

# GRATING-TYPE POLARIZERS USING SMALL NUMBER OF RECTANGULAR GROOVES OPTIMIZED FOR MAXIMUM ISOLATION

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## A. Introduction

Currently available Integrated Circuit technology permits the etching of metalized gratings with an overall accuracy better than  $0.1\ \mu\text{m}$  [1]. This allows for mass production of very accurate gratings that can be used for polarization control and separation at terahertz frequencies and beyond.

This work is concerned with determining the profile of polarizing gratings for operation at terahertz frequencies (and higher), in order to obtain optimum electrical performance with a relatively small number of grooves. The gratings are assumed to have a finite number of infinitely-long metalized rectangular grooves illuminated by a plane wave (see Fig. 1). Two-dimensional Integral Equations are used to rigorously formulate the scattered field problem. These equations are then solved using standard Method-of-Moments techniques. As a case study, the electromagnetic scattering of a finite grating with two rectangular grooves per grating period is analyzed and optimized for maximum polarization isolation.

## B. Formulation

The metallic-grating geometry is assumed to have a finite width  $L$  and thickness  $h$ . A finite number of infinitely-long perfectly-conducting grooves is etched in a flat metallic slab (see Fig. 1). An arbitrarily polarized plane wave illuminates the grating as shown in the figure. The  $\hat{z}$ -direction is assumed parallel to the grooves—the geometry is independent of the  $z$  coordinate. These assumptions permit the present problem to be handled using two-dimensional Electric (to obtain the  $E_z$  electric field component of the TE polarization) and Magnetic (for the  $H_z$  magnetic field component of the TM polarization) Field Integral Equations [2]. These equations were numerically solved using Method-of-Moments and Point-Matching techniques [3]. The  $\hat{z}$ -oriented fields  $E_z$  and  $H_z$  give the normalized scattered power densities:

$$S^{TE} = k\rho \frac{1}{2\eta} |E_z|^2, \quad (1)$$

$$S^{TM} = k\rho \frac{\eta}{2} |H_z|^2, \quad (2)$$

where  $k$  is the wavenumber,  $\eta$  is the free-space wave impedance, and  $\rho$  is the polar radial distance measured from the  $z$ -axis. In this work a plane wave with a 1 Volt/m electric-field amplitude and having equal TE and TM polarizations has been used to illuminate the gratings. Its wavenumber vector  $\vec{k}$  is parallel to the  $z = 0$  plane and makes an angle  $\theta_i$  with respect to the grating normal (see Fig. 1).

A numerical algorithm for the analysis of the two-dimensional scattering using the Method of Moments was created and incorporated inside a numerical optimization

procedure to obtain the optimum grating profile. The numerical optimization was performed using the routine AMOEBA from Ref. [4].

### C. Polarizer Design and Optimization

As a case study, a metallic grating polarizer was designed to produce only three scattered orders (i.e., radiation peaks). At  $\phi = 45^\circ$  (specular reflection) only the TE polarization was desired, at  $\phi = 90^\circ$  only the TM polarization, and at  $\phi = 135^\circ$  (backscattering) no restrictions were imposed. The incident plane-wave angle  $\theta_i$  was assumed equal to  $45^\circ$  (see Fig. 1). The grating period  $G_p$  was obtained from the infinite-grating equation [5]

$$\cos \phi_n = n \frac{\lambda}{G_p} + \sin \theta_i, \quad (3)$$

where  $\lambda$  is the wavelength of the incident wave and  $n$  is an integer number corresponding to the diffraction orders ( $n = 0, -1, \text{ and } -2$  for  $\phi_n = 45^\circ, 90^\circ, 135^\circ$  in the present case, respectively). Eq. 3 yields  $G_p = 1.414 \lambda$  for the present geometry. The grating was assumed to have 10 periods and metal was added to give the grating a length  $L = 14.55 \lambda$  and thickness  $h = 1.5 \lambda$  (see Fig. 1).

For a rectangular groove, it is known from parallel-plate waveguide theory that when the groove width is smaller than  $0.5 \lambda$  the TE polarization (electric field parallel to the groove walls) is not capable of exciting propagating fields inside the grooves [6]. The grating then behaves almost as a flat surface and most of the TE scattered energy is radiated towards the specular reflection ( $\phi = 45^\circ$ ). To maximize the TE scattering in this direction, the groove widths were then kept smaller than  $0.3 \lambda$  during the optimization procedure. Furthermore, the grating profile was optimized to radiate, at  $\phi = 90^\circ$ , the TM polarization with the same scattered power density level as the one of the TE polarization at  $\phi = 45^\circ$ . At the same time, a polarization isolation of about 35 dB was attempted for both  $\phi = 45^\circ$  and  $90^\circ$  directions. Since at least two rectangular grooves per period are needed to conform with the above mentioned constraints, two grooves were used. For the Method-of-Moments analysis, an average of 50 segments per wavelength was used over the grooves' side and 20 segments per wavelength elsewhere—a sufficient number to ensure the numerical convergence. The optimization procedure gave the final geometry shown on Fig. 2. The normalized scattered power densities of the optimized geometry are shown on Fig. 3. The power density peak levels for the TE and TM polarizations are almost identical ( $-3.6$  dB and  $-3.7$  dB, respectively). The isolations between polarizations are 35.2 dB and 31.1 dB, at  $\phi = 45^\circ$  and  $90^\circ$ , respectively.

