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Benchmark Targets for Computational Electromagnetics Programs Modeling Structures with Edges

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Introduction

This paper considers several target structures containing edges which are useful to validate computer codes developed to the purpose of detecting hidden mines and Unexploded Ordnance (UXO).
In particular, we investigate the capabilities of the singular basis functions' approach in Computational Electromagnetics for formulations based on surface integral equations.
We compare the solutions obtained with several analytical/numerical methods and validate the simulations with anechoic chamber measurements performed on metallic targets.

Singular Basis Functions in Computational Electromagnetics

Graglia and Lombardi [1-2] have recently defined singular vector basis functions on curved quadrilateral and triangular cells which are complete to arbitrarily high order. Finite Element (FEM) and Method of Moments (MoM) applications are described in [1] and [2], respectively.
The bases incorporate the edge conditions for penetrable or conducting wedges and they are of additive kind, because they are obtained by incrementing the regular polynomial vector bases [3] with other subsectional basis sets that model the singular behavior of the unknown vector field in the neighborhood of the wedge.
The completeness properties of these singular bases are discussed [1-2], and these bases are proved to be fully compatible with the standard, high-order regular vector bases used in adjacent elements. Our singular bases guarantee normal (or tangential) continuity along the edges of the elements allowing for the discontinuity of tangential (or normal) components, adequate modeling of the divergence (or curl), and removal of spurious solutions. The singular high-order bases provide more accurate and efficient numerical solutions for problems modeled by partial differential equations or by surface integral equations. The following benchmark test-case problems demonstrate the validity of our Method of Moments approach, by providing highly accurate numerical results for the radar cross section and for the current and charge densities induced on three-dimensional structures containing sharp edges.

Benchmark Targets

Metal spheres with concentric disks [4-5] of various thickness and truncated spherical shells [2, 6] are considered. These structures contain edges that are numerically modeled

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in the Method of Moments by the curvilinear elements described in [2]: singular edge and singular vertex elements.
Wings/fins are geometrically modeled by metal sheets of zero thickness when their thickness is much smaller than one wavelength.
The first type of benchmark target is a structure consisting of a sphere intersected equatorially by a concentric metallic circular disk. This target was constructed in aluminum with dimensions: radius a=76mm, radius b=190mm, thickness c=1mm, and is shown in figure 1.D. The disk can be numerically modeled with zero thickness as in figure 1.B, or with a finite thickness and sharp edges as in figure 1.C, or with decreasing thickness as in figure 1.A.
The second proposed benchmark test-case is the truncated spherical shell with very thin wall thickness, that it is usually modeled with a shell of zero thickness and sharp edges, as shown in Fig. 2.B. Different models with non-zero thickness are also considered.

