Parallel Calculation Algorithm for Multi-mode Antenna Design

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Abstract

Recently, a great deal of diversity has emerged in mobile phone handsets with respect to the design and functionality. Since the antenna characteristics generally vary based on the target functionality of the handset, it is difficult to construct antennas that always satisfy the design requirements for multi-type usage. To overcome this difficulty, this paper proposes a novel parallel calculation algorithm employing the genetic algorithm for multi-type antennas. The key technique in the proposed algorithm is to reuse the final solution of one type of antenna as the first population of the other type antenna. There are two forms of the proposed algorithm, a simple one and a functionalized one. These algorithms are applied to the automatic design of a compact multi-band antenna for clamshell type handsets used in the closed and open positions (types). The results show the final antenna constructed using the proposed algorithm achieves the required design conditions for both the open and closed types.

1. INTRODUCTION

Three frequency bands, Band VI (830 to 885 MHz), Band IX (1.749 to 1.88 GHz), and Band I (1.92 to 2.17 GHz), which are allocated as standardized frequencies to Japan by the 3rd Generation Partnership Project (3GPP), will be used for the IMT 2000 system. Band VI will be used for mountain ringed regions and the 1.7 GHz band will be used for IMT 2000 systems corresponding to high density traffic areas in the inner city to widen the coverage area of the IMT 2000 system [1].

As a compact multi-band antenna candidate, we applied the scroll configuration to construct a compact multi-band antenna [2] and the results showed that the genetic algorithm (GA) employing a maze-generating algorithm for the GA chromosome [3] is useful in abating the difficulty in design caused by mutual interaction between the outer and inner layers of the scroll configuration.

In practical use, there are several usage cases for the handset. For example, there are typically two ways to use a cellular phone. When we use it to make or receive a telephone call, it is usually held in the hand and tilted close to the head. When used for data communication such as when sending E-mail, the phone is held in the hand in front of the body. On the other hand, the clamshell type handset is a popular trendy handset configuration that can be used in either the open or closed position. The performance of the antenna in this

