Design of YAGI Array Receiving Antennas Using Genetic Optimization

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Abstract

YAGI array is a very popular antenna for VHF/UHF applications due to its simple construction. It is extensively used in television and FM radio reception. However, design of YAGI arrays to meet a given set of specifications is a very difficult task. This paper presents a genetic algorithm based design technique for YAGI arrays for receiving applications.

INTRODUCTION

Genetic Algorithm (GA) is an optimization technique based on the natural evolution of biological systems. It is based on the structure of a chromosome and its development due to mating of two parents to conduct a global search in the solution space. Many optimization techniques search the solution space around the initial guess, and hence converge only to the best local optimum at the vicinity of the initial guess. The genetic algorithm has shown better results in many applications. It has been used in many engineering fields for optimization. Antenna design, Jet Turbine design, VLSI design are some examples [6]. In antenna design, GA has been used in the design of YAGI Array Antennas [3], Loaded Monopole Antenna [1] and Broad Band Microwave Absorbers [4].

The YAGI array has been used extensively since its introduction in 1928 [5] by H. Yagi due to its simple construction. However, the design of a YAGI array to meet a given set of specification is a complicated task. Cheng et.al. [2] have developed a gradient search technique to design YAGI arrays by optimizing its gain. In many applications, one may have to meet specifications other than the gain. Input impedance, side lobe levels, front-to-back ratio are some other important specifications. Optimization of YAGI arrays with these parameters using the gradient search technique is extremely difficult.

As an alternative, Jones et.al. [3] developed a YAGI array optimization technique based on the genetic algorithm. In this technique, the antenna dimensions are coded into a chromosome and its performance is evaluated when the antenna is in the transmitting mode. A new genetic algorithm based optimization technique for design of YAGI arrays for receiving applications is presented in this paper. A comparison of the performance the designs resulting from the Jones' technique and the new technique for receiving applications is also presented.

GENETIC ALGORITHM

The genetic algorithm is based on the development of species characterized by genes in the nucleus of the chromosome. In natural evolution of species, offspring of a sexual reproduction inherit properties from their parents with some mutations. Each individual species possesses unique structure in its chromosome made up of individual genes.

Individuals who are fit to survive in a given environment will get the chance to create the next generation. This natural phenomena is used in the genetic algorithm. In the genetic algorithm, a set of solutions to a given problem is coded into a set of chromosomes. Each optimization parameter for the given problem is taken as a gene in the chromosome. The fitness of each chromosome is then evaluated with a user defined objective function. The unfit individuals are allowed to die while fit individuals are allowed to mate to produce their offspring. The chromosome of the offspring is generated by breaking the chromosomes of the parents at a randomly chosen location and joining them together to form two children. During this process, few bits are allowed to mutate. This process is repeated for several generations and, as only fit individuals are allowed to mate, the fitness of the generation increases with evolution. This creates better solutions to the given problem as it evolves.

REPRESENTATION OF A YAGI ARRAY BY CHROMOSOMES

A YAGI array consists of one driven element with several parasitic elements known as directors and reflectors. Usually the directors are shorter in length and several of them are placed in front of the driven element. The reflectors are placed behind the driven element and longer than the driven element. Figure 1 shows a typical YAGI array and some important parameters. The spacing between the elements, the lengths of the elements and the diameter of the elements are the design parameters that one can vary to meet the given set of specifications.

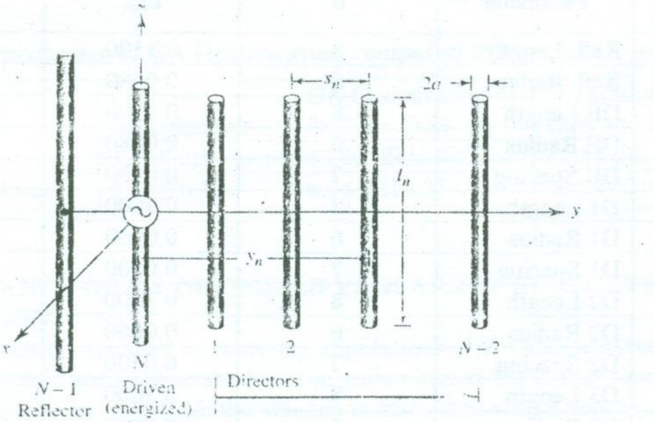

Figure 1: A YAGI Array

In order to exploit the power of the genetic algorithm, the YAGI array must be represented by a chromosome. In [3], Jones *et.al.* proposed a binary string as the chromosome where variable length bit groups are allocated to represent the spacing between the elements, length of the elements and diameters of elements. Each parameter is assigned a maximum and minimum value to limit the search space. Then each parameter is encoded into B bit block where B is determined from the following equation

$$B = \log_2\left(\frac{L_{\max} - L_{\min}}{L_{res}} + 1\right)$$

The parameters L_{max} and L_{min} define the range over which the parameter L can vary and L_{res} is the resolution of discretization. When B is not an integer, it is rounded up to the next integer value. The coded binary representation of the parameter L is given by

$$L = L_{\min} + \sum\nolimits_{k=1}^{B} L_{res} l_k 2^{k-1}$$

Table 1 shows a typical set of maximum and minimum values, number of bits allocated to a four-element YAGI array.

