Characteristic Mode Analysis of a Conformal Patch Mounted on Stratified Cylinder

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Introduction

Conformal cylindrical microstrip structures have been attracted increasing interest in recent years. Due to their conformal capability, they have been employed to many practical applications, such as antennas and antenna arrays in base stations, wireless communications, remote sensing and so on. To design and optimize cylindrically stratified medium structures, various theoretically numerical methods have been widely studied to extract electromagnetic properties. One of the popular methods is method of moments (MoM), which can greatly reduce modelling complexity by using stratified cylindrical Green's functions. In this paper, the mixed potential integral equation (MPIE) for cylindrically stratified medium structures is utilized for computing the characteristic modes (CMs) to further investigate inherent electromagnetic behavior of such structures. The CMs can give a clear physical insight of modal behavior for cylindrically stratified medium structures that is independent on excitations and provide useful information to excite desirable modes. Numerical examples demonstrate the accuracy of the proposed method and show that it can provide an appealing tool to design and optimize arbitrarily-shaped conformal microstrip antennas and antenna arrays.

Formulations

➢ MPIE for Cylindrically Stratified Medium Structures

Matching BC on PEC patch produces mixed potential integral equation (MPIE)

$$\mathbf{E}_{\tan}^{inc} = \left[j\omega \left\langle \bar{G}^A, \boldsymbol{J} \right\rangle + \left\langle \nabla\nabla' \cdot \bar{G}^\phi, \boldsymbol{J} \right\rangle \right]_{\tan}$$

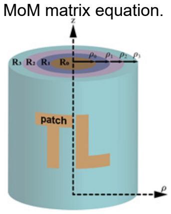
$\bar{G}^A$ and $\bar{G}^\phi$ are spatial vector and scalar potential Green's functions, respectively. The Green's functions can be calculated using DCIM with specially arranged spectral domain Green's functions.

$$\bar{G}^A = \begin{pmatrix} G_{zz}^A & G_{z\varphi}^A & G_{z\rho}^A \\ G_{\varphi z}^A & G_{\varphi\varphi}^A & G_{\varphi\rho}^A \\ G_{\rho z}^A & G_{\rho\varphi}^A & G_{\rho\rho}^A \end{pmatrix}, \quad \bar{G}^\phi = \begin{pmatrix} G_{zz}^\phi & 0 & 0 \\ 0 & G_{\varphi\varphi}^\phi & 0 \\ 0 & 0 & G_{\rho\rho}^\phi \end{pmatrix}$$

The surface currents only have z- and phi- components for such structure. Considering this condition and applying Galerking testing procedure produces MoM matrix equation.

$$\mathbf{ZI} = \mathbf{V}$$

The elements of impedance matrix $\mathbf{Z}$ can be expressed as



$$Z_{mn} = -\int_{S_m} \boldsymbol{f}_m(\mathbf{r}) \cdot \int_{S_n} \begin{pmatrix} G_{zz}^A & \\ & G_{\varphi\varphi}^A \end{pmatrix} \boldsymbol{f}_n(\mathbf{r}') ds ds' + \int_{S_m} (\nabla \cdot \boldsymbol{f}_m(\mathbf{r})) \int_{S_n} G_\phi (\nabla \cdot \boldsymbol{f}_n(\mathbf{r}')) ds ds'$$

Obviously, $\mathbf{Z}$ is complex symmetric. Its Hermitian parts are real symmetric:

$$\mathbf{R} = \frac{1}{2}\left(\mathbf{Z} + \mathbf{Z}^*\right), \quad \mathbf{X} = \frac{1}{2j}\left(\mathbf{Z} - \mathbf{Z}^*\right)$$

➢ MPIE-based CM Formulation

CMs can be obtained using the following generalized eigenvalue equation

$$\mathbf{X} \cdot \mathbf{J}_n = \lambda_n \mathbf{R} \cdot \mathbf{J}_n$$

$\mathbf{J}_n$: the n-th eigenvector λ_n : the n-th eigenvalue

The real eigenvectors are orthogonal, and then modal currents and fields also exhibit orthogonality property. Due to the orthogonality property of modal fields, we can get

$$\lambda_n = \omega \iiint_V \left(\mu \mathbf{H}_n \cdot \mathbf{H}_n^* - \varepsilon \mathbf{E}_n \cdot \mathbf{E}_n^* \right) dV$$

