OPTIMUM DESIGN METHOD OF ARBITRARY ARRANGED WIRE GRID MODEL ANTENNA USING GA-ICT

Tamami MARUYAMA, Naoki HONMA and Toshikazu HORI
Nippon Telegraph and Telephone Corporation
1-1 Hikari-no-oka, Yokosuka, Kanagawa 239-0847, Japan
E-mail:tamami@wslab.ntt.co.jp

1. Introduction

This paper proposes a new numerical analysis model that automatically generates the optimal structure for an arbitrary Arranged Wire Grid Model Antenna. To perform a search for an arbitrary antenna structure, we introduce GA-ICT, a combination of the Genetic Algorithm (GA) [1] for optimization and Improved Circuit Theory (ICT) [2] for antenna analysis.

Recently, the concept of applying GA to antenna design has drawn attention regarding the possibility that a new antenna configuration may be created by genetic operation. Although it is still in its early stages, there are several reports [3],[4],[5] in which GA was applied in attempts to obtain the optimum antenna structure. Although these attempts were constructive, they still encountered problems. When applying GA to the optimization of such an antenna structure, chromosomal forms, which are unknowns in the GA, consist of antenna structure parameters. On one hand, making the GA chromosomal forms a fixed length is generally desirable. Therefore, in the previous study of Yagi-Uda Antenna optimization [4], there was a problem in that the basic antenna structure must be set before optimization. In the crooked-wire genetic antenna [3], restrictions on the basic structure were relaxed and an arbitrary structure was achieved. However, it was still necessary to determine the number of wires beforehand to retain the fixed length chromosomal forms. Consequently, when using the conventional wire antenna-optimization technique for given design conditions, the antenna characteristics were determined based on only parameter study, after that the structure was determined artificially. Therefore, it was difficult to produce new antenna structures by using this method. On the other hand, in the case of the patch antenna [5], a wire grid model of the moment method and GA were combined directly. This methodology adopted the technique of transposing the existence of a wire of “0” or “1” into a chromosomal form. However, applying this technique to a wire antenna such as the Yagi-Uda antenna is difficult because slight differences in element length, wire radius, and element spacing significantly affect antenna performance. it is very difficult to that these slight differences approximate by wire existence. That needs quite many matrix of wire calculation.

The purpose of this study is to establish an automatic generation of the optimum structure of a wire-type antenna when given only the design conditions without using any basic structure or restrictions. To overcome these arbitrary wire-structure difficulties, this paper directly uses the unknown number of ICT as the GA chromosomal form. In this paper, the proposed method deals with the problem of sector-antenna configuration optimization and produces a new sector-antenna configuration by genetic operation to match the design conditions. The approach of this paper does not need any basic structures even though the number of wires is fixed.

2. The optimum design method of sector antenna by GA-ICT

2.1 Analysis Model of GA-ICT

The analysis model and chromosomes of the GA-ICT are given in Figs. 1 and 2, respectively. This proposed approach directly uses the unknown number of ICT as the GA chromosomal form.

The chromosome shown in Fig. 2 was obtained by using element length and coordinate, which were unknown ICT parameters, where Element #1 was regarded as A radiator and Elements #2 and #3 were regarded as parasitic elements in the analysis model.

