Measuring Edge Scattering From Finite-Sized Samples Using a Gaussian Beam

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Introduction

In this paper, we examine the possibility of measuring edge scattering from a material by using a Gaussian beam together with a finite-sized sample of the material. A practical implementation for measuring edge scattering is shown in Fig. 1 [1]. Here a focused beam system, consisting of a horn antenna and a lens, produces a beam that closely resembles a Gaussian beam. The waist of the beam is centered on one edge of a finite-sized object. The object is often a thin, flat rectangular plate of some material that is being investigated for the purpose of minimizing edge scattering. The scattered field is measured, either close to or far from the object, to determine the characteristics of the edge scattering. With this system, various treatments can be applied to the edge while observing the change in the scattering. In this paper, we analyze a canonical problem, described below, for the system shown in Fig. 1. Results from this analysis are used to obtain guidelines for the conditions under which the scattering from the illuminated edge can be isolated from the scattering from the remainder of the object, viz, from the other edges of the plate. The guidelines are obtained by comparing edge scattering due to a

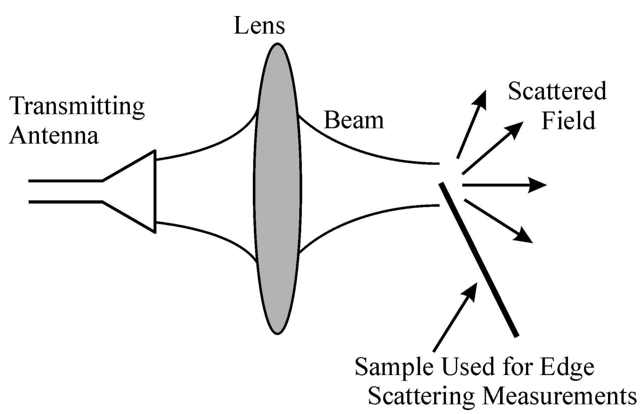

Fig. 1. Schematic drawing showing a focused beam system that is used to illuminate the edge of a sample under investigation. The scattered field can be measured either in the near- or the far-field regions.

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Gaussian beam incident on an infinitesimally thin, perfectly conducting (PEC) plate with the edge scattering due to the same beam incident on an infinitesimally thin, PEC half plane. The half plane can be viewed as the ideal object for studying edge scattering because it contains only one edge. So the comparison between the plate and the half plane determines the effect of the additional edges of the plate on the scattered field. For this study, the waist of the Gaussian beam is centered on the edge of the half plane and on one of the edges of the plate, which is referred to as the primary edge. This concept is illustrated in Fig. 2, where Fig. 2(a) shows the half plane and Fig. 2(b) shows the plate. The size of the plate (W_x and W_z) is varied so that the magnitude of the dominant electric field component of the incident beam, $\left|E^i_{\tan}\right|$, is reduced to a specified percentage of its maximum value at the non-primary edges of the plate. The normalized value of the field on the dashed line, shown in Fig. 2(b), is specified by the following parameter:

$$R_E = \frac{\mathrm{Max}\left(\left|E^i_{\tan}\right|_{\text{non-primary edges}}\right)}{\left|E^i_{\tan}\right|_{\text{peak}}}. \quad (1)$$

The dashed line is an ellipse in Fig. 2(b), because the Gaussian beam is obliquely incident on the half plane/plate.

For the PEC half plane, we use the analytical formulas presented in [2] that describe the scattering due to an incident, three-dimensional, electromagnetic Gaussian beam. For the PEC plate, we use the commercial software package FEKO, which is based on the method of moments [3]. With FEKO, the Gaussian beam is represented by a finite number of plane waves. In our presentation, we will address how many plane waves are needed to avoid aliasing of the beam as well as replication of the beam on the plate. The relationship between the coordinate system for the incident beam (x_i, y_i, z_i) and the coordinate system for the half plane/plate (x, y, z) is shown in Fig. 3. The angles ψ_B and χ_B, shown in Fig. 3(a), determine the orientation of the axis or the vector wave number,

