An Electromagnetic Technique for Packaging Problem Analysis

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ABSTRACT

A new three-dimensional electromagnetic packaging analysis is developed for shielded configurations containing arbitrarily shaped, homogeneous, isotropic regions. Computer implementation uses and extends routines from a computational engine for electromagnetic scattering. The packaging analysis is validated using rectangular waveguide configurations. Preliminary analysis is performed on a filtering structure.

FORMULATION

The solution for fundamental mode scattering in a rectangular waveguide is considered here, although the formulation used is general enough for other shielded configurations excited by fundamental mode signals.

With a general package partitioned into regions of homogeneous, isotropic permittivity and permeability, the equivalence theorem [1] is applied successively to each region to yield a mathematical representation for the solution in that region and null fields outside the region. These fields are supported by surface electric and magnetic current densities existing on the surface bounding the region. These current densities constitute the problem unknowns. The requirement for null fields outside the region permits equating material properties outside the region to those inside. This allows expressing the electric and magnetic fields for that region in terms of the unknown current densities using the potential integral formulation [2] for currents existing in homogeneous space. For the n^{th} such region, having boundary surface denoted by ∂R_n, as shown in [3], the expressions for the fields are written in the form:

$$\mathbf{E}_n(\mathbf{r}) = -\frac{1}{\epsilon_n}\nabla\times\mathbf{F}_n - j\omega\mathbf{A}_n - \nabla V_n \qquad (1)$$

and

$$\mathbf{H}_n(\mathbf{r}) = \frac{1}{\mu_n}\nabla\times\mathbf{A}_n - j\omega\mathbf{F}_n - \nabla\mathcal{F}_n. \qquad (2)$$

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In the above equations the electric and magnetic vector potentials are given respectively by

$$\mathbf{A}_n(\mathbf{r}) = \mu_n \int_{\partial R_n} \mathbf{J}_n(\mathbf{r}')\Phi_n(R)ds' \qquad (3a)$$

$$\mathbf{F}_n(\mathbf{r}) = \epsilon_n \int_{\partial R_n} \mathbf{M}_n(\mathbf{r}')\Phi_n(R)ds' \qquad (3b)$$

and the electric and magnetic scalar potentials by

$$V_n(\mathbf{r}) = \frac{-1}{j\omega\epsilon_n}\int_{\partial R_n}(\nabla'\cdot\mathbf{J}_n(\mathbf{r}'))\Phi_n(R)ds' \qquad (4a)$$

$$\mathcal{F}_n(\mathbf{r}) = \frac{-1}{j\omega\mu_n}\int_{\partial R_n}(\nabla'\cdot\mathbf{M}_n(\mathbf{r}'))\Phi_n(R)ds' \qquad (4b)$$

where the 3-dimensional Green's function, Φ_n, wave number, k_n, and distance, R from source point at position $\mathbf{r}'$ to field point at position $\mathbf{r}$ are

$$\Phi_n(R) = \frac{e^{-jk_nR}}{4\pi R} \qquad (5a)$$

$$k_n = \omega\sqrt{\mu_n\epsilon_n}, and \qquad (5b)$$

$$R = |\mathbf{r}-\mathbf{r}'|. \qquad (5c)$$

Writing similar expressions for each homogeneous region and using them in the boundary condition expressions at each region boundary as described in [3], the system of equations to be solved for the unknown currents is obtained. In addition to specifying the physical boundary conditions, for example dielectric-dielectric interface or perfect electrical conductor(pec), a boundary condition is also applied to represent matched feed structure(s) connected to the package. As described in [3], it is necessary that the distances from scatterers to where this condition is applied be sufficient to assure that only a single mode exists at the boundary.

WE 3F

IMPLEMENTATION

To be able to represent the geometries of arbitrary region boundaries, a triangular grid representation is

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constructed of all region boundaries. This representation is used in conjunction with Rao-Wilton-Glisson [4] vector roof-top functions used in a Galerkin method of moments solution procedure. Figure 1 shows triangles representing the surface boundary on the left side of the package and how the magnetic current at a point within a triangle on that surface, $\mathbf{M}^s$, is determined in terms of the roof-top functions associated with each of the three edges of the triangle and the current coefficients $\mathbf{M}_1$, $\mathbf{M}_2$, and $\mathbf{M}_3$ calculated for each edge in the solution procedure.