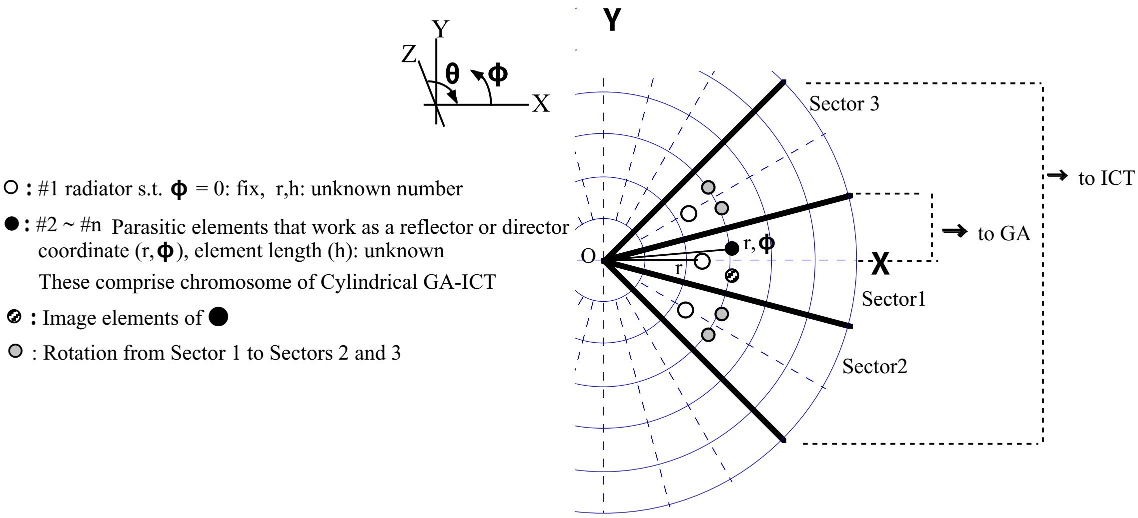
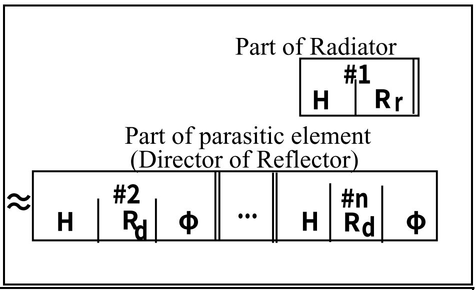


Fig. 1 Analysis model of cylindrical coordinate GA-ICT



H: Element length (0.07 λ to 0.4 λ)
Rr: R coordinate of radiator (0.42λ to 3λ)
Rd: R coordinate of director (0.42λto 5λ)
ϕ: ϕ coordinate of element (0° to15°)
Fig.2 Definition of Cylindrical coordinate GA-ICT chromosome

Parasitic elements #2 to #n operate as reflectors or directors based on the element length or arrangement. They can also approximate metallic plates similarly to corner reflector antennas using a wire approximating technique. Term "n" in Fig. 2 is the temporary number of elements that is used to generate a fixed length chromosome. The feasible region of each variable is shown in Fig. 2. When the same feasible region is adopted for each element, duplicates zof parts of elements may be generated resulting in an inability to calculate the antenna performance. Our approach incorporates a countermeasure, that is to say, when a part of an element is duplicated, one of the elements is eliminated in ICT. By using this technique, the number of elements can be changed using a fixed-length chromosome. We also eliminate short elements such those in which h is less than 0.1 λ (λ: wavelength).

2.2 Adoption of cylindrical coordinate for sector antenna optimization

In this paper, we propose using cylindrical coordinate GA-ICT to obtain the optimum antenna structure to deal with the sector-antenna downsizing problem. The difficulty in downsizing a sector antenna with a large number of sectors and dealing with unwanted radiation from mutual interaction between sectors are significant problems. One solution was reported in [6] using a Multi-sector Monopole Yagi-Uda Array Antenna (MS-MPYA). The purpose of GA-ICT is to determine what type of antenna structure is optimal using the GA operation: Yagi-Uda, corner reflector, or another new antenna structure. These structures can adapt to any given design condition such as the side lobe level, directivity, antenna size, and beamwidth. The size of the sector antenna is determined by the radius from the origin to the outermost element. Therefore, this paper adopts a cylindrical coordinate and directly generates the chromosomal forms based on the coordinate. To reduce the analysis space, the analysis incorporates mutual interaction between sectors at the same time the analysis model uses mirror imaging and a periodic structure. Using these procedures, the chromosomal forms that are used in genetic operators are downsized to half a sector, which is only 1/6 the ICT analysis space. Term "ϕ" in Fig. 2 where {0 ϕ Ns/180˚, Ns = number of sectors} is used to generate the chromosomal form in the half space of one sector. Accordingly, when ϕ equals 0˚ or Ns/180˚, duplicates always occur due to mirror imaging or rotation and the element is eliminated. At that time, the number of elements that are used in the ICT calculation is represented by Nk, Nk = 6*N-Ne (Ne: eliminated number of elements). The analysis model in Fig. 1 includes all Yagi-Uda antennas, corner reflector antennas, the structure of MS-MPYA, and other arbitrary wire grid model sector antenna structures.