The mode will be resonant if its corresponding eigenvalue goes to zero. Meanwhile, modal significance (MS) can be defined as

$$\mathrm{MS}_n = \left| 1/(1 + j\lambda_n) \right|$$

To generate modal near-fields, the spatial domain field Green's functions are used instead of the mixed potential form

$$\mathbf{E}_n = \int_S \bar{G}^E \cdot \boldsymbol{J}_n ds = \int_S \begin{pmatrix} G_{zz}^E & G_{z\varphi}^E & G_{z\rho}^E \\ G_{\varphi z}^E & G_{\varphi\varphi}^E & G_{\varphi\rho}^E \\ G_{\rho z}^E & G_{\rho\varphi}^E & G_{\rho\rho}^E \end{pmatrix} \cdot \boldsymbol{J}_n ds$$

The modal far-fields calculation can be simplified with the asymptotic expression for Hankel functions with a large argument ($\rho \to \infty$)

$$\begin{pmatrix} E_{n\theta} \\ E_{n\varphi} \end{pmatrix} = \int_S \begin{pmatrix} G_{\theta z}^E & G_{\theta\varphi}^E \\ G_{\varphi z}^E & G_{\varphi\varphi}^E \end{pmatrix} \cdot \boldsymbol{J}_n ds'$$

Results

➢ Cylindrical rectangular microstrip patch

❖ *Geometric dimensions of the stratified cylinder:*

The radius of the PEC core: ρ_0

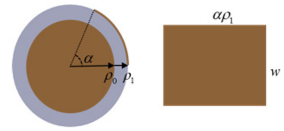
The thickness of the dielectric substrate: $\rho_1 - \rho_0$

The relative permittivity of the dielectric substrate:2.4

❖ *Geometric dimensions of rectangular patch:*

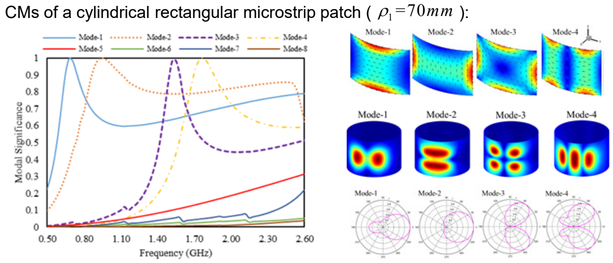
Circumferential dimension size: $\alpha\rho_1 = 70mm$

Axial dimension size: $w = 50mm$



ρ_1=140mm	TCM	Quasi-analytic Result
TM_{10}	1.34GHz	1.38GHz

CMs of a cylindrical rectangular microstrip patch ($\rho_1 = 70mm$):



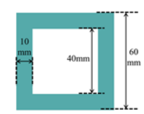
➢ Cylindrical square-ring microstrip patch

❖ Geometric dimensions:

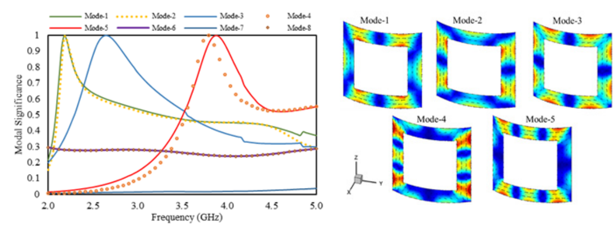
The radius of the innermost PEC cylinder : 52.5 mm

The thickness of the dielectric substrate:2.5 mm

The relative permittivity of the dielectric substrate: :2.4



The similar modal significances and similar distribution of modal currents are because of the symmetry of the square ring patch;
The slight difference between them is due to the curvature of the substrate.



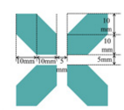
➢ Cylindrical hexagonal microstrip array

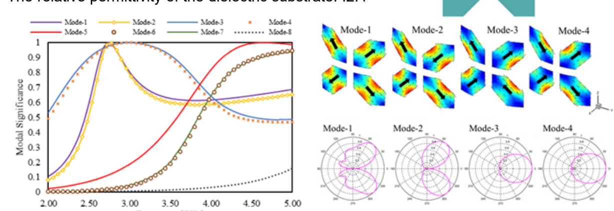
❖ Geometric dimensions:

The radius of the innermost PEC cylinder : 52.5 mm

The thickness of the dielectric substrate:2.5 mm

The relative permittivity of the dielectric substrate: :2.4





Conclusion

The theory of characteristic modes (TCM) for Cylindrically Stratified Medium Structures is proposed by using mixed potential integral equation. The accuracy has been demonstrated by numerical examples. The proposed TCM can handle arbitrarily shaped cylindrical microstrip patches. This approach will provide an appealing tool to design and optimize arbitrarily-shaped conformal microstrip antennas and antenna arrays.

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