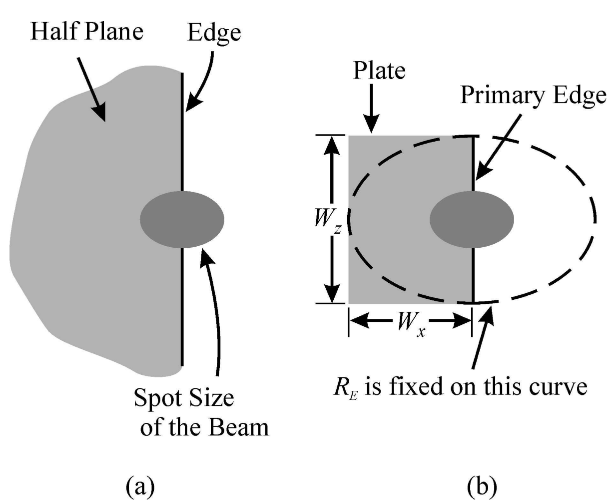
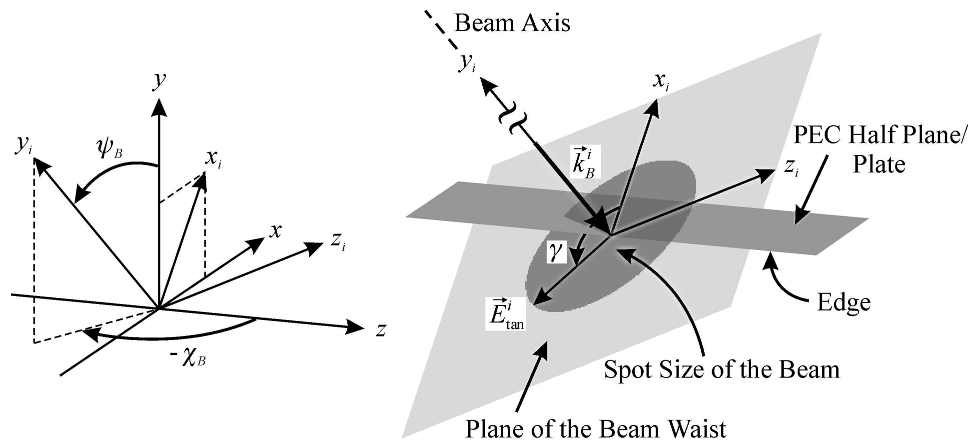


Fig. 2. The geometry for the half plane (a) and the plate (b). In both cases, the beam is obliquely incident on the object.



(a) (b)

Fig. 3. The relationship between the coordinates (x_i, y_i, z_i) associated with the incident beam and the coordinates (x, y, z) associated with the half plane/plate. (b) Graphical description of how the beam is related to the half plane/plate.

$\vec{k}_B^i$, of the incident beam. The angle γ, shown in Fig. 3(b), determines the direction of the incident electric field on the plane of the beam waist, where the exponential taper for $E_{\tan}^i$ is $\exp[-(\rho_i / W_0)^2]$ and ρ_i is the radial distance from the axis of the beam.

A Comparison of Results for Plates with those for the Half Plane

For the results presented here, we use a Gaussian beam with $k_0 W_0 = 2\pi W_0 / \lambda_0 = 10$ and two polarizations of the beam: an *E*-beam and an *H*-beam. The *E*-beam (*H*-beam) is defined as a Gaussian beam with its main electric (magnetic) field component lying in the plane containing the axis of the beam and the edge of the half plane or the primary edge of the plate. The *E*-beam (*H*-beam) is always obtained by letting $\gamma = -90^\circ$ ($\gamma = 0^\circ$). For the half plane, it was demonstrated in [2] that when a beam is incident on the edge of a half plane, a wave, called the edge wave, is formed over a narrow region around the edge. For the *E*-beam, the edge wave propagates in free-space away from the half plane, whereas for the *H*-beam it propagates on the half plane. In the presentation, we will show graphical results comparing the surface current densities as well as the far-zone patterns for plates of different size and for the half plane. The following definition is used as a measure of the difference between the scattered field due to a Gaussian beam incident on the half plane and the plate,

$$\text{Error} = \frac{\int_{\phi=0}^{\pi}\int_{\theta=0}^{\pi}\left|\frac{d\left\langle P_{h.p.}^{s\,r}\right\rangle}{d\Omega} - \frac{d\left\langle P_{plate}^{s\,r}\right\rangle}{d\Omega}\right| d\Omega}{\int_{\phi=0}^{\pi}\int_{\theta=0}^{\pi}\frac{d\left\langle P_{h.p.}^{s\,r}\right\rangle}{d\Omega}\, d\Omega}. \tag{2}$$