Table 1. Design Conditions
Sector number : 12
Half-power Beamwidth in H-plane: 30 °
Higher directivity
Low side lobe
Non-beam division in both V and H planes
Short array length
Input impedance nearly 50 Ω

Table 2. Parameter for GA Operation
Cross probability: σ= 0.5
Mutant occurrence probability: μ= 0.001
Elite preservation: preserve number = 1
Roulette selection
Population: 180

2.3 Design condition and objective function

We set the number of sectors to 12 in the following example. The design conditions are shown in Table 1. The focus is to determine what type of antenna structure is optimal using the GA operation: Yagi-Uda, corner reflector, or another new antenna structure. To satisfy these design conditions, we define the objective function as Equation (1).

$$O(x)=a*GAIN-b*|50-Re(Z)|-c*Im(Z)-d*|30-HBW|-eAL+h(x)+v(x)+s(x)-Nk \quad (1)$$

GAIN: Directivity Gain [dBi]
Re(Z): Input resistance
Im(Z): Input reactance
HBW: Half-power beamwidth in the Horizontal plane.
AL : Array length determined by the radius coordinate, which is set to the outermost point
h(x) : compensation function that avoids beam division in the horizontal plane
v(x) : compensation function that avoids beam division in the vertical plane
s(x) : compensation function to suppress side lobes
Nk : total number of elements

Weights a, b, c, d, and e are set to 200, 2, 2, 100, and 5 respectively. Equation (1) is a polynomial equation in which each part was designed based on the conditions in Table 1. The antenna structure that matches each design condition is not always the same. Therefore, Equation (1) may have many peak functions to suit GA optimization. The calculation parameters used in the GA operation are given in Table 2.

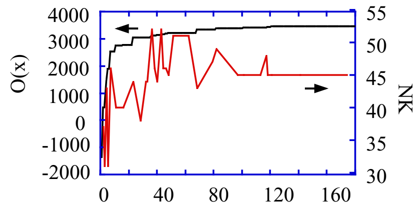


Figure 3 Objective function (max value) and number of element NK vs generation

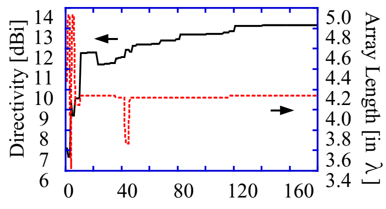


Figure 4 Directivity and Array Length vs generation

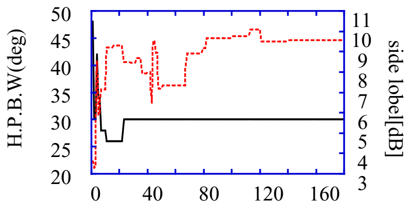


Figure 5 3dB Beam width in H-plane and side lobe lebel vs generation

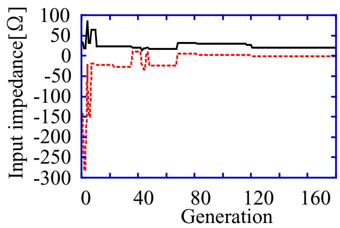


Figure 6 Input iimpedance vs generation

3. Calculated example of sector antenna by GA-ICT

The calculation results based on the parameters given in Table 2 are described in this section.

The maximum value of the objective function in each generation and variations of NK are shown in Fig. 3, respectively. This figure confirms that the genetic operation is accurate and shows that the number of elements comprising an antenna structure can be changed using a fixed-length chromosome. Figure 4 shows that the directivity converges to more than 13 dBi and the array length converges to less than 4.2 λ. Figure 5 shows that the 3-dB beamwidth in the horizontal plane (H-plane) converges to the desired 30 degree value, and the side lobe level that is defined to have a maximum value between $\phi = 45^\circ$ to $\phi = 180^\circ$ is less than -9 dB. Figures 7 and 8 show the radiation pattern and element arrangement of the antenna configuration in the last generation. Both radiation patterns in the H-plane and V-plane generate a sector beam and beam division does not occur. The last antenna configuration is a kind of transformed Yagi-Uda antenna.

