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DESIGN OF MULTI-BAND SMALL PLANAR ANTENNA USING NOVEL CHROMOSOME GENERATION METHOD FOR GENETIC ALGORITHM

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1. Introduction

Recently, genetic algorithms (GAs) have been integrated into antenna design methods to derive the optimum antenna structure through a deductive method [1]. We focus on an antenna design method that can derive any arbitrary antenna structure for the optimum solution without any basic structure by providing only the requirements for the antenna performance. For a wire grid model antenna, this concept was already achieved [2], [3]. Furthermore, as a natural extension, we can apply the findings in Ref. [4] regarding the GA method to planar antennas as follows.

First, the area used to configure a planar antenna is expressed by meshes. Next, the relationship between the planar antenna configuration and the chromosome is simply a mapping between metal patches attached to each mesh and a binary string such that the genes are single bits with “1” indicating the presence of metal and “0” indicating the absence of metal.

There are two main problems in this conventional method. The first problem is that often adjacent cells only connect at a vertex, and this slows the convergence and complicates the manufacturing process. The second problem is that the flexibility of the antenna structure depends on the mesh size. The bandwidth and resonant frequency are greatly dependent on the line width or line length. Therefore, it is important to maintain flexibility in the antenna structure. However, using many small meshes increases the bit length of the chromosome and the convergence slows.

To address the first problem, we proposed a novel chromosome generation method for the GA applied to a planar antenna design [5]. This method applies a maze generation algorithm to chromosome generation and modifies the algorithm to suit the antenna design. The objective of the current paper is to introduce a technique using the proposed method in [5] (hereafter proposed technique) to address the second problem. To confirm the effect of the proposed technique, a small planar antenna is designed based on observations of the bandwidth and multi-band resonant frequency.

2. Chromosome Generation Method and Maintaining Flexibility of Optimized Antenna Structure

To avoid a connection at a vertex between adjacent cells, the proposed technique adopts a maze generation algorithm. Generally, an electrically small antenna is shaped into a meander-line antenna. The maze generation algorithm generates a continuous line randomly on a plane such that a connection between adjacent cells at a vertex does not occur. There are two main methods in the maze generating algorithm, the pole down-pulling method and the hole-digging method. We adopt the pole down-pulling method.

Usually, a maze generation algorithm generates one connected line from the start to the goal, and it is difficult for the algorithm to generate more than two sets of lines. In order to apply the maze generation algorithm to antenna design, we must develop the capability to generate more than two sets of lines so that a feed line or patch and a no-feed line or patch, which is regarded as a parasitic element, can be generated at the same time. To achieve this, we modify the maze generation algorithm and introduce a modified algorithm to the chromosome generation. The procedure for generating the chromosomes is described hereafter based on Fig. 1. In this algorithm, the area for configuring the antenna is expressed by a mesh, the same as in the conventional algorithm. First, reference cells are defined alternately on the mesh as shown in Fig. 1(a), and metal patches are removed from the reference cells. In this paper, white cells represent areas where the patches are removed and the shaded cells are areas with metallic patches. We assign a reference number to each reference point as indicated in Fig. 1(a). The maze generation starts as indicated by the arrow from the upper-right corner of the area and proceeds following sequentially along the reference numbers (No. 1 to 15) in the figure.

