Using Periodicity to Control Spectral Characteristics of an Array of Narrow Slots

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In this paper we consider a frequency selective surface (FSS) consisting of a thin perfectly conducting sheet periodically perforated with narrow slot apertures. For wavelengths greater than the periodicity, such a surface performs similarly to a bandpass filter since the periodic elements within the FSS possess resonance characteristics. The effects on the spectral characteristics of varying the periodicity of a narrow slot array (or its complementary dipole array) was studied by Ott et al[1] and Munk et al[2]. By changing the periodicity, they found it possible to change the location of the resonant wavelength and the bandpass width of the transmission/reflection spectrum. With advances in computational technology, we are able in this paper to study these effects of periodicity in narrow slot arrays in much more detail. In this study we used the methods described by Chen[3] to predict the spectral characteristics of narrow slot arrays designed for use in the middle infrared spectral region. An algorithm was written in FORTRAN for use on either a PC or workstation. Although our work presented here is limited to a normally incident plane wave, the approach can be extended to the case of oblique incidence.

The geometry of the narrow slot array is shown in figure 1. For this study, the slot dimensions were kept constant with a=5.0μm and b=0.5μm, while the periodicity in the *x* and *y* directions were varied between 6.0μm and 12.0μm in 1.0μm increments. Polarization for the normally incident plane wave is limited to TE, where the E-field is perpendicular to the long dimension of the slots, as to produce a resonance effect in the slot. As stated by Chase and Joseph[4], a *single* narrow slot

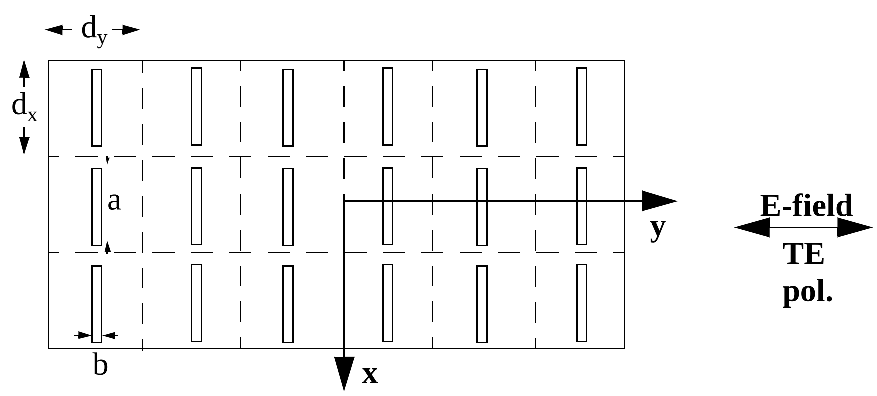

Figure 1 - Geometry used for Frequency Selective Surface consisting of a narrow slot array.

will produce a transmission resonance at

$$\lambda_{res} = 2.1\left(1 + \frac{b}{2a}\right)a \,. \tag{1}$$

Thus for a single slot the resonance wavelength is 11.025μm. Coupling between the slots in the array perturbs the resonance wavelength value from this value depending on the periodicity of the array.

In the first case considered we examine the effects of varying d_x from 6.0μm to 12.0μm in 1.0μm increments while d_y is held constant at 6.0μm. The resulting transmission profiles are presented in figure 2. It should be noted that the diffraction edge, λ_d, is equal to d_x. For wavelengths larger than λ_d, only the zeroth diffraction order propagates. At wavelengths less than the period in the *x*-direction, d_x, multiple diffraction orders are propagating (though only the zeroth order is shown in figure 2). From figure 2 it is clear that as d_x increases (thus increasing λ_d), the diffraction edge "cuts into" the resonance profile. However, the resonance and bandpass character are not drastically affected by varying the period in this direction.

For the next case, we vary d_y from 6.0μm to 12.0μm in 1.0μm increments while d_x is held constant at 6.0μm. Figure 3 shows the resulting transmission profiles. For this example, the diffraction edge corresponds to the value of d_y instead of d_x. Unlike the previous case, varying the period in the *y*-direction (the direction of the E-field) changes both the resonant wavelength and the bandpass width.

To help quantify these variations in resonant wavelength and bandpass width, the values were fitted using the general least squares method to the exponential equation

$$y = a + b\exp\left(-\frac{x}{c}\right), \tag{2}$$

where a, b, and c are the parameters to be fit. The results are presented in table 1.

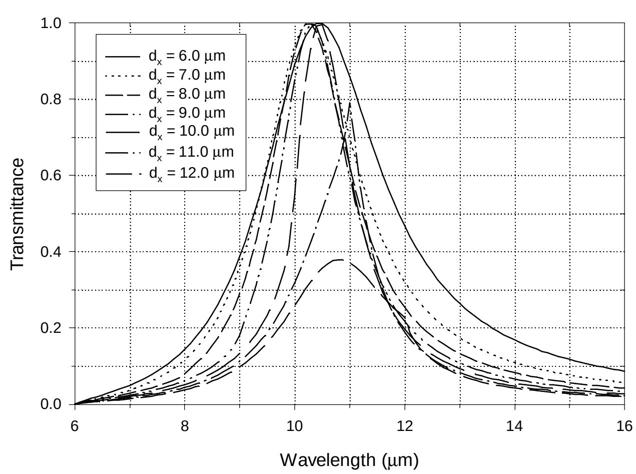

Figure 2 - Transmission profiles for FSS in figure 1 with a=5.0μm, b=0.5μm, d_x varies from 6.0μm to 12.0μm, d_y=6.0μm. The normally incident plane wave is TE polarized.

