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Effects of fabricated error on transmission performance of double layer frequency selective surface configuration

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Abstract: Based on the experimental results, in which the fabricated error of the double layer frequency selective surface (FSS) leads to the transmission loss and the resonant frequency leaves away the design resonant frequency, the inter-layer separation distance (ISD) and the unit cell aligning error (UAE) were used as main variables to study the transmission performance attenuation of the double layer FSS configuration. The numerical analysis model for ISD and UAE was established and also was used to simulate the ring unit cell FSS transmission performance by the finite element and periodic moment methods. The double layer ring aperture FSS configuration designed was used as the numerical model. As a result of the numerical analysis, it is shown that both ISD and UAE produce insertion transmission loss (ITL) and insertion phase distortion (IPD) directly. Furthermore, ISD results in more loss of the amplitude of the transmitted signal for the FSS than UAE. It is significant for the designer of the multiplayer FSS to assign the fabricated error of the FSS dielectric layers. The UAE introduces the insertion phase variation badly.

Key words: double layer frequency selective surface, inter-layer separation distance, insertion transmission loss, insertion phase delay

1　Introduction

The double layer frequency selective surface (FSS) has flat tops and sharp skirts and has been widely applied to the antenna reflector for satellite communication and various radome. Up to the present, most of the single-layer and multi-layer FSSs are designed by using infinite plane periodic resonant configuration model, which satisfies the infinite periodic boundary condition of Floquet theorem. Therefore many numerical analysis methods based on Floquet periodic model are employed to simulate the multi-layer FSS electromagnetic transmission performance.

However, the theoretical infinite periodic plane boundary stated above is not in existence in practical applications. Many researchers have given more attention to the geometric size error leading to the transmission attenuation of electromagnetic wave in the multi-layer FSS configuration. Based on the experimental measurement results, the literature[1-3] proposed the restricted boundary condition for using infinite plane Floquet model to design the finite plane period structure. In addition, the inter-layer separation distance (ISD) resulting in the transmission loss of the FSS was discussed in literature[4-6]. According to the multi-layer FSS transmission experimental experience, we found that unit cell aligning error (UAE) of the double layer FSS due

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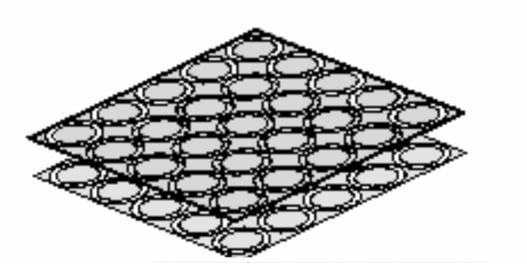
to each layer FSS fabrication tolerance is also an influent variable for double layer FSS transmission performance. To assign reasonably and predict accurately the fabrication tolerance for the double layer FSS structure design, both ISD and UAE in the design and manufacture of the FSS structure should be studied completely. Note that, to the best of our knowledge, there are no reports about UAE effects on the transmission properties of double layer FSS. In this paper, our goal is as follows: firstly we develop the numerical analysis model for ISD and UAE of the ring unit cell FSS built up by the practical experience of the multi-layer FSS manufacture. Secondly these models are used to simulate and analyze the transmission power and phase properties for the ring unit cell aperture FSS. Finally, we summarize the evaluation rule of the multi-layer FSS design tolerance.

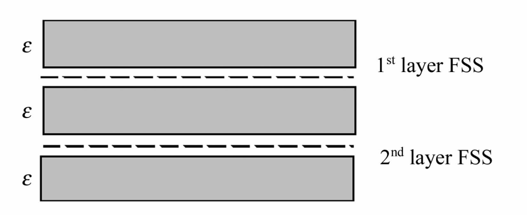
2 Tolerance model for double layer FSS plane periodic structure

2.1 Basic constraint condition

The double layer FSS periodic structure is composed of two single-layer FSS and reasonable dielectric layers. The manufacture tolerance of each single-layer FSS, for example, the inter-element distance error and the shape distortion of unit cell, could produce the inserting loss of frequency selective surface transmission and the phase distortion at the resonant frequency. Fortunately, the duplicated precision of the FSS unit cell figure on copper film with advanced optical eroding technique has reached the order of 10 μm or less. To put much emphasis on the consideration of the inter-layer separation distance and unit cell aligning error, without loss of generality, we will take no account of the transmission distortion due to the single-layer FSS manufacture error and also presume that there would not be ISD and UAE without manufacture tolerance. Furthermore, the first layer FSS is defined as standard basic surface in the double layer FSS periodic configuration. The other layer FSS should be aligned with the first layer FSS. The double layer FSS periodic structure is illustrated in Fig. 1.



