A Novel C-band Frequency Selective Surface Based on Complementary Structures

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***Abstract*-A new design method for band-pass frequency selective surfaces (FSSs) using complementary loading structure is introduced, which is applied to achieve C pass-band performance in 60 degree angle of incidence. Each FSS element consists of three square patches and two square apertures as complementary patterns etched in the middle tier, which is backed by dielectric slabs. The effect to the transmission characteristics of the square apertures screens as the load of the square patches screens is investigated. This novel design method provides a new design thought for tailoring the response of the FSS and has proved efficacy in designing high performance FSS. An equivalent circuit model is given for predicting the characteristics of the designed FSS, and a good match between the simulated and required transmission coefficients is obtained. Furthermore, the cases of different angles of incidence waves and cascading FSSs are also measured and examined.**

I. Introduction

The technology of frequency selective surfaces (FSSs) has been developed rapidly, which can be widely applied to space filters, reflectors, radar absorbers and frequency windows of radomes [1]. FSSs have been developed since many years ago (50's). Classical books on this topic were written by B. A. Munk [2]. FSSs are usually constructed of periodic metallic patches or aperture elements within one or more metallic screens backed by dielectric slabs. The first type behaves like a band-stop filter while the second type like a band-pass filter. In recent years this topic has received new breaths coming from the new concepts of complementary structure. It stems from Babinet's principle, whereby a hybrid of two closely coupled FSS, a layer of conducting elements and a layer of aperture elements are etched either side of a dielectric substrate. Babinet's principle, relating to optics, states: 'when the field behind a screen with an opening is added to the field of a complementary structure, the sum is equal to the field when there is no screen' [3]. In 1994 H. Wakabayashi proved the reflection properties of the inverse and normal type FSS are complementary to each other [4]. Soon after, researches on the electromagnetic model for complementary FSSs of linear dipoles and single rings were developed. The dipole complementary structure was used to design band-pass filter by D. S. Lockyer [3]. Then, Shunli Li and Liguo Liu investigated the effect to the transmission characteristics of the Jerusalem complementary FSS [5].

In this paper, a multi-layer FSS structure based on complementary structure is designed which is aimed at achieving low-loss pass-band in 4-8GHz. These metal screens are tightly coupled, producing stable resonant frequency and wide band.

II. FSS Design

A. *Basic Structure*

According to design requirements for C-band transmission characteristics, the basic thought is using multilayer FSSs to produce multiple resonance points to support a wide band and complementary structure to adjust transmission performance.

Under the condition of large incident angle, resonance points of different polarization modes will change a lot; in addition, ripple amplitude in the pass-band will increase obviously so that transmission characteristics may be damaged. Aiming at these problems, some ideas are concluded as follows:

(1) Too much layers for FSSs coupling design are not recommended, and the number of resonance points used to support pass-band should be considered.

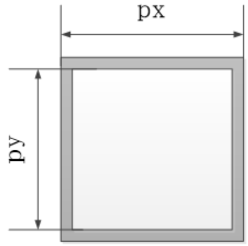
With less resonance points supporting wide frequency band, low Q-value resonant units are needed to balance the low-frequency cut-off characteristic and pass-band flatness. Using more resonant points, the low-frequency cut-off characteristic seems better, but ripple amplitude will increase obviously under the condition of large angle. A third-order design with five-layer FSSs are discussed here.

(2) Medium layers should be used reasonably to improve the impedance matching characteristics of structure and air under the condition of large incident angle.

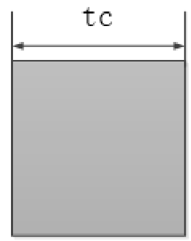
The use of the dielectric layers can help improve the TE and TM polarization stability, and reduce the ripple in the pass-band. The typical multilayer dielectric layers matching design for structure with wide band in large incident angle is arrange dielectric constant decrease progressively from inside to outside.

(3) Complementary units are chosen, because their opposite trend of resonant frequency on transmission characteristics.