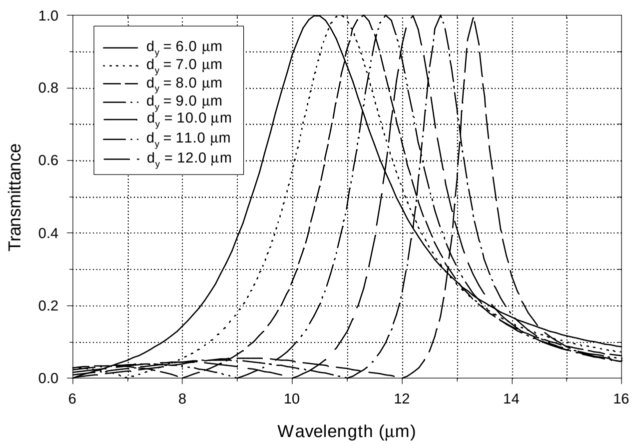

Figure 3 - Transmission profiles for FSS in figure 1 with a=5.0μm, b=0.5μm, d_x=6.0μm, d_y varies from 6.0μm to 12.0μm. The normally incident plane wave is TE polarized.

The error measurement, StdErr, listed in table 1 is the root mean square error, found by

$$StdErr = \sqrt{\frac{\chi^2}{DegreesofFreedom}}. \quad (3)$$

In the final case under consideration, we varied both d_x=d_y from 6.0μm to 12.0μm in 1.0μm increments. The transmission profiles are shown in figure 4. Again, the resonant wavelength, λ_r, and the bandpass width, $\Delta\lambda$, were fitted to an exponential, using the same procedure as in the previous example. Since variation of the periodicity only in the *x*-direction (figure 2) produced little effect on λ_r and $\Delta\lambda$, it should be expected that variation of both d_x=d_y (figure 4) should produce results similar to that of the variation of d_y alone (figure 3). Comparisons of figures 3 and 4 show that effects of the two variations are similar, but not exactly the same. Examination of the parameter values in table 1 confirms this.

Varying both d_x and d_y together produces a more pronounced non-linear increase in both λ_r and $\Delta\lambda$ than varying just d_y alone. In fact, the variation in λ_r as d_y changes is nearly linear in nature. While the relationship between $\Delta\lambda$ vs. d_y for

Table 1: Parameters fitted to equation y = a + b exp(-x/c)

Figure	y	x	a	b	c	StdErr
Figure 3	λ_r	d_y	5.5418	3.1377	-13.3097	0.0228
	$\Delta\lambda$	d_y	-0.8481	7.5578	7.6991	0.0149
Figure 4	λ_r	p (=d_x=d_y)	9.5337	0.2653	-4.8386	0.0193
	$\Delta\lambda$	p (=d_x=d_y)	0.0454	22.8311	2.7417	0.0440

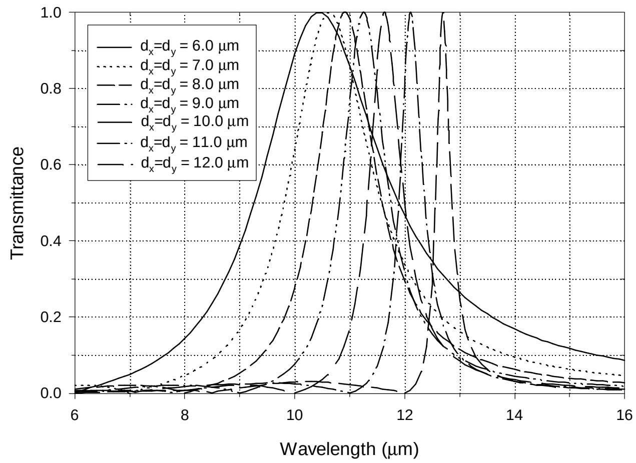

Figure 4 - Transmission profiles for FSS in figure 1 with a=5.0μm, b=0.5μm, $d_x=d_y$ varies from 6.0μm to 12.0μm. The normally incident plane wave is TE polarized.

the case of varying d_y alone is not quite as linear as for λ_r vs. d_y, it is much closer to being a linear relationship than for the corresponding case of varying both d_x and d_y together. To confirm this, one need only compare the ratio of the third and second terms in the expansion of equation (2), $\frac{1}{2c}$, for each case in question. If the condition

$$\frac{1}{2|c|} \ll 1\,, \tag{4}$$

occurs, then the exponential relationship is approaching a linear one. In the λ_r case described in figure 3, this ratio is 0.003, while for the case in figure 4, it is 0.021, or nearly a factor of ten. In the $\Delta\lambda$ case, these values are 0.065 (figure 3) and 0.182 (figure 4), or a factor of nearly 3.

In conclusion, establishment of a more explicit relationship between d_y and λ_r, and d_y and $\Delta\lambda$, make periodicity variations in the *y*-direction an attractive way to "fine tune" the location of the resonant wavelength and bandpass width when designing a narrow slot array FSS. These design parameters become important when trying to account for design specifications of infrared filters.

References

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