Table 1: Parameters for a Typical Four-Element YAGI Array

Gene Number	Parameter	B	L_{min}	L_{max}
1	Refl. Length	8	0.3500	0.6060
2	Refl. Radius	6	0.0080	0.0120
3	DE Length	8	0.3500	0.6000
4	DE Radius	6	0.0080	0.0100
5	DE Spacing	7	0.0500	0.5620
6	D1 Length	8	0.3000	0.5560
7	D1 Radius	6	0.0060	0.0090
8	D1 Spacing	7	0.0500	0.5000
9	D2 Length	8	0.3000	0.5560
10	D2 Radius	6	0.0060	0.0090
11	D2 Spacing	7	0.0500	0.5000
12	D3 Length	8	0.3000	0.5560
13	D3 Radius	6	0.0060	0.0090
14	D3 Spacing	7	0.0500	0.5000

EVOLUTION PROCESS OF THE GENETIC ALGORITHM FOR YAGI ARRAY DESIGN

In order to carry out the evolution process, the genetic algorithm requires a simulator to obtain the performance of each individual represented by a chromosome. In the YAGI array design, the antenna represented by a chromosome is decoded into its geometric structure and simulated to obtain its performance. The well-known Numeric Electromagnetic Coding (NEC) has been used extensively to evaluate the performance of wire antennas. The NEC is capable of simulation of a wire antenna under any given condition. It can provide simulation results on many parameters such as gain in any give direction, received power or current from any direction, driving point impedance etc.

In [3], Jones. et.al. proposed the following objective function for the evolution process of the YAGI array design problem for an antenna with a 50 Ω input impedance.

$$O(x) = aG(x) - b|50 - \mathrm{Re}(Z(x))| - c|\mathrm{Im}(Z(x)| - d\mathrm{MaxSLL}(x)$$

Here *G(x)* represents the gain, *Z(x)* represents the driving point impedance and MaxSLL(*x*) represents the maximum side lobe level of the antenna. The constants were set to $a=40, b=c=1$ and $d=2$. The parameters *G(x)*, *Z(x)* and MaxSLL(*x*) in the above equation are extracted from the NEC simulation runs. In order to extract above parameters the antenna is simulated when it is in the transmitting mode. The results reported in [3] for a six-element YAGI array are tabulated in Table 2. These results indicate that the genetic algorithm based YAGI array designs provide a better gain and impedance matching than a YAGI array based on the gradient optimization method.

Table 2: Performance of GA Optimization compared to Gradient Optimization

	Gradient Optimization	GA Optimization for Gain Only	GA Optimization for Gain and Impedance
Gain	12.98 dB	13.60 dB	12.58 dB
Input Impedance	8.4+j20.1	6.14+j216.21	49.64-j5.08

PERFORMANCE OF GA OPTIMIZED YAGI ARRAY IN RECEVING APPLICATIONS

Many YAGI arrays are used in receiving applications. FM radio receiving antennas, TV receiving antennas are some examples. The author tested the design reported in [3] as a TV receiving antenna. Although the antenna is associated with a very high gain, the tests failed to produce good results. This led the author to investigate the performance of the antenna in receiving mode. The antenna was simulated in receiving mode by NEC with a uniform plane wave (UPW), and simulation results indicated a gain lower than 13 dB which is in agreement with the field tests. This led to the investigation of alternative GA optimization techniques for design of YAGI array antennas for receiving applications. Hence, we refer to the technique presented by Jones et.al. as “GA based Transmit

Optimization (GATO) technique" and the new technique presented in this paper as "GA based Receive Optimization (GARO) technique".

GA OPTIMIZATION OF YAGI ARRAYS IN RECEIVING APPLICATIONS

For receiving applications, it is proposed to evaluate the antenna with UPW excitation. For evaluation, the antenna terminals are loaded with the load impedance and the current delivered to the load for different UPW arrival directions are taken into consideration. Let us assume the current delivered to the load from a UPW arriving from the direction θ_j is given by I_j. Now the objective function is formulated as

$$O = \sum_{j=1}^{N} a_j I_j$$

where a_j is a weighting factor. Assigning high values to the weighting factor gives preference to selected wave arrival directions. With this objective function, the GA optimization was carried out for different sizes of the YAGI array. First 2-element YAGI array was designed using GARO technique with a population size of 10 members evolved over 5 generations with $a_1=1$ and $a_2=a_3=..a_N=0$. The current delivered to the load by the best individual is given in Table 3 for ten different design sessions. In order to compare the performance of the new technique, currents delivered to the load by designs created by GATO technique are also tabulated. The design having the maximum current is depicted with bold characters and the design having the minimum current is depicted with italic characters for easy comparison.

