A Multi-objective Evolutionary Algorithm with Decomposition for Optimal Design of Yagi-Uda Antennas

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Abstract - **This paper presents a multi-objective evolutionary algorithm based on decomposition (MOEA/D) to design broadband optimal Yagi-Uda antennas. A multi-objective problem is formulated to achieve maximum directivity, minimum voltage standing wave ratio and maximum front-to-back ratio. It is solved with a modified differential evolution algorithm based on Gaussian mutation and Tchebychev decomposition. The algorithm was applied to the design of optimal Yagi-Uda antennas of 3 to 10 elements, whose optimal Pareto fronts are provided in a single picture.**

I. Introduction

Designing broadband Yagi-Uda antennas is a hard task due to the required trade-off of conflicting specifications, like directivity (D), standing wave ratio (VSWR), and front to back ratio (FBR) that should be handled as better as possible through the entire design spectrum. One way to treat this problem is optimizing the aforementioned specifications at different frequencies, so that a problem with many conflicting objectives must be solved. This complex problem can be solved using stochastic techniques as genetic algorithms (GAs) [1]-[2], deterministic techniques [3] among others.

This paper presents an extension of multi-objective evolutionary algorithm with decomposition (MOEA/D) based on the algorithm proposed by [4] applied in the optimization of Yagi-Uda antennas. MOEA/D uses a decomposition method to convert a multi-objective problem into a set of mono-objective problems and tries to approximate the Pareto front by solving all these subproblems together. We replace the operators proposed in [4] by the operators the method of Differential Evolution and Gaussian mutation. The MOEA/D was used to find approximate samples of the Pareto optimal set for antennas with 3 to 10 elements.

II. The optimization problem

The Yagi-Uda antenna is an array of linear elements, composed by a driven element (dipole) with a reflector parasitic element in the rear and director parasitic elements in the front, as shown in Fig. 1.

The element centered at the origin is the reflector, followed by the centered-fed driven element and directors. The distance $d_i = x_{i+1} - x_i$ between consecutive elements and the lengths of each element h_i, are the parameters to be optimized.

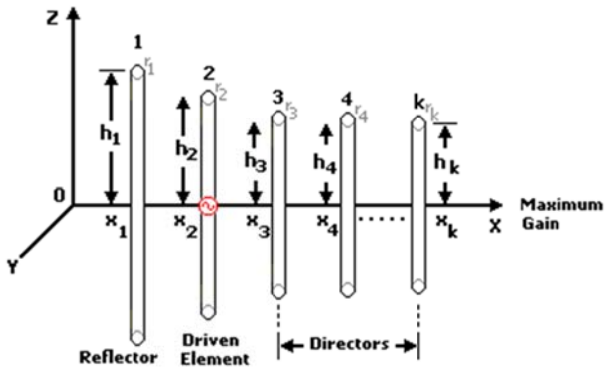

Fig. 1. Geometry of a k elements Yagi-Uda antenna.

This paper studies the design of broadband Yagi-Uda antennas considering three conflicting specifications: the directivity (D), standing wave ratio (SWR), and front to back ratio (FBR). These should be handled as better as possible through the entire design spectrum to guarantee the desired broadband characteristic.

The antenna must be able to operate over a band, not only a single frequency. In order to take this into account, the objective functions were defined as a function of the lower, central and upper frequencies f of the desired band of operation. This leads to an optimization problem with 9 conflicting objective functions. The reference wavelength λ is the one relative to the central frequency.

The problem can be mathematically stated as:

$$\min_s \max_i z(s,f_i) = (-D(s,f_i), -FBR(s,f_i), SWR(s,f_i)) \qquad (1)$$

where s are the decision variables formed by elements length and the gap between adjacent elements. Each antenna with k elements defines a problem with $2k - 1$ variables. With this approach, the goal is to improve the worst case performance over the entire bandwidth, which is sampled at three different frequencies. When antennas are optimized to operate over a range of frequencies, they are, somehow, robust to perturbations.

