On the Prediction and Measurement of the Electromagnetic Fields Close to a Coated Diffracting Edge at Grazing Incidence

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1 Abstract

A material coating applied to the edge of a conducting plane can be used to reduce monostatic edge diffraction of electromagnetic waves from it for obtuse incidence angles. The role of such a material coating is briefly discussed. A reference coated-edge has been used as a 10-GHz test piece for optically modulated scatterer (OMS) measurements of the electric field close to such an edge, and for far field RCS measurements.

2 Introduction

Methods for controlling edge diffraction that have been widely analyzed include edge corrugations and resistive edges and tapers. The application of a material coating to the diffracting plane is a less widely explored method. A surface coating is an attractive method for reducing diffraction – it may be applied post-manufacture, and it requires little alteration to be made to the structure of the diffracting edge. The practical benefits of using a coating arise from the fact that the scattering reduction strategy may be de-coupled from the design of the edge structure. Because the coating is supported by a conducting plane, it is also mechanically robust.

It is necessary to measure and predict edge diffraction effects in order to optimize the electromagnetic properties of a material coating. There is substantial interest within the electromagnetics community in predicting diffraction effects, as evidenced by the many hundreds of papers on the subject. However, there are remarkably few published articles that show measured diffraction data. Amongst these, a far-field technique for isolating and measuring diffraction at microwave frequencies has been described that utilizes a diamond-shaped test fixture [1]. It has been shown how more precise data from a two-dimensional diffracting edge may be obtained using a near-field technique [2]. In this contribution, measured far- and near-field data from a reference coated diffracting edge are presented. The near-field data have been obtained using an OMS (optically modulated scatterer) [3].

3 The Geometry of the Problem

The geometry of a coating designed to control the energy scattered by a conducting plane is shown in Figure 1. The taper section is necessary to reduce diffraction at the discontinuity between the coating and the conducting plane. The conducting plane (more precisely, a halfplane) is assumed to be many wavelengths in transverse length at its lowest operating frequency.

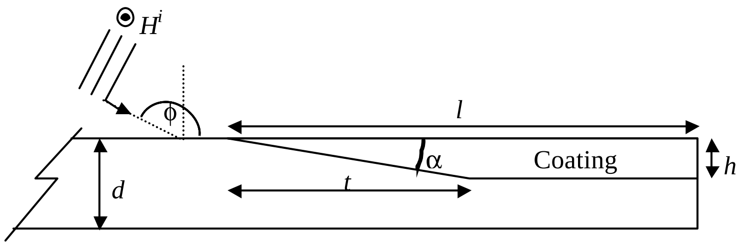

Figure 1 A coated conducting halfplane edge illuminated by an H-polarized wave. The dielectric coating has a relative permeability of μ_r=1 and a relative permittivity ε_r . The coating has a taper of length t at its front edge, a total length of l and thickness h. $0 \le t \le l$.

4 The Edge Coating

A detailed description of the electromagnetic consequences of placing a coating close to a diffracting edge has been presented elsewhere [4]. Reference [4] may be summarized as follows: the geometric similarity between a coated PEC (perfect electrical conductor) edge and a halfplane comprising two face impedances enables the PEC edge to be modelled asymptotically (*e.g.*[5]), assuming the coating is represented by the equivalent surface impedance. The data obtained from an asymptotic analysis show that any complex surface impedance, including a lossless impedance, causes a significant reduction in monostatic RCS (radar cross section) at obtuse incidence angles. However, RCS data derived from an FD-TD analysis show that only high loss coatings reduce edge RCS. An explanation of this apparent contradiction is found in the finite thickness of the practical coating. The lossless coating traps and guides waves that, when re-radiated, increase edge scattering. These waves are not included in the asymptotic analysis. Coating loss is necessary to attenuate the trapped and guided waves. Loss has only a minor impact on the edge diffracted RCS. The taper section of the coating serves to increase the energy deposited in the coating through a process related to total internal reflection of waves that enter the taper.