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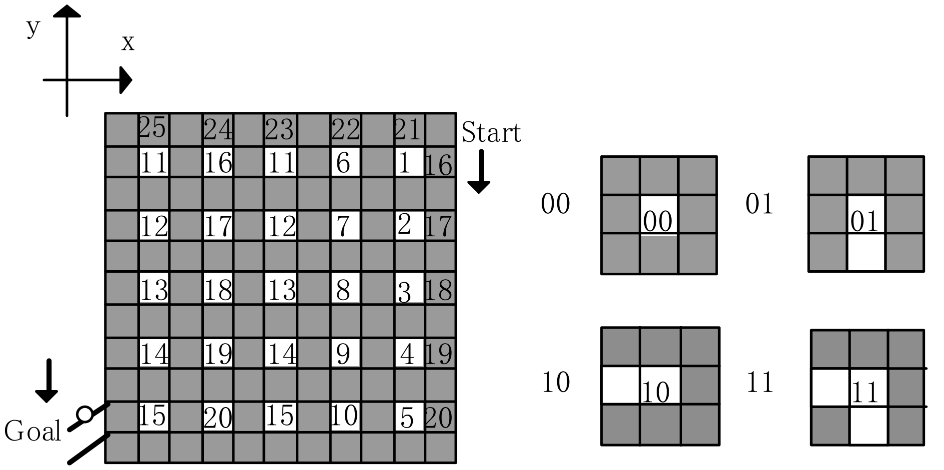


(a) Reference points on antenna surface (b) Method of generating antenna surface using bit information attached to a reference point.

▨ : Metallic patch ☐ :Removed patch

Figure 1. GA chromosome construction employing modified maze generating algorithm.

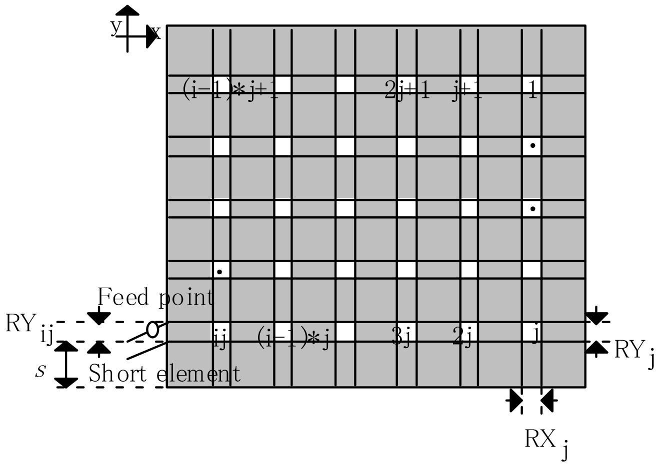


Figure 2. GA analysis model in which sizes of reference points are varied by RYk,RXk (k is reference point number).

Four patterns are defined to assign metal patches to the non-reference cells as shown in Fig. 1(b). One of the four patterns is selected at each reference cell and then a pattern is selected for the next reference cell following the arrow shown in Fig. 1(a). By following the above procedure from the upper-right to the lower-left, a chromosome that does not include any vertex connections and that can include multiple lines can be obtained. Since the four patterns can be expressed by two-bit data, the chromosome is expressed by the connection of the two-bit information. Note that since the cells above and to the right cannot be defined using the above procedure, the metal patch assignment of the cells is defined independently. We set one bit on each reference point from No. 16 to 25 to determine the cells existence and append this bit information to the chromosome. Using this chromosome generation method, which adopts the modified maze generating algorithm, arbitrary meander-lines are constructed on the plane. Moreover, we note that the antenna analysis model constructed using this method can be applied to planar antenna such as micro strip antennas. The reason for this is that when the mesh size is adequately small and a wire grid model using the moment method or a mesh model using the FDTD method is constructed, the analysis model of an isolated reference point surrounded by metal patches is the same as the metal patch model. To address the second problem described previously and in order to enable fine regulation of the line length or line width, we propose arbitrarily changing the size of the reference point. Figure 2 show a GA analysis model in which the sizes of the reference points are varied and represented by RY_k, RX_k (k is the reference point number).

