Design of Frequency Selective Surface Loaded to Multilayer Dielectric Plate for Loss Reduction over Wide Incident Angle

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Abstract - Thickness of windshield, radomes, plastic cases of wireless systems are comparable with a wavelength in the millimeter-wave band. In this case, the total reflection from the boundary surfaces of the dielectric plate increases depending on frequency and input angle of incident wave. To solve the problem increasing reflection, Frequency Selective Surface (FSS) is loaded to the dielectric plate. Transmission efficiency is significantly improved by canceling the reflections. We propose the design technique to find the required characteristics of FSS from the desired characteristic of whole multilayer dielectric plate with FSS. Reflection loss of the windshield was declined in the range of incident angle from 30 to 60 degrees at 76.5GHz.

Index Terms — Frequency Selective Surface, equivalent circuit, multiple reflections, wide incident angle.

1. Introduction

Antenna systems are generally housed in plastic cases or radomes to protect from moisture, and dust. When the dielectric plate is located in front of the antenna, it causes loss due to reflection from the surfaces. The thickness of the dielectric plate is small in low frequency band. The reflections from the both surfaces are approximately 180 degrees out of phase because the reflection coefficient is negative when the wave incidents from the air to the dielectric and positive when incidents from the dielectric to the air. However, in high frequency, although the reflection phases of the both surfaces are still out of phase, a large phase shift by travelling through the electrically thick dielectric plate causes return loss. Therefore, the return loss of the dielectric plate cannot be ignored in the millimeter-wave band.

A windshield of a car is made of a laminated safety glass which consists of two sheets of glass with a plastic layer laminated between them for safety. There are four boundary surfaces with different dielectric constant. The total reflection from the whole structure is formed by combining reflected waves from the four boundary surfaces. Thus, the significantly fluctuated reflection loss depending on the frequency and the incident angle are serious problems for millimeter-wave systems equipped in the car cabin.

The same square loop slot FSSs (SLS-FSS) are printed on the both outer surfaces of the windshield as shown in Fig. 1. The SLS-FSSs are expected to work for a bandpass filter which operate to transmit at the design frequency. We propose the simple and straight-forward design procedure of FSS to obtain required reflection coefficient |R| of FSS from the desired characteristic of the whole multilayer dielectric plate with FSS. Equivalent circuit of the FSS and reflection coefficient |S11| including multiple reflections are simply evaluated in this work.

2. Equivalent Circuit of FSS and reflection coefficient including multiple reflections

FSS is designed to reduce return loss of the windshield. Dielectric constant, loss tangent and thickness of the glass are 6.15, 0.0038 and 2.286mm. Those of the laminate film in the middle are 2.6, 0.0019 are 0.789mm. The characteristics of the windshield with FSS printed on the both outer sides are calculated by equivalent circuit.

(1) Equivalent circuit of FSS

The resonant frequency and the bandwidth of FSS can be controlled by its parameters shown in Fig. 1 [1]. When the FSS with zero thickness is inserted on the boundary between the different characteristic impedances Z1 and Z2, the FSS can be expressed by a shunt susceptance B as shown in Fig. 2 [2]. Complex S-matrix of the FSS between Z1 and Z2 can be expressed by a function of only a reflection amplitude |R| of FSS by eliminating susceptance B and deriving the relations between reflection and transmission amplitude and phase [3]. When B is inductive, reflection phase is a positive value. When B is capacitive, reflection phase is a negative value.

![Fig. 1. FSS loaded to multilayer dielectric plate.](image1)

![Fig. 2. Equivalent circuit.](image2)
(2) Reflection coefficient including multiple reflection

Total reflection coefficient $S_{11}$ of multilayer dielectric plates with FSSs can be calculated by synthesizing reflection coefficients of dielectric surfaces and FSSs. SLS-FSSs are printed on the both outer sides of the windshield as shown in Fig. 1. In the three-layer windshield, four boundary surfaces exist between the air and the glass, and between the glass and the film. Reflection coefficient $S_{11}$ consists of multiple reflections and is calculated by using an infinite geometric series of each layer shown in Fig. 3. Then, reflection coefficients of multilayer dielectric plates can be calculated in order from the lower layer. The reflection coefficient $\gamma_1$ of the lower glass layer terminated by the air boundary can be calculated including multiple reflections shown in Fig. 3(a). The reflection coefficient $\gamma_2$ of the film terminated by $\gamma_1$ can be calculated as shown in Fig. 3(b). Reflection coefficient $\gamma_3$ of whole structure can be calculated by termination of $\gamma_2$ as shown in Fig. 3(c).

The reflection coefficient $S_{11}$ of the whole structure is computed as function of the magnitude $|R|$ of the reflection coefficient of the FSS and frequency, thus, characterized as contour maps shown in Fig. 4. When the susceptance $B$ is negative value, the reflection phase is positive. When susceptance $B$ is positive value, reflection phase is negative. Thus, two graphs are required to cover all conditions. Reflection amplitude $|S_{11}|$ of the whole structure can be obtained by superimposing the frequency dependency of the reflection coefficient $|R|$ of the FSS on the contour map.

Fig. 3. Multiple reflection in each layer.

(a) Calculation of $\gamma_1$  (b) Calculation of $\gamma_2$  (c) Calculation of $\gamma_3$

Fig. 4. Contour map when FSS is loaded.

(a) $B<0$  (b) $B>0$

3. Design by using contour maps

(1) Normal Incidence

The SLS-FSS was designed by the contour map so that the reflection $|S_{11}|$ of the whole structure is reduced at 76.5GHz. Electromagnetic simulation of the isolated FSS between different dielectric materials was carried out under the infinite periodic condition [4]. Reflection level $|S_{11}|$ of the whole structure was improved below $-10$dB at 76.5GHz by loading SLS-FSSs.

Fig. 5. Reflection $|S_{11}|$ of the whole structure in normal incidence.

(2) Oblique Incidence

The SLS-FSS was designed to reduce $|S_{11}|$ of whole structure in the incident angle from 30 to 60 degrees by using contour maps. The horizontal axis was replaced by the incident angle. Loading the designed FSS on the both sides of the windshield, the reflection level was lower than $-10$ dB between 30 and 60 degrees as shown in Fig. 6.

Fig. 6. Reflection $|S_{11}|$ of the whole structure in oblique incidence.

4. Conclusion

By calculating reflection coefficients including multiple reflections, FSS design was simplified by using contour maps. Using these maps, reflection of the windshield is reduced to be less than $-10$dB at the incident angle from 30 to 60 degrees at 76.5GHz.

References


