Closely packed dense frequency selective surface

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In order to realize wideband filtering properties of frequency selective surface (FSS), FSS of closely packed elements is presented. The Y loop elements are chosen as the graphics elements. Based on the spectral domain method, the frequency response is analyzed for different incident angles and polarizations. The result of the numerical analysis shows that the dense FSS has wide passband with better independence of angle and polarization.

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Frequency selective surface (FSS), which has widespread applications as filters for microwave and optical signals, has been the subject of extensive studies in recent years[1−5]. FSS is a structure consisting of two-dimensional (2D) periodic elements, whose properties depend upon the element's shape and dimensions, the thickness and permittivity of the loading dielectric layers, as well as the layer number of FSS screen[6−9]. FSS is known to have several limitations. One of them is that the band of typical FSS is generally narrow. FSS with wideband transmission property has wide applications in the stealth field. Frequency selective properties of buildings also require wideband FSS for their wideband electromagnetic (EM) screening capabilities as walls for screened enclosures. There is therefore a need for FSS design suitable for wideband applications. Although the double layer FSS is often selected to get the wideband transmission property[10], its fabrication is more difficult than single layer FSS. Another way to solve the problem is to use the single layer FSS with $\lambda/4$ thick dielectric symmetrically loading on both sides[11], but dielectric often causes great losses of transmission ratio.

In this letter we present a millimeter-wave bandpass filter by the means of the closely packed dense FSS. In the given structure wideband property can be achieved. Based on spectral domain approach[2], the frequency response of this dense FSS structure is analyzed, including the angle and polarization effect. The dense single layer FSS design can give wide passband with a stable transmission response for wide incident angles and different polarizations.

Dense FSS design is shown in Fig. 1. Y loop elements are chosen for the FSS. The elements are arranged on a regular triangle lattice.

Parameters of the element array are illustrated in Fig. 2. They are Y loop length $L = 1.46$ mm, Y loop width $w = 0.5$ mm, slot width $d = 0.1$ mm, inner Y element width $w' = 0.3$ mm, Y loop element spacing $D_x = 3.464$ mm in the x direction, $D_y = 2$ mm in the y direction.

The frequency responses of dense FSS structure are analyzed based on the spectral domain method. Several assumptions have been made: 1) the FSS is infinite in extent, so diffraction from the edges of the surface in a practical situation is ignored, 2) the incident radiation is a monochromatic plane wave, 3) the conducting screen is infinitesimally thin. The solution is obtained by modifying the integral equation corresponding to a single slot element to the contributions from an array of slots. The magnetic-field integral equation of spatial domain expression for the slot element array is obtained as

$$-\begin{bmatrix} H_x^{\rm inc}(x,y) \\ H_y^{\rm inc}(x,y) \end{bmatrix} = \frac{4\pi}{j\omega\mu_0 ab} \times \sum_{m=-\infty}^{\infty}\sum_{n=-\infty}^{\infty} \begin{bmatrix} k_0^2-\alpha_{mn}^2 & -\alpha_{mn}\beta_{mn} \\ -\alpha_{mn}\beta_{mn} & k_0^2-\beta_{mn}^2 \end{bmatrix} \times\tilde{\tilde{G}}(\alpha_{mn},\beta_{mn})\cdot\begin{bmatrix} \tilde{M}_x(\alpha_{mn},\beta_{mn}) \\ \tilde{M}_y(\alpha_{mn},\beta_{mn}) \end{bmatrix} {\rm e}^{j\alpha_{mn}x}{\rm e}^{j\beta_{mn}y}, \quad (1)$$

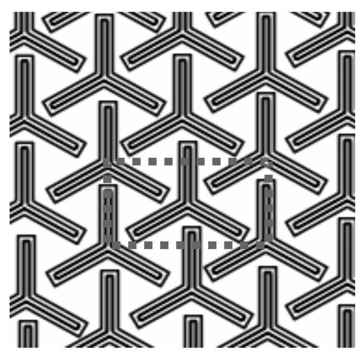

Fig. 1. Dense Y loop element FSS.

