Multiband Single-layer Frequency Selective Surface Optimized by Genetic Algorithm with Geometry-Refinement Technique

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1 Introduction

Single-layer frequency selective surface (FSS) using the novel element shape have been recently investigated [1], [2]. These FSSs are very light in weight and very compact in volume, comparing with the multilayer FSSs. The optimization technique based on a genetic algorithm (GA) has been applied to the design of the single-layer FSS [1], [3]. However, most of the FSS element shapes generated by the GA have the critical points, which mean that the conductors have the touch only at the lattice points generated when discretizing the unit cell into the grid for the analysis. If the optimized FSS element has the critical points, the fabricated FSS does not work well as we design because the electrical length for the resonance is changed through the critical points. Therefore this paper proposes the FSS design method based on the GA with geometry-refinement method (GRM), that can remove the critical points not by the natural selection and the evolution, but by forcing to eliminate them. As a design example, we design the multiband single-layer FSS for L band (1.5GHz), S band (2.5GHz band) and Ka band (20/30GHz band) separation, and prove the efficiency of the GRM by comparing with the conventional GA technique. And the effectiveness of the present design method is also confirmed experimentally.

2 Design Method

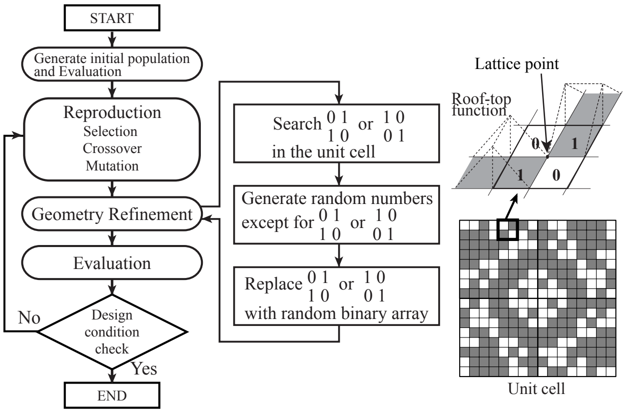

Figure 1: Design method based on genetic algorithm with geometry-refinement method.

In this paper, the FSS under consideration is assumed to be the infinite periodicity without a dielectric substrate. Figure 1 shows the flow chart to design the multiband FSS by using the GA with the geometry-refinement method (GRM) to remove the critical points in the unit cell. The relation of the basis functions with 1s and 0s of the GA is shown in the inset of Fig. 1. The 1 and 0 correspond to the perfectly conducting plate and the free space, respectively. As shown in Fig. 1, most of FSS element shapes generated by the GA have the touch of the conductors only at the lattice points inside the resonant element itself and/or between the adjacent resonant elements. If the conductors of the optimized FSS elements have these points, this means that they do not touch each other analytically, but touch physically. As a result, the fabricated FSS has the different characteristics from the designed FSS at the specified bands. Therefore the FSS element shapes should be avoided to have the touch between the conductors only at the lattice points.

In the present method, the unit-cell geometry has the four-fold symmetry independent of the polarization of the incident wave. So the GA operates on a quarter region of the unit-cell geometry. The size

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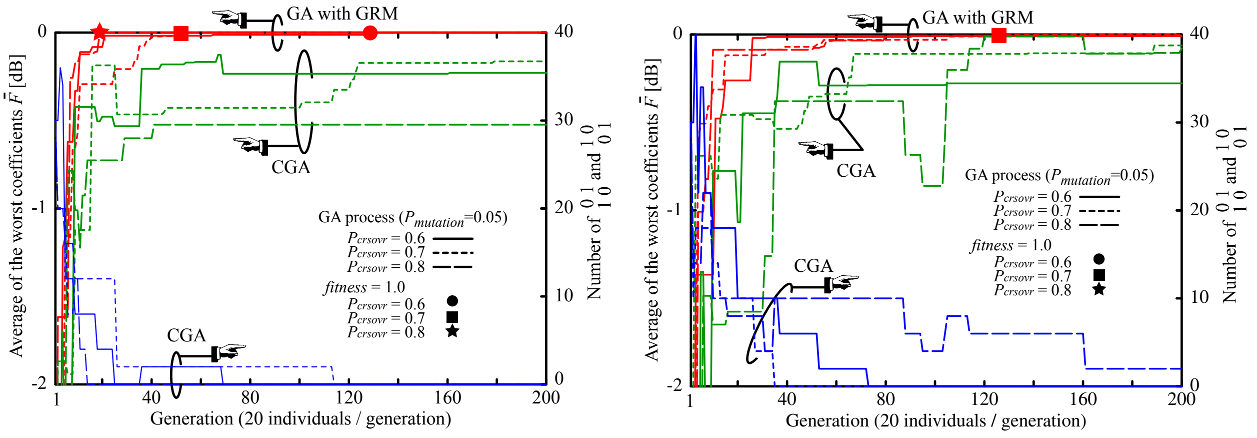
of the unit-cell geometry must be determined not to yield the grating lobe in the specified bands. The GRM proposed here firstly finds the two-dimensional arrays $\begin{matrix}0\,1\\1\,0\end{matrix}$ and $\begin{matrix}1\,0\\0\,1\end{matrix}$ in the FSS element shape generated by the GA operators (crossover and mutation), and secondarily replaces these arrays with the other two-dimensional arrays generated by the random numbers. This routine is repeated until all the two-dimensional arrays $\begin{matrix}0\,1\\1\,0\end{matrix}$ and $\begin{matrix}1\,0\\0\,1\end{matrix}$ are completely removed not only from the unit cell and but also from the boundaries between the neighboring cells. The characteristics of the FSS generated through the GRM is evaluated by the fitness function, which is defined as $1/(1+\bar{F})$ where $\bar{F}$ is the average of the differences between the desired characteristics and the worst reflection or transmission coefficient (in dB) in each specified band. If the fitness of the best individual reaches 1.0, the FSS unit-cell geometry is considered as the optimum element shape.