The two-stage coating geometry shown in Figure 1 is helpful in identifying the various scattering mechanisms present in the vicinity of the coating. However, this geometry is inconvenient from a practical viewpoint as it necessitates the manufacture of two planar surfaces (on both the coating and the PEC plane) separated by a large obtuse angle. The two-stage geometry also introduces a discontinuity (at the junction between the planar and taper sections) that contributes to the combined diffracted field. A practical alternative to the two-stage geometry is to remove the planar section and construct the coating entirely from a tapered material. In fact, for applications that require treatment post-manufacture, the taper may be placed on the surface of the PEC plane (rather than embedded within it) with no significant performance reduction.

Zenneck surface waves (*i.e.* two-dimensional surface waves that propagate along an infinite impedance plane) are excited at each diffraction site on the coating and represent one of the modes supported by a lossless coating. Surface waves do not exist on the untreated edge. Although the excitation of surface waves on the coating is not part of the diffraction control strategy, it is necessary for the coating to attenuate Zenneck surface waves if the coating is to control and reduce edge diffraction. The current anecdotal use of the term ‘surface wave absorber’ to describe an edge coating is therefore not wholly inappropriate.

5 Measurements

5.1 The Radar Cross Section of a Triangular Coated Edge Test-Piece

The characterization of an edge with a nominally lossless coating is an important part of our analysis because, compared to PEC and to lossy edges, the lossless edge combines a reduction in the edge diffracted field with an increase in non-diffracted scattering contributions. Near and far-field data from a lossless edge therefore contain features related to the different modes scattered by the coating; these features are attenuated in data from absorbing edges. Table 1 lists the parameters of a reference coating test-piece, see Figure 1. This test piece has been analyzed theoretically using the FD-TD technique [4], and experimentally using RCS data and near-field OMS data.

Figure 2 shows the measured and predicted RCS of the triangular test-piece described in Table 1. RCS measurements were performed using an off-axis quasi-optic reflectometer. The measurement method and calibration procedure are described in [2]. The measured data in Figure 2 exhibit two interference features. The feature whose period is approximately 1 GHz is an uncorrected measurement error caused by reflections from the structure used to support the reflectometer. The larger feature that comprises two maxima is a dispersive interference pattern that is also visible in predicted data. The dispersive interference is caused by the re-radiation of Zenneck surface waves from the lossless coating [4]. The cause of the slight compression of measured data along the frequency axis is not known. However, the test-piece was manufactured using a water-based coolant; it is therefore possible that, at the time the measurements were made, the permittivity of the sample was higher than the value given in Table 1.

Parameter	Value	Parameter	Value
f	160.0 degrees	loss tangent	7600 microradians
l	100.0mm	h	8.0mm
t	100.0mm	d	10.0mm
ε'_r	2.66	-	-

Table 1 Test-piece parameters.

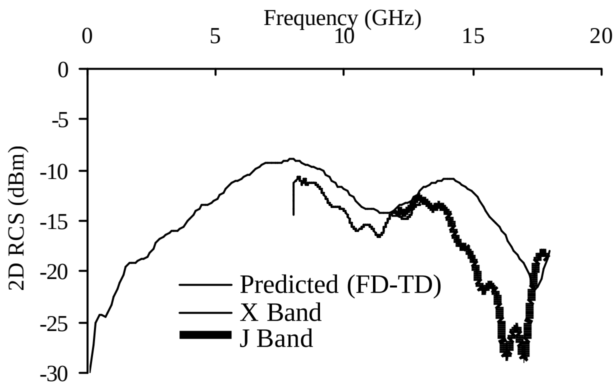

Figure 2 Measured and predicted data of a coated edge.

5.2 Near-Field Measurements on the Coated Edge Test-Piece

Near-field measurements on the coated diffracting edge were made using an optically modulated scatterer (OMS) technique. The modulated scatterer is a device designed for measuring the magnitude and phase of microwaves in a minimally invasive way. The OMS facility at NPL is described in a companion paper [3].

