Design of Yagi-Uda Antenna Using Genetic Algorithm Employing Radii Perturbations

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Abstract:

Genetic algorithms are being widely used for electromagnetic and antenna array optimization problems because of their global nature and flexibility over conventional methods. The Yagi-Uda antenna has already been optimized using gradient approach by length and spacing perturbations i.e. the variation of lengths of antennas and spacing between antennas constituting the array, to achieve maximum directive gain. In this paper, this optimized design has been further improved using Genetic Algorithm (GA) employing element radii perturbations. Methods of Moments (MoM) is an electromagnetic analysis technique based on solution of integral equations in the design problem. SuperNec is a software tool developed by Poynting Innovations and is based on MoM. To evaluate the performance the antenna designs generated using GA, SuperNec have been used. The results are comparable to those obtained using GA taking length and spacing of elements as variables.

Keywords: Antenna array optimization; Evolutionary approaches; Directive Gain

1 Introduction

The conventional design of a wire antenna involves the formulation of an integral equation or use of a simulator, which gives the current distribution on the wires of the antenna, from which, electromagnetic properties can be obtained. The design parameters (e.g. spacing, length, and feed current) are optimized using guides such as intuition, experience, simplified equations or empirical studies. The conventional design technique has produced many different antenna designs, but it is time consuming, and if there are many unknowns it is unlikely to produce truly optimum results. Further, conventional techniques can stuck in local optimum points. Genetic Algorithm (GA) is a global stochastic method based on the natural process of evolution. Due to their global nature, these do not suffer from problem of being stuck in local optimum points. Also, GA does not heavily depend on choice of initial solution. GA has been found to work better than conventional design methods for antenna design [1].

Yagi-Uda arrays are quite common in practice because they are light weight, simple to build, low cost and provide moderately desirable characteristics for many applications.

Yagi-Uda antenna was developed by Uda and Yagi during 1920s. Since then, it has received much attention in the literature. Chen and Chang have applied the gradient-based approach for optimization of directive gain of Yagi Uda antenna taking spacing between elements as variable [2]. Also, Chen and Chang applied the gradient-based approach for optimization of directive gain of Yagi Uda antenna taking length and spacing between elements as variables [3]. A gradient-based method for Yagi-Uda antenna optimization has also been used in [4]. The shortcoming of gradient-based methods is that they are vulnerable to stuck in local optima. A local optima is a point which is optimum (i.e. minimum or maximum depending upon the goal) with respect to the neighbouring points in the region, but when seen globally in the complete region, it is not optimum i.e. there is some other point (known as global optima), which is optimum than the local optimum point. Haupt have compared GA and gradient based methods for electromagnetic problems and found that the genetic algorithms are better than gradient based methods [5].

Jones and Joines have applied the GA for the design of Yagi Uda antenna taking length and spacing as variables and constant radii [6] . The performance evaluation of design generated by GA has been done using a method of moments code, NEC2 [7]. Correia et.al. have applied the GA for optimization of directive gain, impedance and bandwidth matching of Yagi-Uda antenna using length and spacing between elements as variables [8]. The GA has also been used to optimize for directive gain and Voltage Standing Wave Ratio (VSWR) using length and spacing among elements as variables by Lohn et.al. in [9]. Kuwahara have carried out multi objective optimization of Yagi-Uda antenna using GA for directive gain, VSWR, side lobe level taking length and spacing as variables [10].

Till now, optimal design of Yagi Uda antenna has been obtained using GA taking length and spacing of elements as variables, to achieve maximum directive gain or maximum direction gain and impedance matching, and band width requirements. These design optimizations have been carried out using GA by taking length and spacing among elements as variables.

In this paper, the optimized design of Chen and Chang [4] has been further improved by using GA taking element radii perturbations. Every dipole antenna in the Yagi-Uda antenna has certain radius associated with it. It is also a design parameter and can be varied. The Genetic algorithm has been explained in next section. A Yagi-Uda antenna design example has been given in section 3. Conclusion and guidelines for future work has been discussed in section 4.

2. The Genetic Algorithm

GA optimizers are particularly effective when the goal is to find an approximate global maximum in high dimension, multi modal function domain in near optimal manner. GA Optimizers have been found to be much better than local optimization methods at dealing with solution spaces having discontinuities, constrained parameters, and/or a large no. of dimensions with many potential local maxima. As such they represent an intelligent exploitation of a random search space within a defined search space to solve a problem.The basic Genetic Algorithm performs the following steps:

1. Generate an initial population, randomly.
2. Compute and save the fitness for each individual in the current population.
3. Define selection probability for each individual so that it is proportional to its fitness.
4. Generate the next current population by probabilistically selecting the individuals from the previous current population, in order to produce offspring via genetic operators.
5. Repeat step 2 until a satisfactory solution is obtained. Flowchart of a basic genetic algorithm is given in Figure 1.

