rue Barrault, 75013, Paris, France.

Abstract — A novel approach to broadband log-periodic antenna design is presented, where some of the most powerful evolutionary algorithms (EAs) are applied and compared for the optimal design of log-periodic dipole arrays (LPDA) using NEC (Numerical Electromagnetics Code). The target is to achieve an optimal antenna design with respect to maximum gain, Front to Rear ratio and SWR (Standing Wave Ratio). The parameters of the LPDA optimized are the dipole lengths, the spacing between the dipoles, and dipole wire diameters. The evolutionary algorithms compared are the: Differential Evolution (DE), Particle Swarm (PSO), Taguchi, Invasive Weed (IWO) and Adaptive Invasive Weed (ADIWO) Optimization.

Keywords— Adaptive Invasive Weed Optimization, Broadband log-periodic antenna, Differential Evolution, Evolutionary algorithms, Front to Rear ratio, IWO, NEC, Numerical Electromagnetics Code, LPDA, Particle Swarm, PSO, Standing Wave Ratio, SWR, Side Lobe Level, SLL, Taguchi, UHF-TV Band.

#### Ι. INTRODUCTION

Broadband log-periodic antenna optimization is a very challenging problem for antenna design. However, up to now, the universal method for log-periodic antenna design is Carrel's method dating from the 1960s, [1-3]. This paper compares five antenna design optimization algorithms (Differential Evolution, Particle Swarm, Taguchi, Invasive Weed, Adaptive Invasive Weed) as solutions to the broadband antenna design problem. The algorithms compared are evolutionary algorithms which use mechanisms inspired by biological evolution, such as reproduction, mutation, recombination, and selection. The focus of the comparison is given to the algorithm with the best results, nevertheless, it becomes obvious that the algorithm which produces the best fitness values (Invasive Weed Optimization) requires very substantial computational resources due to its random search nature.

Log-periodic antennas (LPDA: Log-Periodic Dipole Arrays) are frequently preferred for broadband applications due to their very good directivity characteristics and flat gain curve. The purpose of this study is, in the first place, the accurate modelling of the log-periodic type of antennas, the detailed calculation of the important characteristics of the antennas under test (gain, SWR, and Front-to-Rear ratio that is equivalent to SLL: Side Lobe Level) and the confrontation with accurate measurements results.

In the second place, various evolutionary optimization algorithms are used, and notably the relatively new (2006) Invasive Weed Optimization (IWO) algorithm of Mehrabian & Lucas, [4], for optimizing the performance of a log-periodic antenna with respect to maximum gain, Front to Rear ratio (F/R), and matching to 50 Ohms, SWR. The multi-objective optimization algorithm is minimising a so-called fitness function including all the above requirements and leads to the optimum dipole lengths, spacing between the dipoles, and dipole wire diameters. In some optimization cases, a constant dipole wire radius could be adopted in order to simplify the construction of the antenna.

#### CLASSICAL DESIGN ALGORITHM FOR LPDAS II.

The most complete and practical design procedure for a Log-Periodic dipole array (LPDA) is that by Carrel, [1-2]. The configuration of the log-periodic antenna is described in terms of the design parameters:  $\tau$ ,  $\alpha$ , and  $\sigma$ , related by:

$$\alpha = \tan^{-1} \left[ \frac{1 - \tau}{4\sigma} \right] \tag{1}$$

Once two of the design parameters are specified, the other can be found. The proportionality factors that relate lengths, diameters, and spacings between dipoles are:

$$\tau = \frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n}, \ \sigma = \frac{s_n}{2L_n}$$
(2)

where,  $L_n$  and  $d_n$  are respectively the length and the diameter of the n-th dipole, and  $s_n$  is the spacing between the n-th and (n+1)-th dipoles. However, for many practical log-periodic antenna designs, wire dipoles of equal diameters d<sub>n</sub> are used, or for some advanced designs, three or four groups of equal diameter dipoles are used to cover the whole frequency range. In order to reduce some anomalous resonances of the antenna, a short-circuited stub is usually placed at the end of the feeding line at some distance behind the longest dipole. Directivity in dB contour curves as a function of  $\tau$  for various values of  $\sigma$  are shown in [2], as they have been corrected in [3]. A set of design equations and graphs are used, but in practice it is much easier to use a software incorporating all the necessary design

procedure, such as LPCAD, [5-6]. LPCAD also produces a file that can be used for the detailed simulation of the antenna using the NEC software, which employs the Method of Moments for wire antennas, [7-9].