Table 3: Performance Comparison for GA Optimization, 2-Element YAGI Array, Population size = 10, Generation Size = 5, Mutilation probability = 0.02, Cross over probability = 0.8, Input impedance = 50 Ohms, Frequency = 299.8 MHz.

	Current Delivered to a 50 Ohm load by a UPW arriving from the front of the antenna (A/V)	
	GARO Technique	GATO Technique
Design Session 1	0.004432	0.004267
Design Session 2	0.004397	**0.004436**
Design Session 3	0.004386	0.004047
Design Session 4	0.004337	0.003158
Design Session 5	0.004123	0.003554
Design Session 6	**0.004450**	*0.002956*
Design Session 7	0.004364	0.003352
Design Session 8	0.004316	0.003948
Design Session 9	0.004210	0.003760
Design Session 10	*0.004124*	0.003742
Mean	0.004314	0.003722
Standard Deviation	0.0001206	0.0004755

The results tabulated in Table 3 indicate that the designs resulting from GARO technique have delivered the highest load current while a significant variation in load current is observed for the designs resulting from GATO technique.

In order to compare the performance of large YAGI arrays, a 9-element YAGI array was then designed with a population size of 10 members evolved over 5 generations. The current delivered to the load by the best individual is given in Table 4 for ten different design sessions.

Table 4: Performance Comparison for GA Optimization, 9-Element YAGI Array, Population size = 10, Generation Size = 5, Mutilation probability = 0.02, Cross over probability = 0.8, Input impedance = 50 Ohms, Frequency = 299.8 MHz.

	Current Delivered to a 50 Ohm load by a UPW arriving from the front of the antenna (A/V)	
	GARO Technique	GATO Technique
Design Session 1	**0.006471**	0.003032
Design Session 2	0.005561	0.004006
Design Session 3	0.005261	0.004085
Design Session 4	0.004750	0.005381
Design Session 5	*0.004713*	0.004102
Design Session 6	0.005002	*0.002934*
Design Session 7	0.006287	0.003544
Design Session 8	0.005603	0.003368
Design Session 9	0.005356	0.003968
Design Session 10	0.005101	**0.006349**
Mean	0.005411	0.004076
Standard Deviation	0.0005928	0.001057

The results tabulated in Table 4 indicate that the designs resulting from GARO technique have delivered the highest load current while a significant variation in load current is observed for the designs resulting from GATO technique. The variation in load current for designs resulting from GATO technique has increased as the dimension of the array increases.

In order to compare the performance with increased population size and generation size, a 9-element YAGI array was then designed with a population size of 20 members evolved over 10 generations. The current delivered to the load by the best individual is given in Table 5 for ten different design sessions.

Table 5: Performance Comparison for GA Optimization, 9-Element YAGI Array, Population size = 20, Generation Size = 10, Mutilation probability = 0.02, Cross over probability = 0.8, Input impedance = 50 Ohms, Frequency = 299.8 MHz.

	Current Delivered to a 50 Ohm load by a UPW arriving from the front of the antenna (A/V)	
	GARO Technique	GATO Technique
Design Session 1	**0.007036**	0.004057
Design Session 2	0.006799	0.004221
Design Session 3	0.006225	0.004095
Design Session 4	0.005937	0.004627
Design Session 5	0.005197	**0.005630**
Design Session 6	0.006708	0.003761
Design Session 7	0.005821	*0.003518*
Design Session 8	0.005396	0.003715
Design Session 9	0.005235	0.005088
Design Session 10	*0.005151*	0.005608
Mean	0.005950	0.004432
Standard Deviation	0.0007142	0.0007735

The results tabulated in Table 5 indicate that the designs resulting from GARO technique have delivered the highest load current while a significant variation in load current is observed for the designs resulted from GATO technique. The variation in load current for designs resulting from GATO technique has decreased as the population size and number of generations are increased. However, this reduction is achieved with a significant increase in computer simulation time.

The best 9-element YAGI array design generated by the GARO techniques delivers a load current of 0.007036 A/V. A half-wave dipole operating under same conditions delivers a load current of 0.002536 A/V, hence the gain of this antenna is approximately 11dB. Field tests carried out with this antenna verify its superior performance.

CONCLUSION

The GARO technique presented in this paper generates YAGI arrays with better receiving capabilities compared to the GATO technique reported in literature. The YAGI antennas used for Television reception and FM radio reception are always used in receiving mode. Hence design of such antennas using GARO technique guarantees better performance.

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