In order to study the impact of the number of grating periods on the polarizer performance, this number was increased to 20, yielding  $L = 28.69 \lambda$ . The groove geometries and the plane-wave illumination remained the same as before. The normalized scattered power densities for this case are shown on Fig. 4. The TE and TM power density peak levels continue to be practically equal (2.4 dB and 2.2 dB, respectively). However, the polarization isolation decreased to 31.8 dB at  $\phi = 45^\circ$  and increased to 39.8 dB at  $\phi = 90^\circ$ . For comparison purposes we also considered an infinite number of grating periods (analyzed with the help of Floquet's theorem). The corresponding results are shown on Fig. 5 and were obtained assuming an infinite grating to get the current distribution over each period and truncating the grating to 50 periods for the evaluation of the scattered fields. From the figure we

can observe that both the TE and TM peak levels continue to have the same order of magnitude (9.9 dB and 8.8 dB, respectively) and the polarization isolations are now 15.9 dB and 37.4 dB at  $\phi = 45^\circ$  and  $90^\circ$ , respectively.

Using array theory one knows that the scattered fields of the infinite grating can be treated as a product of an element factor (produced by the current distribution over a single grating period) multiplied by the array factor, with the polarization isolation given by the element factor. On Fig. 6 the scattered power densities produced by the element factor are shown, confirming that the polarization isolations at  $\phi = 45^\circ$  and  $90^\circ$  are the same as those of Fig. 5. Because the TE polarization is almost insensitive to the grooves' presence (the electromagnetic field does not penetrate into the grooves), its scattered field can be expected to be close to the one of a flat metallic surface with dimensions identical to the ones of the grating. To confirm this fact the Physical Optics (PO) approximation has been used to compute the field scattered by an infinite metal strip with a width equal to the grating period ( $1.414 \lambda$ ). This result is also shown on Fig. 6 for the TE polarization, revealing an almost perfect agreement between the PO and Method-of-Moments results, outside the low-scattering regions.

#### D. Conclusions

A 10-period metallic grating-type polarizer capable of separating the two polarizations of an incident plane wave with an isolation better than 30 dB was presented. The polarizer separates the TE and TM components of the incident wave along two directions not coinciding with the backscattering direction. The results of this work indicate that the polarization isolation yielded by the finite grating polarizer is somewhat different from the one of an infinite polarizer. A possible cause of this is the diffraction originating from the grating edge region. However, the infinite grating geometry can be used as a starting design and refined using a numerical optimization procedure. This initial design can be put together from the scattering characteristics of a single period, since the polarization isolation comes primarily from the element factor of the grating. The results obtained also show that simple modeling tools (such as the PO approximation for the TE polarization) can be judiciously used to partially determine the polarizer scattering characteristics, and hence reduce the numerical burden associated with the design process.

#### References

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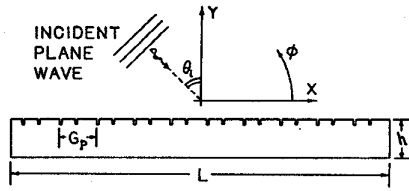


Fig. 1 - Basic grating geometry.

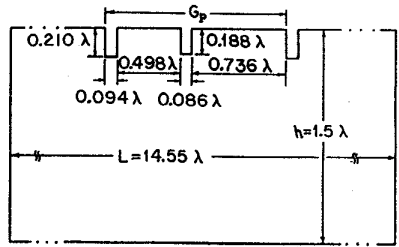


Fig. 2 - Optimized grating geometry.

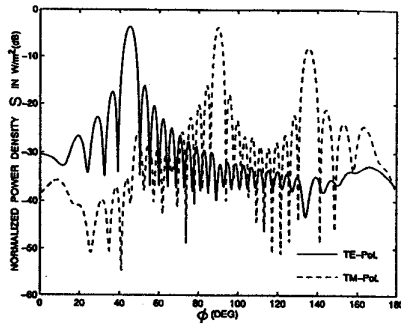


Fig. 3 - Scattering of the 10-period grating.

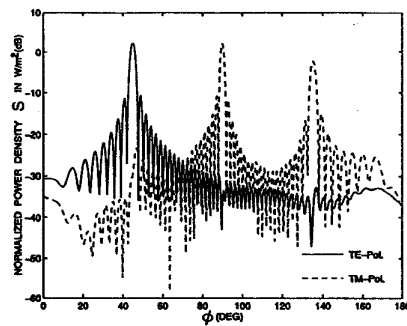


Fig. 4 - Scattering of the 20-period grating.

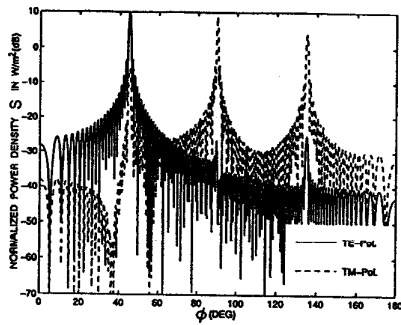


Fig. 5 - Scattering of the infinite grating.

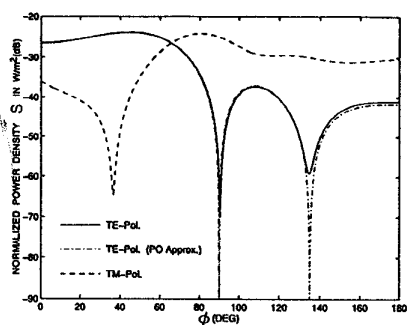


Fig. 6 - Scattering of one grating period.