

FE-BI METHOD FOR ANALYZING P-BAND CYLINDRICAL CONFORMAL MICROSTRIP ANTENNA AND ARRAY

HongLi Peng, Zheng Huang ,WenBin Han

ABSTRACT

An edge-based hybrid finite element boundary integral (FE-BI) method using cylindrical shell elements is described for analyzing conformal quarter-wave patches embedded in a circular cylinder. Special care is also taken to deal with weight functions, dyadic Green's function, and feed model. Some types of the patch arrays embedded in different circular radius have been developed. The tests of their VSWRs and radiation characteristics are in good agreement with the theoretical results.

KEY WORDS

FE-Method, Quarter Wavelength Patches, Circular Cylinder

INTRODUCTION

Microstrip antennas and arrays are being widely used on cylindrical flights because they are conformal, easy configuration, low profile, lightweight, and have the ability to bear high acceleration and great range of temperature variation if special techniques are used. Consequently, much literature exists on their operation, analysis and design. In most cases, however, available models such as the cavity model, when it deals with the arrays, the mutual couple among each patch have generally been neglected, which makes the analysis results inaccurate or full-wave integral method will lead to great storage requirements and cost much time, and will severely restrict them to small scale applications. Recently, the finite element boundary integral (FEBI) method was successfully employed for planar/unplanar arrays analysis. In the paper, this method is used to analyze the characteristics of the quarter-wavelength rectangular patches and arrays embedded in some circular cylinders.

1. Analysis Model Using FE-BI

The three-dimensional structure associated with a coordinated system is illustrated in Fig.1. Using the variational approach, the weak form of the wave equation for Fig.1 can be written as (1), Where, \bar{w}_j are vector basis functions with support over the volume V_i , which

is associated with the i th degree of freedom, and in a similar fashion, S_i and S_j represent the aperture surface associated with the i th and j th degrees of freedom, respectively.

$$\int_{V_i} \left\{ \frac{\nabla \times \vec{W}_j(\mathbf{r}, \mathbf{f}, z) \cdot \nabla \times \vec{W}_i(\mathbf{r}, \mathbf{f}, z)}{\mathbf{m}_r(\mathbf{r}, \mathbf{f}, z)} - k_0^2 \mathbf{e}_r(\mathbf{r}, \mathbf{f}, z) \vec{W}_j(\mathbf{r}, \mathbf{f}, z) \cdot \vec{W}_i(\mathbf{r}, \mathbf{f}, z) \right\} r dr dz + (k_0 a)^2 \mathbf{d}_a(j) \cdot \mathbf{d}_a(i) \quad (1)$$

$$\int_{S_i} \int_{S_j} [\vec{W}_i(a, \mathbf{f}, z) \cdot \hat{\mathbf{r}}(a, \mathbf{f}, z) \times \vec{G}_2(a, \bar{\mathbf{f}}, \bar{z}) \times \hat{\mathbf{r}}(a, \mathbf{f}', z') \cdot \vec{W}_j(a, \mathbf{f}', z')] d\mathbf{f}' dz' df dz = f_i^{\text{int}} + f_i^{\text{ext}}$$

The appropriate dyadic Green's function denoted by \vec{G}_2 has convolutional ($\bar{\mathbf{f}} = \mathbf{f} - \mathbf{f}', \bar{z} = z - z'$) form when evaluated on the surface of the cylinder. The free-space propagation constant is given by $k_0 = 2\pi / \lambda_0$, where λ_0 is the freespace wavelength. The cavity is filled with an inhomogeneous material having relative constitutive \mathbf{e}_r and \mathbf{m}_r . The function $\mathbf{d}_a(i) \cdot \mathbf{d}_a(j)$ is the product of two kronecker delta functions. Hence, it identifies which pairs of unknowns belong to the aperture and accordingly contribute to the boundary integral submatrix. The right hand side contains an internal source (f_i^{int}) and an external source (f_i^{ext}) term.

