SURFACE MODELLING FOR EM INTERACTION ANALYSIS

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ABSTRACT

This paper deals with the numerical modelling of the surface of a structure with a wire grid or a surface patch for Electromagnetic (EM) interaction analysis. Surface currents and fields on a wire grid model are computed using the Numerical Electromagnetic Code (NEC). The results are compared with those obtained on a triangular surface patch model using an Electric Field Integral Equation (EFIE) formulation. Simple structures such as a square plate as well as complicated structures such as an aircraft are considered. Good agreement is obtained in most cases.

INTRODUCTION

Numerical modelling of a surface with a wire grid has been used for many electromagnetic antenna radiation and scattering problems [1-4]. It has many attractive features and is capable of giving reliable far-field results if a proper choice of wire diameters and grid size is made [5]. However, some questions have been raised regarding the validity of using wire grid models of a closed surface when calculating electromagnetic pulse (EMP) interactions [6]. These questions arise because, for calculating EMP interaction, one must determine the currents and current densities induced on the surface. In the case of a structure with a closed surface, the field must vanish identically in the interior region, whereas for the wire grid model, there is an evanescent reactive field clinging to both sides of the grid. Even for a structure with an open surface (e.g. a plate) there are questions regarding the variation of the current around the wire circumference, and regarding the behaviour of the fields between the wires and at the junctions.

There are also questions regarding the choice of the wire diameters in a wire grid representation. There are rules for choosing wire diameters for obtaining reliable results for far field quantities. It is not clear whether the same rules apply for the estimation of currents and current densities induced on a structure exposed to EMP.

This paper attempts to answer some of these questions by comparing wire grid and surface patch modelling for a number of structures. Simple structures such as a square plate as well as complicated structures such as an aircraft are considered. The Numerical Electromagnetic Code (NEC) [1] is used for the wire grid models and the Electric Field Integral Equation (EFIE) [7] is used for the surface patch models. Surface currents and current densities induced on a structure due to an incident electromagnetic wave are computed using the two techniques and compared. Some modifications are required in the existing codes in order to deal with large number of wire or patch segments and to overcome difficulties involved in modelling surfaces where three patches have one common edge. Although the comparison is done in the frequency domain, the time domain behaviour can be obtained using the Fourier transform.

PROCEDURE

A wire grid representation of the surfaces of the body which is to be analyzed is first made following the rules given in the NEC documentation [1]. For a simple structure such as a square plate this is fairly straightforward. However, for a complicated structure the creation of a wire grid model is difficult and one must use specialized software such as DIDEC.DREO [8]. The diameter of the wires is chosen to follow the criterion that the surface area of the wire parallel to one linear polarization should be equal to the surface area of the solid surface being modelled [9]. The NEC is then used to determine currents at the centre of each wire segment. The induced H-field or surface current density at a point on the equivalent surface represented by the wire is then computed by

$$H_{induced} = \mathbf{I}/2\pi\mathbf{a},$$

where **I** is the current induced in the wire obtained by NEC computations and **a** is the radius of the wire.

In order to check the accuracy of the wire grid representation for determining surface current and currents, a surface patch model is created. This surface patch model uses the Electric Field Integral Equation (EFIE) instead of the magnetic field integral equation (MFIE) as proposed in the NEC. The surface of the body is modelled by triangular patches and a modified version of the program EFIE [10] is used to compute the surface current distribution. The modifications to the EFIE include the use of a new matrix LU factorization routine and the addition of a solution polisher. The new matrix factorization routine results in a great reduction in time. The solution polisher gives some extra significant digits whenever the impedance matrix is ill-conditioned. The induced H-field output of the EFIE is available at the edges of every triangular patch and is directed perpendicular to the edge and the normal to the surface.

Since the NEC wire grid modelling computations yield current and induced H-field along the axis of a wire and the EFIE triangular surface patch modelling computations yield induced H-field perpendicular to the triangle edge, care has to be taken in comparing data from the two models. The need for this care is demonstrated in Figures 1a to 1c which show the wire grid and the equivalent surface patch models for a square plate. The Figures show 90 wire rectangles for the wire grid representation and 84 triangular patches for the surface patch representation. This discretization is chosen to allow easy comparison of induced fields or charge densities along two principal cut lines of the square plate. Other discretizations are permitted as long as the rules of EFIE and NEC are not violated. The points along the two axes (XX' and YY') at which the surface fields are evaluated on the wire grid and the surface patch representation are shown in the Figures. These points are not identical but can be made so if required without much difficulty. It is obvious that making a choice of points for comparison also presents little difficulty in this simple case. However the choice of points for making a proper comparison between two representations is not always straightforward for a complicated structure such as an aircraft.

Figure 2a shows the J_x current density distribution along two principal cut lines (XX' and YY' in Figure 1) on a 1.0 wavelength square plate, illuminated by a plane electromagnetic wave incident normally on the plate. In Figure 2a and the subsequent Figures the induced current density normalized by the incident magnetic field intensity is plotted on the vertical axis. Because of the normalization this quantity has no units. The comparison between the wire grid and triangular surface patch results is very good except at the edges of the plate. The normalized current densities obtained by the wire grid model are smaller at the edges because the equivalent surface area is larger and the "equal-area" rule can no longer be followed.