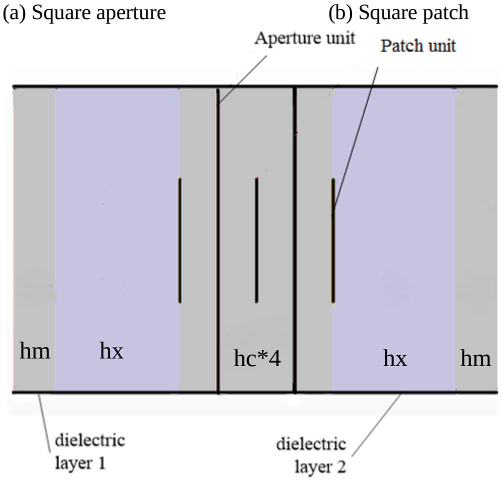
The configuration of the novel structure is shown in Figure 1. It's symmetrical. There are two types of elements in this design, namely the square aperture and square patch element which are complementary in geometry [3]. We choose the square element due to its simplicity and better bandwidth. The difference is the dimension of the patch element is smaller than the aperture one. The structure constitutes coupled inductive and capacitive surfaces, resulting in a band-pass response. It is composed of three dielectric substrates and five metal layers including two square apertures and three square patches etched in the middle substrate.



(a) Square aperture



(b) Square patch

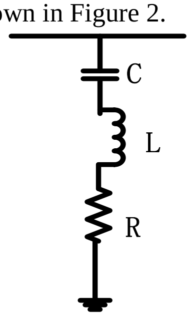


(c) Array of designed structure

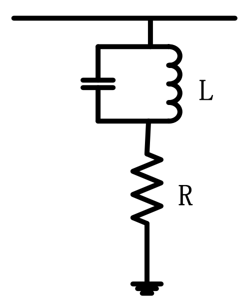
Figure 1. The proposed FSS and its periodic cells

B. Analysis of Equivalent Circuit Model

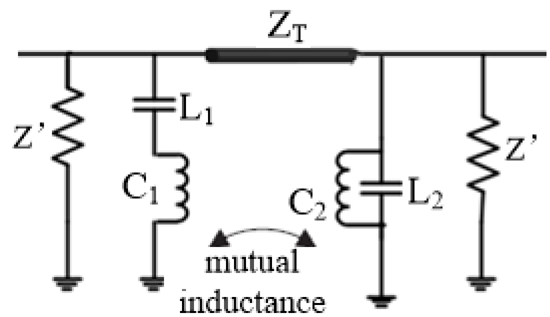
Each aperture screen behaves like a series LC circuit and the patch one behaves like a parallel LC circuit [2]. With the coupling effect between the metallic layers represented by a relatively small mutual inductance, a unit cell of the proposed FSS can be modeled by a simplified equivalent circuit model as shown in Figure 2.



(a) Simple model of square aperture



(b) Simple model of square patch



(c) Simplified equivalent circuit

Figure 2. Model of designed structure

The substrates between metal screens can be considered as a short transmission line [6].The equivalent circuit model of the FSS can be simplified into a lumped-element model. The value of mutual inductance can be ignored because it’s relatively small, and its impedance is derived as

$$Z = \frac{jwL_2 + 1/(jwC_2)}{-w^2 L_2 C_1 - 1/(w^2 L_1 C_2) + L_2/L_1 + C_1/C_2 + 1} \qquad (1)$$

III. NUMERICAL SIMULATIONS

In order to demonstrate the properties of this structure, we have numerically simulated the incidence plane waves at 60 °.

Study shows that changes of some parameters have great influence on model's performance. The laws of key parameters' influence are summarized in table 1(take the value gets bigger as an example).

TABLE I
LAWS OF KEY PARAMETERS’ INFLUENCE

parameters	TE polarization	TM polarization
Thickness of outermost layer(hm)	Pass-band become narrower	Pass-band become narrower
Thickness of second layer(hx)	Effective bandwidth drops	Little effect
Distance between two metal screens(hc)	pass-band moves to lower frequency	Pass-band become wider
Length of square patch(tc)	pass-band moves to lower frequency	pass-band moves to lower frequency
Length of square aperture(py)	Pass-band become wider	pass-band moves to lower frequency
Period of unit(px)	pass-band moves to higher frequency	Pass-band become narrower

By optimizing, a set of curves which meet the requirements of application are completed. The transmission character of TE and TM polarization is shown in Figure 3.