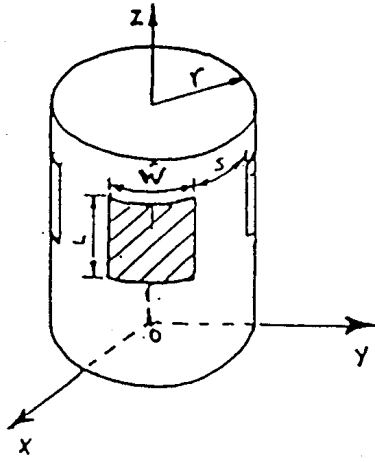


Fig.1 The antennas structure and associated coordinate system

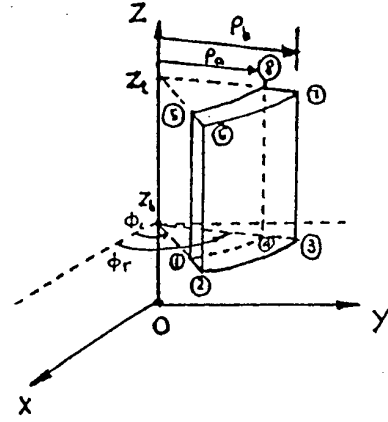


Fig.2 Cylindrical shell element

1.1 Finite Element Discretization and Governing Equations

To construct a system of equations from (1), the volume V is first subdivided into a number of small elements. Each of those elements occupies a volume V_e ($e=1,2,3,\dots,M$). The field (total) in each element is then approximated by:

$$\mathbf{E}^e = \sum_{j=1}^M \mathbf{E}_j^e \vec{W}_j^e = \{\vec{W}^e\}^T \{\mathbf{E}^e\} \quad (2)$$

in which \vec{W}_j^e are the (vector)expansion basis functions .The unknown expansion coefficients E_j^e are obtained from (1) by Rayleigh-Ritz procedure[1] obtaining

$$\sum_{e=1}^M [A^e] \{E^e\} + \sum_{s=1}^{M_s} [B^s] \{E^s\} + \sum_{s=1}^{N_s} \{g_s\} + \sum_{p=1}^{M_p} \{C^p\} = 0 \quad (3)$$

where:

$$\begin{aligned} A_{ij}^e &= \iiint_{V_i} \left[\frac{1}{\mathbf{m}_r} (\nabla \times \vec{W}_i^e) \cdot (\nabla \times \vec{W}_j^e) - k_0^2 \mathbf{e}_r \cdot \vec{W}_i^e \cdot \vec{W}_j^e \right] dv \\ C^p &= \iiint \vec{W}_i^p \cdot \left[jk_0^2 z_0 \vec{J}_i + \nabla \times \left(\frac{1}{\mathbf{m}_{r1}} \vec{M}_i \right) \right] dv \\ B_{ij}^s &= jk_0 z_0 \iint_{S_r^s} \frac{1}{R} (\hat{n} \times \vec{W}_i^s) \cdot (\hat{n} \times \vec{W}_j^s) ds \\ g_i^s &= jk_0 z_0 \iint_{S_r^s} \vec{W}_i^s \cdot (\vec{H}^{scat} \times \hat{n}) ds \end{aligned}$$

1.2 Cylindrical Shell Element Model

Consider a cylindrical shell element shown in Fig.2. The element has eight nodes connected by twelve edges given by Volakis. Their three fundamental vector weight functions are rewritten here:

$$\begin{aligned} \bar{W}_r(\mathbf{r}, \mathbf{f}, z; \tilde{\mathbf{r}}, \tilde{\mathbf{f}}, \tilde{z}, \tilde{s}) &= \frac{\tilde{s} \mathbf{r}_b (\mathbf{f} - \tilde{\mathbf{f}})(z - \tilde{z})}{ah\mathbf{r}} \hat{\mathbf{r}} \\ \bar{W}_f(\mathbf{r}, \mathbf{f}, z; \tilde{\mathbf{r}}, \tilde{\mathbf{f}}, \tilde{z}, \tilde{s}) &= \frac{\tilde{s} (\mathbf{r} - \tilde{\mathbf{r}})(z - \tilde{z})}{th} \hat{\mathbf{f}} \\ \bar{W}_z(\mathbf{r}, \mathbf{f}, z; \tilde{\mathbf{r}}, \tilde{\mathbf{f}}, \tilde{z}, \tilde{s}) &= \frac{\tilde{s} (\mathbf{r} - \tilde{\mathbf{r}})(\mathbf{f} - \tilde{\mathbf{f}})}{th} \hat{\mathbf{z}} \\ : t &= \mathbf{r}_b - \mathbf{r}_a, a = \mathbf{f}_r - \mathbf{f}_l, h = z_t - z_b \end{aligned} \quad (4)$$

Having considered the shell element the next step is to assemble all such elements in the solution region. The process by which individual element coefficient matrices are assembled to obtain the global coefficient matrix is illustrated with Fig.3.