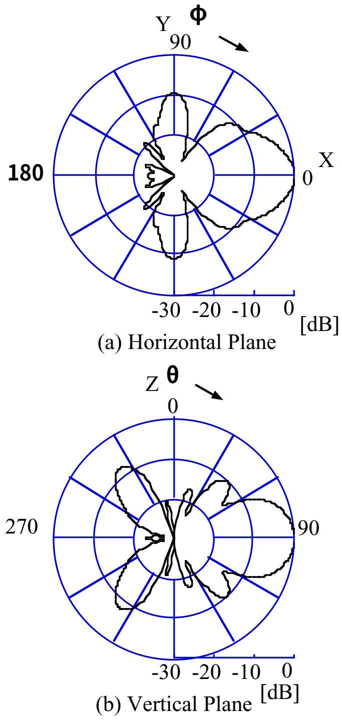


Fig.7 Radiation Pattern

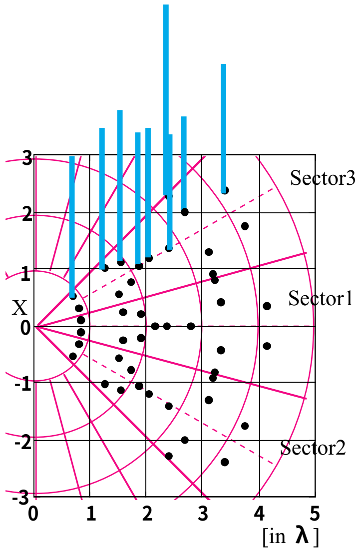


Fig.8 Parasitic element arrangement

4. Conclusion

This paper presented a design method that automatically generates the optimal structure for an arbitrary wire-grid model antenna using GA-ICT. The proposed GA-ICT uses the same unknown parameters for GA and ICT and the element coordinate parameters are used to generate GA chromosomes while duplicate elements are eliminated from the antenna structure. Using this technique, the number of elements can be successfully changed using fixed chromosomes. Our approach employs a cylindrical coordinate for sector antenna optimization, which is especially useful in dealing with the downsizing problem. This method reduces the analysis space using mirror imaging and a periodic structure. An objective function to deal with the sector antenna downsizing problem was presented. Using the genetic operation of GA-ICT, a new antenna structure or element arrangement was constructed. The 12-sector antenna with the array length of less than 4.2 λ, the antenna configuration of which is transformed into a Yagi-Uda antenna, was designed and exhibited good antenna performance satisfying 30° in the H-plane of the radiation pattern.

Acknowledgment

The authors thank Dr. H. Mizuno, Mr. M. Shimizu and Mr. A. Ando of Nippon Telegraph and Telephone Corporation for their constant encouragement and advice.

References

[1] D. E. Goldberg, Genetic Algorithm. New York: Addison-Wesley, 1989, ch. 1-4.
[2] N. Inagaki: *IEEE Trans.*, *Antennas Propagat.* Vol. 17, 2, p. 120, March 1969.
[3] E. E. Altshuler and D. S. Linden, *IEEE Antennas Propagat. Mag.*, vol. 39, pp. 33-43, Apr. 1997.
[4] E. A. Jones and W. T. Joines, *"IEEE Trans., Antennas Propagat,* vol. 45, pp. 1386-1392, Sept. 1997.
[5] J. M. Johnson and Y. Rahmat-Samii, *IEEE Trans.*, *Antennas Propagat.* Vol. 47, 10, pp. 1606-1614, Oct. 1999.
[6] T. Maruyama, K. Uehara, T. Hori, and K. Kagoshima: Int.J.Numer.Model.12, pp. 341-351 (1999).