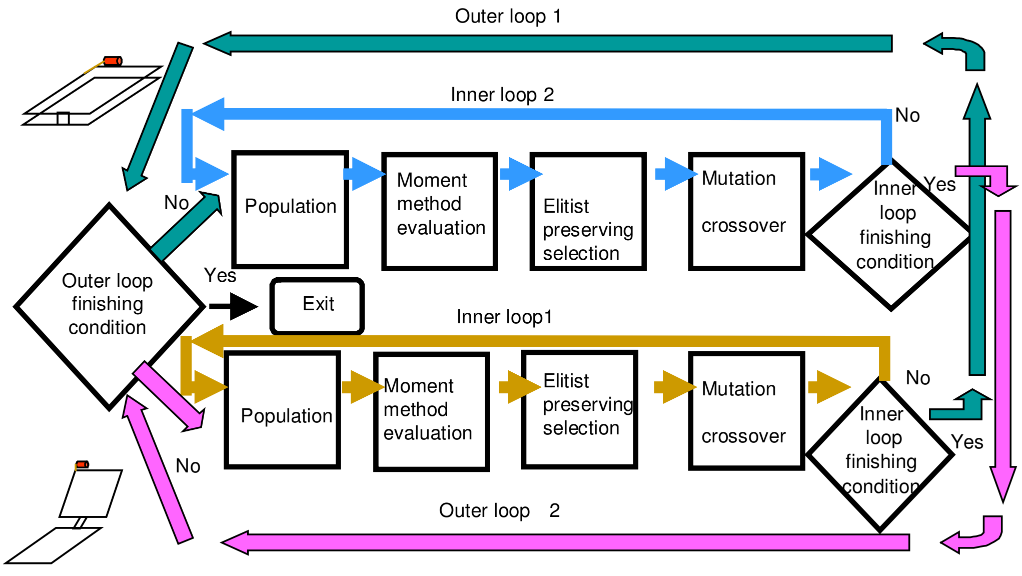


Figure 1. Parallel Calculation Algorithm Using GA for Multi-type Antennas

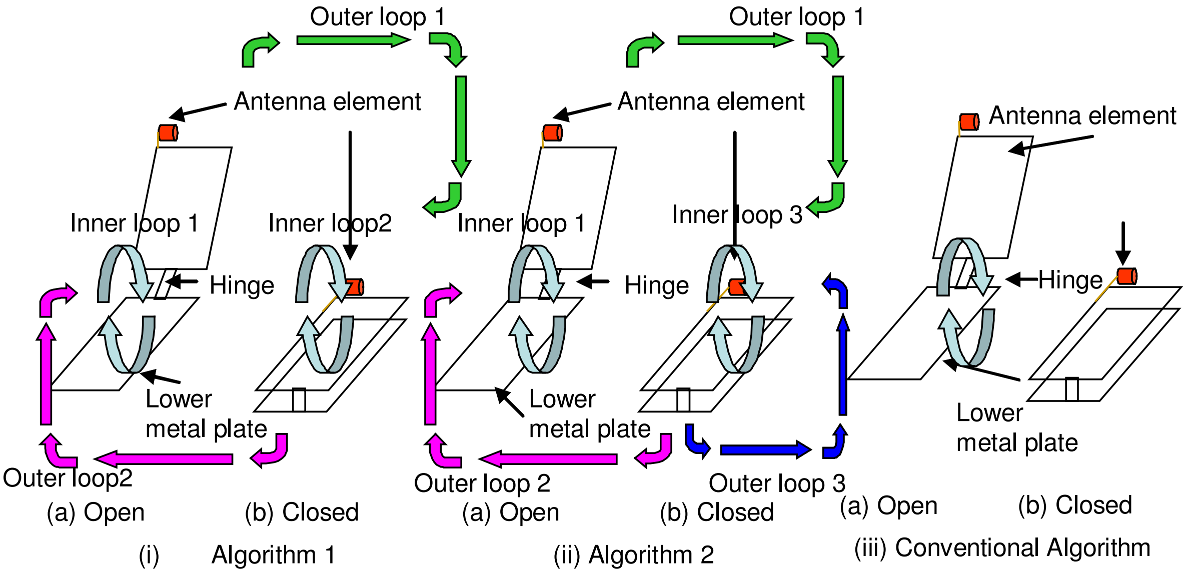


Figure 2. Three Kinds of Algorithms

configuration including the shift of the frequency resonance or degradation in the VSWR usually varies according to the position. Therefore, it is difficult to satisfy multi-band antenna characteristics in multi-type usage, because the antenna must satisfy the desired condition for both positions (types). To overcome these difficulties, this paper proposes a novel parallel calculation algorithm employing the GA that achieves automatic design of an antenna for multi-type usage handsets.

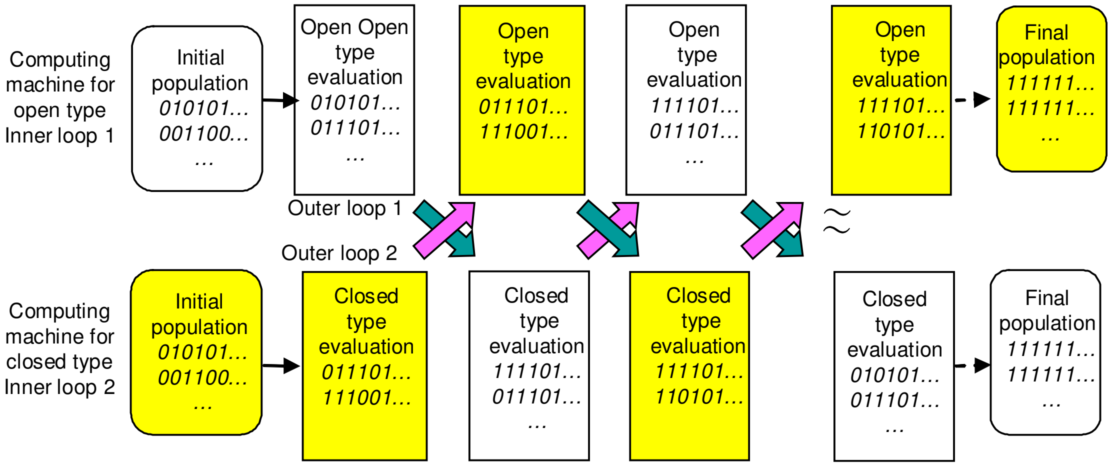
The algorithm applies vector evaluation [6]. We developed the method to overcome the difficulty of convergence caused by the non-linear effect of each antenna characteristic [4], [5]. Usually, this method employs a weighting effect in the objective function. Although the vector evaluation method was effective, as the number of evaluation terms increases due to the consideration of multi-bands and multi-types, the more difficult convergence becomes because the number of terms for the objective function increases resulting in non-linear characteristics affecting the convergence.