If the diameter of the wires at the edges is reduced by half (Figure 1c), the wire grid results seem to match very well with the surface patch results even at the edges. This is shown in Figure 2b. The wire grid results at the edges of the plate perpendicular to the y-axis are, however, still not correct. Because of discontinuity, the normalized current density function is singular (i.e. has an infinite value) at these edges [7]. This infinite value can only be approached by the wire grid results in the limit, when the edge wire diameter and the area it represents become infinitesimally small. The surface patch results are not obtained at these edges.

Figure 3b shows the dominant current density distribution along a cut (line XX') through the symmetry plane of a 1.0 wavelength bent square plate (Figure 3a). The distance S shown in Figures 3b and 3c is measured along the plate from point X indicated in Figure 3a. The bend is located at two-third the plate width from this point and is parallel to the plate edge. A plane wave with the E-field parallel to the bend is incident normal to the large section of the plate. The smaller section is bent at an angle of 50° towards the shadow side of the plate. There are 72 (or 6x6x2) triangular patches for the EFIE solution versus 156 (or 13x12) wire rectangles for the wire gird model NEC solution. The diameter of the wires is chosen to satisfy the equal-area rule discussed earlier (although for simplicity they are not shown in Figure 3a). The comparison of the wire grid and the triangular surface patch models is again very good except close to the edges of the plate.

As discussed before, the discrepancy results from the non-compliance of the equal-area rule at the edges. Again, if the diameter of the wires at the edges is reduced by half, the agreement between the wire grid and the surface patch results is improved. This is shown in Figure 3c. Earlier comments on the singularity of the induced current density at the edges also apply here.

Figure 4a shows an example of a complicated wire grid model of an aircraft that is analyzed here. Figure 4b shows the equivalent surface patch model. The wire grid structure has already been analyzed for scattering and radiation properties [9]. In our case, the wire grid structure consists of 326 wire segments and the surface patch representation consists of 398 triangular patches. A plane wave with the electric field polarized parallel to the long axis of the aircraft is incident normal to the top of the aircraft. The x-axis runs parallel to the length of the aircraft (hence parallel to the incident electric field), with the reference point x=0 located in the middle of the attachment of the wings to the fuselage, and with positive x-coordinate values towards the front of the aircraft. Figure 5a compares the normalized current densities of the two models along the top fuselage of the aircraft at 20 MHz. The comparison shows a good agreement between the surface patch and the wire grid models. Figure 5b compares the normalized current density around the circumference of the fuselage at the front of the aircraft at 10 MHz. The agreement between the wire grid and the surface patch models is again quite good.

The discrepancy is partly explained by the fact that the points of observation are not identical in this case. In a complicated structure such as an aircraft, it is difficult to maintain the same observation points for the wire grid and the surface patch models.

Figure 6 shows the wire grid and the triangular surface patch models of a metallic cube with an open top. Each side of the cube is 1.0 wavelength long. The models consist of 405 wire rectangles and 408 triangular surface patches, respectively. A polarized plane wave is incident on the open face as shown. Figure 7 shows the normalized induced current density along the lines XX' and ZZ' on one face of the cube for the two models. The agreement between the models is very good even at the edges of the cube. It is to be noted that the wire diameters at the top edges (only at the open end) parallel to the incident field have been reduced to follow the equal-area rule. The current density at the open edge again exhibits a singular behaviour, and the earlier comments on the wire grid results apply.

EMP INTERACTION ANALYSIS

The above analysis can be performed for a number of frequencies as long as the rules of the wire grid and those of the surface patch representation are followed. Response to a pulse excitation such as the EMP can be obtained by convolution with the EMP spectrum and taking a fast Fourier transform of the response at a proper number of frequencies [11]. The procedure is simple for the cases of the flat square plate, the bent square plate, and the open-topped cube. However, for the case of the aircraft, difficulties arise because of the large number of wire segments or triangular patches required at the upper end of the EMP spectrum. The CPU time required in this case is considerable even for a single frequency.

CONCLUSIONS

We have computed induced surface fields for a number of structures for plane wave incidence. The limited number of examples treated indicate that the results obtained by the wire grid and the triangular surface patch models show good agreement and both models may be used to compute induced surface fields.

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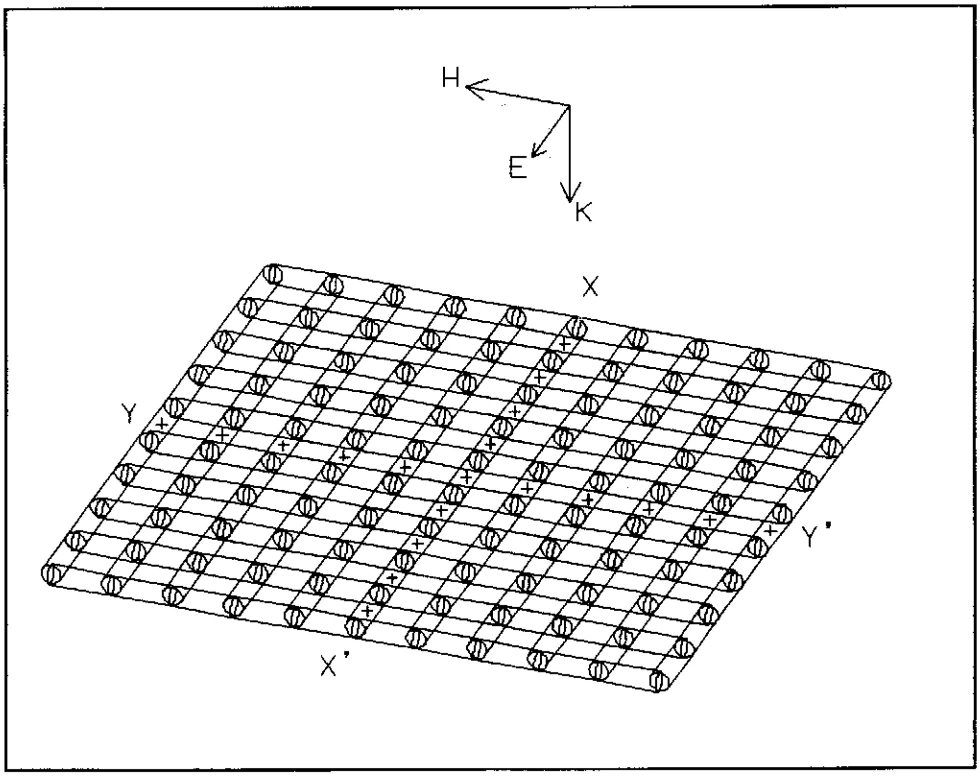

