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Bandwidth Enhancement and Size Reduction of Period for Dual-band Loop-slot Frequency Selective Surfaces on Plastic Board

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1. Introduction

To reduce cars' weight, plastic materials are being used in bodies and windows of cars. Electromagnetic shielding capability in plastic is much less than metal and glass. Therefore, electromagnetic interferences between devices of car equipments are concerned in the replacement from metal and glass to plastic of car body and windows. To solve this problem, a Frequency Selective Surface (FSS) [1] is one of the solutions. FSS consists of arrangement of identical elements. Only the waves at some specific frequencies penetrate FSS, as shown in Fig. 1. Using this property, FSSs are widely used for antenna's reflectors, radomes, and electromagnetic filters [1], [2]. Actually, the intended waves for car applications are not only one, for example, GPS, mobile phone, ETC and so on are used, simultaneously. Therefore, the bandwidth enhancement or multi-band FSS is required [3]. Furthermore, as only the limited area is often allowed to mount FSS, the size of the period is designed to be small to obtain periodic property.

To yield dual-band property, two different elements are arranged in one period. In addition, close arrangement of inner elements operates in broad bandwidth of higher resonance. Fractal path of loop slot in FSS achieves both double resonance and size reduction of the period. Polarization independent FSSs are developed by using vertically and horizontally symmetrical loop slot. To confirm simulation validity, measurement system is developed. Simulated and measured performances are presented in this paper.

2. Periodic structures of FSS

Four different FSSs are developed to investigate bandwidth and resonant frequency controls of dual band property, and size reduction. Figure 2 shows metal patterns of a period printed on the Polycarbonate board (ε_r=2.9). Figure 2(a) is a single loop slot FSS that performs a transparent property when the loop length equals one wavelength. Therefore, the resonant frequency is expressed by

$$f_0 = \frac{c}{\lambda\sqrt{\varepsilon_r}} = \frac{c}{4(a-w)\sqrt{\varepsilon_r}},$$

where c is light speed, a is one outer side length of the square loop slot and w is a slot width. The resonant frequency is able to be controlled by these parameters.

Based on the FSS (a), the dual-band FSSs (b), (c), (d) are designed. As for the FSSs (b), (c), the outer loop creates a lower resonant frequency and the inner loops are for a higher resonant frequency [3]. Four smaller loops are arranged in the outer loop of the FSS (c) for broad bandwidth. The size of the period is gradually smaller from FSS (a) to (c). It could be caused by increasing mutual coupling between loops. Regarding the FSS (d) with fractal path, overall length of the loop is almost one wavelength as well as other FSSs. Consequently, dual resonance is achieved and the period of the FSS can be smaller than the other FSSs, simultaneously [4].

3. Simulation and Measurement

The periodic structures are effectively analyzed by assuming periodic boundary condition in electromagnetic simulation. Figure 3 shows the analytical model of the periodic structure. Perfect magnetic conductor (PMC) and perfect electric conductor (PEC) are set for boundary condition of a period. On the PMC, tangential component of the magnetic field equals to zero. On the other hand on the PEC, tangential component of the electric field equals to zero. Therefore, the analytical model simulates periodic condition when y-polarized plane wave input to –z direction normal to FSS. HFSS is used in this simulation. Figure 4 shows the developed measurement system. The size of acrylic frame is H2300mm x D810mm x W810mm. The spherical wave radiated from the double-ridge horn antenna is transferred to the plane wave by the dielectric lens. The plane wave is scattered by the fabricated FSS. Reflection and transmission waves are transferred again to the spherical wave and are received by the horn antennas. The fabricated FSS is printed on 500mm-square Polycarbonate board by silk-screen printing, and set at the middle of the measurement setup horizontally. To reduce the effect of circumference, the acrylic frame is surrounded by wave absorber during measurement.

