NOVEL MULTI-BAND SCROLL CONFIGURED THIN-MONOPOLE ANTENNA DESIGNED USING GENETIC ALGORITHM EMPLOYING MAZE-GENERATING ALGORITHM FOR CHROMOSOME

Tamami MARUYAMA and Keizo CHO
NTT DoCoMo, Inc.
3-5 Hikari-no-oka, Yokosuka-shi, Kanagawa-ken, 239-8536 Japan
E-mail: maruyamatam@nttdocomo.co.jp

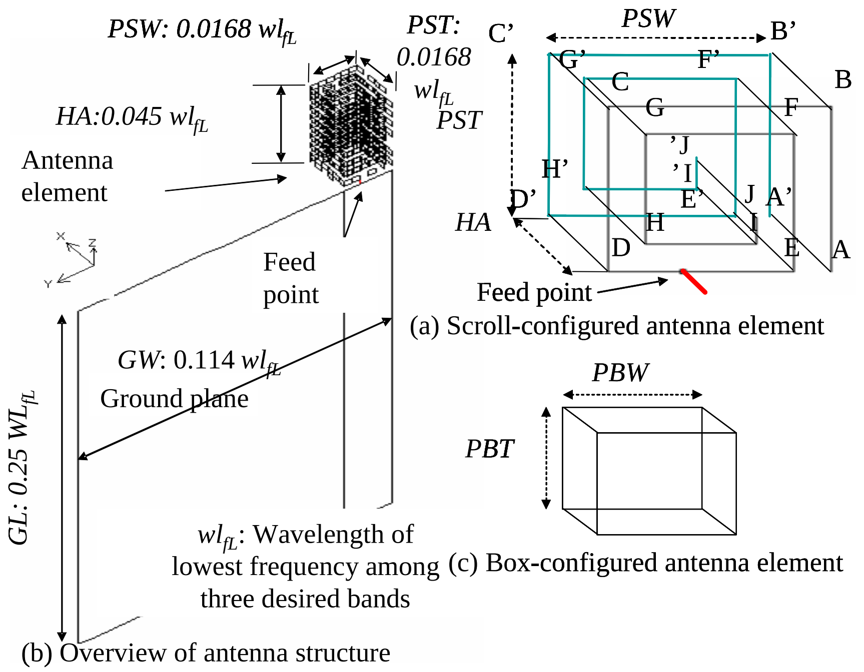
1. INTRODUCTION

As wireless communication systems have developed, the third generation system as well as Personal Digital Cellular (PDC) and Global System for Mobile communications (GSM) have become widespread, and currently the fourth generation system is being proposed. To be compatible with these systems, the requirements of compact multi-band antennas for handsets must be increased. In the field of mobile communications, a dual frequency antenna was proposed that works for both the GSM and Digital Cordless System (DCS) [1]. Moreover, a dual frequency antenna that satisfies both 802.11a and 802.11b/g standards was reported for wireless LAN systems [2]. The downsizing of these multi-band antennas for mobile terminals is indispensable to avoid the coupling between the circuit board and antenna element and to increase the degree of flexibility in aesthetic design. Toward this goal, Sun *et al.* [1] reported on a technique in which a meander-line configuration antenna was formed into a box (hereafter box configuration) with the dimensions of 0.046×0.037×0.021 WL_{fL} (WL_{fL}: wavelength of the lowest center frequency). However, in this technique, the surface of the meander-line antenna can only be constructed on the sides of the box. Therefore, it is difficult to construct a thin-monopole antenna while maintaining the same antenna surface size.