3 Efficiency of Design Method

In order to show the efficiency of the GRM, the convergence to obtain the optimum geometry is compared between the GRM and the conventional GA technique (CGA). The CGA searches the optimum geometry, which does not include $\begin{matrix}0\,1\\1\,0\end{matrix}$ and $\begin{matrix}1\,0\\0\,1\end{matrix}$ (critical points), by the natural selection and the evolution. Therefore the fitness function evaluates the number of the critical points in the unit cell in addition to the characteristics of the FSS. So it can be defined as $1/(1+\bar{F}+P)$, where the penalty P means the number of critical points weighted by the coefficient β.

Figure 2 shows the GA optimization process (the average of the worst coefficients and the number of critical points of the best individual) when optimizing for various GA parameters. For the comparison, we design the FSS for transmitting L band (1.5GHz band) and S band (2.5GHz band), and also reflecting Ka band (20/30GHz band). Our design goal for the characteristics of the FSS is -0.5dB in the transmission band and -0.2dB in the reflection bands only for normal plane-wave incidence. The unit-cell resolution is 16×16 grids and the element spacing is fixed to be 8.0mm. The population size per a generation is 20. The weighting coefficient β is chosen to be 0.1 because the CGA with $\beta = 0.1$ has the convergence faster than those with $\beta = 1.0$ and 0.01. As shown in Fig. 2, the GA with the GRM obtains the optimum



(a) Single-point crossover

(b) Uniform crossover

Figure 2: Comparison of convergence between the GRM and the CGA.
(P_{crsovr} : crossover rate, $P_{mutation}$: mutation rate)

geometry faster than the conventional GA technique. For $P_{crosovr} = 0.6$ and 0.8 in Fig. 2(b), the GRM does not obtain the individual with the fitness=1.0 but the fitness values are very close to 1.0. So, it can be concluded that the GRM is the more efficient method comparing with the conventional GA technique.

4 Design Example and Experiment

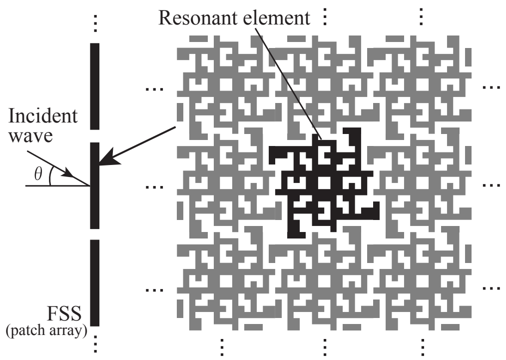
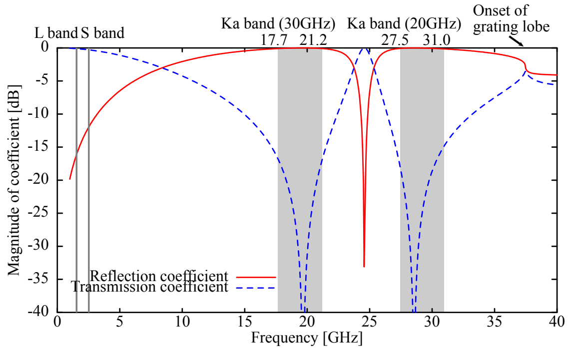
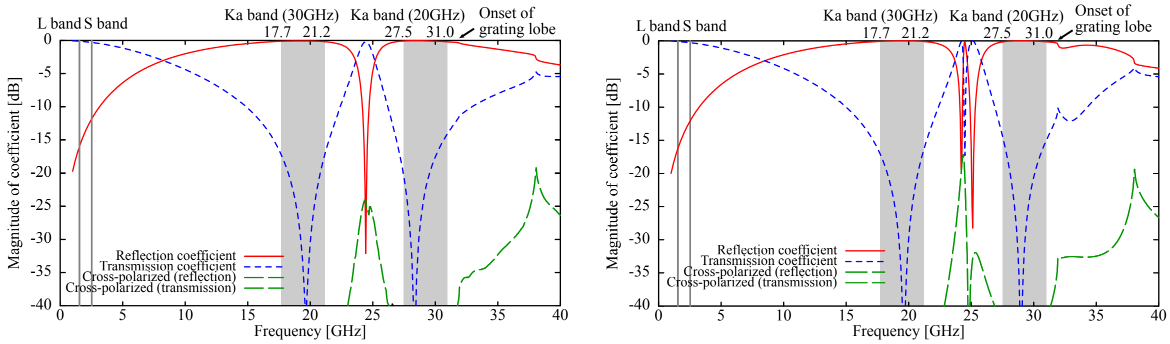


