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SCATTERING OF ELECTROMAGNETIC WAVES FROM THE OPEN-ENDED WAVEGUIDE CAVITIES

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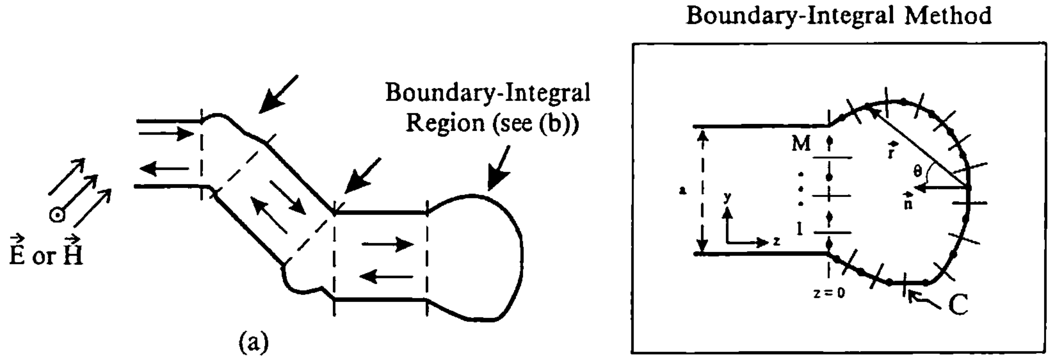
1. Introduction

The problem of scattering from open-ended cavities has received much attention recently in connection with radar cross section (RCS) reduction and electromagnetic penetration problems [1, 2]. Since a number of objects (ships, airplanes, and thelike) has a wide range of open-ended cavities (jet engine intakes, antenna windows, and so on), thus there is no way to decrease the secondary electromagnetic field of an object as a whole without a reduction of the secondary electromagnetic field of its cavities. In this connection the problem of the secondary electromagnetic field reduction of the open-ended cavities can be solved only by the computer simulation of the electromagnetic scattering from open-ended cavities.

In this paper, the problem of the electromagnetic sattering from open-ended cavities is presented. The open-ended cavity is considered as an open three-dimensional waveguide cavity with perfect electric conducting walls (Fig. 1). The cavity consists of several uniform waveguide sections (rectangular or circular waveguides) connected by arbitrary discontinuity regions (an amplifier, a phaser, and others) and a termination with a complex shape.



(b)

Fig. 1. Scattering from waveguide cavities by the hybrid boundary-integral/modal approach. (a) Geometry of the waveguide cavity. (b) Boundary-integral region.

2. Theory

The hybrid boundary-integral/modal method (BIM/modal) [2-4] is used for analayzing the electromagnetic scattering from an open-ended waveguide cavity. The validity of this hybrid approach ranges from a cavity opening of one wavelength all the way up to more than ten wavelengths with moderate computational resources.

This approach bridges the gap between low-frequency numerical techniques and high-frequency ray techniques.

The BIM/modal method consists of the following four steps.

1) The three-dimensional cavity is broken down into the uniform and discontinuity regions (Fig. 1(a)).

2) The generalized scattering matrices of individual discontinuity regions (Fig. 1(b)) are calculated [2]. The initial boundary-integral equation for the electric field at the observation point P onto the boundary can be writtern as

$$E_x(P)=\int_C\left[\left(-\frac{jk}{2}\right)\cos\theta H_1^{(2)}(kr)E_x+\left(-\frac{\omega\mu}{2}\right)H_0^{(2)}(kr)J_x\right]ds. \tag{1}$$

Here $J_x=\left(\bar{n}\times\bar{H}\right)\cdot\bar{x}$ is the x-directed equivalent current along the boundary, r is the vector pointing from the source point along the boundary to the observation point P, and θ is the angle between the inward-pointing normal $\bar{n}$ at the boundary and $\bar{r}$. Via pulse expansion and point-matching, the above integral equation can be discretized into an matrix equation which can be solved numerically.

3) The generalized scattering matrix of the entire open-ended waveguide cavity is found by cascading the generalized sattering matrices of various regions. For uniform waveguide sections wich are long compared to the wavelegth, only the propagating modes are considered in the scattering matrix.

4) The radar cross section of the cavity is calculated using a reciprocity formulation in conjunction with the Kirchhoff's approximation. We should emphasize that the 2-D BIM/mode formulation can be extended to 3-D [2]. It has been found that an approximate relationship exists between the 2-D echo width (EW) of a parallel-plate waveguide and the 3-D RCS of a rectangular waveguide taken in the principal yz-plane [5]. This relationship is given by

$$RCS\approx\frac{2B^2}{\lambda}(EW) \tag{2}$$

where B is the x-dimension of the rectangular waveguide. It also becomes a better approximation at high frequencies $(a/\lambda>>1)$ and as $B\rightarrow\infty$.

Only the backscattering contribution due to the cavity interior is considered (when cavity aperture ranges between 1λ and 10λ), since other contributions such as rim diffraction and exterior reflections are only significant for very large aspect angles (measured from the longitudinal direction).

3. Results

The calculational procedure for determing of the characteristics of the open-ended waveguide cavities, the mathematical algorithm of the computer simulation of the problem and the computer program for the IBM PC 486 have been developed on the basis of the BIM/modal method.