The proposed algorithm in this paper does not need to increase the number of terms in the objective function. This method is applied to the design of a small multi-band antenna for handsets.

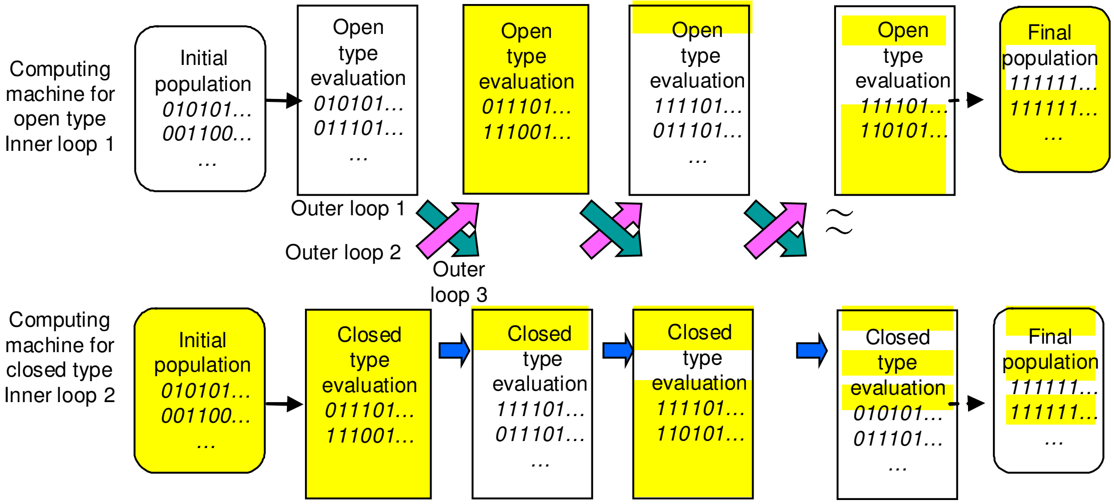
2. Parallel Calculation Algorithm Employing GA for Multi-type Antennas

The parallel calculation algorithm for automatically designing an antenna that achieves multi-type usage is shown in Fig. 1. This figure shows an example in which the same antenna is used for the closed and open positions for the clamshell type handset. This algorithm comprises an inner loop algorithm and an outer loop algorithm. The inner loop algorithm is operated as an ordinary GA for each type of antenna. We express the antenna configuration as a chromosome and optimize the antenna element configuration using the objective function. The objective function in each inner loop comprises the antenna characteristics of their respective type, i.e., open or closed, using the moment method. We adopt an elitist preservation selection method [6]. After the inner loop satisfies the finishing condition, the final population of the closed type in Inner loop 2 is treated as the initial population of the open type in subsequent Inner loop 1 after passing through Outer loop 2. In a similar way, the final population of the open type in Inner loop 1 is treated as the initial population of the closed type in subsequent Inner loop 2 after passing through Outer loop 1. Repeating this algorithm, we can expect to introduce an antenna that satisfies the conditions for both antenna design types.

