ELECTROMAGNETIC SCATTERING FROM A FINITE STRIP GRATING

G. Manara[1], P. Nepa[1], F. Bertoncini[2], O. Aydin Civi[3], V.B. Erturk[4]

[1]*Dept. of Information Engineering, University of Pisa, Pisa, Italy*
[2]*Dept. of Electrical Systems, University of Pisa, Pisa, Italy*
[3]*Dept. of Electrical and Electronics Eng., Middle East Tech. University, Ankara, Turkey*
[4]*Dept. of Electrical and Electronics Eng., Bilkent University, Ankara, Turkey*

Abstract: An analysis of plane wave scattering from a finite 1-D periodic penetrable screen is presented with the aim of demonstrating the effectiveness and the accuracy of high frequency asymptotic solutions when combined with approximate homogeneous transition boundary conditions. The results of the numerical investigation are relevant to the electromagnetic scattering from a large planar semi-transparent strip, composed of a dense free-standing strip grating. The Uniform Geometrical Theory of Diffraction (UTD) is applied to obtain the asymptotic expression for the scattered field, starting from an analytical solution available for plane wave scattering at the edge of a semi-infinite strip grating. The data for the scattered field are compared with those obtained from a pure numerical method (the Method of Moments, MoM) which is applied to the actual scattering structure (without using any approximate boundary condition). Specific attention is also devoted to the phenomenon of surface wave (SW) excitation and diffraction, which appears in both the UTD and the MoM data.

INTRODUCTION

Artificial surfaces, as for instance, metamaterial slabs, dichroic screens, frequency/polarization selective reflectors, absorbers, or more general multi-layer and periodic surfaces, are receiving an increasing interest in antenna and microwave device technology [1]-[2]. The analysis of multilayer/periodic surfaces is usually focused on their reflection and transmission properties, and it is performed by considering an infinite surface under plane wave excitation. However, in actual applications there is the need to include edge effects. In this framework, efficient numerical methods have been developed to study electrically large finite periodic surfaces, as well as accurate diffraction coefficients have been proposed to evaluate the scattering from edges in artificial surfaces when they can be characterized by proper impedance boundary conditions [3]. In particular, the latter approach represents an extension of analytical high frequency techniques (e.g., the Uniform Geometrical Theory of Diffraction, UTD, and the Physical Theory of Diffraction, PTD) to the analysis of edge effects in non-metallic composite surfaces and it seems to be a very promising alternative to pure numerical methods, when dealing with large reflectors or screens. The first step in deriving a UTD diffraction coefficient for a scattering canonical problem is the development of an analytical model of the surface. This model should be able to recover the reflecting and transmitting properties of the material slab, in a given frequency interval and for a sufficiently wide angular sector around normal incidence [3]. Starting from the analytical model of the surface, a canonical wedge diffraction problem can be defined. The most suitable techniques for solving the above canonical diffraction problem are the Wiener-Hopf and the Maliuzhinets methods. In spite of their recent significant extensions, the solutions to the diffraction from edges in composite material slabs require the calculation of complicated special functions and in many cases the problem cannot be solved in a closed form. This is due the fact that the analytical models available to characterize the above mentioned artificially composite material surfaces are usually more involved than standard impedance boundary conditions. Consequently, major research activities are focused on the extension of exact solutions valid for specific scattering problems, with the objective of deriving more general heuristic or approximate diffraction coefficients, able to efficiently evaluate the most important edge field contributions in electromagnetic scattering from electrically large objects characterized by non-metallic surfaces.

This paper is aimed at presenting some numerical results relevant to the analysis of the scattering from a finite large planar semi-transparent strip made of parallel dense free-standing metallic strips. The geometry of the problem is shown in Fig. 1. Let L be the distance between the two edges of the large planar strip. The smaller parallel metallic strips are in air; their periodicity and width are denoted by p and w, respectively. The orientation of the metallic strips with respect to the edge is defined by the angle γ ($\gamma = \pi/2$ or $\gamma = 0$, when the strips are parallel or perpendicular to the edge, respectively). It is worth noting that gratings of parallel metallic wires or strips behave as polarization selective screens and are widely employed in reflector antennas with high levels of polarization isolation (for instance, they are used in dual gridded reflector systems and in shaped reflectors to reduce the cross polarization that is intrinsic in offset systems employing linear polarization).