The antenna is numerically analyzed using the method of moments (MoM) [5], which will be detailed in an extended version of this paper.

III. MOEA/D

The main idea of this algorithm is to use a decomposition method to transform a multi-objective problem into a set of mono-objective problems. MOEA/D tries to solve the set of mono-objective problems linking the aim them to the global, find the Pareto front. Each optimal solution of the problem mono-objective is a Pareto solution of the multi-objective problem.

In this paper, we have used the Tchebychev decomposition to derive the mono-objective problems as:

$$\min z\,(x|\lambda,\mu) = \max_{\mathrm{i}} \lambda_i \,|z_i(x) - \mu_{\mathrm{i}}| \qquad (2)$$

which defines a scalar function z to be minimized, where $\lambda \in R^m$ is a weight vector and $\mu \in R^m$ is a goal vector, typically set to the utopian solution.

The population in MOEA/D is based on the creation of subproblems, where each individual is initially assigned to a subproblem, and each subproblem is assigned to a weight vector λ. The fundamental idea is to find a point that minimizes the objectives functions z_i, given the weight vector λ assign to each objective i.

The weight vector is created proportional to population size, the representativeness of the search space is better when we have larger populations, because we can create the vector of weight in a more distributed.

MOEA/D exploits information from neighbors in the optimization process, i.e. the subproblems which are considered neighbors will have similar fitness landscapes and their optimal solutions should be close in the decision space. The neighborhood relationship employed in this algorithm is defined from Euclidean distance between weight vectors used in the decomposition method.

The paper used the operator of the method Differential Evolution (DE) was proposed in [6], it is a simple and efficient optimization operator widely used in nonlinear optimization with continuous variables. Another operator also used in this paper is known in literature as the Gaussian mutation that consists in the perturbation of the solution from a normal distribution with mean x and standard deviation σ.

The MOEA/D algorithm starts with a random population of subproblems, from where the respective fitness and global goal point μ are initialized. After initialization, the evolutionary process takes place over the subproblems (individuals). The process continues until a stop condition is met (e.g. number of iterations).

IV. Results

Table 1 shows the trade-off among directivity, VSWR and FBR of optimal antennas selected according to lower VSWR. The results consider the mean of the respective quantity at three frequencies. A cross-section radius of 0.003369 wavelengths was considered for all elements at a central frequency of 859MHz within a 7% bandwidth.

TABLE I
OBJECTIVE FUNCTIONS OF OPTIMAL ANTENNAS WITH 3 TO 10 ELEMENTS

Antenna	D(dBi)	VSWR	FBR (dB)
3 elements	7.03	1.48	13.66
4 elements	8.27	1.15	11.84
5 elements	8.61	1.13	13.20
6 elements	9.17	1.10	12.88
7 elements	10.89	1.16	12.36
8 elements	11.05	1.18	11.90
9 elements	10.66	1.08	11.66
10 elements	11.08	1.24	13.56

Fig. 2 presents the approximate Pareto optimal fronts of Yagi-Uda antennas with 3 to 10 elements for the directivity (D) and standing wave ratio (VSWR). As expected, an optimal Pareto front relative to antennas with higher number of elements dominates a Pareto optimal front relative to antennas with lower number of elements.

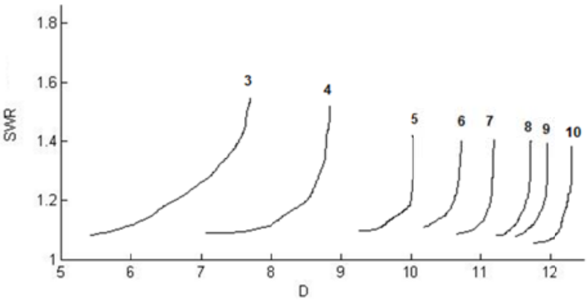

Fig. 2. Approximation Pareto optimal fronts for D and SWR for antennas with 3 to 10 elements.

V. References

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