Figure 1a. Wire grid (NEC) model of a flat square plate with equal-area wire diameters.

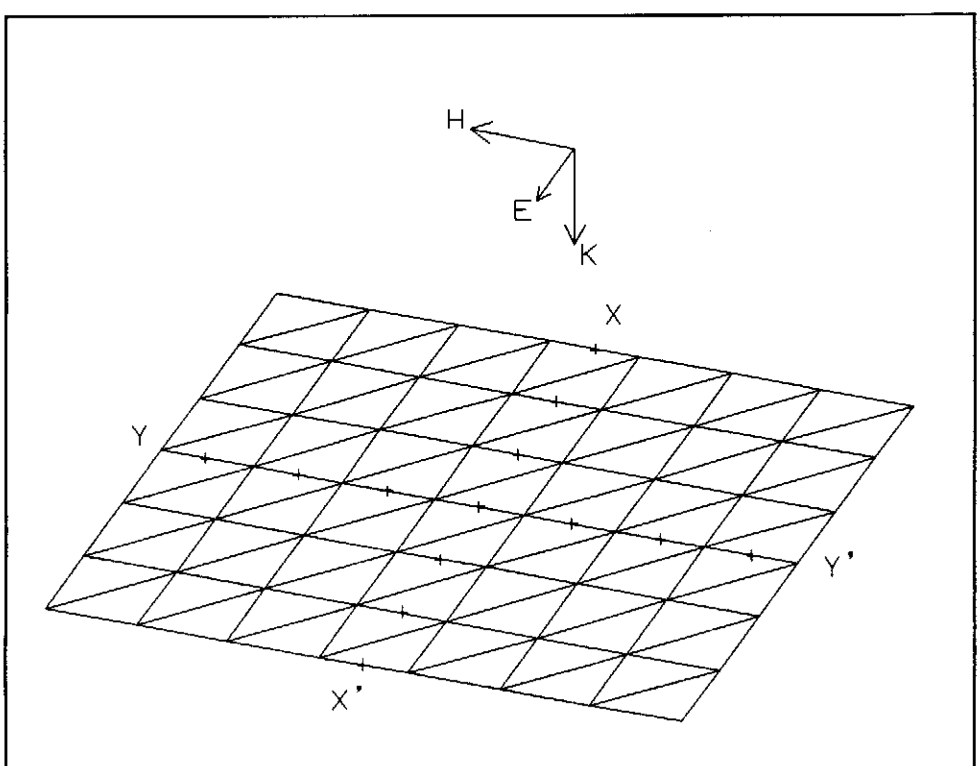

Figure 1b. Surface patch (EFIE) model of the flat square plate, equivalent to the wire grid model of Fig. 1a.