To address this issue, we propose a configuration in which the antenna surface resembles a scroll as shown in Fig. 1(a) (hereafter scroll configuration). By using the scroll configuration, the volume of the monopole antenna can be reduced while maintaining the same antenna surface area compared to the box configuration. However, because the scroll configuration involves multiple layers, it is necessary to consider the mutual interaction between the inside and the outside layers. Therefore, generally the antenna design tends to be difficult. To overcome this difficulty, we adopt the automatic antenna design method using the genetic algorithm (GA) [3], [4], [5]. Our method proposed in [5] employs the GA to design a meander-line configuration monopole antenna with a three dimensional structure and this method can change the antenna configuration in the optimization process. The key technique of the method is to employ a maze-generation algorithm for the GA chromosome to avoid vertex-only connections in the meshes and to construct a continuous line [3], [4]. We adapt this technique to the scroll-configured thin-monopole antenna in this paper. This paper shows that a multi-band antenna with the frequency ratio of 1.0 : 2.1 : 2.4 can be designed in order to confirm that the proposed scroll antenna configuration is effective in achieving a thin-monopole antenna and that the GA employing the maze-generation algorithm for chromosomes is successful in designing a multiple-layer configuration meander-line antenna considering the mutual interaction between the layers.

2. SCROLL-CONFIGURED THIN-MONOPOLE ANTENNA AND DESIGN METHOD USING GA

The antenna configuration is shown in Fig. 1. Figure 1(a) shows the antenna element. For the proposed technique to achieve a thin-monopole type antenna, we construct the antenna element using the scroll configuration shown in Fig. 1(a). In this paper, the scroll configuration is formed by nine faces that are S1: AA’B’B, S2:BB’C’C, …., S8:HH’I’I and S9:II’J’J. The meander-line antenna is constructed on the surface of the structure. Figure 1(c) shows the box configured antenna element that was adopted in [1] and [5]. The meander-line antenna was constructed on the side of the structure regarding the box as a four-angle pillar. In the case of the scroll-configured antenna, the mutual interactions between each surface are higher than that for the box configuration antenna because the scroll configuration antenna



(a) Scroll-configured antenna element

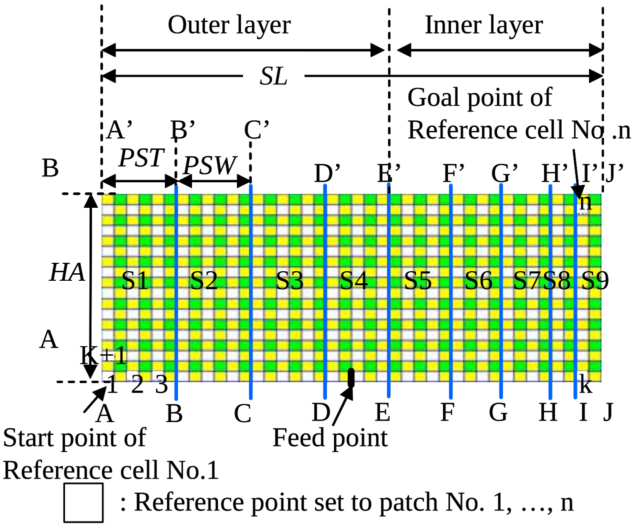
(c) Box-configured antenna element

(b) Overview of antenna structure

Figure 1. Scroll-configured thin-monopole antenna

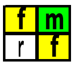
has multiple layers. In this paper, we apply the method proposed in [5], which automatically designs a meander-line configuration monopole antenna, to the scroll-configured antenna element and examine the efficiency of the method.

Figure 2 shows the GA analysis model, which is applied to the scroll-configured thin-monopole antenna. Figure 2(a) shows the faces (S1 through S9) of the scroll represented as one flat plane. *HA* represents the height of the scroll configuration antenna element, *SL* represents the length, *PST* represents the thickness, and *PSW* represents the width. The faces S1, S2, S3 and S4 comprise the outer layer of the scroll and faces S5, S6, S7, S8 and S9 comprise the inner layer. The volume of the scroll is defined as *PST* × *PSW* × *HA*. In Fig. 2(a), the faces (antenna surfaces) are divided into meshes and the existence or absence of a patch in each mesh determines the antenna line or surface configuration. The feed point is set between D and E because the face S4:DD'E'E is connected to the ground plane. We set meshes on the space between the antenna element and the ground plane. If the metal patches exist on a lower rank and between D and E, then the metal patch works as a short element between the antenna element and the ground plane. In the commonly used chromosome definition for planar antennas [6], the existence and absence of metal patches in each mesh are represented by 0 and 1 of the gene, respectively. However, using this definition generates adjacent meshes that are only connected at a vertex, and this makes it difficult to generate a continuous line. Our method adopts the maze-generation algorithm for the GA chromosome [3], [4], [5] to overcome these problems. The maze-generation algorithm defines reference cells as No. 1 to n as shown in Fig. 2(a) and metal patches are removed from the reference cells. Four