## III. RESULTS

The evolutionary optimization algorithms compared in this study are the: IWO, [10-17], ADIWO, [18], PSO, [19-23], DE, [24], and Taguchi, [14]. In order to compare the results of each optimization algorithm, the algorithms were applied to an LPDA antenna for the UHF-TV band (470-790 MHz) with 10 dipoles and a rear shorting stub. A slightly larger frequency band of 450MHz to 800MHz was used for the optimization with respect to maximum gain, Front to Rear ratio (SLL) and matching to 50 Ohms: Standing Wave Ratio (SWR). Consequently, the fitness function is a linear combination of the above three performance parameters, which are calculated by applying the NEC engine (Numerical Electromagnetics Code) in the 4NEC2 software, [9], for every candidate solution and for all frequencies by steps of 10MHz, i.e. for 35 discrete frequencies. The optimized parameters of the antenna are the dipole lengths and diameters as well as the distances between each dipole and the characteristic impedance of the transmission line that feeds the dipoles. Each evolutionary algorithm has been coded in Matlab and was executed for a total of 44,000 fitness evaluations, i.e. 44,000 NEC calculations. At the end of the execution of each algorithm the best fitness and the geometry of the optimized antenna were produced that was then extracted to a '.nec' file. The 4NEC2 software was used to run the NEC file produced by Matlab, to derive the SWR, Gain, F/R Ratio, while the convergence diagram figures were derived directly from the optimization algorithms.



Fig. 1. Standing Wave Ratio for a log-periodic optimized antenna.

In Figure 1 the comparison of SWR between the evolutionary algorithms which were used to generate the geometries of five different LPDAs shows that the results are very satisfying for all of the algorithms, since the SWR values

are all below 1.8. Nonetheless, as it is expected some algorithms performed better than others, with PSO being the leading algorithm with the lowest values across the frequency range while the Adaptive IWO had the poorest results, being the only method which exceeded the value of 1.5. The Differential Evolution, Taguchi and Invasive Weed methods show a standing wave ratio which oscillates around the 1.25 value, which translates to a return loss of 19.1dB.



Fig. 2. Gain (dBi) for a log-periodic optimized antenna.

Comparing the gain of the LPDAs generated by each algorithm gives a better view of the performance of the algorithms than the SWR figure where all the algorithms have a similar average. In Figure 2, it is very clear that the best performance comes from IWO and Differential Evolution. IWO is the best performer since its gain shows a flat value of approximately 8dBi and is higher compared to the other algorithms across the whole UHF-TV band. The Differential Evolution optimized antenna performs similarly but its gain values are oscillating across the desired frequency range, which is clearly worse than the flat frequency response of the IWO-based optimization. On the other extreme, the Taguchioptimized antenna exhibits the poorest performance with relatively low gain.



Fig. 3. Front to Rear ratio for a log-periodic optimized antenna.

Similarly to the gain figure, the Front to Rear ratio Figure 3, confirms the previous conclusion that the best results are produced by the LPDAs generated from the IWO and Differential Evolution algorithms with F/R ratio values much higher compared to the rest of the algorithms. The PSO method exhibits an average performance while the poorest results are again shown by the Taguchi method (lowest F/R ratio across the desired frequency range) and Adaptive IWO (very poor low frequency F/R ratio values).



Fig. 4. Convergence diagram for the five evolutionary optimization algorithms used.