To accomplish the Galerkin solution mentioned, use was made of the CARLOS-3D^{TM} computer program for unbounded electromagnetic scattering, [5], which represents geometry and basis functions as described above. It also calculates and solves the method of moments system for plane wave excitation. As described in [3], modifications were made to model fundamental mode rectangular waveguide excitation and the strategy described to use this code, or generally any such routine or utility, as a computational engine in the shielded packaging formulation presented.

TEST CASES

To demonstrate the correctness of this formulation and implementation, simple terminations on the right side of the package(the S2-plane) of Figure 1 are considered. For the case of z-directed TE_{10} illumination from the left side, reflection coefficients are calculated at z=0(the S1 plane).

Figure 2 shows the reflection coefficient magnitude calculated with this formulation and values obtained from basic transmission line considerations.

The reflection coefficients presented in this paper are determined from averages of the reflection coefficients calculated at triangle centroids of the two center columns of triangles shown in Figure 1. Details are given in [3]. It is noted that actual fields and reflection coefficients could have been calculated by using the current coefficients calculated in a numerical evaluation of the potential integrals given earlier, but the efficient method used here exploits the geometry of the S1 plane and the equivalence theorem relations between tangential fields and equivalent currents on the S1 plane. Figure 3 gives the actual distribution of reflection coefficients calculated at triangle centroids for a shorted termination at the S2 plane.

Figure 4 gives reflection coefficients, calculated and theoretical, for a step change in the dielectric constant at the package midpoint.

Finally, Figure 5 applies this general approach to a thin symmetrical inductive iris in the plane at the package midpoint and compares the results with those obtained using a more specialized approach [6].

EXAMPLE

A structure of interest in filtering applications [7] is analyzed with reflection coefficient magnitudes presented in Figure 8 for three structure thicknesses - 0.0 mm, 0.635 mm, and 1.27 mm. Figure 7 shows the 0.635 mm thick structure in the waveguide. Reflection coefficient magnitude and reactance for the zero thickness structure alone, located in the plane at the midpoint of the package, is shown in in Figure 6.

References

[1] R. F. Harrington, *Time-Harmonic Electromagnetic Fields*, p. 106. McGraw-Hill, New York, 1961.

[2] E. C. Jordan and K. G. Balmain, *Electromagnetic Waves and Radiating Systems*, p. 468. Prentice-Hall, Englewood Cliffs, N.J., 1968.

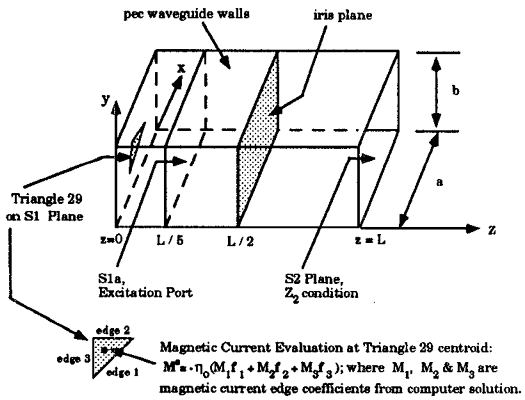
[3] K. E. Krause, *An Electromagnetic Technique for Packaging Problem Analysis.* Dissertation, Washington University, St. Louis, MO, Aug 1995.

[4] S. M. Rao, D. R. Wilton, and A. W. Glisson, "Electromagnetic scattering by surfaces of arbitrary shape," *IEEE Trans. on Antennas and Propagation*, vol. AP-30, pp. 409–418, May 1982.

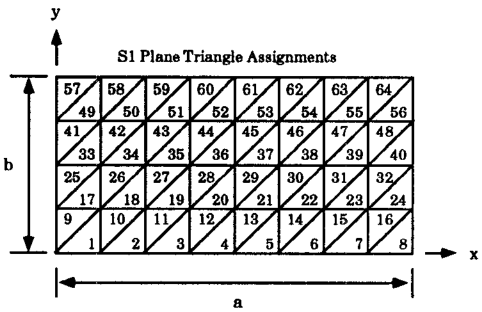
[5] L. N. Medgyesi-Mitschang, J. M. Putnam, and M. B. Gedera, "Generalized method of moments for three-dimensional penetrable scatterers," *J. Opt. Soc. Am. A*, vol. 11, pp. 1383–1398, April 1994.

[6] N. Marcuvitz, *Waveguide Handbook*, pp. 221–224. McGraw-Hill, New York, 1951.