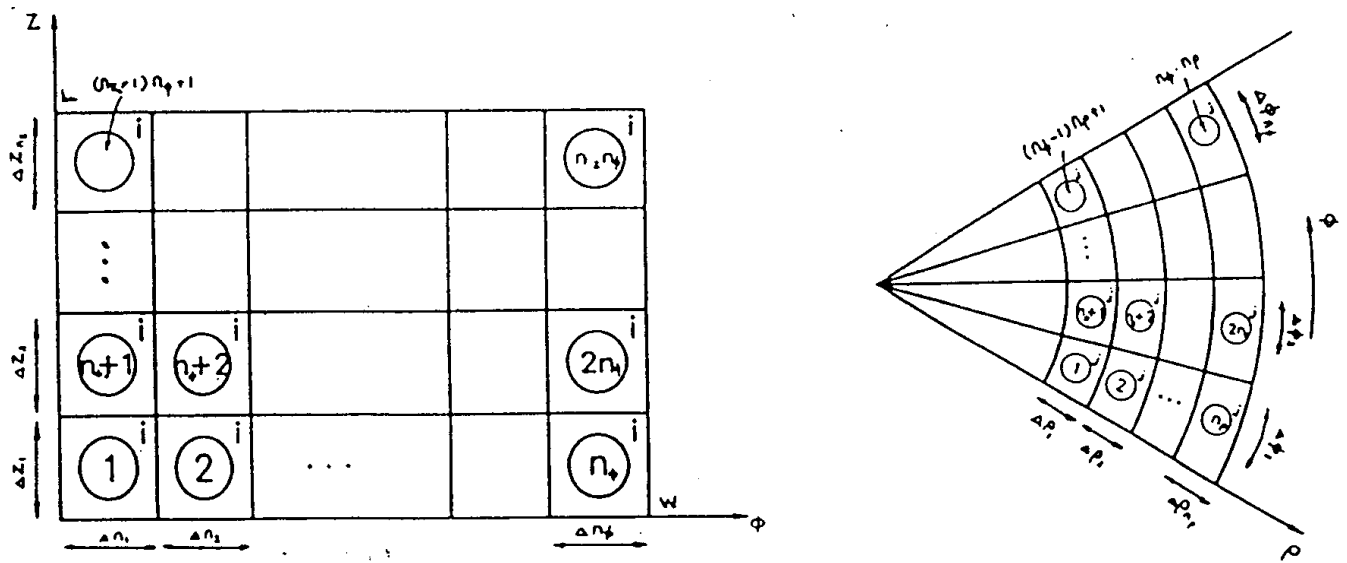


Fig.3 Discretization of a 3D cylindrical rectangular region in a nonuniform mesh layered element code

2. Results

We present below some representative numerical results to illustrate the validation of our method as well as the effect of various factors on the performance of the patch antenna/array. In each case the computed result via the FE-BI method are compared with measured data.

