

# Design of Yagi-Uda Antennas Using Genetic Algorithm

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**Abstract** Yagi-Uda antennas are widely used for television broadcast reception. However, deriving the optimum design for these antennas is difficult because there are many parameters. This paper describes the optimum design methods for Yagi-Uda antennas using a genetic algorithm (GA). The relationship between the directivity and gain-bandwidth factor is shown with the input resistance as a parameter. A comparison is presented to verify the proposed antenna design method. Moreover, the relationship between the directivity and the relative bandwidth is discussed.

**Keywords:** Yagi-Uda Antennas, Genetic Algorithm, Directivity, Gain-Bandwidth Factor

## 1. INTRODUCTION

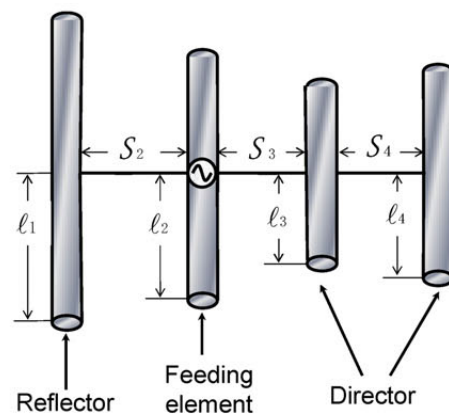
Yagi-Uda antennas are widely used for television broadcast reception. Common Yagi-Uda antennas comprise a reflector, a feeding element, and some director elements. The directivity of the antenna is determined by geometrical dimensions such as the element length, space, and radius. However, deriving the optimum design is difficult because the antenna has many parameters. Therefore, recent optimum design methods for Yagi-Uda antennas that use a genetic algorithm (GA) have drawn much attention. Jones *et al.* [1] designed Yagi-Uda antennas using a genetic algorithm, and compared their method to the gradient method. Linden *et al.* [2] compared the performance of the Yagi-Uda antennas designed using a GA to that using a previous technique, and reported that when using the same total length of the antennas, a higher gain was obtained. Kojiya *et al.* [3] applied quasi-Yagi antennas to phased array antennas to prevent variation in gain due to beam scanning. On the other hand, Maruyama *et al.* [4] designed sector antennas for cellular phone base stations using a GA and reported that downsizing the antennas can be achieved without degrading the performance compared to conventional antennas.

Taking into consideration the design methods using a GA, we applied this methodology to the optimum design of Yagi-Uda antennas to achieve high gain using the element length and space as parameters. In this paper, the design methods for Yagi-Uda antennas using a GA are described, and the relationship between the directivity and gain-bandwidth factor is shown with the input resistance as a parameter. In Section 3, a comparison is presented to verify the proposed antenna design method. In Section 4, the relationship between the directivity and the relative bandwidth is presented with the element radius as a parameter. Moreover, the relationship between the directivity and the relative bandwidth is discussed.

## 2. DESIGN OF YAGI-UDA ANTENNAS USING GA

### 2.1 Design Technique Using GA

The structure of a four-element Yagi-Uda antenna is



**Fig.1 Structure of four element Yagi-Uda antennas**

shown in Fig. 1. We treat the element length ( $\ell_n$ ) and element space ( $S_n$ ) as genes in the GA. Each parameter is expressed as eight bits, and these parameters are expressed in one-bit rows. Furthermore, we used Eq. (1) as an object function.

$$o(x) = a \cdot G'(x) - b \cdot \text{Re}'(Z(x)) - c \cdot \text{Im}'(Z(x)). \quad (1)$$

Here,

$$G'(x) = 10 \cdot \log_{10} G(x) \text{ [dBi]}, \quad (2)$$

$$\text{Re}'(Z(x)) = \left| \alpha - \text{Re}(Z(x)) \right| \text{ [\Omega]}, \quad (3)$$

$$\text{Im}'(Z(x)) = \left| \text{Im}(Z(x)) \right| \text{ [\Omega]}, \quad (4)$$

In these equations,  $G(x)$ ,  $\text{Re}(Z(x))$ , and  $\text{Im}(Z(x))$  are the gain, input resistance, and input reactance, respectively.  $\alpha$  is a constant, which is equivalent to the target value of the input resistance. Moreover,  $a$ ,  $b$ , and  $c$  are weighting factors.