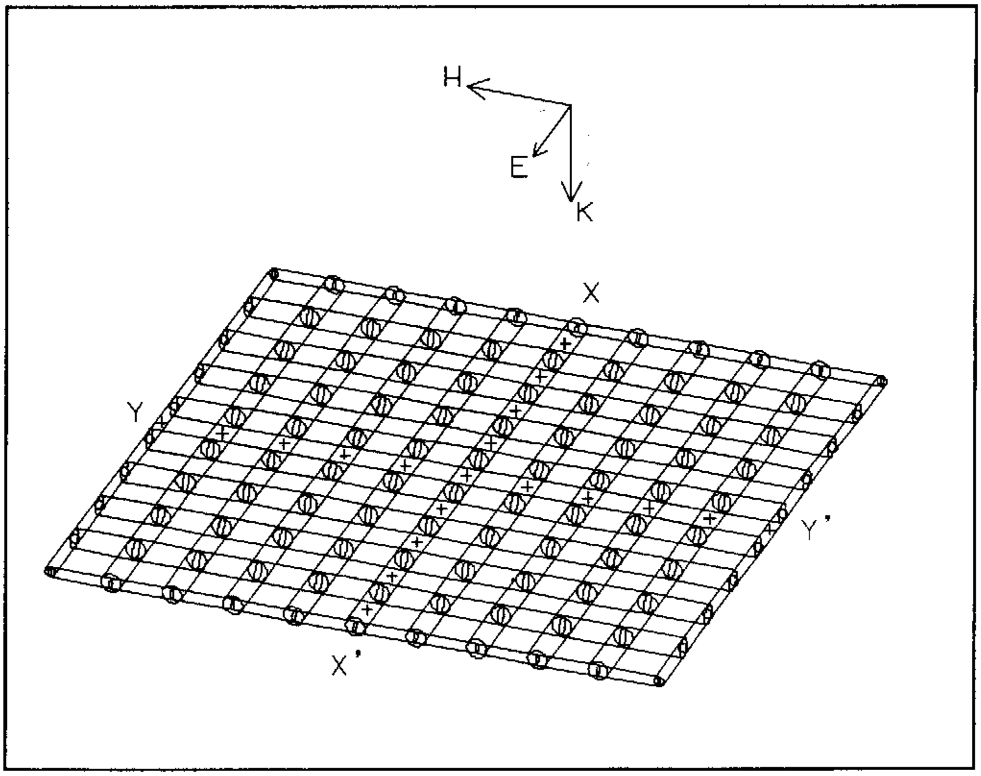

Figure 1c. Wire grid (NEC) model of the flat square plate with edge wire diameters halved.

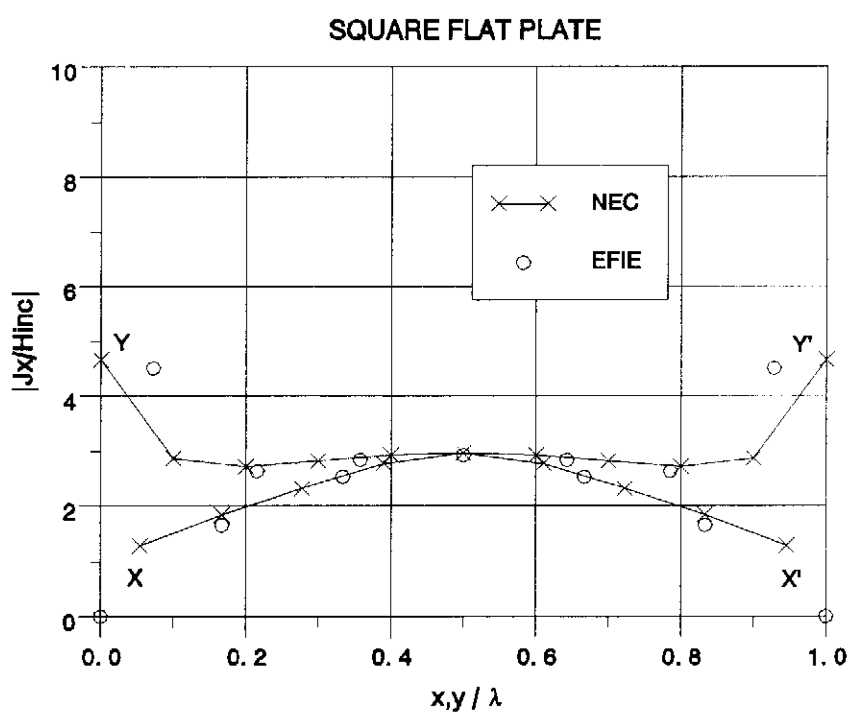

Figure 2a. Distribution of dominant component of current density along XX' and YY' on 1.0 lambda plate; x and solid line = wire grid (NEC) model of Fig. 1a, o = surface patch (EFIE) model of Fig. 1b.

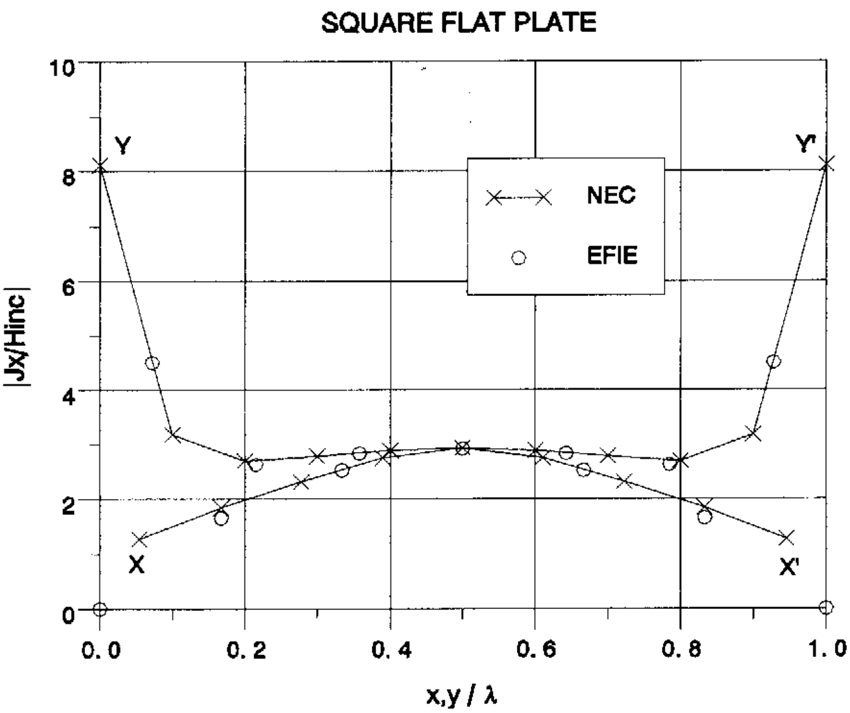

Figure 2b. Same as Fig. 2a, but with the wire grid (NEC) model of Fig. 1c (i.e. with edge wire diameters halved).