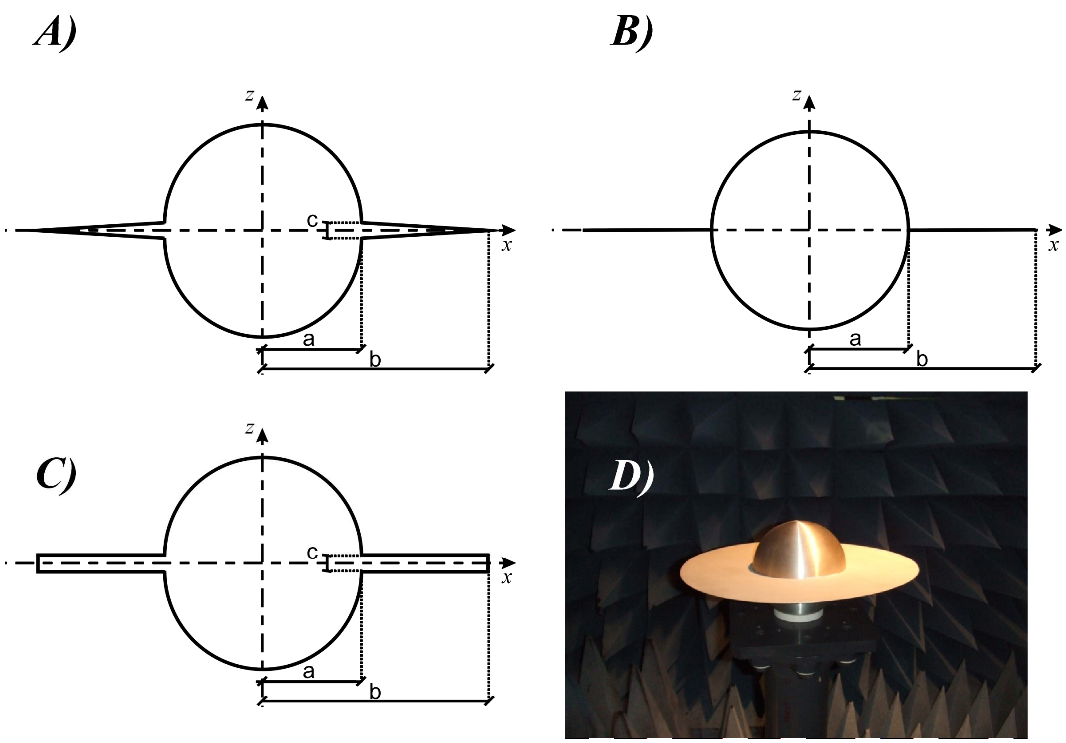

Fig. 1: A, B, C) Cross sectional view of the models for a metal sphere with disks of decreasing thickness, zero thickness, and finite thickness, respectively; D) Aluminum manufactured sphere with disk of radius a=76mm, radius b=190mm, thickness c=1mm.

Numerical Modeling

All the geometrical models described in Fig.1 have some drawbacks. First of all, the sharp edge is never really sharp (zero thickness). However, the sharp-edge approximation is necessary to reduce the cell density near the edge region in numerical simulations (Fig. 2).

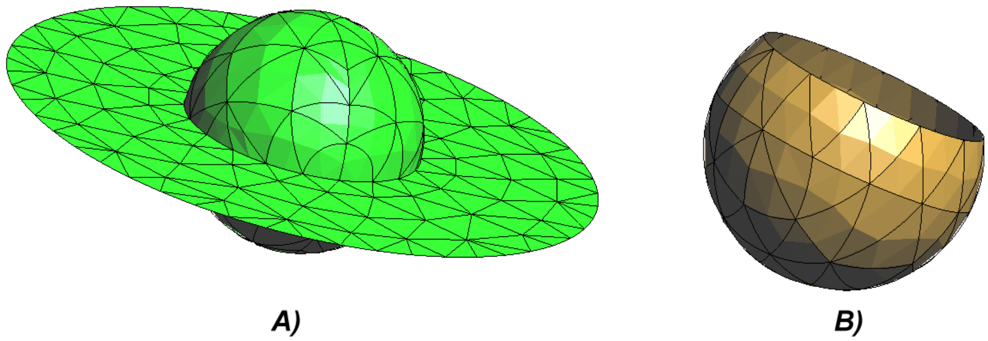

Fig. 2: A) Geometrical discretization of the model shown in Fig. 1.A with curvilinear triangular elements, B) Geometrical discretization with curvilinear triangular elements of the metal truncated spherical shell with zero thickness, radius $a=\lambda/(2\pi)$, and aperture angle of the hole $\theta_0=120°$ (as seen from the center of the sphere).

Another issue is the mathematical formulation of the problem [7]. While the truncated spherical shell with zero thickness can be dealt with Electric Field Integral Equation (EFIE) formulations, the metal sphere with concentric disk of zero thickness must be treated with a mixed integral equation formulations, i.e. the EFIE on the disk and the Combined Integral Equation (CFIE) on the sphere, in order to avoid spurious resonances.
The metal sphere with the zero-thickness disk shows a further modeling requirement for the equatorial region of the sphere attached to the disk, where the used triangular elements must satisfy the Kirchhoff Current Law in terms of the basis functions used to model the current density.

The numerical results obtained with our Method of Moments code and the singular basis functions will be compared with high-frequency analytical solutions based on the Geometrical Theory of Diffraction (GTD) and on Physical Optics (PO), as well as with measurements performed in the anechoic chamber of the Andrew Electromagnetics Laboratory of the University of Illinois at Chicago.
It should be noted that in the open literature results for the currents induced on structures with sharp edges are not readily available. In particular for the circular disk, available results are those obtained by Bouwkamp [8].

Conclusion

The proposed targets may be useful for radar calibration, and for the validation of computer codes developed for the numerical analysis of complex structures, such as hidden mines and Unexploded Ordnance (UXO).
In particular, singular high-order bases are able to provide accurate and efficient numerical solutions for problems modeled by surface integral equations.

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