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Original Citation

Mistry, Keyur, Lazaridis, Pavlos, Glover, Ian, Holmes, Violeta, Khan, Faheem A., Ahmed, Qasim Z., Zaharis, Zaharias D. and Xenos, Thomas D. (2017) Measurement, simulation and optimization of wideband log-periodic antennas. In: URSI GASS 2017, 19-26 August 2017, Montreal, Canada.

Measurement, simulation and optimization of wideband log-periodic antennas

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Abstract

Log-periodic antenna is a special antenna type utilized with great success in many broadband applications due to its ability to achieve nearly constant gain over a wide frequency range. Such antennas are extensively used in electromagnetic compatibility measurements, spectrum monitoring and TV reception. In this study, a log-periodic dipole array is measured, simulated, and then optimized in the 470-860 MHz frequency band. Two simulations of the antenna are initially performed in time and frequency domain respectively. The comparison between these simulations is presented to ensure accurate modelling of the antenna. The practically measured net gain is in good agreement with the simulated net gain. The antenna is then optimized to concurrently improve voltage standing wave ration, net gain and front-to-back ratio. The optimization process has been implemented by using various algorithms included in CST Microwave Studio, such as Trusted Region Framework, Nelder Mead Simplex algorithm, Classic Powell and Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES). The Trusted Region Framework seems to have the best performance in sufficiently optimizing all predefined goals specified for the antenna.

Keywords — Boom, CST, dipoles, directivity, electromagnetic compatibility, gain, log-periodic antenna, LPDA, measurements, optimization, evolutionary algorithms, TV reception, UHF.

1. Introduction

Log-periodic antennas are widely used because of their broadband characteristics in TV reception, electromagnetic compatibility measurements and wideband precision measurements. LPDAs present a flat gain and a flat frequency response within their wide frequency range of operation [1]. The gain of the antenna can be increased by increasing the number of dipoles [2]. LPDAs provide a better front-to-back performance but relatively less gain than the Yagi-Uda array antenna [3].However,the LPDA has a much larger bandwidth as compared to the Yagi-Uda antenna. Furthermore, the most important difference between the two antennas is in their feeding patterns. Each dipole element of the LPDA is an active element (all the dipoles connected to the feeding source) whereas the Yagi-Uda antenna consists of only one active dipole element and all other dipole elements are passive [4]. A very useful design procedure of the LPDA has been proposed by Carrel, [5].

The LPDA is designed using several dipoles of different lengths. Each dipole is operating at a specific frequency. A dipole operates in the active region when the dipole length L, is equal to half the wavelength. However, the dipole acts as a reflector if the dipole length L, is greater than half the wavelength and acts as a director if the dipole length L, is less than half the wavelength. Due to this reason and by employing dipoles of varying lengths, the LPDAs can operate at a wide frequency range [4].

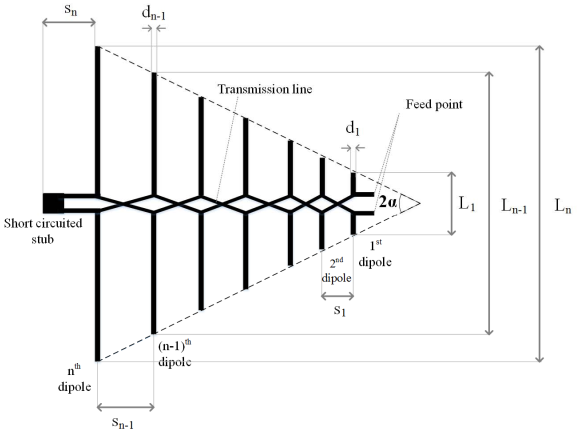

Figure 1. Log-periodic dipole antenna geometry.