Within the numerical investigation presented in this paper, the field scattered by a finite large strip grating is evaluated by means of both a UTD solution and an efficient and accurate MoM solution. The UTD solution has been obtained by using the diffraction coefficients derived in [4] and [5], where two different approximate transition conditions have been used to model the strip grating. The MoM current induced on the metallic strips will be used to evaluate the exact field scattered from the actual finite surface (without using any approximate boundary condition). The comparison between the UTD scattered field and the MoM data is aimed to assess the accuracy of the asymptotic solution as well as the limits of validity of the approximate boundary conditions used to model the strip grating surface. The comparison will be carried out as a function of the geometrical and electrical parameters of the scattering problem. Specific attention is also devoted to the phenomenon of surface wave excitation. Indeed, a spectral analysis of the MoM data is performed to analyze the surface wave excitation phenomenon already experienced by other authors in investigating a finite array of metallic dipoles in air [6]-[7]. The propagation constant and complex amplitude of the surface waves propagating along the surface will be compared against those exhibited by the UTD asymptotic solution [4], [5], [8].

A UTD SOLUTION FOR THE SCATTERING FROM EDGES IN A FINITE METALLIC STRIP GRATING

The reflecting and transmitting properties of infinite metallic gratings primarily depend on both the polarization of the incident wave and the ratio between the grating period p and the free-space wavelength λ. When the grating period is small compared to the free-space wavelength, accurate analytical expressions for the amplitude of the reflected and the transmitted fields have been derived by adopting either the average field method developed by Kontorovich or other approaches that are able to derive higher-order boundary conditions [3]. In particular, the homogenization method represents a systematic technique to derive approximate transition conditions (ATCs) of any order with respect to the ratio p/λ. The zero-th order ATC model for a grating of free-standing thin metallic strips coincides with the Unidirectionally Electric Conducting (UEC) screen model, which is the simplest adopted for strip or wire gratings. The UEC screen is assumed to be perfectly conducting along the direction parallel to the conductors and perfectly insulating in the orthogonal direction, and its reflecting and transmitting properties do not depend on the grating parameters. On the contrary, the first order ATC model obtained through the homogenization approach explicitly depends on the grating period p and strip width w, and provides accurate results for the reflected and transmitted fields up to $p/\lambda=0.3$ [5]. High-frequency diffraction coefficients for the scattering from a semi-infinite planar strip grating have been presented in the literature, when either the UEC model [4] or the above cited first order ATC model [5] have been adopted. Therefore, high frequency expressions for the scattering from the edge of a semi-infinite metallic strip grating are available, when an arbitrarily polarized plane wave is obliquely incident on its edge, and the strips are arbitrarily oriented with respect to the edge itself. The solution can be expressed in the UTD format [9] and is valid for dense strip gratings. It is important to mention that the analytical solution in [5] recovers in the limit that for the UEC half-plane and that relevant to the PEC half-plane, when $p/\lambda \rightarrow 0$ and $w/p \rightarrow 1$, respectively. The asymptotic solution also contains a surface wave field contribution associated with a surface wave excited at the edge of the semi-infinite strip grating and propagating along the surface. Both the propagation constant and the complex amplitude of the surface wave are known in a closed form. Therefore, it results that the field scattered by a large semi-transparent strip made of smaller metallic strips can be evaluated by considering high frequency diffraction terms accounting for: *i*) first order diffraction contributions and surface wave excitation phenomena at each of the two parallel edges; *ii*) surface wave diffraction at the opposite edge; *iii*) double diffraction contributions; and terms associated to other higher order scattering mechanisms. The analysis of the surface wave diffraction when the latter is impinging at one of the two strip grating edges can be performed by an analytical continuation of the diffraction coefficients in [4] and [5] to complex incidence angles [10]. Double diffraction contributions can be evaluated by applying the same procedure already used to evaluate the scattering from parallel edges in either metallic or impedance surfaces [11].

A MOM SOLUTION FOR THE SCATTERING FROM A FINITE ARRAY OF PARALLEL METALLIC STRIPS

An efficient and accurate pure numerical solution for the scattering problem shown in Fig. 1 has also been implemented. An electric field integral equation (EFIE) has been set up by enforcing the boundary condition that the total electric field tangential to the conducting strips must vanish. Since the geometry is periodic (formed by identical parallel conducting strips) and infinite along one direction, the Floquet theorem can be applied so that the boundary conditions are enforced only at a single periodicity cell. Consequently, the size of the resulting MoM impedance matrix remains reasonable even when an electrically large strip is considered (L greater than a few wavelengths). The actual current induced on the metallic strips of the grid will be used to evaluate the field scattered from the large strip.

THE SURFACE WAVE CONTRIBUTION

The 1-D periodic structure analyzed in this paper can support surface wave modes. When considering an infinite planar strip grating, SWs can be excited under dipole or line source excitation. SW excitation under plane wave illumination can be experienced only when the surface is finite, since the diffracted field continuous spectrum can excite guided modes on the surface. In the present paper, an eigenmode analysis is applied to the MoM matrix to determine the propagation constants of the excited surface waves; the results have been obtained by following a spectral domain procedure as in [12], [13].