At this point it should be noted, that the performance of the optimization algorithms is mainly judged by their ability to produce the lowest possible fitness value, which as mentioned before is a linear combination of the SWR, gain, and the F/R ratio. This means that the algorithm to produce the lowest fitness value is expected to derive the LPDA with the best performance. Figure 4 depicts the convergence diagram (fitness value versus number of fitness evaluations, or equivalently, calls to the NEC calculation engine) of all of the algorithms for a total of 44,000 fitness evaluations except for the Taguchi method which terminates automatically at about 4,200 fitness evaluations. This number of total fitness evaluations was chosen in order to show which algorithm produces the best fitness value, because after this point, the algorithms are unable to lower much further the fitness value. This is obvious from the observation of the last 10,000 fitness evaluations in Figure 4.

As expected, the algorithm which produced the lowest fitness value is IWO (best fitness is 12.36) which also had the best performance shown in the previous Figures, while Differential Evolution produces the second best fitness value 13.08. Nonetheless, it is remarkable that PSO (fitness 13.80) has a very fast drop rate during the first 200 fitness evaluations compared to the rest. Similarly, the adaptive IWO (fitness 14.10) has a better initial drop rate compared to IWO and Differential Evolution, but not quite as fast as the PSO. Finally, the Taguchi method has the worst fitness of 16.32 but at just one tenth of the computation time.

## IV. CONCLUSIONS

Five evolutionary algorithms were employed to design Log-Periodic Dipole Arrays, to compare their performance, and to have the opportunity for the first time to determine which algorithm shows the best performance when it comes to LDPA design. All of the algorithms generated LPDA geometries with very satisfying properties (SWR, Gain and F/R Ratio). Some algorithms, however, were able to initially reduce the fitness function faster than others (PSO and Adaptive IWO), while Invasive Weed and Differential Evolution show the best final results and lowest fitness values. Overall, the IWO algorithm exhibits the best performance.

#### ACKNOWLEDGMENT

This work is sponsored by NATO's Public Diplomacy Division in the framework of "Science for Peace" through the SfP-984409 ORCA project.

## V. REFERENCES

- R. Carrel, Analysis and design of the log-periodic dipole antenna. Urbana: Electrical Engineering Research Laboratory, Engineering Experiment Station, University of Illinois, 1961.
- [2] C. Balanis, Antenna theory, Analysis and Design, 2nd ed. John Wiley & Sons, 1997, pp. 551-566.
- [3] P. Butson and G. Thompson, 'A note on the calculation of the gain of log-periodic dipole antennas', *IEEE Transactions on Antennas and Propagation*, vol. 24, no. 1, pp. 105-106, 1976.
- [4] A. Mehrabian and C. Lucas, 'A novel numerical optimization algorithm inspired from weed colonization', *Ecological Informatics*, vol. 1, no. 4, pp. 355-366, 2006.
- [5] Wb0dgf.com, 'WB0DGF Antenna Site LPCAD Log Periodic Antenna Design', 2015. [Online]. Available: <u>http://wb0dgf.com/LPCAD.htm</u>.
- [6] Antennex.com, 'LPCAD30', 2015. [Online]. Available: <u>http://www.antennex.com/shack/Feb06/lpcad.html</u>.
- [7] G. Burke and A. Pogio, *Numerical electromagnetics code (NEC)*. San Diego, Calif.: Naval Ocean Systems Center, 1981.
- [8] L. Cebik, 'A beginner's guide to modeling with NEC', *QST Magazine*, pp. 40-44, 2000.
- [9] Qsl.net, '4nec2 antenna modeler and optimizer', 2015. [Online]. Available: <u>http://www.qsl.net/4nec2/</u>.
- [10] Y. Li, F. Yang, J. OuYang and H. Zhou, 'Yagi-Uda Antenna Optimization Based on Invasive Weed Optimization Method', *Electromagnetics*, vol. 31, no. 8, pp. 571-577, 2011.
- [11] S. Sedighy, A. Mallahzadeh, M. Soleimani and J. Rashed-Mohassel, 'Optimization of Printed Yagi Antenna Using Invasive Weed Optimization (IWO)', *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 1275-1278, 2010.