(a) Double layer plane FSS without dielectric support



(b) Double layer FSS with dielectric support

Fig. 1 Double layer plane FSS periodic structure

2.2 Model of ISD

The each layer frequency selective surface needs to be supported by the dielectric material with designed thickness. The supported dielectric thickness exactly equals to the design value for the FSS periodic structure so that the expectant transmission performance will be obtained. Therefore the inter-layer separation distance (ISD) variable would change the frequency selective properties for the double layer FSS con-

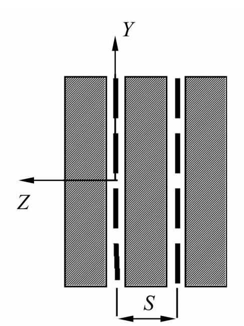
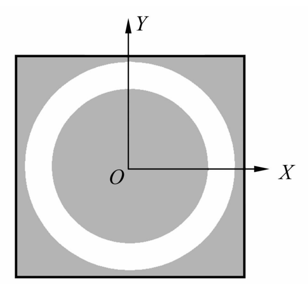


Fig. 2 Analysis model of FSS separation distance error

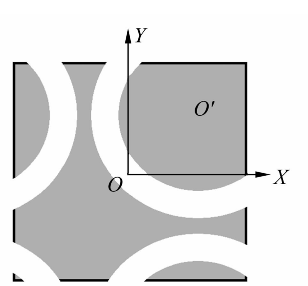
figuration directly. The numerical analysis model for ISD of the ring FSS periodic structure is illustrated in Fig. 2. The dielectric thickness is denoted by $S = S_0 \pm \Delta S$, where S_0, ΔS denote the design value and error for the dielectric thickness.

2.3 UAE model

The unit cell figure of the each layer FSS in the double layer FSS periodic structure is geometrically symmetrical. Thus the geometrical center of the first layer unit cell should be aligned with that of the second layer in theory. However whether in design or in practical fabrication there is the unit cell aligning tolerance or error. Based on the experimental experience, the UAE numerical model of the double ring FSS periodic structure is shown in Fig. 2. The basic unit cell of the first layer FSS and the distortion unit cell of the second layer are illustrated, respectively in Fig. 3. (a) and (b), where the geometrical center of the first layer unit cell is denoted by O and that of the second layer unit cell by O'. The excursion error of the second layer FSS unit cell geometrical center can be defined as $E_0 = (X^2 + Y^2)^{1/2}$, where the X and Y denote the error value in X and Y coordinated axis, respectively.



(a) First layer FSS cell



(b) Various aligning error geometry distribution on second layer

Fig. 3 FSS unit cells aligning model

3 Double layer transmisson performance with fabrication error

3.1 Design structure model

The part of the single layer ring unit cell FSS periodic configuration is illustrated in Fig. 4, where the ring aperture width $W = 0.762$ mm, the unit cell distribution period $D_x = D_y = 10.668$ mm, the ring inner and outer radii are $R_i = 4.318$ mm and $R_o = 5.08$ mm. The double layer FSS periodic configuration is illustrated in Fig. 2, where the design dielectric layer thickness $S_0 = 5.38$ mm, relative dielectric constant $\varepsilon = 1.2$, loss tangent $\tan\delta = 0.005$.