Figure 1 presents the basic geometry of a log-periodic dipole antenna. The LPDA consists of several parallel linear dipoles of varying lengths, which are arranged in a sequence in such a way that they are contained within an angle 2α. The angle of intersection can be defined as:

$$\alpha = \tan^{-1}\left[\frac{1-\tau}{4\sigma}\right] \qquad (1).$$

The ratio of the lengths of consecutive dipoles is a constant (scaling factor, τ) and the ratio of the spacing between two consecutive dipoles is another constant (spacing factor, σ). The dipoles of the LPDA are connected to the source in such a way that a phase reversal is obtained between consecutive dipoles [6]. The relations of proportion between the lengths of the dipoles, the diameter of the dipoles and the spacing between the dipoles is written as:

$$\tau = \frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n} \qquad (2).$$

$$\sigma = \frac{s_n}{2L_n} \qquad (3).$$

where, L_n is the length of nth dipole whereas d_n is the diameter of the n^{th} dipole and s_n is the spacing between the n^{th} dipole and its consecutive (n+1) th dipole. In some designs, a constant diameter dipoles are used in order to lower the cost, [7]. The value of τ and σ can be chosen by the user to design the antenna with specific radiation characteristics by using appropriate graphs [3-8].

2. LPDA measurements and simulations

This study presents the measurement results of a ten-element log-periodic antenna conducted in open field conditions in the UHF TV frequency band of 470-860 MHz. The measurements were performed using a Rohde & Schwartz FSH8 portable spectrum analyzer. The gain of the antenna was measured using the reference antenna method with the help of calibrated biconical dipole antennas. A model of this antenna was developed in CST Studio Suite 2016, so that the simulation results could be compared with the measured results of the antenna. The simulated results of the model obtained from CST include the VSWR and net gain versus frequency. The net gain of the antenna is defined as the difference between gain and mismatch loss of the antenna. Furthermore, the optimization of this antenna has been performed in CST using Trusted Region Framework, Nelder Mead Simplex algorithm, Classic Powell and CMA-ES that are included in this simulator. The simulation of the antenna model is performed by the time domain solver and by the frequency domain solver. Figure 2 shows the comparison of net gain from time domain simulation and frequency domain simulation respectively.

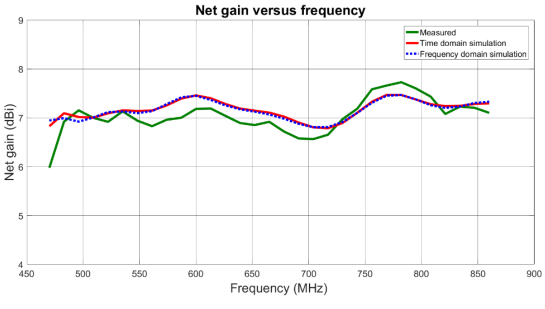

Figure 2. Comparison of the net gain from time domain simulation, frequency domain simulation and open-field measurements.

After this preliminary check of the antenna model, there was confidence that results from the time domain solver and the frequency domain solver are correct and that they accurately model antenna performance. The difference between simulated and measured net gain is less than ±0.5 dBi in the whole frequency range. The optimization of this antenna was then performed using various algorithms included in CST.

3. LPDA optimization

CST includes global optimizers and local optimizers. However, the search capability is larger in global optimizers compared to the local optimizers. Trusted Region Framework (TRF), Nelder Mead Simplex algorithm and Classic Powell algorithm are examples of local optimizers. On the other hand, Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) is an example of a global optimizer.

In TRF optimizer, a linear model is created based on the primary data collected from a trust region around the starting point. The new model then acts as a new starting point until it converges to obtain an accurate model of the data. It is one of the most robust optimization algorithms included inCST. Trusted Region Framework algorithm has a unique ability to predict improved fitness values by adjusting the limits and providing global convergencel [9]. Nelder and Mead (1965), introduced Nelder Mead Simplex search algorithm, which is an improved version of the Simplex search algorithm proposed by Spendley, Hext and Himsworth (1962) [10]. This algorithm utilises multiple number of points which are distributed across the parameter search space, so that the optimum value can be identified. It can be used as a solution for complex problem domains consisting of relatively few parameters. Classic Powell algorithm is a simple and robust optimizer which can be used for a problem involving a few parameters. The time of termination of the optimization process is decided by the accuracy set before the start of the optimization. It is a relatively slow algorithm compared to other algorithms. However, it provides accurate results in some cases. CMA-ES is a self-adaptive evolution strategy and a global optimizer which was developed by Hansen and Ostermeier [11]. CMA-ES initialises strategy parameters like the number of variables, population size and their bounds in a well-defined fashion and thus does not require parameter tuning by the user [11-12]. This algorithm is based on the evolution of a population of individuals. The comparison of CMA-ES with PSO (Particle Swarm Optimization) is presented in [13]. CMA-ES solves a problem by generating a population of individuals using a Gaussian distribution [14].