The open-ended waveguide cavity under consideration is the offset bend (with perfect electric conducting walls) shown in Fig. 2. The waveguide opening is 5λ $(\alpha=30^\circ,\beta=20^\circ)$. The 2-D numerical results generated using the hybrid BIM/modal approach in E-polarization case are shown in Fig. 3.

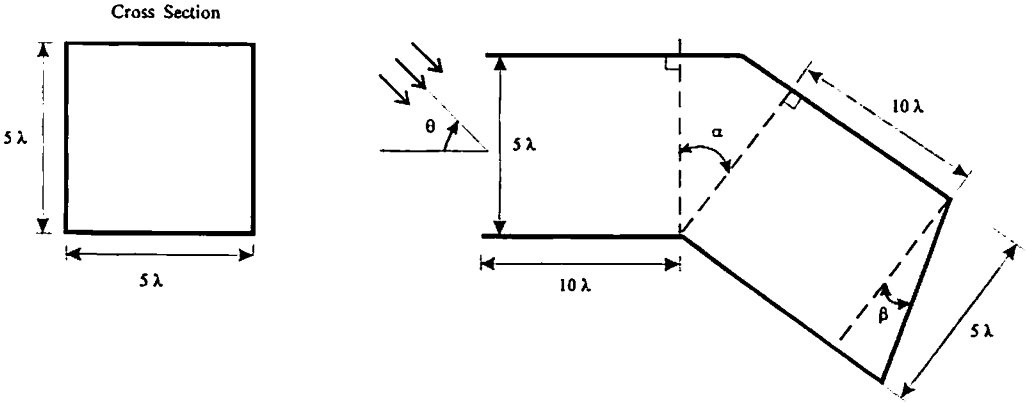


Fig. 2. Geometry of the offset bend ($\alpha = 30^\circ, \beta = 20^\circ$).

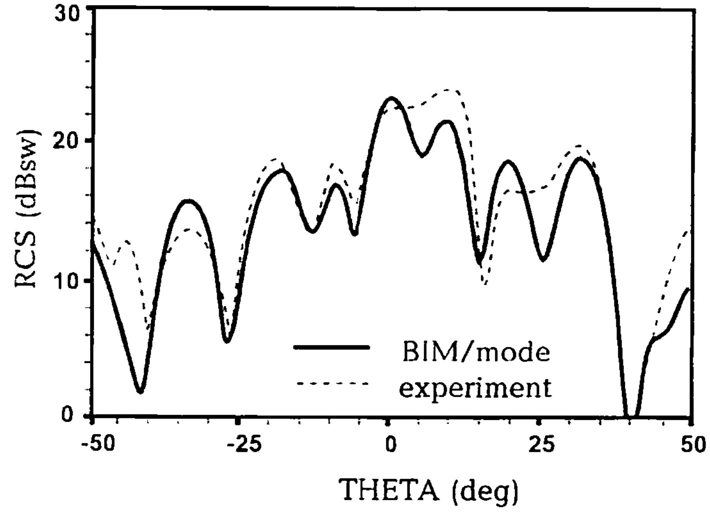


Fig. 3. Comparison between BIM/mode results and experiment. RCS versus θ of E-polarization.

We have investigated a convergence process stability of BIM/mode numerical solution. We have found that when a waveguide opening exceeds approximatly 3λ we come up against the problem of solution "ill-conditioning" matrix equation [6,7]. In our case we have solved the problem by putting "ill-conditioning" matrix equation in the "well-conditioning" form. The idea of this procedure is as follows. Let us assume that N is the number of equations obtained after discretization of the integral equation (1). As this takes place, M is the number of discretization points onto a waveguide opening (aperture). For calculation of a generalized scattering matrix of a discontinuity region taking into consideration K propagating modes (existing in an adjacent uniform region) we should solve a system of (N+K) equations. For calculation of the integral equation (1) with a good accuracy we should increase N. Therefore M will be also increased. When M exceeds K we match the tangential fields of adjacent uniform and discontinuity regions in aperture matching points locating at a distance exceeding a boundary discretization interval.

The good convergence in the scattering matrix of the waveguide cavity is obtained using the proposed procedure for the boundary discretization interval $W = 0.2632\lambda$ in the E-polarization case. In this case the number of equations for calculating the generalized scattering matrix of the one-port discontinuity termination equals 28, the condition number cond(28)=548.57, the power conservation condition $[S]^{*}[S]^{T} = I$ is satisfied within 3.5%. The number of equations for the two-port discontinuity (offset bend) equals 56, cond(56)=564.24 and the power conservation condition $[S]^{*}[S]^{T} = I$ is satisfied within 3.6%. The RCS data of the waveguide cavity are even less sensitive to the discretization size of the cavity boundary. Computational timewise, it takes less than 20 sec of CPU time on a IBM PC 486 to calculate the scattering matrix of a discontinuity with boundary perimeter of 20 wavelengths. Once the scattering matrices of individual sections are computed and stored, it takes a little additional time for cascading the scattering matricets and calculating the RCS of the waveguide cavity versus aspect angle data.

The hybrid BIM/mode results have been validated against the experimental data for the above offset bend. Shown in Fig. 3 is the comparison between 2-D numerical results generated using the hybrid BIM/modal approach and the obtained experimantal data. Excellent agreement between the 2-D theory and the actual 3-D experiment is observed up to an aspect angle of 35° before additional diffraction effects and exterior scattering come into play.

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