This paper investigates three kinds of algorithms as shown in Fig. 2 based on the algorithm described above. In Fig. 2, Algorithm 1 is the same as that depicted in Fig. 1. Therefore, in Algorithm 1, after the second iteration of Inner loops 1 and 2, all initial populations of one type come from the final population of the other type. Anticipating that the optimum solution for one type will be a good solution for the other type, we reuse the population. Using Algorithm 1, all populations are always evaluated both for the open and closed types. Algorithm 1 can introduce a good solution if we adequately set the initial condition. However, convergence is not always achieved. If the initial setting condition or the finishing condition of the inner loop is not good, Outer loops 1 and 2 of Algorithm 1 may always exchange the same population. For example, if Population set A is changed to Population set B through Outer loop 1 and Population set B is



(i) Algorithm 1



(ii) Algorithm 2

Figure 3. Flow Pattern Diagram of Population

changed to Population set A through Outer loop 2, the loop would be continued infinitely.

To avoid this and construct a stronger algorithm, we arranged Algorithm 1 to Algorithm 2 as shown in Fig. 2(ii).

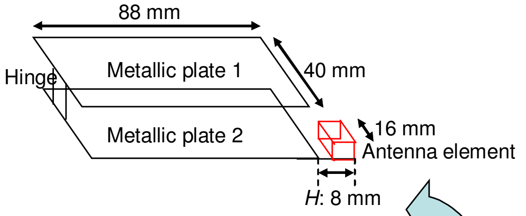
The feature of Algorithm 2 is that each inner loop is given its own role. The role given to Inner loop 2 of the closed type in Fig. 2(ii) is to promote convergence. The role given to Inner loop 1 of the open type in Fig. 2(ii) is to generate a population that satisfies both objectives for the open and closed types. Each inner loop plays its own role following the procedure. Inner loop 1 of the open type receives the initial population only from the final population of Outer loop 2 of the closed type. Therefore, the population in Inner loop 1 is always evaluated for both types. Otherwise, Outer loop 3 of the closed type receives the initial population not only from the final population from Outer loop 1 of the open type, but also from the final population from Outer loop 3 of the closed type. Using Algorithm 3, we send the elitist population to both types as the initial population. In the closed type of antenna for Algorithm 2, through the action of Inner loop 3, we maintain the elitist population preserving the selection not only in the inner loop, but also in the outer loop. Therefore, Algorithm 2 does not generate an infinite loop. Figure 2(iii) shows the conventional method.

There is no conventional algorithm that functions for two different types of antennas. For comparison, we show in Fig. 2(iii) the antenna characteristic using a single calculation result with the results using the proposed algorithm.

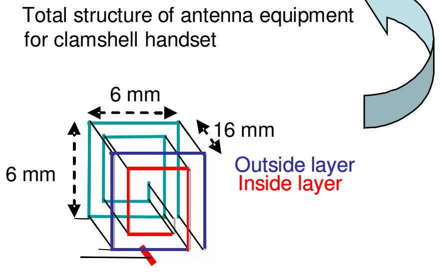
The population flow is shown in Fig. 3. Parallel calculations are performed using two machines, one for the open type and one for the closed type. In Algorithm 1, since the total population always changes, there are two independent calculations. In Algorithm 2, since the closed type data is retained in Outer loop 3, the total population is mixed. In Fig. 3, we show the evolution from the initial population set using yellow and white. In Algorithm 1, each population set follows a separate evolution path. In Algorithm 2, there is crossover in the evolution paths of the population sets. However, in the calculations for the open type, we always evaluate only the data that comes from the closed type. Through these procedures we can evaluate the final population that passes to both the open and closed types.