OMS measurements have been made using the (nominally) lossless reference edge described in Table 1 except that ϕ = 165degrees. Figure 3 shows a surface plot of the measured *x* component of electric field at 10 GHz in the vicinity of the edge. Figure 4 shows a comparison between the measured and predicted (FD-TD) total electric field 19 mm above the lossless coating. At 10 GHz, the propagation constant of the Zenneck surface wave supported by the coating is similar to the free space propagation constant [4]; the maxima of the ripples in the field above the layer in Figures 3 and 4 (in the *z*-direction) are therefore separated by a distance of approximately 15 mm – one half the free space wavelength. These maxima are principally caused by interference between the edge diffracted field and the incident field. A second feature in Figure 3 is the set of minima emanating from the diffracting edge. This feature lies approximately on the reflection boundary of the layer, a boundary that coincides with a maximum in the diffracted field [5]. The level of agreement between measured and predicted data in Figure 4 is again likely to have been influenced by variations in the permittivity of the coating material. Another factor which could have contributed to the differences observed is discussed below.

6 Conclusions

A simple edge coating is a juxtaposition of tapered and planar material sections, and diffracting edges. The geometric complexity of a coated edge is beyond rigorous closed-form analysis – a fact that has perhaps contributed to its omission from the published literature. Because a practical edge coating is amenable only to numerical analysis, measured data are necessary to validate the conclusions drawn from numerical analysis. In this paper, near- and far-field measurements of a reference edge coating have shown reasonable agreement with predicted data, thus supporting the coating design strategy described in [4]. Near-field OMS measurements also provide an insight into the behaviour of practical coatings, an insight that does not come from either numerical, far-field or asymptotic analysis techniques.

The near- and far-field measurements were made using a triangular test-piece. Two edges of the test-piece were beveled; the third rear edge was straight and resembled that depicted in Figure 1. This triangular geometry is described in [1] and was optimised for its monostatic RCS characteristic, rather than for near-field OMS measurements in which waves diffracted from the triangle front edges will have added to the waves under study, giving rise to some of the differences observed in Figure 4. In fact, several of the measurement norms that relate to monostatic procedures have to be re-thought for measurements in which data are recorded in the near-field. These observations will be taken into account in the design of new test-pieces in further studies.

7 Acknowledgements

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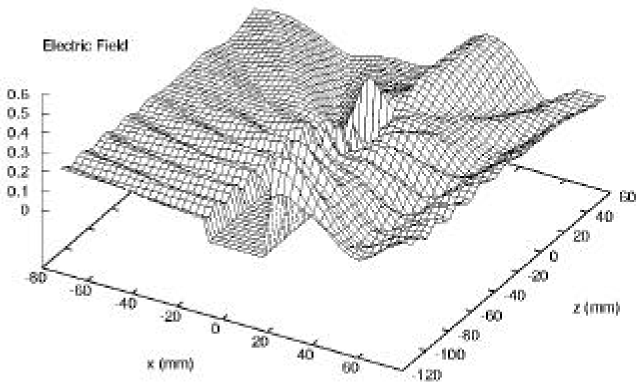

Figure 3 3_D representation of the magnitude of the E-field near the rear end of the test-piece, which is positioned at $x = 0$, $z < 0$. The dielectric taper is positioned in the quadrant $x > 0$, $z < 0$, as are the fields above it . The finite size of the OMS prevents it from measuring in the rectangular region close to the test-piece shown with zero field. The vertical axis shows the electric field in arbitrary units.

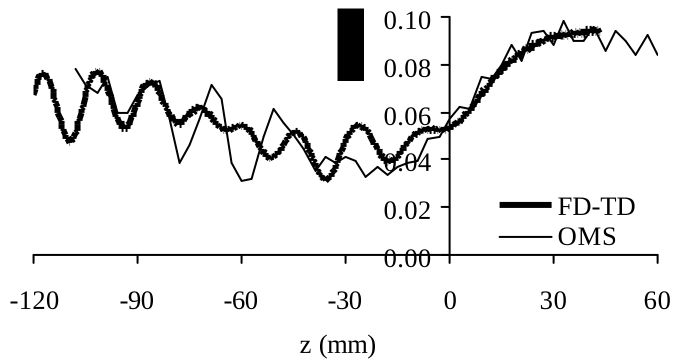

Figure 4 A comparison between the measured (OMS) and predicted E field magnitude 19 mm above the lossless coating. The vertical axis shows the electric field in arbitrary units.

8 References

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