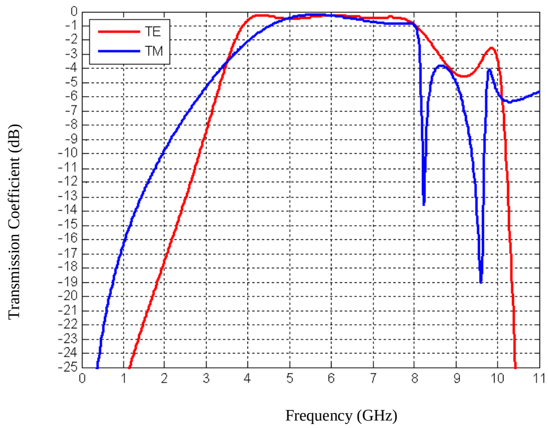
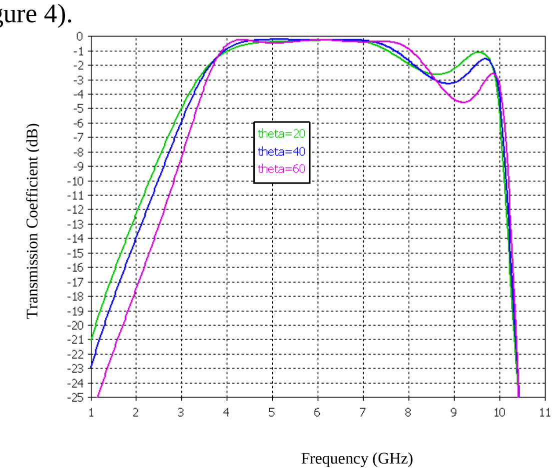
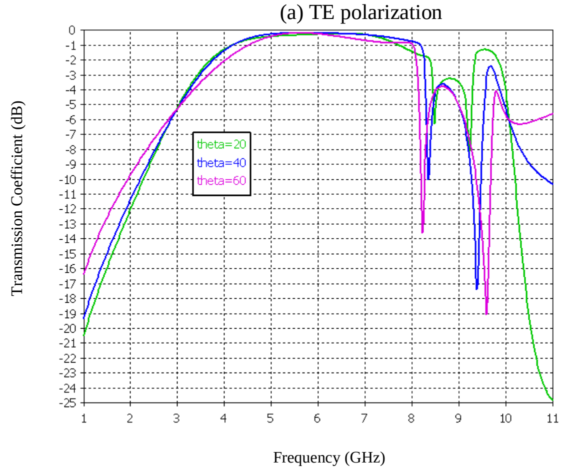


Figure 3.Curves of transmission coefficients at 60°

This design can realize a stable pass-band and gain desired transmission coefficients of TE polarization and TM polarization which are limited between 0 and -2 dB in C-band. At the same time, angle stability is analyzed (as shown in figure 4).



(a) TE polarization



(b) TM polarization

Fig.4. angle stability

According to these figures, the transmission curves for TE and TM waves remain quite well in C-band.

The Q-value of designed FSS combination unit is low so that a wide pass-band can be realized. The bandwidth of TE polarization is close to 4.6GHz, and that of TM is close to 4.1GHz.The transmission coefficients in pass-band are all lower than -2dB. Its polarization stability in C band is quite well in 60 degree angle of incidence, and the resonant frequency is stable when angles change from 20° to 60°。

IV. CONCLUSION

In this paper, a FSS working at C-band is designed based on a new design method for band-pass characteristic using complementary loading structure. The designed FSS meets the requirements even under the condition of large incidence angle, and realizes stable resonant frequency .This novel design provides a new way to realize band-pass performance and has practical value for the development of FSS in the future.

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