The flow of the GA used in this paper is shown in Fig. 2. An initial group (the population) is set up first. Next, an object function is evaluated, and it is terminated if the convergence conditions are satisfied; otherwise, the groups are passed to the next generation. In the flow of the GA, the object function is evaluated, and supernal individuals (bit row) remain (selection). The proposed design employs Roulette selection. Next, a new bit row is generated (crossover). In the proposed design, the rate of crossover is set to 0.8 using a one-point crossover. Finally, in order to avoid falling into a local solution, a bit is reversed in low probability (mutation). In the proposed design, the rate of mutation is set to 0.01. The GA performs this repetition and calculates the optimal solution.

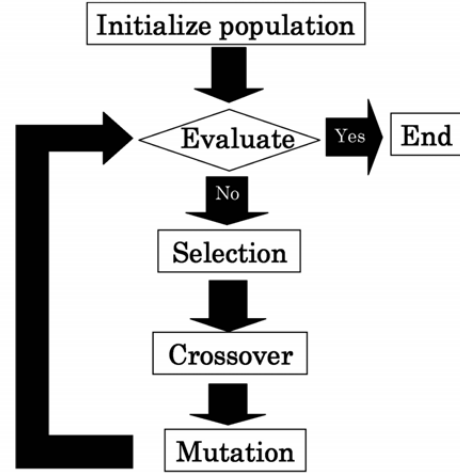


Fig.2 Flow of GA

## 2.2 Performance of Yagi-Uda Antennas

The performance of the four-element Yagi-Uda antenna after the algorithm achieves convergence is shown in Fig. 3. Here, we introduce the GB (Gain-Bandwidth) factor as an evaluation parameter, which is the product of directivity and the relative bandwidth below 2 for VSWR (Voltage Standing Wave Ratio). The value of  $\alpha$  is 10, 20, 30, 40, or 50. The population, the number of generations, and the element radius are 50, 1000, and  $0.003 \lambda_0$ , respectively.

From Fig. 3, we find that the smaller the input resistance, the higher the directivity. However, the relative bandwidth is narrow when the input resistance is below  $30 \Omega$ . Consequently, it is necessary to set the input resistance above  $30 \Omega$  in order to increase the bandwidth.

## 3. VALIDATION OF DESIGN METHOD

The performance of the four-element Yagi-Uda antenna after the algorithm achieves convergence is shown in Fig. 4. The value of  $\alpha$  is 35, 40, 45, or 50. The population, the number of generations, and the element radius are 50, 1000 and  $0.0225 \lambda_0$  (the same as in Ref. [1]), respectively. In this paper, the total length of the antenna is expressed by  $S = S_2 + S_3 + S_4$ . The

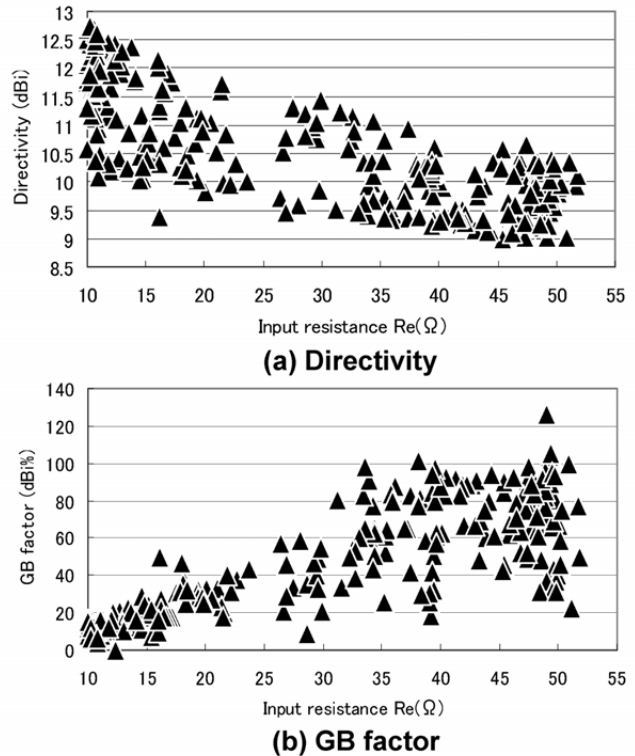


Fig.3 Performances of four-element Yagi-Uda antennas

marks,  $\square$ , in Fig. 4 indicate the four-element Yagi-Uda antenna. The figure indicates that the proposed design exceeds  $30\Omega$ , and  $\blacktriangle$  in Fig. 4 represents the four-element Yagi-Uda antenna in Ref. [1]. Here, the input resistance, the total length, the directivity, the relative bandwidth, and the GB factor in Ref. [1] are  $46.9\Omega$ ,  $0.741\lambda_0$ ,  $9.664$  dBi,  $7.93\%$ , and  $76.66$  dBi%, respectively.

