FREQUENCY SELECTIVE SURFACES WITH APPLICATIONS IN MICROWAVES AND OPTICS

R. Mittra, C.H. Tsao, and W.L. Ko
Department of Electrical Engineering
University of Illinois
Urbana, Illinois 61801

Summary

There are numerous applications at microwave and optical frequencies for frequency selective surfaces, e.g., perforated screens which can either be free-standing or printed on dielectric substrates (see Figure 1). At optical frequencies, these surfaces can be used as mirrors [1-2] for solar power applications, where it is desired to selectively filter out the UV or IR radiation, while retaining the visible range of the spectrum. These surfaces also find important applications at far-infrared [3-4] where they can be used for enhancing the spectral purity of a laser. Other applications at far-infrared include filtering and beam-splitting, as described in a review article by Uhlrich [5]. At microwave frequencies, frequency selective surfaces are employed in radomes [6] and satellite antennas [7-8].

In the process of designing systems which have certain specified frequency characteristics, it becomes necessary to develop a capability for analyzing these surfaces accurately and efficiently for a wide range of parameters and arbitrary angles of incidence.

The purpose of this work is to present a new technique for solving the problem of scattering from periodic screens. The new technique is not only accurate, but extremely efficient as well. In addition, it has several unique features not found in conventional approaches, e.g., the moment method: (i) it does not require the time-consuming steps of generating a matrix equation and its inversion; (ii) it is capable of handling 2^{11} or more unknowns (conventional approaches are limited to 2^8 unknowns unless an exorbitant price is paid for computer cost and storage) (iii) the CPU time on the computer is only on the order of a few seconds even with 2^{11} unknowns; (iv) an accurate solution can be generated for large cell sizes; (v) the solution procedure has a built-in boundary condition check. Hence, the reliability of the solution is assured.

The solution is constructed using the spectral or transform domain approach which was introduced recently [9] for solving a class of open region problems, but is found to be equally well-suited for solving periodic grating problems of the type being considered here. A brief summary of the method is now given.

The first step is to formulate an integral equation for the two components of the unknown currents on the conducting patch (or the unknown fields in the aperture), employing the usual field-matching procedure applied to the various subregions. For the two-dimensional grating problem, the equation takes the form

$$\int_0^b f(x')\, K(x,x')\, dx' = g(x) \ , \ 0 < x < b \qquad (1)$$

$$K(x,x') = \sum r_n \phi_n(x)\phi_n(x')$$

where $f(x')$ is proportional to the aperture electric field

$0 < x < b$ is the extent of the aperture with the zeroth cell

$g(x)$ is known from the incident field

$\phi_n(x) = \exp(2jn\pi\, x/a)$

γ_n = Floquet wave number in the z-direction

a = cell dimension

Because of the particular nature of the kernel, the above equation would be exactly invertible if the upper ranges of x and x' were equal to the cell dimension a. We can achieve this by introducing an additional unknown $h(x)$. We rewrite (1) as

$$\int_0^a \theta f(x')\, K(x,x')\, dx' = \theta g(x) + \hat{\theta} h(x) \ , \ 0 < x < a \qquad (2)$$

where

$$\theta = \text{truncation operator} = \begin{cases} 1 & , \ 0 < x < b \\ 0 & , \ b < x < a \end{cases}$$

and $\hat{\theta}$ is the complementary operator. Note that the new function h is as yet unknown.

This paper describes the use of the FFT algorithm for rapidly solving (2) using a combination of variation-iteration procedures. As mentioned earlier, the method has a built-in accuracy check, which is based on the satisfaction of the boundary condition and hence is extremely reliable.

To illustrate the application of the method, we have studied a number of representative problems with one-dimensional and two-dimensional gratings.

As a first test, we have applied the spectral domain method to the problem of an iris discontinuity in a parallel-plate waveguide (see Figure 2). It is well-known that, for certain angles of incidence, the problem of a one-dimensional grating in free space becomes equivalent to that of the iris problem in a waveguide. The E-field distribution in the aperture of the plane of the discontinuity is plotted in Figure 2 for two different frequencies. Note that the boundary condition on the conducting iris is satisfied extremely well even though the discontinuity under consideration is by no means a "small geometrical perturbation" in the guide.

Figure 3 shows a one-dimensional grating structure in free space, illuminated by a normally incident plane wave. The field on the grating plane has been computed for two different incident fields, viz., the electric polarizations of the incident field perpendicular and parallel to the edge of the strips. The results are given in Figure 3. Note that the edge behavior of the aperture electric field is significantly different for the two cases and that the solution appears to follow the predicted edge-behavior for the two polarizations very well. The power transmission and reflection coefficients for the grating, which have been computed as functions of number of iterations, are shown in Figure 4. Rapid convergence of the iteration procedure is evident from these plots.

Finally, in Figure 5, we present the results for a two-dimensional grating illuminated by a normally incident plane wave. The aperture area is approximately $10\lambda^2$ whereas the cell area is about $44\lambda^2$. The dominant component of the E-field on the screen surface is shown with the incident electric field polarized in the y-direction. Even for the large cell and aperture sizes under consideration here, no difficulty is experienced in generating an accurate field solution. In all of these computations, we have chosen a 32 term Floquet expansion for the unknown field along each of the two dimensions in a unit cell. For the two-dimensional grating problem, this leads to 2^{11} equivalent unknowns to be solved. We have found that a large number of unknowns are easily handled by the method and that the computation time required to derive the solution is very moderate (5 - 6 secs of CPU time). Finally, the accuracy of the solution can be ascertained on the basis of the satisfaction of the boundary condition by using the spectral domain approach.