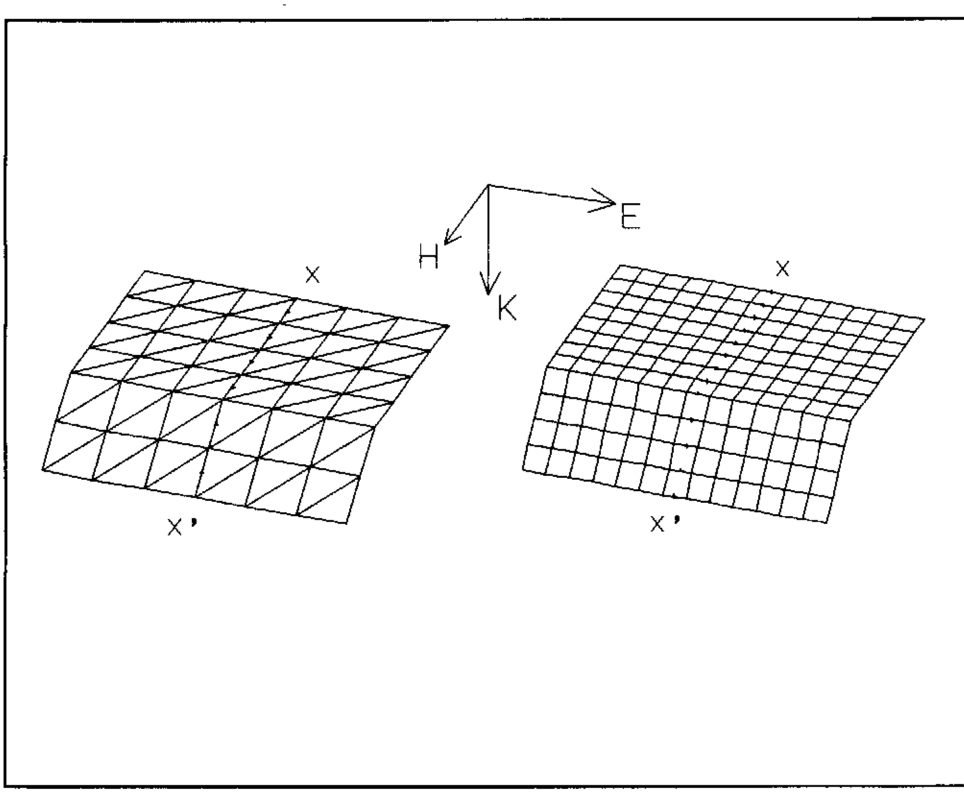

Figure 3a. Surface patch and wire grid models of a bent square plate

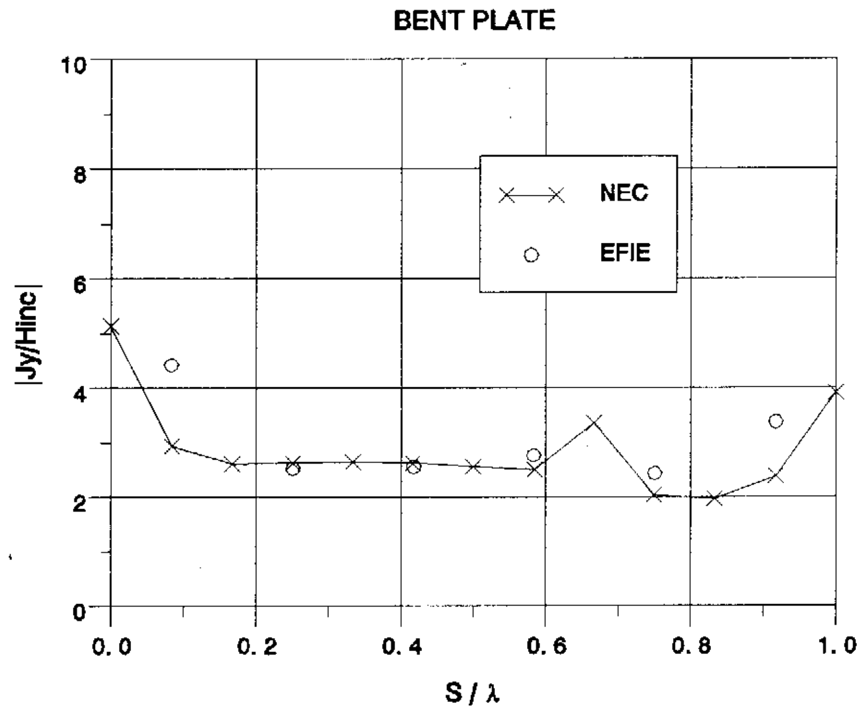

Figure 3b. Distribution of dominant component of current density along XX' on the bent square plate of Fig. 3a; x and solid line = wire grid (with equal-area wire diameters), o = surface patches.