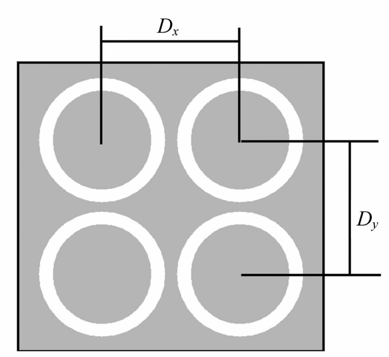


Fig. 4 Ring unit cell construct distribution design

3.2 Insertion loss for ISD variation

Based on the numerical model in 2.2, the transmission performance for the ring unit cell FSS with respect to the relative variation of ISD was analyzed by the numerical method for the infinite periodic plane FSS configuration. The numerical results in Tab. 1 show that the resonant frequency will move 10% relative to the resonant frequency and the bandwidth at -0.5 dB of the transmission power will be broader or narrower of 15% relative to that of the design when $\Delta S/S_0$ varying 20%. The insertion loss of the transmission power at $f_0=10.5$, which is the resonant frequency without ISD change, increases nearly four times while $\Delta S/S_0$ increases by 20%. Consequently the ISD relative variation should be restricted below 10% of the expected dielectric thick.

Tab. 1 Transmission performance with ISD variation

$\Delta S/S_0$ (%)	−0.5dB Bandwidth (GHz)	−3dB Bandwidth (GHz)	f_0' (GHz)	$f_0=10.5$ Inserting loss (dB)
0	2.1	4.1	10.5	−0.1
10	2.0	4.0	9.8	−0.2
20	1.8	3.9	9.4	−0.43

3.3 Insertion loss and phase distortion for UAE

The transmission performance for the UAE on X axis is similar to that on Y axis because of the geometric symmetry of the ring unit cell. Accordingly we will analyze the transmission property for UAE on Y axis, where $X=0, E_0=Y$, according to 2.3. The numerical results for the transmission power in Tab. 2 show that the insertion loss of the transmission power at the resonant frequency while $E_0/D_x=10\%$ increases almost two times as much as that at $E_0=0$ and are similar nearly while E_0/D_x is the other cases. The curve of phase distortion via frequency is illustrated in Fig. 5. Compared with the phase performance without UAE there is the phase distortion of approximated 2° while $E_0/D_x=50\%$ at the resonant frequency $f_0=10.5$ GHz. In other words, the effects for UAE on the amplitude of the transmitted signal is much less than that of the insertion phase variation introduced by UAE of the double layer FSS. However the boresight error resulted from the insertion phase variation is a vital feature for the radome rather than the amplitude of the transmitted signal in an applied sense. Therefore it is very important for the designers to control the UAE of the double layer FSS configuration so as to obtain less boresight error introduced by the insertion phase variation.

Tab. 2 Transmission performance change with unit cell aligning error

E_0/D_x or E_0/D_y (%)	−0.5dB Bandwidth (GHz)	−3dB Bandwidth (GHz)	$f_0=10.5$ Inserting loss (dB)
0	2.1	4.1	−0.1
10	2.4	4	−0.22
25	2	3.8	−0.13
50	2.4	4.4	−0.14

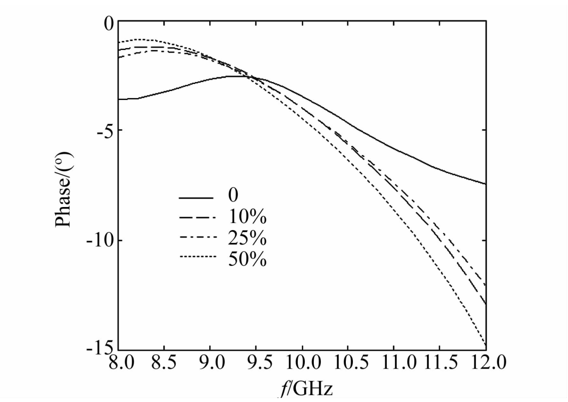


Fig. 5 Curve of phase variation

4 Conclusion

Based on the measurement experimental experience for the double layer ring unit cell FSS configuration, we built up the numerical model of both ISD and UAE by means of the finite element and periodic moment method. It is shown that the significant effects of both ISD and UAE on the transmission performance for the configuration have been verified obviously by the numerical analysis. The ISD of the double layer FSS introduces the insertion loss of the amplitude of the transmitted signal at the resonant frequency while $\Delta S/S_0 = 20\%$ four times as much as the expected design value. Also the UAE produces the insertion phase variation of 2° at the resonant frequency while $E_0/D_x = 50\%$. Therefore designers who design the double layer FSS configuration, especially those who expect to load FSS on the radome, should pay more attention to the effects of UAE on the insertion phase variation of the transmitted signal.

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