Based on the results, 1) without regard to the total antenna length, the antenna gain reported in this paper is higher than that in Ref. [1]. 2) The GB factor value is higher than that in Ref. [1] when the total length is almost the same. Consequently, it can be said that the proposed design method is effective in deriving an antenna that has a high gain and wideband properties.

#### 4. WIDEBAND YAGI-UDA ANTENNA

##### 4.1 Number of Elements Affect Performance of Yagi-Uda Antennas

The performance of three, four, and seven element Yagi-Uda antennas are shown in Fig. 5. The population, the number of generations, and the element radius are 100, 1000, and  $0.015\lambda_0$ , respectively.

Based on these results, the directivity increases as the number of elements increases. However, the element spacing becomes wider as the number of elements increases. Accordingly, the total length of the antenna becomes longer. We can find a unique situation in Fig. 5(b) in which the relative bandwidth is increased beyond the 25% level. Except for this unique situation, the relative bandwidth is below 20% independent of the number of elements.

In general, when the directivity is high, the relative bandwidth is narrow; however, when the total length of the antenna is from  $0.6\lambda_0$  to  $0.7\lambda_0$  for a three element antenna, the unique situation exists in which the relative bandwidth is increased beyond the 25% level.

##### 4.2 Wideband Three Element Yagi-Uda Antenna (Unique Situation)

In order to verify the case of a wide relative bandwidth, we evaluated the relationship between the element spacing and the relative bandwidth. Figure 6(a) indicates the relationship between the relative bandwidth and the spacing from the reflector to the feeding element, and Fig. 6(b) indicates the relationship between the

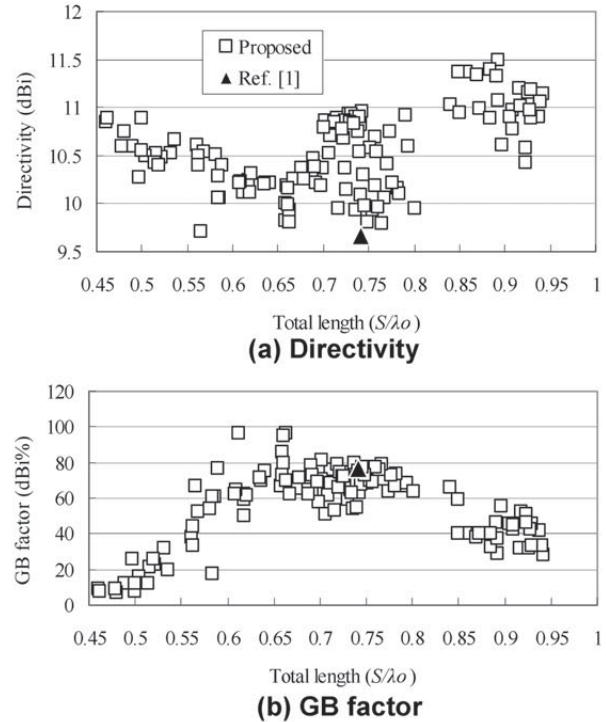


Fig.4 Comparison of proposed method to that in Ref. [1]