Figure 5 shows the simulated and measured S_{11} of the loop slot FSS (a) for 1.5GHz or 5.8GHz. As for the FSS of 1.5GHz, the measured data are disturbed in contrast to the simulation. It could be caused by the effect for the limited size of the fabricated FSS. However, resonances are observed and measured resonant frequencies agree well with the simulated ones in both designs of 1.5 and 5.8 GHz. Simulation validity is confirmed by the measurement.

Figure 6 shows the simulated comparison of S_{11} for dual-band FSSs (b), (c), (d) at both 1.5GHz and 5.8GHz. Broad bandwidth is observed at the higher resonant frequency (5.8GHz-band) by using FSS (c) because four loops are arranged closely. Figure 7 shows the measured S_{11} of FSSs (c) and (d). Broad bandwidth at the higher frequency in FSS (c) and small period in FSS (d) are confirmed by the measurement. All FSSs perform transparent property at the design frequencies.

4. Conclusion

Dual-band FSSs on plastic board that transmit 1.5GHz and 5.8GHz are developed and are evaluated by HFSS analysis and measurement. As for the close arrangement of inner elements in FSS (c), broad bandwidth is observed at higher resonant frequency than the other FSSs. The period of the FSS can be smaller by using fractal structure. Measurement system is developed and its validity is confirmed by comparison of simulation with measurement. The bandwidth and resonant frequencies of FSS are confirmed by the system.

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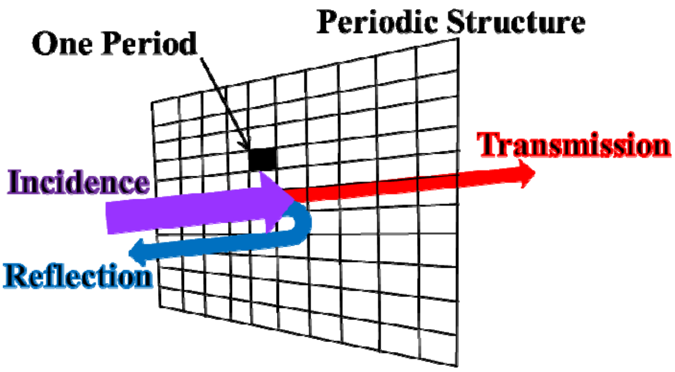