3. CALCULATION RESULTS

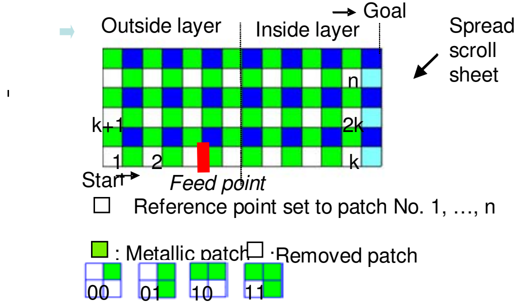
We simultaneously tested the algorithms shown in Figs. 2(i), 2(ii), and 2(iii) for the automatic design of a compact multi-band antenna for the clamshell type handset to satisfy the antenna requirements for both types at 800 MHz, 1.7 GHz, and 2.0 GHz.



(i) Total structure of antenna equipment for clamshell handset



(ii) Scroll configuration antenna element



(iii) Method of generating antenna surface using Maze generation algorithm

Figure 4. Scroll Configuration Thin-Monopole Antenna

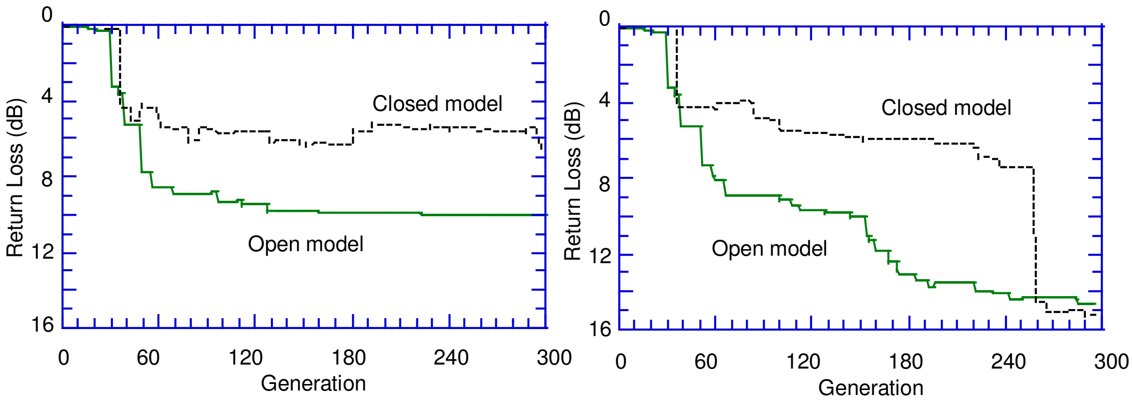
This paper adopts the scroll configuration antenna as the antenna element. We arranged the antenna model based on [2] using two metallic boards and a hinge as a mock up of the clamshell type handset. We attached the scroll configuration antenna element in the horizontal direction so that distance *H* between the edge of the metallic plate and the top of the antenna is as short as possible to attain a low profile as shown in Fig. 4. We use the scroll configuration antenna to achieve a thin compact antenna while maintaining a wide area for the meander line as shown in Fig. 4(ii). The antenna element volume is 6×6×16 mm^3 and each metallic board is 88 ×40 mm^2. The antenna is designed following the design in [2]. We divide the scroll sheet into meshes and decide the mesh configuration using the GA employing the maze generation method for the antenna chromosomes as shown in Fig. 4(iii).

For the objective function, *f(x)*, we use the weighting constrained method as described in [4]. To resonate three frequency bands, 857 MHz, 1.795 GHz, and 2.045 GHz, the function is constructed using the return loss level as in (1) and this equation comprises only one type, either the open type or closed type. In Inner loop 1, the function is constructed using the calculation results for the open type and in Inner loop 2, the function is constructed using the calculation results for the closed type.