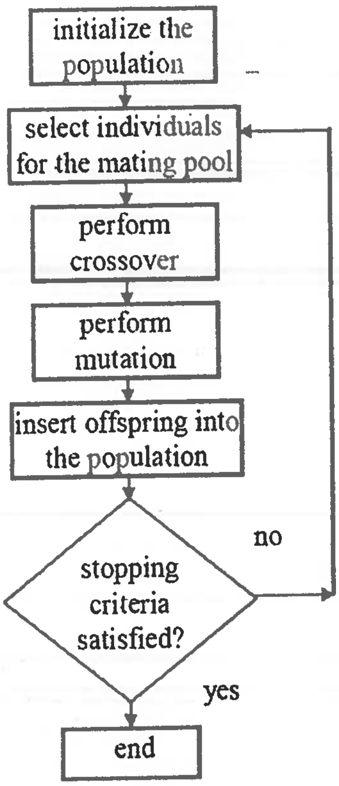

Figure 1: Flowchart of a Genetic Algorithm

The GA starts with a large population of potential solutions determined by constraints of the problem and the method of encoding the problem information. To apply GA, the problem parameters have to be coded using binary or decimal coding. In binary coding, parameters are converted into strings of 1s and 0s called a binary chromosome. The GA selects a small set of chromosomes and evaluate their fitness of each chromosome using the cost function. A cost or objective or fitness function is the function, which is to be optimized using GA. The GA is independent of the choice of cost function. Depending upon the particular problem, it can be different. The more details about GA can be found in [11-2].

3. Yagi -Uda Antenna Design Example

The geometry of a *K* element Yagi Uda array has been shown in Fig. 2. The currents assumed are sinusoidal because the antenna lengths are of the order of half-wavelength. The electrical characteristics of the antenna, necessary to the establishment of the objective function, are attained by a numerical analysis based on the method of moments (MoM) [13]. Consider a *P* element Yagi-Uda array antenna. The electrical current densities over each dipole moment p (p = 1,2 ..., according to Fig. 2) are expanded as [13]

$$I_p(z)=\sum_{n=1}^{N} I_{np}\cos\left[\frac{(2n-1)\pi z}{L_p}\right] \quad (1)$$

Where N controls the number of sinusoidal basis functions used to represent the current densities and L_p is the length of pth dipole element. The series expansion in (1) is chosen such that $I_p(z)$ vanishes at the dipole tips, enforcing the continuity condition. Also, note that the azimuthal variation is being neglected, which is reasonable as $a << \lambda$.

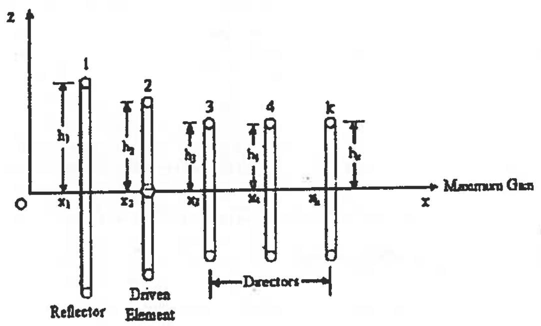

Fig. 2 : *K* element Yagi-Uda Array

The integral equation to be evaluated is given by [13],

$$E_z^i(\vec{r})=\frac{j\eta}{4\pi k}\sum_{p=1}^{6}\int_{-L_p/2}^{L_p/2} I_p(z')G_E(\vec{r}\vec{r}')dz' \quad (2)$$

Where $\vec{r}$ and $\vec{r}'$ locate the observation and the source points, respectively.

E_z^i is the z component of the incident electric field, I_p is given by (1),

$\eta=\mu/\varepsilon$, $k=2\pi/\lambda$, and

$$G_E(\vec{r};\vec{r}') =[(1+jkR)(2R^2-3a^2)+(KaR)^2]\frac{e^{-jkR}}{R^5}$$

With

$$R=\sqrt{(x-x')^2+(y-y')^2+(z-z')^2+a^2}$$

Equation (2) is numerically evaluated by MoM technique using point matching. After determining the coefficients I_{np}, the electric current representation given by (1) is applied to determine the radiated field and, consequently, the antenna radiation pattern and input resistance [13].

Assume that the length and separations are such that the maximum gain is towards endfire, that is, towards è = *90o, ö = 0o*. The forward and backward gains are defined as:

$g_f = g_{max} = g(90°,0°)$, $g_b = g(90°,180°)$,

It follows that the normalized gain will be,

$$g_n(\theta,\phi)=\frac{g(\theta,\phi)}{g_f}$$

Integrating it over all solid angles, the beam solid angle and hence the directivity of the Yagi-Uda array are obtained:

$$\Delta\Omega=\int_0^{\Pi}\int_0^{2\Pi} g_n(\theta,\phi)\sin\theta \quad d\theta \quad d\phi$$

$$D=\frac{4\Pi}{\Delta\Omega}$$

in dB, the directivity is 10 $\log_{10}$D.

It is necessary to associate antenna with an individual (chromosome) to use GA for antenna array optimization. The relationship between elements of GA and antenna arrays as shown in Table 1 [14].