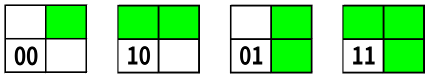
□ : Reference point set to patch No. 1, …, n

(a) Flat plane scroll antenna element and reference points.



(i) Cell *r* : Reference cell, non-metal
(ii) Cell *f* : Free cell, metal or non-metal
The material is decided by gene attached to reference cell
(iii) Cell *m*: Metallic cell

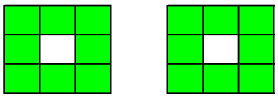
(b) Definition of each cell on flat plane scroll antenna element.



(c) Method for generating antenna surface using bit information attached to a reference point

Figure 2. GA analysis model for scroll configuration thin-monopole antenna using the maze generating algorithm for GA chromosome

patterns are defined in order to assign metal patches to the non-reference cells as shown in Fig. 2(c). Since the four patterns can be expressed by two-bit data, the chromosome is expressed by the connection of the two-bit information. This method can avoid vertex only connections; however, there is an area in which a patch is always removed or is always a metallic patch such as that shown in Fig. 2(b) and Fig. 2(c). Our method can increase the flexibility of the structure in this case. When an isolated patch cell emerges as shown in Fig. 3(a), we regard that the cell can be removed. We can obtain the same antenna performance if the cell does not exist. In the same way, if an isolated cell for removal emerges as shown in Fig. 3(b), we can regard the cell as a patch cell. Indeed, when we use the wire grid of the moment method, this is completely true. Based on this feature, we can construct several kinds of antenna configurations.


(a) Isolated cell for removal can be regard as metallic cell

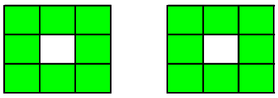

(b) Isolated metallic cell can be regard as a cell for removal

Figure 3. Rule applied to isolated cell of proposed design method

2. CALCULATION RESULTS OF SCROLL-CONFIGURED THIN-MONOPOLE ANTENNA

Table I. Antenna Parameters

	Type	Volume (unit: wl_{fL}^3)	Perimeter (unit: wl_{fL}) $2*PBW + 2*PBT$	Scroll Length (unit: wl_{fL})
Type A	Scroll	*PSW* by *PST* by *HA* $=(0.0168)^2 * 0.045$	-	0.114
Type B	Box	*PBW* by *PBT* by *HA* $=(0.0168)^2 * 0.045$	0.0552	-
Type C	Box	*PBW* by *PBT* by *HA* $=(0.028)^2 * 0.045$	0.114	-

To show that the proposed design method works for the automatic design of a scroll-configured thin-monopole antenna and to show the effectiveness of downsizing by adopting the scroll configuration, we designed a multi-band scroll-configured monopole antenna. We set the desired frequency ratio to 1.0 : 2.1 : 2.4. The desired return loss (*DRL)* at each of these frequencies is greater than 10 dB. For the objective function, *f(x),* we use the weighting constrained method as described in [3]. To confirm the effectiveness of the downsizing of the proposed scroll-configured monopole antenna compared to the previous box structure, we show the calculation results of both structures. The size of each structure is shown in Fig. 1(b). The parameters of both the proposed and previous antenna configurations are given in Table I. In Table I, Type A represents the antenna structure of the proposed scroll-configured monopole antenna and Types B and C represent the box structure. The volume of Type B is the same as that of Type A. For Type C, the antenna structure parameters are set so that the perimeter of the antenna element box and the length of scroll configured monopole antenna are the same. The volumes of the Type-C antenna and that described in [1] are almost the same. The unit wl_{fL} indicates the wavelength of the lowest frequency in the desired frequency band. The dimensions of the ground plane are GL: 0.25 wl_{fL} ×GW: 0.114 wl_{fL}. We compare the antenna characteristics of the final antenna structure of Types A to C that are obtained for a quasi-optimum solution using the GA. In the calculation of the quasi-optimum solution using the GA for each type of antenna. The same size mesh is adopted for each antenna type to maintain fairness in the comparison. The calculation results are shown in Figs. 4 and 5. Figure 4 shows the value of the return loss versus the number of generations of genes for each of the three types of antennas that has the highest value of the object function among the population in each generation. In Fig. 4, the symbols are plotted on the line when the objective function value