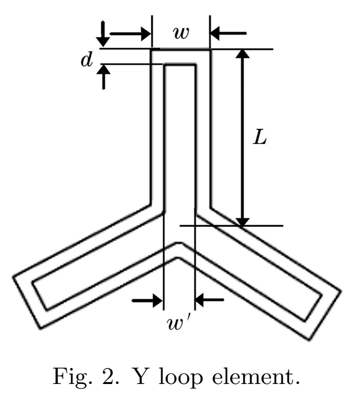

Fig. 2. Y loop element.

where $\alpha_{mn} = \frac{2m\pi}{a} + k_x^{\text{inc}}$, $\beta_{mn} = \frac{2n\pi}{b\sin\Omega} - \frac{2m\pi}{a}\cot\Omega + k_y^{\text{inc}}$, k_0 is the wave number, $k_0 = \omega\sqrt{\mu_0\varepsilon_0}$, the superscript inc corresponds to the incident field. M is the equivalent magnetic surface current at the aperture. The elements in rectangular frame are selected as the unit cell, as shown in Fig. 1, which are discretized by employing rooftop subdomain basis function. a and b are the periodicities of the unit cell in the x and y directions, respectively, and $a = 2D_x$, $b = D_y$, Ω is the oblique angle, here, $\Omega = 90°$.

For $k_0^2 > \alpha^2 + \beta^2$, $\tilde{\tilde{G}} = \frac{-j}{2\sqrt{k_0^2-\alpha^2-\beta^2}}\bar{\bar{I}}$, otherwise $\tilde{\tilde{G}} = \frac{1}{2\sqrt{\alpha^2+\beta^2-k_0^2}}\bar{\bar{I}}$.

Equation (1) can be solved with the method of moments, which yields the unknown magnetic surface current distribution in the aperture of an inductive FSS. Then we can determine the transmission coefficients. The plots of the transmission coefficient versus frequency of dense FSS structure are obtained for different incident angles and polarizations, as shown in Figs. 3 and 4, respectively.

The primary distinguishing feature of the presented dense FSS structure is the wide passband. Calculated transmission curve gives 14-GHz bandwidth at frequencies where the transmission loss is −2 dB for normal incidence of TE polarization. If the incident wave is the normal incidence, the frequency response for the horizontal polarization can be found to be exactly identical to that of vertically polarized case for the traditional FSS structure with symmetric elements. But for the oblique incidence, the desired performance is adversely affected.

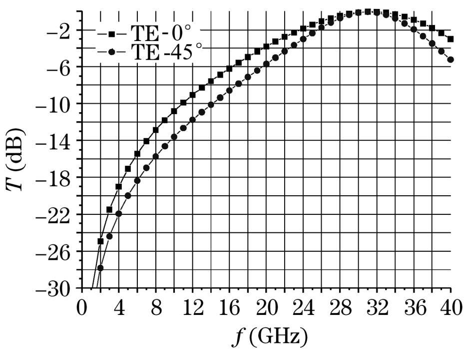

Fig. 3. Frequency responses of dense FSS for different incident angles.

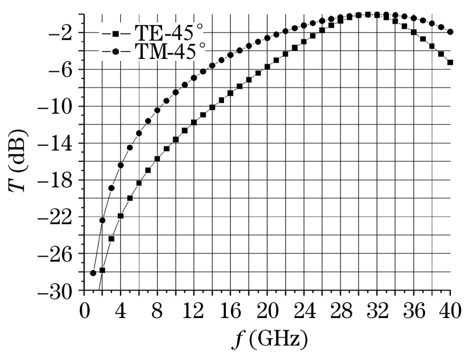

Fig. 4. Frequency responses of dense FSS for different polarizations at 45° incidence.

The proposed compact design allows the slot elements to be packed more densely, which enhances mutual coupling of elements, resulting in better performance for large angles of incidence and different polarizations. The resonant frequency of the FSS is 31 GHz which remains independent of incident angles and polarizations. The −2-dB transmission band changes with the incident angles and polarizations which decreases to 10 GHz for 45° TE incidence and expands to 18 GHz for the TM polarization.

The pass bandwidth is determined by the spacing between apertures on the screen. As the aperture spacing decreases to half, the FSS bandwidth doubles. The spacing can be chosen very easily according to our requirements.

Closely packed dense FSS is presented for wideband application and analyzed based on the spectral domain method. The unique feature of the dense FSS is the wide passband, and the resonant frequency is independent of the incident angles and polarizations. In addition, the fabrication of the single FSS with closely packed dense elements is relatively easier. The dense FSS design with wide passband is suitable for spacecraft systems and other applications.

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