Here $d\left\langle P_{h.p.}^{s\,r}\right\rangle / d\Omega$ and $d\left\langle P_{plate}^{s\,r}\right\rangle / d\Omega$ are the time-average powers per unit solid angle in the far zone for the scattered field from the half plane and the plate, respectively.

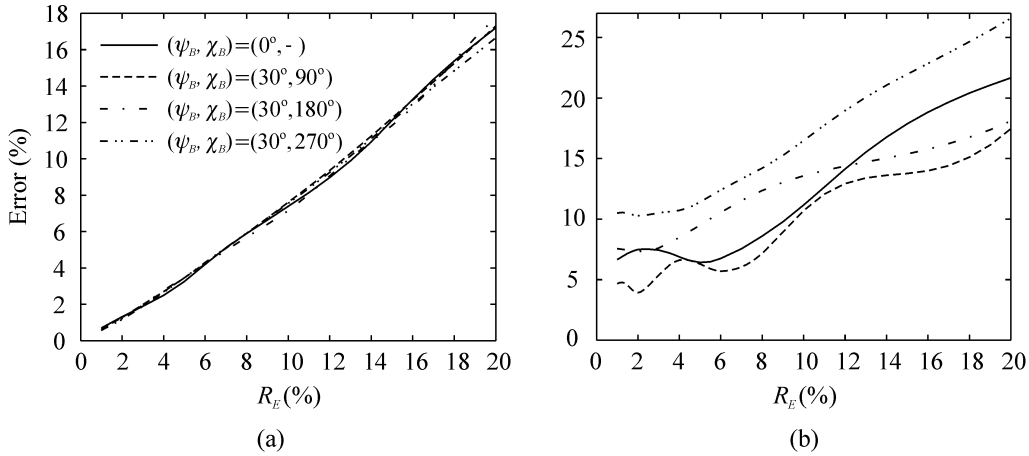


Fig. 4. A comparison of the error due to the finite size of the plate versus the size of the plate: (a) incident *E*-beam (k_0W_0 = 10), (b) incident *H*-beam (k_0W_0 = 10).

Figure 4 displays the error, defined in (2), due to the finite size of the plate for four different directions of incidence for the beam. The size of the plate is continuously varied so that R_E covers the range 1% to 20%. For the *E*-beam, Fig. 4(a), the error varies almost linearly with R_E, and it is nearly independent of the direction of incidence. The calculated error ranges from around 0.7% to around 17%. For the *H*-beam, Fig. 4(b), the error is worse than for the *E*-beam for all cases considered, and the error varies significantly with the direction of incidence. The error is the largest for the case $\psi_B = 30^\circ$, $\chi_B = 270^\circ$; it is 10.3% for the largest plate and 26.6% for the smallest plate.

Based on our observations, the scattering from an edge of a finite size test object (plate) can be isolated for an incident *E*-beam as long as the size of the test object is large enough so that it contains the cross section of the incident beam. However, for an incident *H*-beam, it is more difficult to isolate the edge scattering for a finite size test object. The edge wave is the main reason for this complication because it propagates along the object for this case, whereas for the *E*-beam, it propagates away from the object. Moreover, for the *H*-beam, the ability to isolate edge scattering depends significantly on the angles of incidence of the beam. The guidelines given in this paper for isolating the scattering from an edge are based on a PEC plate. For the PEC plate, there is strong edge scattering and no absorption of energy in the plate. Therefore, these guidelines represent a worst case and should be adequate for plates of other materials.

References

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[2] L. E. R. Petersson and G. S. Smith, “Three-dimensional electromagnetic diffraction of a Gaussian beam by a perfectly conducting half-plane,” *J. Opt. Soc. Am. A*, vol. 19, pp. 2265-2280, Nov. 2002.

[3] FEKO suite 3.2.2, EMSS Corporation.