[7] D. Swanson. PRIVATE COMMUNICATIONS, Jan. - April, 1995.



(a)



(b)

Figure 1: Determining Waveguide Package S1 Plane Scattered Magnetic Currents: (a) Configuration, (b) S1 Plane Triangle Assignments.

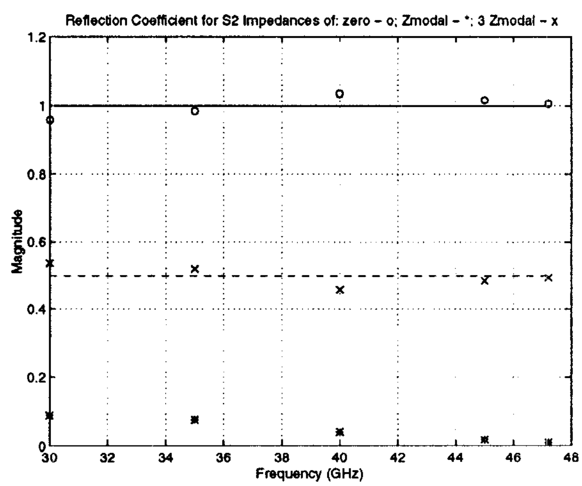


Figure 2: Reflection Coefficient Magnitude for Three S2 Plane Impedance Conditions.

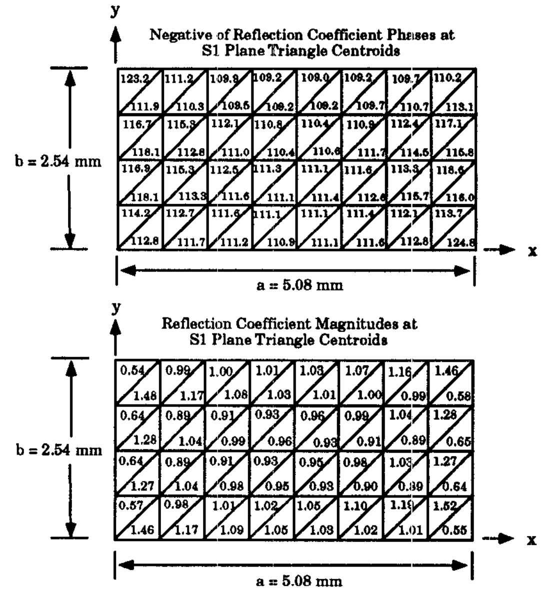


Figure 3: Reflection Coefficient Distribution over S1 plane for S2 a pec 6.35 mm from S1; Theoretical Magnitude is 1.0 and Phase is approximately -107.1 at 35 GHz.

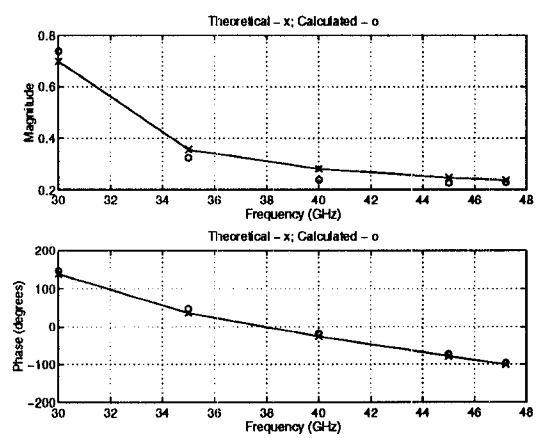


Figure 4: Reflection Coefficients, referred to $z = 0$, for Rectangular Waveguide Package with step change in relative dielectric constant from 1 to 2 at $z = 3.175$ mm. Waveguide cross-section is 5.08 mm x 2.54 mm

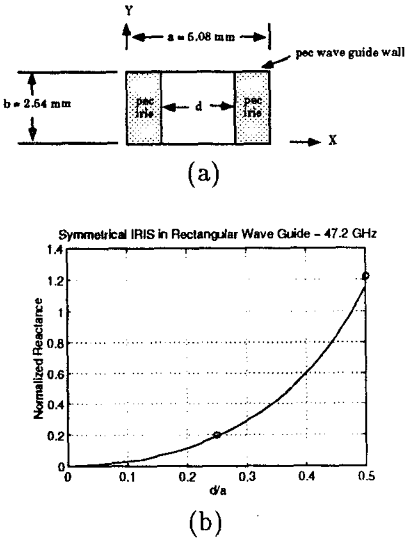


Figure 5: Symmetrical Inductive IRIS Obstacle: (a) Configuration, (b) Reactance Comparisons, Marcuvitz [6] - solid, New Approach - circles.