Figure 3: FSS element shape designed by the present method (periodicity:8.0mm).

As a design example, the GA evaluates the characteristics of the FSS not only for the normal plane-wave incidence and but also for both TE and TM wave incidences at the incident angle $\theta = 10°$. The specified bands and GA parameters are the same as those of the previous section. The individuals are reproduced through the tournament selection, the single-point crossover and the mutation. The crossover and mutation rates are chosen to be 0.8 and 0.05, respectively. Figure 3 shows the optimized unit-cell geometry (3×3 cells in the infinite periodic structure). The frequency characteristics for the optimized FSS is shown in Fig. 4. The designed FSS has the novel element shape and works well at the specified bands because the designed FSS has the dual resonances at Ka band. The previous multi-band FSS [2] (convoluted square loop FSS) has the bandwidths $\Delta f_{r1}/f_{r1} = 0.18$ at 20 GHz band and $\Delta f_{r2}/f_{r2} = 0.22$ at 30 GHz band, where the bandwidth refers to -10dB level of the transmission coef-



(a) Normal incidence



(b) $\theta = 10°$(TE wave incidence) (c) $\theta = 10°$(TM wave incidence)

Figure 4: Frequency characteristics of single-layer FSS illustrated in Fig. 3.

ficient. While the designed FSS has the broader bandwidths $\Delta f_{r1}/f_{r1} = 0.37$ and $\Delta f_{r2}/f_{r2} = 0.23$.

Finally, Figure 5 shows the photograph of the fabricated FSS for the measurement and Fig. 6 compares the measured result with the simulated one for the normal incidence to the FSS. In the measurement, its element spacing is scaled up twice for the designed FSS. The agreement between the calculated and measured results proves the validity of the present method.

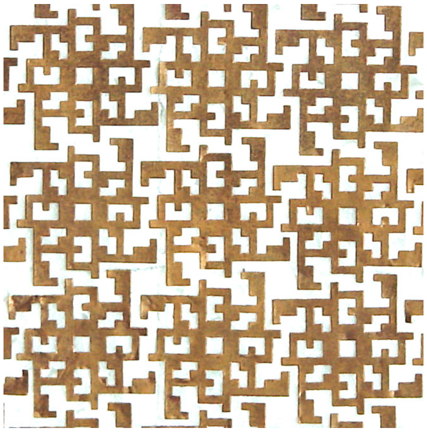


Figure 5: Photograph of fabricated FSS for measurement (periodicity:16mm).

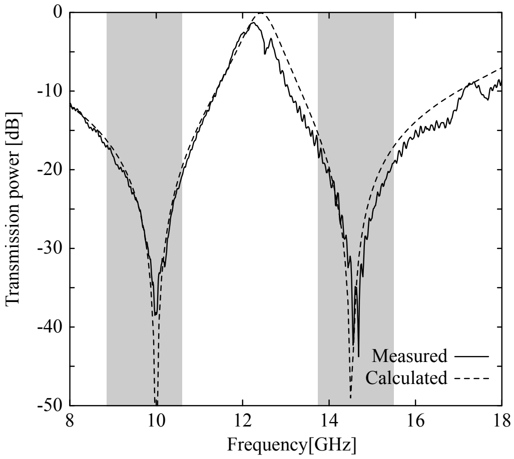


Figure 6: Comparison of the transmission response between the simulated and measured results.

5 Conclusions

We have developed the multiband single-layer FSS by using the optimization-design technique based on the GA into which the geometry refinement method is incorporated. This method can remove the critical points which means that the adjacent conductor plates touch at a point, so that the designed FSS without the point contact of the conductor can be easily fabricated. Furthermore, we have show that the present method can obtain the optimum FSS element shape faster than the conventional GA technique by the natural selection. As a example, we design the FSS for transmitting 1.5/2.5GHz band and reflecting 20/30 GHz band. The designed FSS has the novel element shape, which causes the dual-resonant behavior. The characteristics of the designed FSS are superior to those of the previous FSS in the bandwidth at two reflection bands. The agreement between the calculated and measured transmission responses for the designed FSS proves the validity of the present method.

Acknowledgement

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