Fig. 1 FSS property

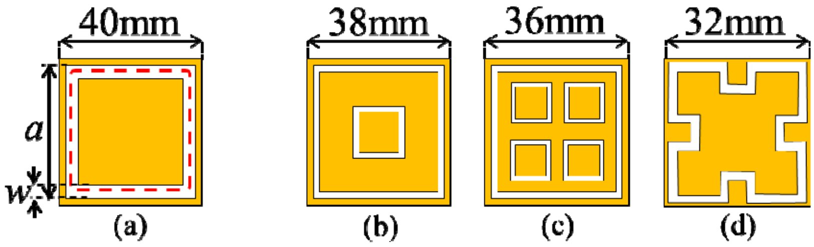

Fig. 2 Structures of period in FSS

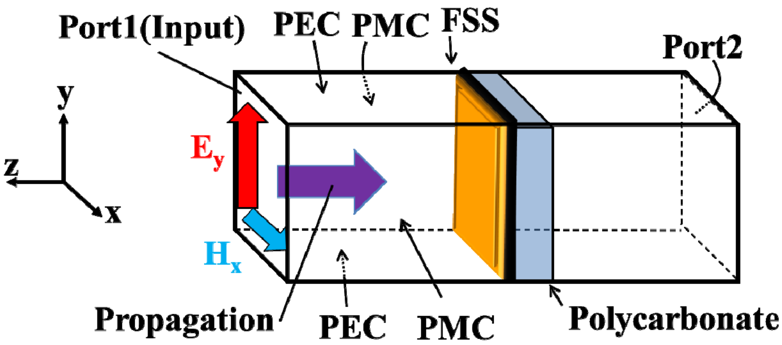

Fig. 3 Analytical model of FSS in the periodic boundary condition

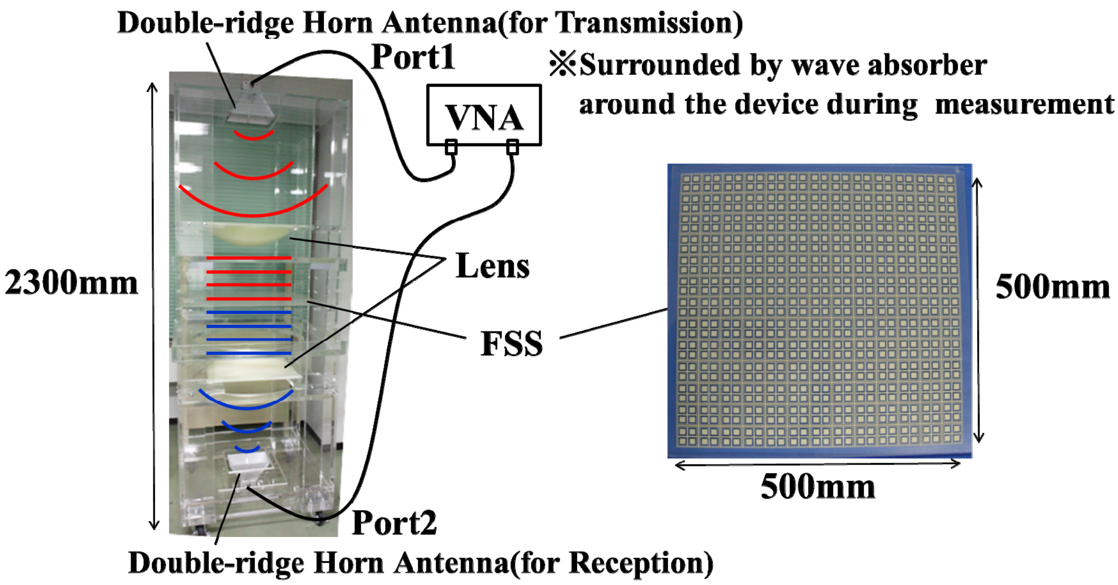

Fig. 4 Measurement system and fabricated FSS

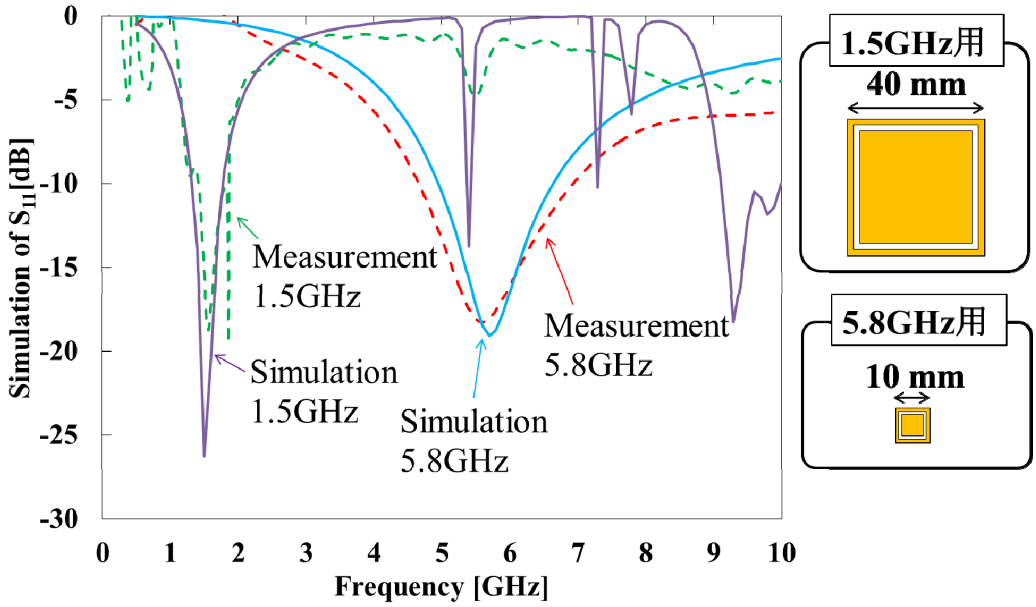

Fig. 5 Simulated and measured S_{11} of loop slot FSS (a)