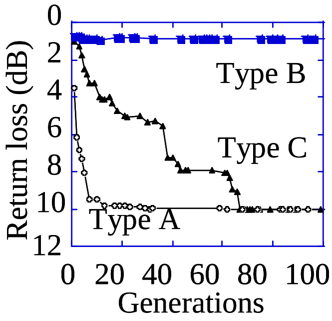


Figure 4. Worst return loss of three desired frequencies vs. generation

is changed in the optimum process. The figure shows that the return loss values of Type A and Type C converge toward the desired value, and Type B does not converge. From the frequency dependency of the return loss for each antenna type of the final configuration as shown in Fig. 5, we can see that it is hard for the Type-B antenna to resonate at the lowest frequency. The reason for this can be considered that because the perimeter of Type B is the shortest among the three types, a sufficiently long meander line cannot be constructed for Type B to enable it to achieve a lower frequency which has the longest wavelength. Finally, based on these findings, we confirm that the proposed scroll configuration (Type A) satisfies the desired antenna characteristics for the reduced size monopole antenna while the box configuration requires a larger volume (Type C) to satisfy the same antenna characteristics. The final antenna configuration of Type A is shown in Fig. 6. Figure 6(a) shows the side view and Fig. 6(b) shows the top view. These views show the novel scroll-configured thin-monopole antenna created using the proposed method. The volume of the Type-A antenna is approximately 36% that of Type C and that in [1].

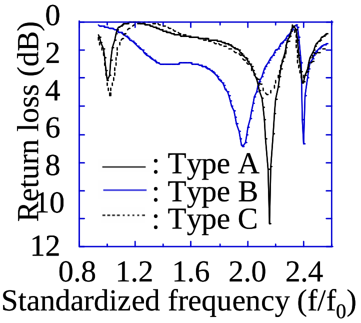
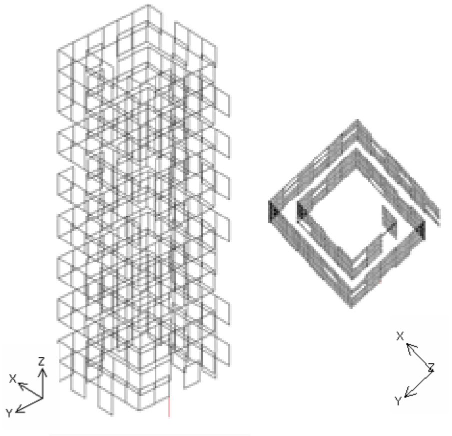


Figure 5. Return loss vs. standardized frequency (f/f_0) of final antenna structure constructed using proposed method



(a) Side view (b) Top view

Figure 6. Final antenna structure of scroll configuration thin-monopole antenna

4. CONCLUSION

To achieve a thin-compact multi-band monopole antenna, this paper proposed a novel antenna configuration. The key technique in the construction of the proposed antenna is adopting the scroll configuration for the monopole antenna and meander line. To address the difficulty in design caused by mutual interaction between the outer and inner layers of the scroll configuration, we adopt our GA employing maze-generating algorithm for the GA chromosome. We compared based on the quasi-optimized solutions introduced by the method, the proposed scroll configuration antenna and the box structure for the antenna that have the frequency ratio of 1.0: 2.1: 2.4. The results show that the downsized box structure has difficulty obtaining the desired characteristics while the two-layer scroll-configured antenna obtains the desired characteristics and at 36% the volume of the box structure.

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