The propagation constant and complex amplitude of the surface waves excited at the edges of the large planar strip will be compared against the same quantities appearing in the UTD analytical solution. It is worth noting that both the homogeneous boundary conditions used in [4] and [5] provide the same expression for the propagation constants of the SWs that can propagate along the strip grating. The SW wavevector exhibits a real component parallel to the surface and an imaginary component perpendicular to the screen, the latter accounting for the exponential decay of the SW amplitude far from the surface. The above real component is not parallel to the strips but the amplitude of its projection in the direction of the strips matches the free space wavenumber. Moreover, it can be shown that the real component of the SW Poynting vector is parallel to the strips, denoting that the SW energy flows along the strips themselves, as expected.

NUMERICAL RESULTS AND CONCLUSIONS

Some preliminary numerical results for the electric field scattered from the large strip are shown in Fig. 2, when the electric incident field is either parallel (Fig. 2a) or perpendicular (Fig. 2b) to the metallic strips . The scattered field is evaluated around the strip at a distance $\rho=10\lambda$ from the center of the strip itself whose width is L=2λ. The strip is illuminated by a plane wave impinging from the direction $\beta=\pi/2$, $\phi'=\pi/2$. The strips periodicity and width are $p/\lambda=0.2$ and $w/p=0.5$, respectively. The strips form an angle $\gamma=\pi/3$ with the normal to the edge. The UTD solution (continuous line) has been obtained by considering only the first order diffraction contributions arising from the two parallel edges. The UTD solution exhibits a quite good agreement with the MoM data (dashed line) around the specular direction. A better agreement in the directions outside the main scattering beam can be obtained by including higher order diffraction terms. Other numerical comparisons will be shown at the conference.

Finally, the numerical investigations addressed in this paper will be extended to the analysis of more complicated periodic surfaces (as for example 2D periodic structures) with the main goal of checking the accuracy of heuristic diffraction coefficients which are obtained from either approximate boundary conditions or the reflecting and transmitting coefficients derived for the corresponding infinite periodic surface.

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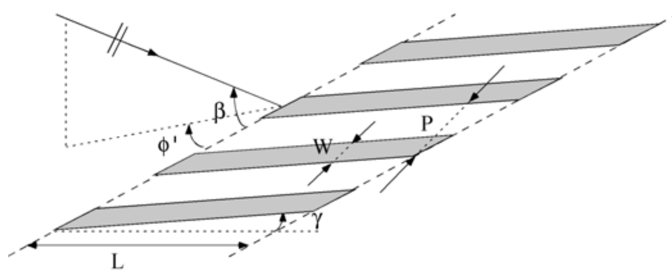

Fig. 1 - Geometry for the scattering from a large planar strip made of parallel free-standing dense metallic strips, and illuminated at oblique incidence by an arbitrarily polarized plane wave. The distance between the two edges of the planar strip is equal to L. The parallel metallic strips are in air, their periodicity and width are denoted by *p* and *w*, respectively. The orientation of the metallic strips with respect to the edge is given by the angle γ. ($\gamma = \pi/2$ when the strips are parallel to the edge and $\gamma = 0$ when the strips are perpendicular to the edge).

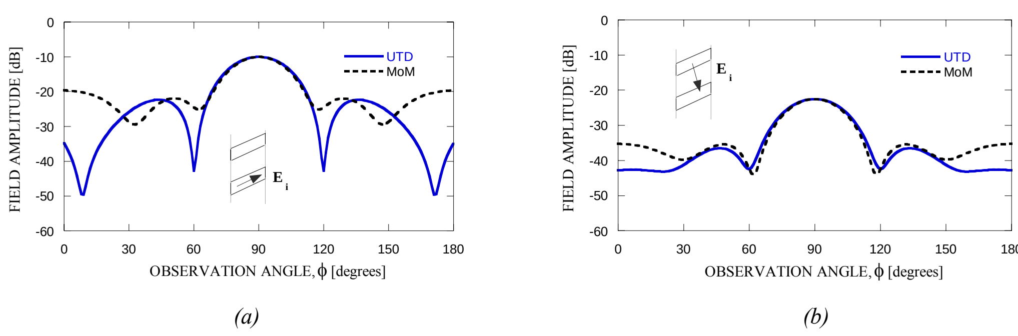

Fig. 2 – Amplitude of the scattered field evaluated around the strip at a distance $\rho = 10\lambda$ from the center of the strip itself. The strip is illuminated by a plane wave impinging from the direction $\beta = \pi/2$, $\phi' = \pi/2$. The geometrical parameters are: L=2 λ, $p/\lambda = 0.2$, w/p=0.5, $\gamma = \pi/3$. Continuous line: UTD solution with first order diffraction terms; dashed line: MoM data. *(a)* Incident electric field parallel to the metallic strips; *(b)* incident electric field perpendicular to the metallic strips.