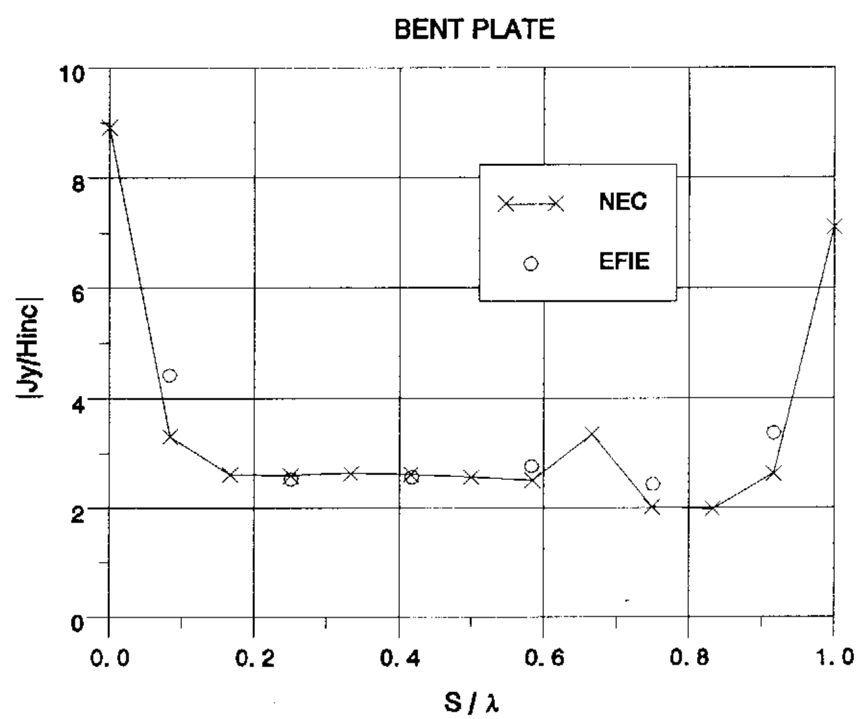

Figure 3c. Same as Fig. 3b, but the wire grid model has edge wire diameters halved.

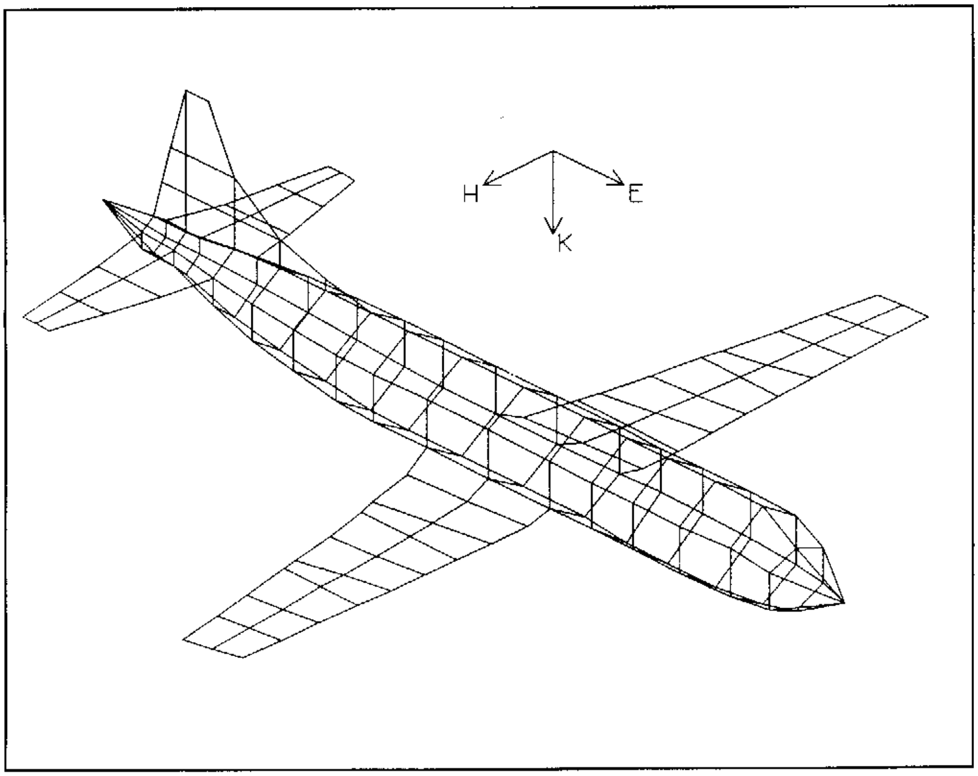

Figure 4a. Wire grid model of an aircraft.