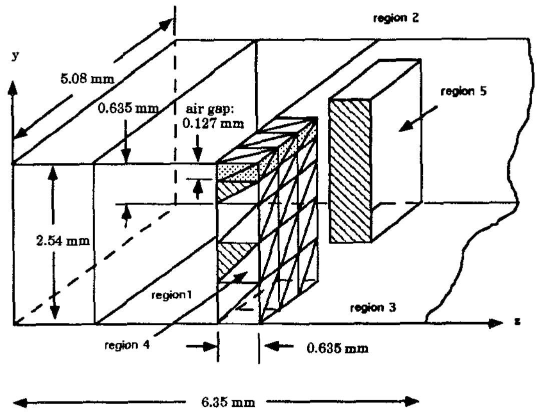


Figure 7: Waveguide Regions in Partial Iris Build Out Simulations. All rendered gap triangles(size exaggerated for clarity) are shown shaded and some pec areas are shown cross-hatched for reference.

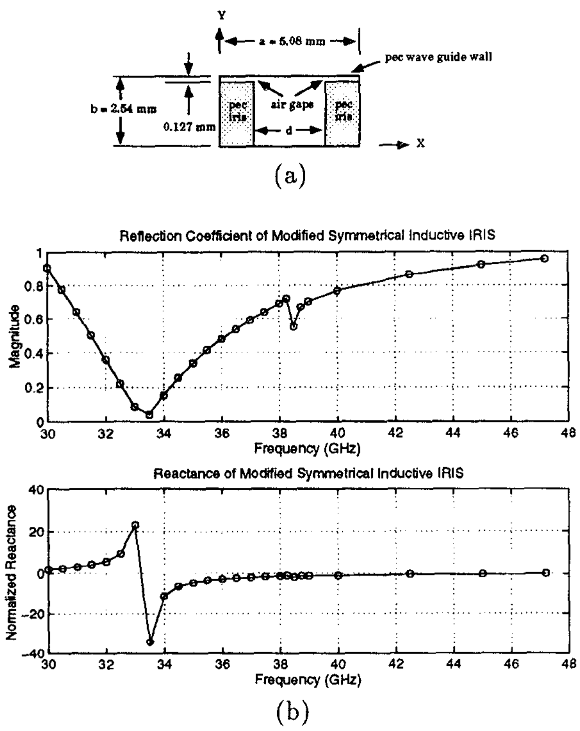


Figure 6: Modified Symmetrical Inductive IRIS Obstacle: (a) Configuration, (b) Plots of Reflection Coefficient Magnitude and Normalized Reactance.

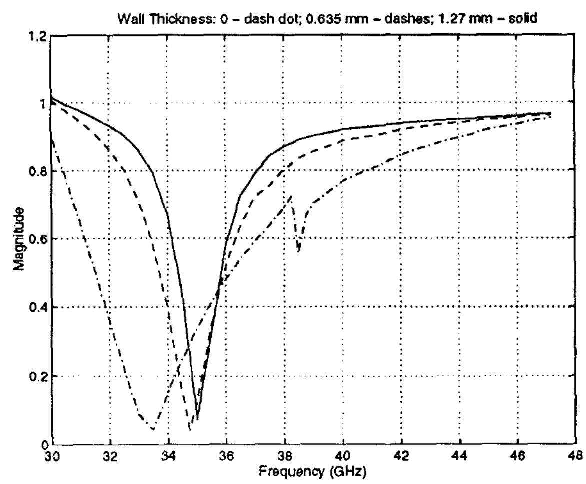


Figure 8: Reflection Coefficient Magnitude for Three Filter Configurations
All curves contain values at the 23 frequencies of 30.0, 30.5, 31.0, 31.5, 32.0, 32.5, 33.0, 33.5, 34.0, 34.5, 35.0, 35.5, 36.0, 36.5, 37.0, 37.5, 38.0, 38.5, 39.0, 40.0, 42.5, 45.0, and 47.2 GHz. In addition, the dashed curve has a value at 34.75 GHz and the dash dot curve has values at 38.25 and 38.75 GHz.