3. Analysis Model and Calculation Results

Using the method proposed in [5], we design a small planar antenna based on observations of the bandwidth and multi-band resonant frequency. The antenna configuration before optimization is shown in Fig. 3. This antenna has a finite ground plane and a short element. The size of the elements on the antenna surface is approximately $(0.1\ \lambda_{fl})^2$. The optimized configuration is assumed to be a kind of modified planar or meander-line antenna because it is electrically small. In this analysis model, the size of the reference point is changed based on RX_k and RY_k shown in Fig. 3 to regulate the line width and line length of the antenna surface. Here, the distances to feed point from the short element (RYij) and the distances to short element from the edge of antenna surface(S) significantly affect the impedance [6]. Therefore, we set RYij and S to 0.012 λ_l when the size of the other reference points is changed. The desired frequency ratio is 0.9 : 1.5 : 1.9. The desired return loss (DRL) at each of these frequencies is greater than 10 dB. The bandwidth of each of the three frequencies is greater than 5.2%.

We define the objective function using the weighting method [3] below.

$$\begin{aligned}F(x) = {} & w1*MIN\,(DRL,\ MIN\,(RL\,f1_L\,(x),\ RL\,f1_H\,(x),\ RLf2_L\,(x),\ RLf2_H\,(x),\ RLf3_L\,(x),\ RLf3_H\,(x))) \\ & +w2*\ MIN\,(DGAIN,\ MIN\,(Gf1_L\,(x),\ Gf2_L\,(x),\ Gf3_L\,(x))) \\ & +w3*RL\,f1_L\,(x) +w4*RLf2_L\,(x) +w5*RLf3_L\,(x) +w6*\ Gf1_L\,(x) +w7*Gf2_L\,(x) +w8*Gf3_L\,(x) \\ & +w9*\ RL\,f1_H\,(x) +w10*RLf2_H\,(x) +w11RLf3_H\,(x) \qquad \ldots (1)\end{aligned}$$

RLf k (x) and Gf k (x) represent the return loss and gain at frequency fk of gene x, and wi (i = 1,..11) is the weight. Index L and H yield the lowest frequency and highest frequency for each band, respectively. Term MIN is defined as the minimum value used to select the lowest return loss or gain among the three frequencies. Figure 4 shows a comparison of the GA calculation of the return loss results in the desired frequency bands for each reference point size when RX is 0.012 λ_L (solid line) and 0.009 λ_L (dotted line), respectively. Figure 4 shows the return loss versus the number of generations of genes that have the highest value of objective functions F(x) among the population in each generation. The return loss in Fig. 4 is the worst return loss of the three frequencies as described in the first term of Eq. (1). In the optimization process, we use the same population size, crossover probability, mutant probability, and objective function weights in the proposed and conventional methods.

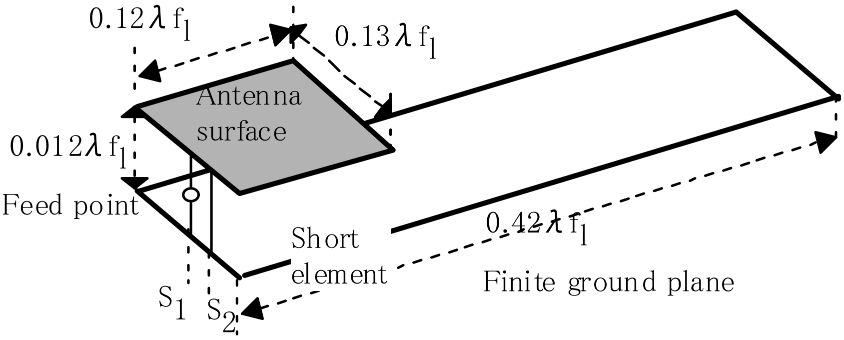


Figure 3. Analysis model of planar antenna with finite ground plane and short element.