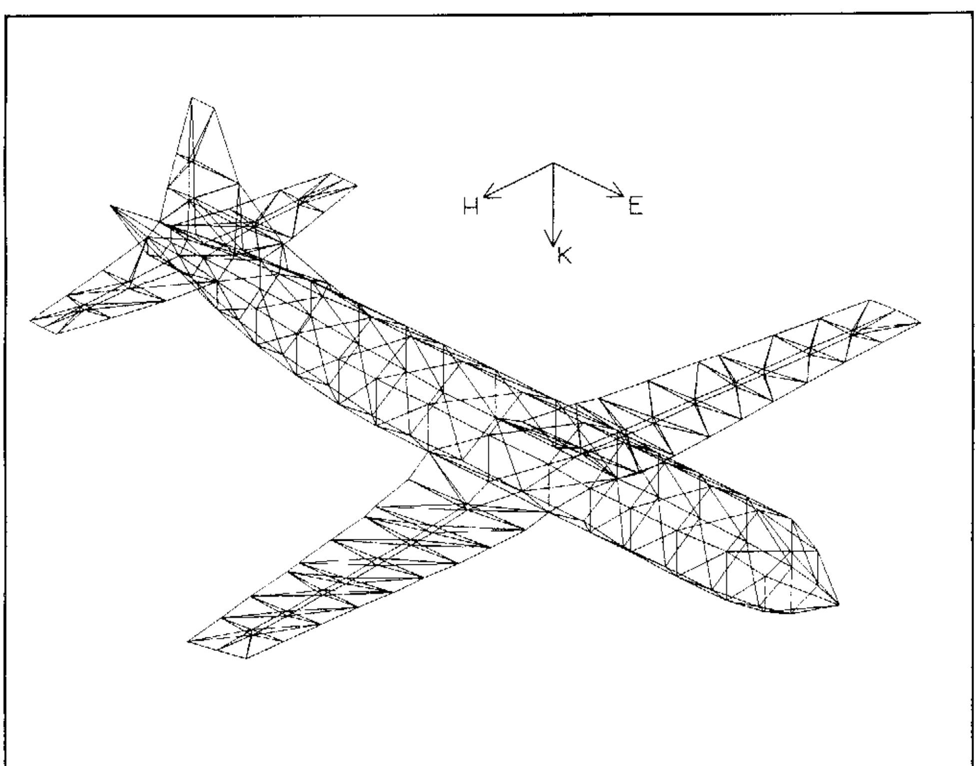

Figure 4b. Equivalent surface patch model of the aircraft in Fig. 4a.

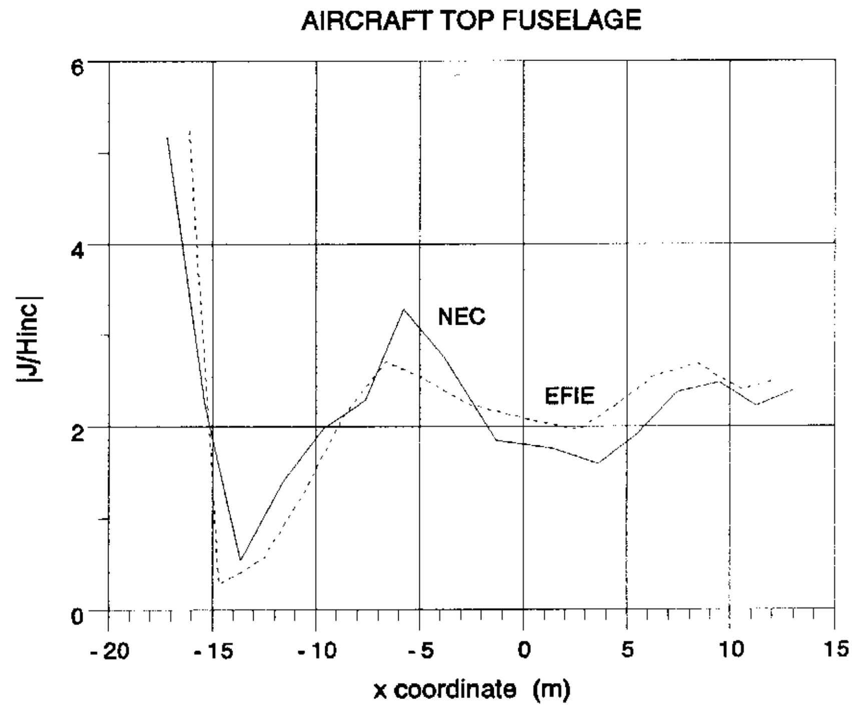

Figure 5a. Normalized current density distribution along the top of the fuselage of the aircraft in Fig. 4 at 20 MHz; solid line = wire grid (NEC), dashed line = equivalent surface patches (EFIE).

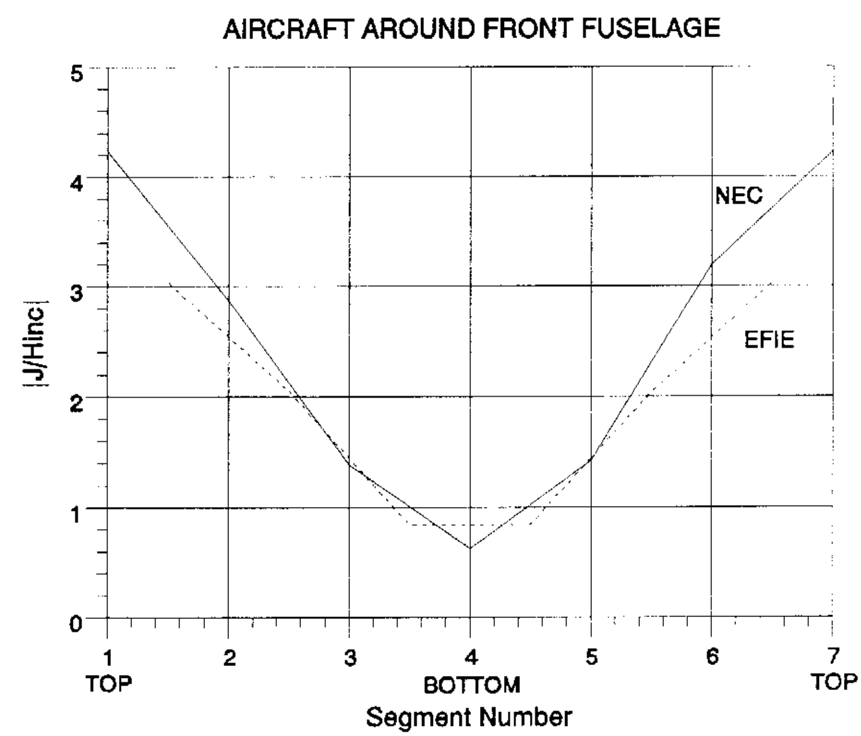

Figure 5b. Normalized current density distribution around the front fuselage of the aircraft in Fig. 4 at 10 MHz; solid line = wire grid (NEC), dashed line = surface patches (EFIE).