The GA starts with a large population of potential array configurations determined by constraints of the problem. In antenna optimization problems, the evaluation of cost function involves the simulation of each antenna configuration with electromagnetic code (such as MoM) and comparing the results with those desired. The fitness function used is:

$$fitness=\left(\frac{actual\ gain}{required\ gain}\right)^2$$

Table 1: Relationship between elements of GA and antenna array.

Genetic Parameter	Antenna Array
Gene	Bit chain (string): (amplitude, phase)
Chromosome	One element of Array
Individual	One array
Population	Several arrays

A six element Yagi-Uda antenna array has been considered. The only parameter to be optimized here is directive gain. The number of chromosomes taken is 30 and total numbers of generations taken are 100. The crossover probability is 1 and probability of mutation is 0.10. The selection scheme used is Tournament Selection. To evaluate various antenna configurations a method of moments code SuperNec [15] developed by Poynting Innovations, has been used.

Table 2 shows the comparative results of Yagi-Uda antenna optimization using GA for maximum directive gain only. The length, spacing and radii are in terms of wavelength. The performance of gradient optimized Yagu-Uda array is improved after radii perturbations using GA. The results are comparable to those obtained using GA taking length and spacing of elements as variables and it is better than gradient based methods. The radiation pattern of optimized Yagi-Uda antenna is as shown in Fig. 3. It can be seen from the radiation pattern that side lobes close to the main lobe are of very low level but those farther from main lobe are of considerable strength. This is particularly significant for applications such as tracking radar, where adjacent lobe has to be very down as compared to the main lobe.

4. Conclusions

The Yagi Uda antenna has been optimized for directive gain using GA by element radii perturbations. An improvement of 0.18 dB has been achieved over the gradient optimized design. Also, the results are comparable to those obtained using GA taking length and spacing as variable. The simulation time is comparatively less in this implementation because of only one optimization variable. In this design, the closest side lobe is 17 dB down the main beam and farthest is 10 dB down the main beam, which is particularly desired for applications such as tracking and search radar. Although, a variation of design has been presented that results in slight improvement of directive gain, but practical issues associated with variation of radii need to be addressed. More control over the pattern can be obtained by taking length, spacing and radii i.e. all three as variables to achieve maximum directive gain of Yagi-Uda antenna.

Table 2: Yagi-Uda Antenna Optimization for Directive Gain

	GA using radii perturbations			Chen and Chang [3]			Chang [4]			GA using length and spacing perturbations. Jones and Joines [6]		
Element	Length	Spacing	Radii	Length	Spacing	Radii	Length	Spacing	Radii	Length	Spacing	Radii
1	0.470	-	0.005237	0.470	-	0.003369	0.238	-	0.003369	0.252	-	0.003369
2	0.452	0.250	0.005874	0.452	0.250	0.003369	0.226	0.250	0.003369	0.301	0.101	0.003369
3	0.436	0.289	0.003179	0.436	0.289	0.003369	0.218	0.209	0.003369	0.221	0.321	0.003369
4	0.430	0.406	0.002893	0.430	0.406	0.003369	0.215	0.406	0.003369	0.219	0.274	0.003369
5	0.434	0.323	0.002718	0.434	0.323	0.003369	0.217	0.323	0.003369	0.210	0.428	0.003369
6	0.430	0.422	0.003999	0.430	0.422	0.003369	0.215	0.422	0.003369	0.211	0.435	0.003369
Directive Gain (in dB)	13.59			13.41			13.35			13.60		

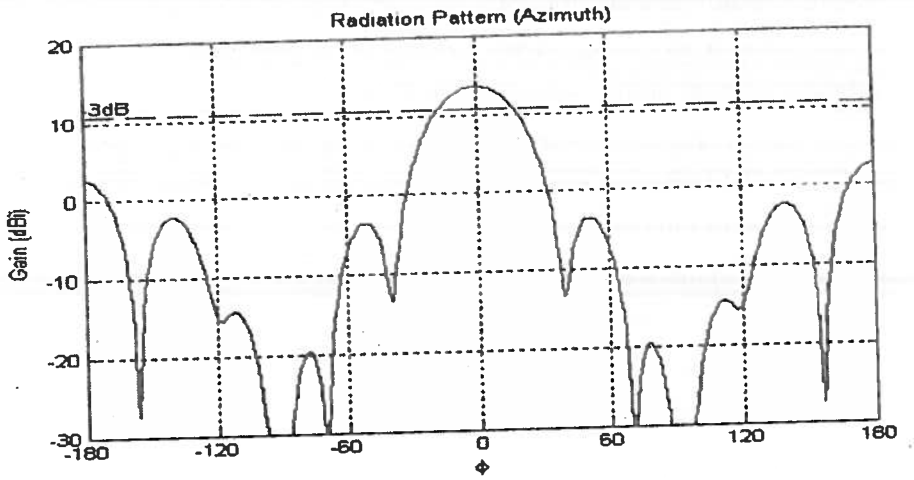

Fig 3: Azimuthal Radiation pattern

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