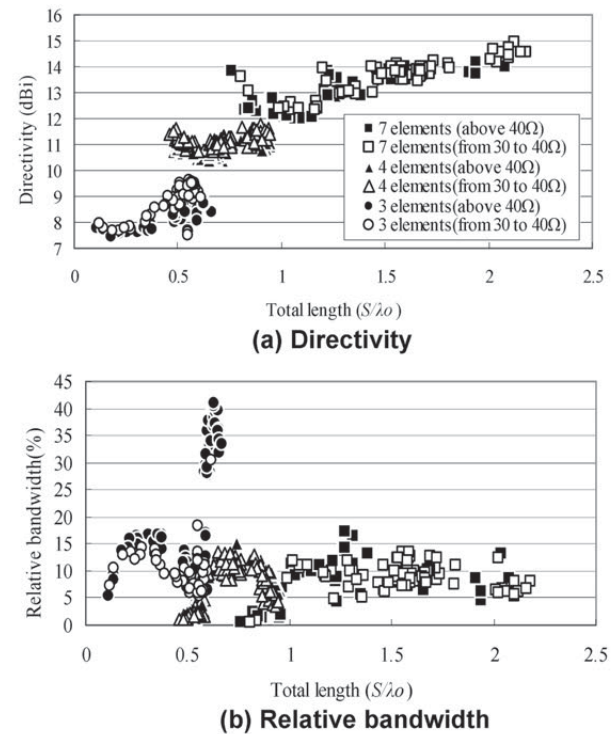


Fig.5 Performance of three, four, and seven element Yagi-Uda antennas

relative bandwidth and the spacing from the feeding element to the director element. In Fig. 6,  $\blacklozenge$  is the input resistance greater than  $40\Omega$  and  $\square$  is the input resistance from  $30\Omega$  to  $40\Omega$ .

From Fig. 5, when the total length of the antenna is from approximately  $0.6\lambda_0$  to  $0.7\lambda_0$  and the input resistance is greater than  $40\Omega$ , the relative bandwidth can be secured at 25%. However, when the total length of the antenna is longer than  $0.6\lambda_0$ , the directivity becomes low. Therefore, when the total length of the antenna is from approximately  $0.6\lambda_0$  to  $0.65\lambda_0$ , a relative bandwidth higher than 25% and a directivity value of greater than 8.5 dBi are guaranteed.

Moreover, based on Fig. 6, the antenna should be designed such that the space from the feeding element to the director element is from  $0.3\lambda_0$  to  $0.45\lambda_0$  and the input resistance is greater than  $40\Omega$ . Furthermore, the spacing from the reflector to the feeding element should from  $0.15\lambda_0$  to  $0.35\lambda_0$ . However, the relative bandwidth is less than 20% when the spacing from the reflector to the feeding element is less than  $0.2\lambda_0$ .

## 5. CONCLUSION

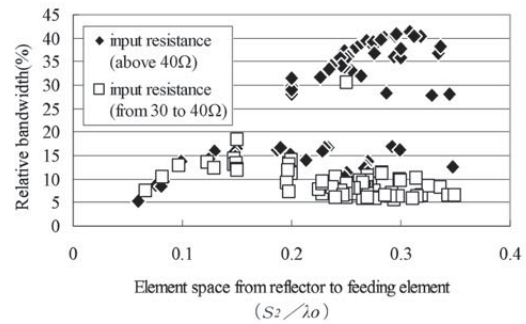
We proposed a design method employing a GA, to derive the optimum Yagi-Uda antenna design to achieve high gain using the element length and spacing as parameters. It has been clarified that the smaller the input resistance, the higher the directivity becomes; however, the input resistance must be set to greater than  $30\Omega$  in order to increase the bandwidth.

Moreover, we presented a comparison to verify the antenna design method. The performance of three, four, and seven-element Yagi-Uda antennas was presented, and we indicated that the unique solution which had wide bandwidth beyond the 25 % was exist. However, except for a unique situation, we found that the relative bandwidth was below 20% independent of the number of elements.

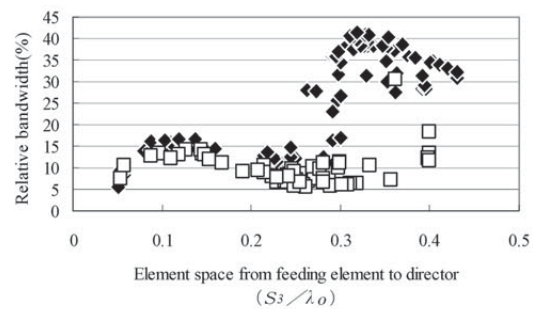
In the future, we would like to apply a weighted GA to the bandwidth in order to design wideband Yagi-Uda antennas.

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(a) Between reflector and feeding element



(b) Between feeding element and director

**Fig.6 Relationship between element space and relative bandwidth**