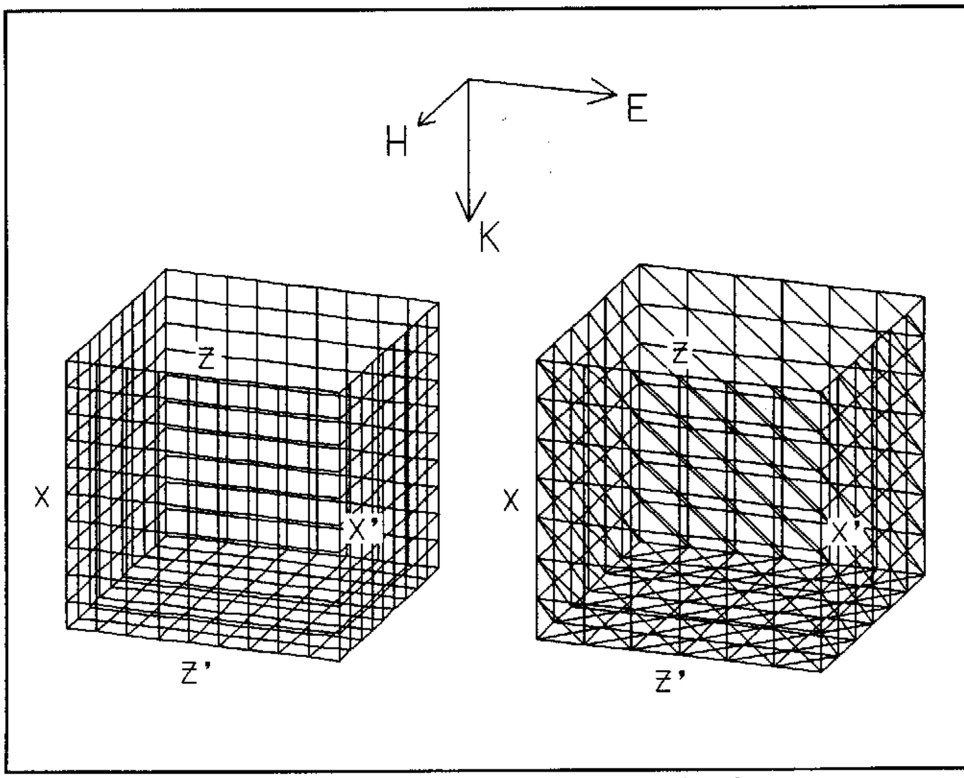

Figure 6. The wire grid and surface patch models of an open-topped cube.

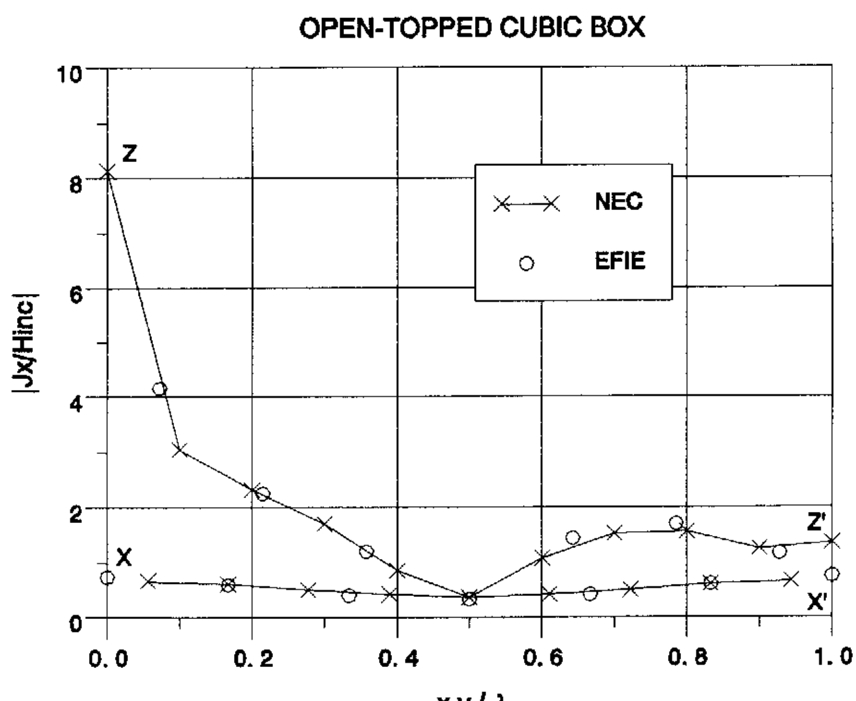

Figure 7. Normalized current density along XX' and ZZ' on the open-topped cube of Fig. 6; x and solid line = wire grid (NEC), o = surface patches (EFIE).