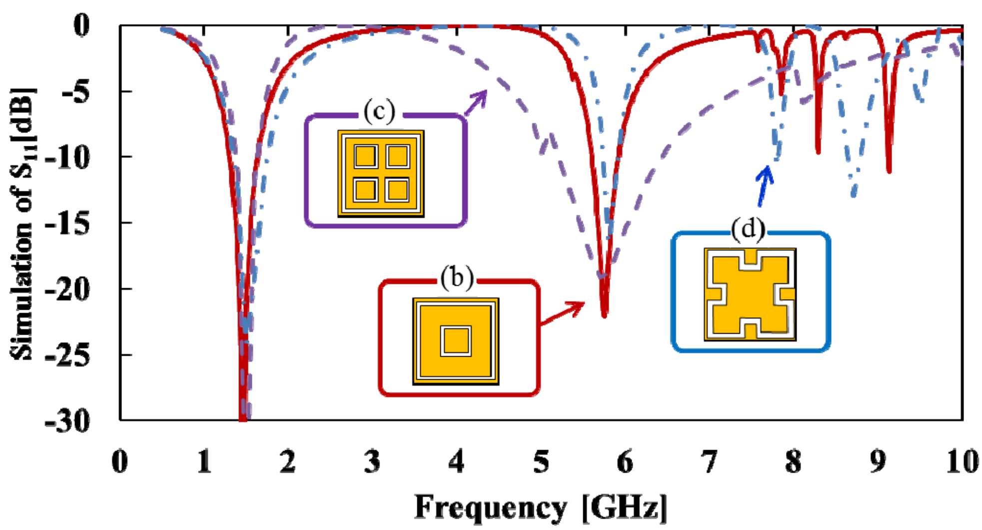

Fig. 6 Simulated comparison of S_{11} for FSSs (b),(c),(d)

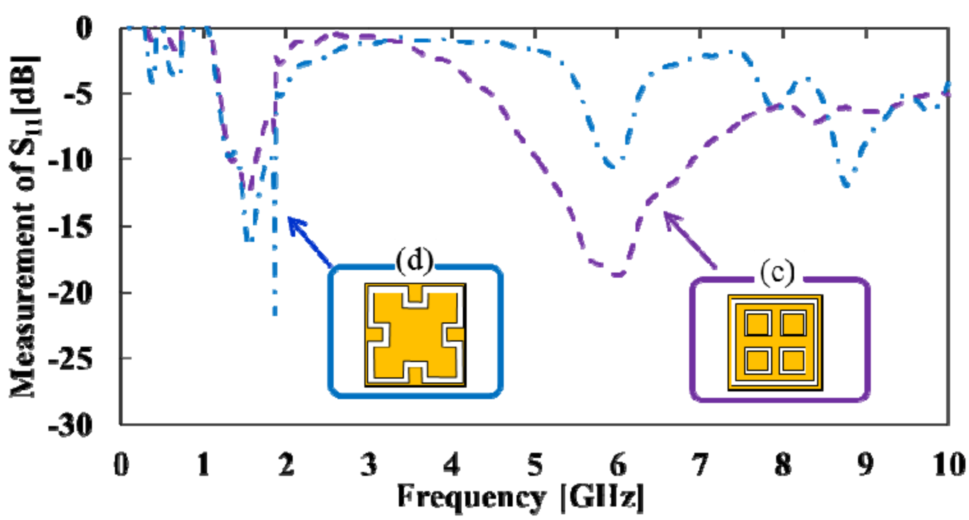

Fig. 7 Measured comparison of S_{11} for FSSs (c),(d)