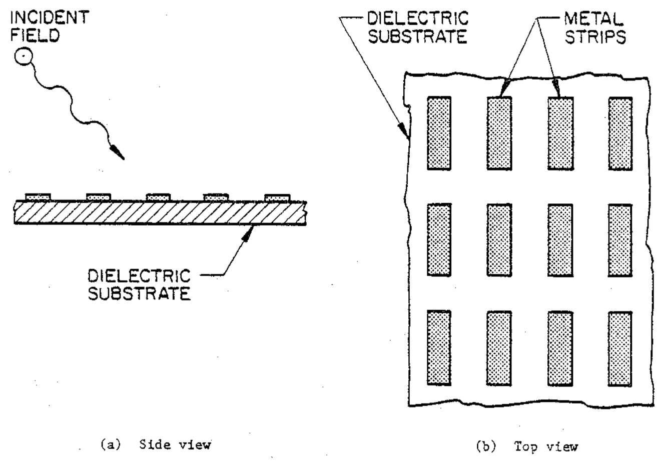

Figure 1. Frequency Selective Surface.

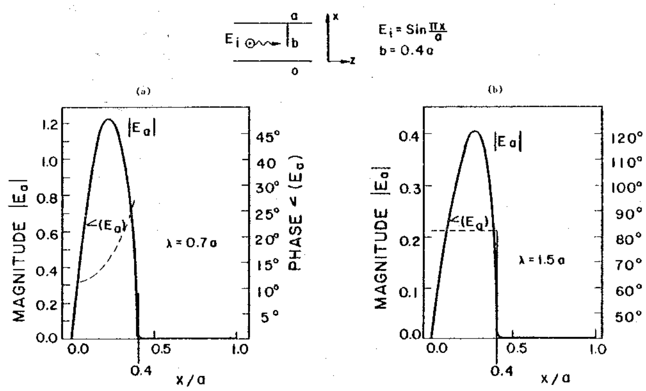

Figure 2.

Amplitude $|E_a|$ and phase $\angle(E_a)$ of the E-field sampled along the x-axis in the plane of an iris discontinuity in a parallel-plate waveguide illuminated by a TE_1 mode incident wave of wavelength (a) $\lambda = 0.7a$; (b) $\lambda = 1.5a$.

References

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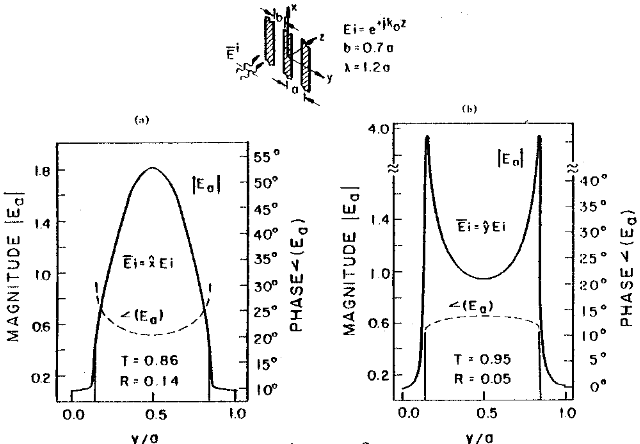

Figure 3.

E-field distribution sampled along the y-axis of a plane grating illuminated by a normally incident plane wave. Electric polarization (a) parallel; (b) perpendicular to the edge of the strips.

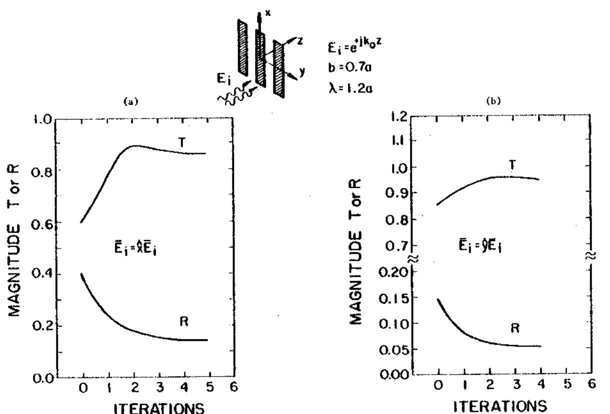

Figure 4.

Power transmission and reflection coefficient computed as a function of the number of iterations for a grating illuminated by a normally incident wave. Electric polarization (a) parallel; (b) perpendicular to the edge of the strips.

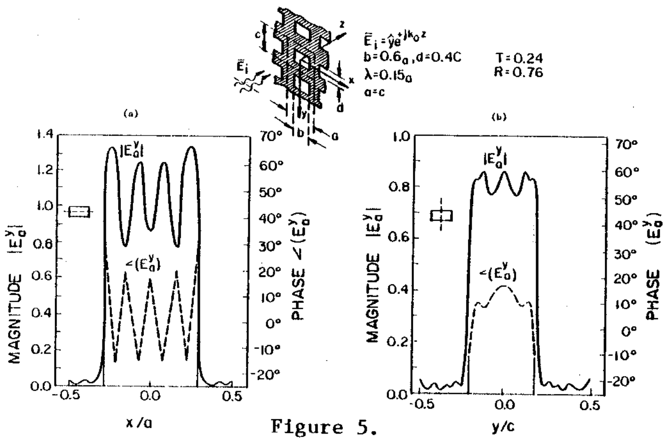

Figure 5.

Distribution of the dominant component of E-field in the plane of a perforated screen with rectangular apertures. (a) E_y-field sampled along the x-axis; (b) E_y-field sampled along the y-axis.