- [12] A. Mallahzadeh, H. Oraizi and Z. Davoodi-Rad, 'Application of the Invasive Weed Optimization Technique for Antenna Configurations', *PIER*, vol. 79, pp. 137-150, 2008.
- [13] S. Pal, A. Basak and S. Das, 'Linear antenna array synthesis with modified invasive weed optimisation algorithm', *International Journal of Bio-Inspired Computation*, vol. 3, no. 4, p. 238, 2011.
- [14] Z. Zaharis, P. Lazaridis, J. Cosmas, C. Skeberis and T. Xenos, 'Synthesis of a Near-Optimal High-Gain Antenna Array With Main Lobe Tilting and Null Filling Using Taguchi Initialized Invasive Weed Optimization', *IEEE Trans. on Broadcast.*, vol. 60, no. 1, pp. 120-127, 2014.
- [15] P. I. Lazaridis, Z. D. Zaharis, C. Skeberis, T. Xenos, E. Tziris, and P. Gallion, 'Optimal design of UHF TV band log-periodic antenna using invasive weed optimization', *Wireless VITAE conference*, Aalborg, Denmark, May 2014.
- [16] Z. D. Zaharis, C. Skeberis, T. D. Xenos, P. I. Lazaridis, and D. I. Stratakis, 'IWO-based synthesis of log-periodic dipole array', *TEMU International conference*, Crete, Greece, July 2014.
- [17] Z. Zaharis, C. Skeberis, P. Lazaridis, and T. Xenos, 'Optimal wideband LPDA design for efficient multimedia content delivery over emerging mobile computing systems', *IEEE Systems*, vol. PP, no. 99, Jan. 2015.
- [18] Z. Zaharis, C. Skeberis, T. Xenos, P. Lazaridis and J. Cosmas, 'Design of a Novel Antenna Array Beamformer Using Neural Networks Trained by Modified Adaptive Dispersion Invasive Weed Optimization Based Data', *IEEE Trans. on Broadcast.*, vol. 59, no. 3, pp. 455-460, 2013.

- [19] M. Pantoja, A. Bretones, F. Ruiz, S. Garcia and R. Martin, 'Particle-Swarm Optimization in Antenna Design: Optimization of Log-Periodic Dipole Arrays', *IEEE Antennas Propag. Mag.*, vol. 49, no. 4, pp. 34-47, 2007.
- [20] R. Golubovic and D. Olcan, 'Antenna optimization using Particle Swarm Optimization algorithm', J Autom Control, vol. 16, no. 1, pp. 21-24, 2006.
- [21] M. Aziz-ul-Haq, M. Tausif Afzal, U. Rafique, Q. ud -Din, M. Arif Khan and M. Mansoor Ahmed, 'Log Periodic Dipole Antenna Design Using Particle Swarm Optimization', *International Journal of Electromagnetics and Applications*, vol. 2, no. 4, pp. 65-68, 2012.
- [22] Z. D. Zaharis, D. G. Kampitaki, P. I. Lazaridis, A. I. Papastergiou, and P. B. Gallion, 'On the design of multifrequency dividers suitable for GSM/DCS/UMTS applications by using a particle swarm optimization-based technique', *Microwave* and Opt. Tech. Letters, vo. 49, No. 9, pp. 2138-2144, Sept. 2007.
- [23] Z. Zaharis, D. Kampitaki, A. Papastergiou, P. Lazaridis and M. Spasos, 'Optimal design of a linear antenna array under the restriction of uniform excitation distribution using a particle swarm optimization based method', WSEAS Trans. on Communications, vol. 6, no. 1, pp. 52-59, 2007.
- [24] D. Kampitaki, A. Hatzigaidas, A. Papastergiou, P. Lazaridis, and Z. Zaharis, 'Dual-frequency splitter synthesis suitable for practical RF applications', *WSEAS Trans. on Communications*, vol. 5, No. 10, pp. 1885-1891, Oct. 2006.