Trusted Region Framework algorithm, Nelder Mead simplex algorithm, Classic Powell and Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) were used to optimize the antenna so that it satisfies the requirements stated in Table 1. The dipole lengths (d_n), radius of the dipoles (rad), gap between the boom (gap), length of the boom (l_boom), width of the boom (b_boom), height of the boom (h_boom), length of the connector (l_connector) and spacing between the dipoles ($s_{n,n+1}$) were the parameters which were taken into consideration while performing the optimization.

Table 1. Goals and weights for antenna optimization.

Parameter	Operator	Goal value	Weight
VSWR	<	1.5	10
Gain (dB)	>	8 dB	0.5
Front-to-back ratio (dB)	>	20 dB	0.2

The aim of the above mentioned algorithms is to find the minimum value of the fitness function, so that all goals are satisfied. The sum of all the goals is merged into a single fitness function and then the global minimum of the fitness function is achieved by the algorithms by changing the design parameter values taken into consideration for the optimization. The optimized results of VSWR and net gain obtained with various optimization algorithms are shown in Figures 3 and 4 respectively.

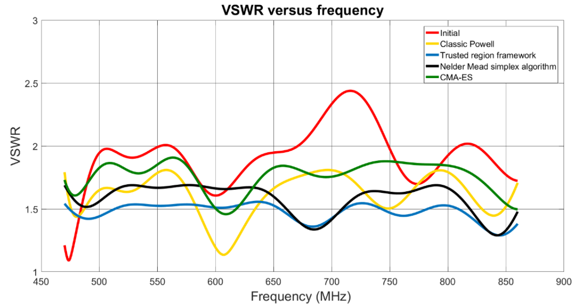

Figure 3. Comparison of the optimized VSWR with the initial VSWR of the antenna.

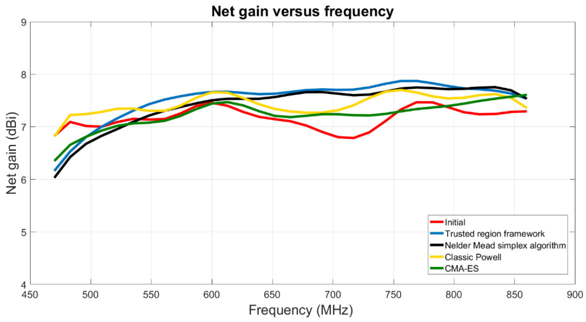

Figure 4. Comparison of the optimized net gain with the initial net gain of the antenna.

In Figure 3, presenting the comparison of the optimized VSWR to the initial VSWR, it is evident that the best performance is obtained from Trusted Region Framework algorithm followed by Nelder Mead Simplex algorithm. Trusted Region Framework algorithm was successful in minimizing the VSWR to approximately 1.5. Other algorithms presented a VSWR oscillating between 1.5 and 2. The CMA-ES algorithm exhibits the poorest performance with the highest VSWR.

In Figure 4, the best performer for optimizing the net gain is again the Trusted Region Framework algorithm since it produces a relatively flat net gain approximately equal to 7.8 dBi. The other algorithms exhibited an average performance by obtaining a flat net gain between 7 dBi to 7.8 dBi above 550 MHz. Furthermore, an important improvement of approximately 1 dB in net gain is observed between the initial net gain and the optimized net gain by the TRF algorithm in the frequency range of 670 MHz - 750 MHz. On the other hand, the lowest gain was again obtainedby the CMA-ES algorithm.

4. Conclusion

The accurate modelling and simulation of a ten-dipole LPDA has been successfully performed in the time domain and frequency domain. The simulated results and practically measured net gain results were compared to ensure the validity of the model. A comparative study of the optimization of an LPDA using various optimization algorithms included in CST, has been performed to obtain the best results for VSWR, net gain and front-to-back ratio. The Trusted Region Framework algorithm demonstrated the fastest and the best results with the lowestl fitness function value.

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