In (1), $RL_{fl}(x)$, RL_{fm}, and RL_{fh} are the return loss levels for 857 MHz, 1.795 GHz, and 2.045 GHz, respectively. The desired return loss (*DRL*) at each of these frequencies is greater than 8.0 dB.

$$O(x)= w_1 \cdot MIN(DRL, MIN(RL_{fl}(x), RL_{fm}(x), RL_{fh}(x))) \\ +w2 \cdot MIN(DRL, RL_{fl}(x)) + w3 \cdot MIN(DRL, RL_{fm}(x)) \\ +w4 \cdot MIN(DRL, RL_{fh}(x)) \quad \ldots (1)$$

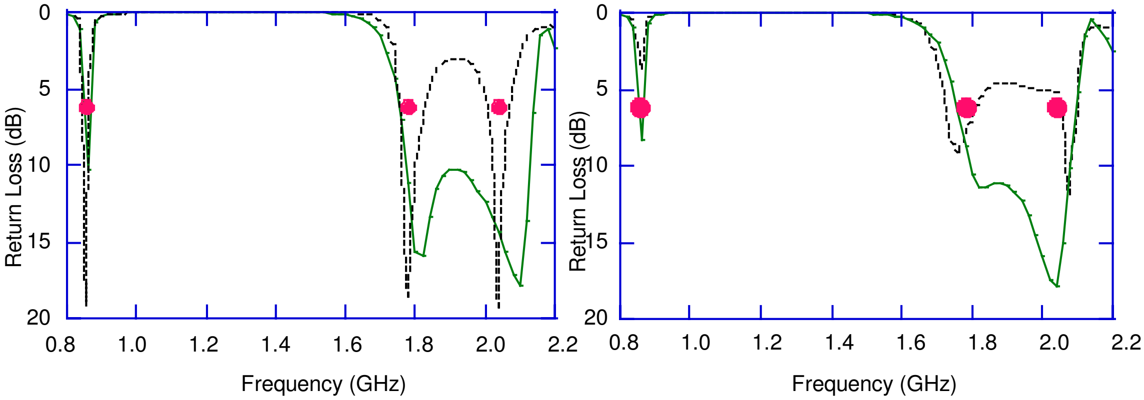
We select the individual that has the highest value of the object function among the population in each generation and show its worst return loss level in the three desired frequencies versus the generation calculation results of Algorithms 1 and 2 in Fig. 5(i) and 5(ii), respectively. We adopt the same initial condition for the GA in both algorithms and decide the finishing condition for the inner loop based on the number of generations of the inner loop of *12*. The closed model of Algorithm 1 is sometimes degraded by exchanging the initial population every 12 generations. Therefore, beyond approximately 150 generations, the characteristics of the open type model for Algorithm 2 are better than those when using Algorithm 1. In Algorithm 2, both models achieve less than 12 dB, while in Algorithm 1, the return loss value of the open type and closed type are limited to approximately 10 dB and 6 dB, respectively. The final results of Algorithm 2 and the conventional algorithm are shown in Fig. 6. In Fig. 6(i), we select the best antenna element from the final solution of the closed type and construct the open type using the same antenna element. In the conventional algorithm shown in Fig. 6(ii), although the open mode return loss is less than 8 dB at each frequency, the closed mode return loss cannot satisfy the requirement at 857 MHz and 2.045 GHz. Using proposed



(i) Algorithm 1

(ii) Algorithm 2

Figure 5 Return Loss vs. Generation Results Applied to Algorithm 1 and Algorithm 2



(i) Algorithm 2

(ii) Conventional method

Figure 6. Results of Return Loss vs. Frequency for Algorithm 2 and Conventional Algorithm

Algorithm 2 shown in Fig. 6(i), we can confirm that both the open and closed type return loss levels are less than 8 dB.

4. CONCLUSION

This paper proposed a novel parallel calculation algorithm employing the GA for multi-type antennas. The point of this algorithm is to reuse the final solution of one type of antenna as the first population of the other type antenna in the next generation loop. In a comparison of the two kinds of proposed algorithms and the conventional algorithm, the effectiveness of Algorithm 2 was clarified. Using this algorithm, we designed a 3-band frequency clamshell type handset antenna that satisfies the return loss level requirement of less than 8 dB for both the closed and open types.

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