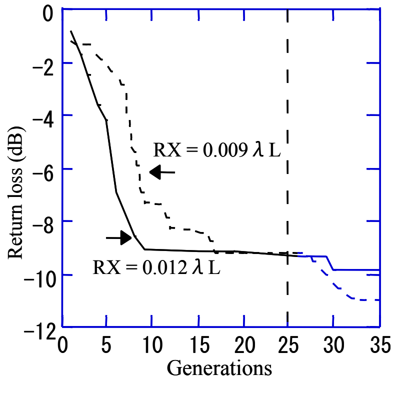
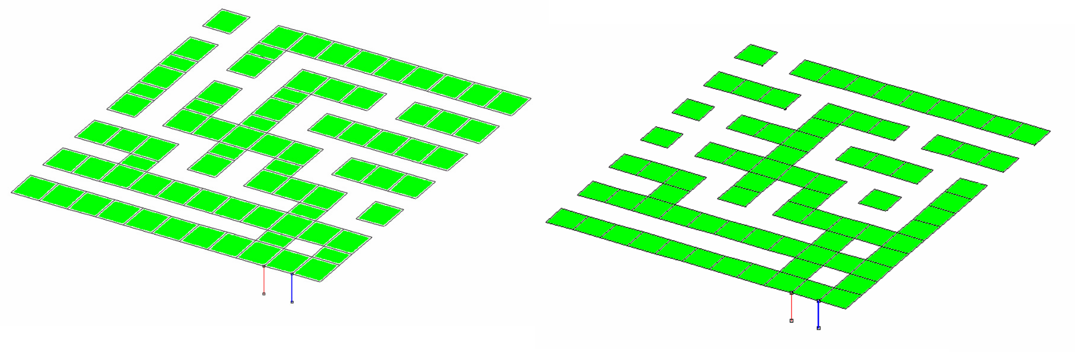


Figure 4. Worst return loss of three desired frequencies bands

In generations 1 to 25, each calculation is performed independently under the same conditions and over the 18 generations there are only a few changes in each generation. Therefore at the 25 generation, we merge the top data in the population and restart the calculation. Even though the same initial value is used in the 25 generations, the performance of a smaller RX (= 0.009 λ_L) is better and satisfies the desired conditions. It is easily deduced that when a small reference point is used, the line width becomes large and the bandwidth widens.

The final antenna configurations using the method are shown in Fig. 5. Figures 5(a) and 5(b) show the results when reference point RX is 0.009 λ and 0.012 λ, respectively. We confirm that the line width in Fig. 5(a) is wider than that in Fig. 5(b). We can also confirm that there is no vertex connection in the antenna configuration in either result. The frequency dependency of the return loss and the gain of the final configuration obtained using the proposed method are shown in Fig. 6.

We find that a return loss of greater than 15 dB is obtained using the method at the three desired frequencies. Each bandwidth of greater than 10 MHz satisfies the return loss of greater than 10 dB.



(a) RX = 0.009 λ_L (b) RX = 0.012 λ_L

Figure 5. Final antenna surface configuration by GA

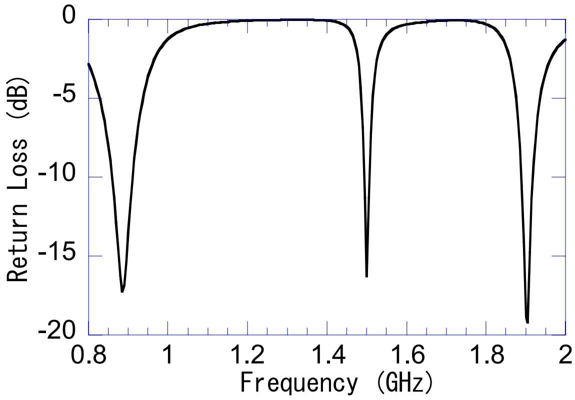


Figure 6. Return loss vs. Frequency of final antenna structure constructed using proposed method

4. Conclusion

This paper proposed introducing a maze-generating algorithm to a novel chromosome generation method for the Genetic Algorithm (GA) that optimizes the antenna configuration of small planar and meander line antennas to overcome the problems related to the conventional chromosome generation method such as slow convergence and difficulty in manufacturing. To achieve fine regulation of the line width and line length, we changed the size of the reference points. The effect of employing the method was confirmed through the optimum design of a multi-band small antenna.

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