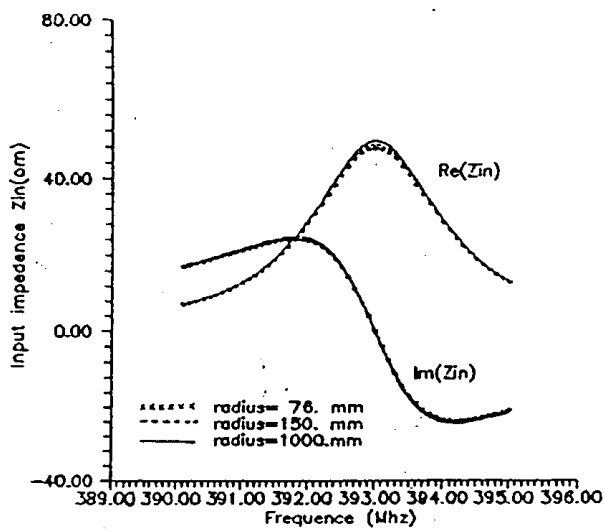


Fig 4 The single patch's input impedance with the different cylinder diameters

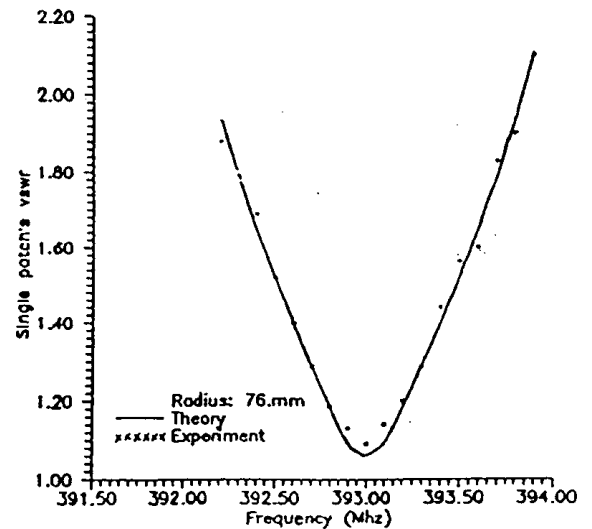
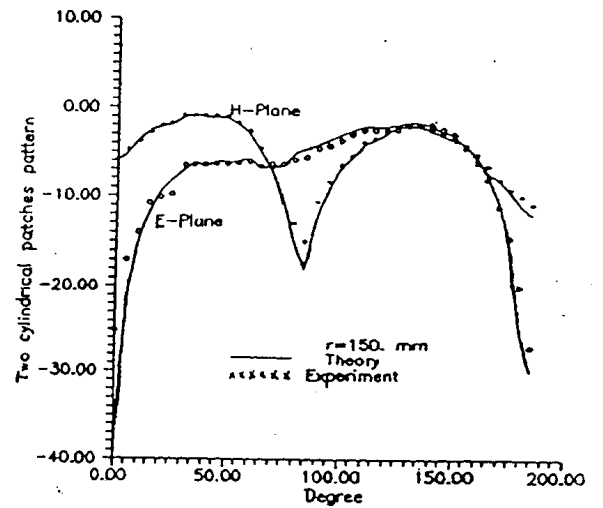
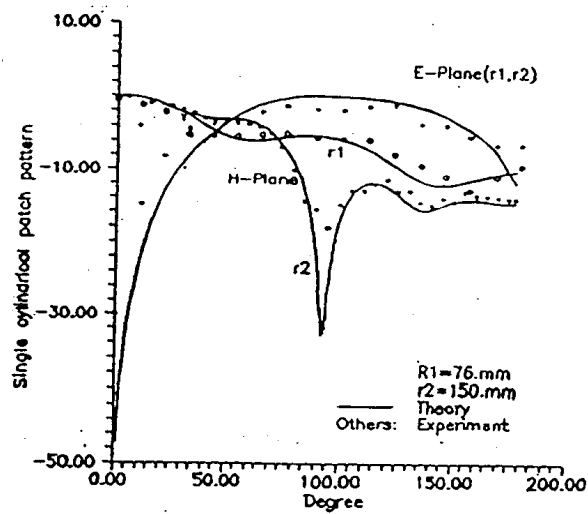


Fig.5 The single patch's VSWR compared with the test



(a) The single patch embedded in different cylinder diameters ($r=76.,150.,1000.$ mm)

(b) The double patch embedded in diameter ($r = 150.$ mm)

Fig.6 The patch's radiation characteristics

The specific single patch geometry size is 70mm132mm2.0mm and relative dielectric $\epsilon_r=2.2$ with one circular side shorted. The patch was housed in a 110mm152mm4 mm cylindrical rectangular cavity. Fig.4 shows the single patch's input impedance properties varying with different cylinder diameters. Fig.5 shows the single cylindrical patch's VSWR property compared with its experimental result. The radiation characteristics of single and double patches embedded in different cylinder diameters are also given and tested in Fig.6. The results of both the computations and tests show the validation of our method in the development of this type of antenna and arrays.

3. Acknowledgments

The author here thanks to Proferssor QiZhong Liu and Proferssor YongChang Jiao for their help.

4. References

- [1] Leo.C.Kempel and J.L.Volakis, "Scattering by Cavity-Backed Antennas on a Circular Cylinder," IEEE Trans.AP., Vol.42, NO.9, Sept.1994
- [2] J.M.Jin and J.L.Volakis, "Electromagnetic Scattering by and Transmission Through a Three-Dimensional Slot in a Thick Conducting Plane," IEEE Trans.AP, Vol.39, No.4, April 1994