A NETWORK APPROACH FOR DESIGNING CONFORMAL MULTILAYERED CYLINDRICAL ANTENNAS

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ABSTRACT

In this paper an efficient systematic design and optimization approach for cylindrical conformal antennas is presented. The approach is based on Integral Equation Method (IEM) in connection with Method of Moment (MoM).

The dyadic Green's function is computed in Spectral Domain (SD) in a *Generalized Transmission Line* (GTL) model of the spectral domain representation of the dyadic Green's function [10]. The current density distribution is computed by method of moment in SD as described in [8].

The Space Domain (SPD) representation of the dyadic Green's function is obtain using the *Generalized Pencil of Function* method (GPOF) [7, 6, 3].

To demonstrate the power of the method, a systematic beam-shaping technique is introduced. Using an asymptotic approximation for obtaining the radiation characteristic, we show that a beam-shaping optimization can be done efficiently and systematically based on network concepts. As an example a conformal dipole antenna embedded in the multilayered cylindrical radome structure is modelled and its radiation pattern is optimized. The optimization goal is to minimize the influence of the multilayered radome on the antenna pattern. For this purpose, a reference simulation of a dipole in the presence of a cylindrical metallic reflector is first performed without the radome structure. Then, the same conformal dipole antenna is simulated together with a one-layer radome. The new far-field mode coefficients are then normalized to the coefficient of the lowest angular mode. The error value for the optimization procedure is defined as the norm of the difference vector of the modes coefficients goal and iterated characteristics changing the GTL parameters. A computer code based on the developed method has been realized. Validation has been done by comparison with the results obtained from measurement and CAD softwares. The developed program exhibits excellent agreement and its running time is a factor around 500 smaller than a commercial CAD software.

The paper is organized in the following way. In Section 1 a summary of the method is given. In Section 2 an overview on the beam-shaping technique is presented. In Section 3 an application of the method is presented and validation with measurement and a commercial tool are given.

1 Theory

We consider a circular cylindrically multilayered lossless structure with M layers, infinitively extended in z-direction, Figure 1. The radiating elements are conformal sheets of current. The field is related to the current sources by the integral equation representation as follows [1, 2]

$$\mathcal{E}^i(\mathbf{r}) = \int_{V'} \mathcal{G}_e^{ij}(\mathbf{r},\mathbf{r}') \wedge \mathcal{J}^j(\mathbf{r}') \tag{1}$$

where $\mathcal{G}_e^{ij}(\mathbf{r},\mathbf{r}')$ is the dyadic Green's function, $\mathcal{J}^j(\mathbf{r}')$ is the current density form distribution, $\mathbf{r}$ and $\mathbf{r}'$ are the observation and source coordinate, V' the volume containing the sources, i and j are the observation and source layer. Since the problem problem exhibits circular cylindrical symmetry, the field distribution is uniform in φ- and z- directions in each cylindrical layer. Therefore, we reduce the problem to a radial boundary value problem introducing a Spectral Domain (SD) representation by an eigenfunction expansion in φ and a Fourier integral in z [9, 10]. In SD at each boundary surface the current sources are related to the tangential electric field components as follows

$$\begin{bmatrix} E^i_{\varphi_n}(\rho) \\ E^i_{z_n}(\rho) \end{bmatrix} = \begin{bmatrix} G^{ij}_{\varphi\varphi'_n}(\rho,\rho') & G^{ij}_{\varphi z'_n}(\rho,\rho') \\ G^{ij}_{z\varphi'_n}(\rho,\rho') & G^{ij}_{zz'_n}(\rho,\rho') \end{bmatrix} \begin{bmatrix} J^i_{\varphi}(n) \\ J^i_z(k_z) \end{bmatrix} \tag{2}$$

The $J^i_z(k_z)$ and $J^i_\varphi(n)$ are computed by MoM solution and the Green's function is computed following the GTL approach [10]. Once that (2) is solved, the field can be is obtained in space domain by inverse Fourier transformation

$$E^i_p(\mathbf{r}) = \frac{j}{8\pi}\sum_{n=0}^{\infty} e^{-jn(\varphi-\varphi')} \int_{k_z} G^{ij}_{pq}(\rho,\rho',k_z,n) \left\{ \begin{array}{c} J^i_\varphi(n) \\ J^i_z(k_z) \end{array} \right\} e^{-jk_z(z-z')}\mathrm{d}k_z \tag{3}$$

where p denotes the field component and q is the source orientation. The Fourier integral in (3) is performed using the Generalized Pencil of Function (GPOF) method to approximate the integrand function [3, 6].

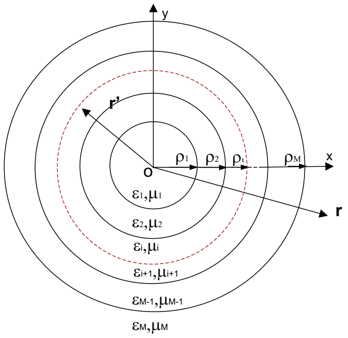


Figure 1: Cylindrical multilayered structure

2 Radiation Pattern Shaping

It was shown in [10] dyadic Green's function describing the cylindrical multilayer structure, can be computed in SD by a GTL analogy. In the GTL model the the TE and TM waves with the transverse electric and magnetic field amplitudes of $E^i_{p_n}$ and $H^i_{p_n}$, can be represented by generalized voltages and currents V^n_l and I^n_l where l is the port number [10], (see also Figure 2).

We consider a Hertzian dipole oriented in z-direction but the results are readily usable also for φ-oriented dipoles. In this case (3) becomes

$$E^i_z(\mathbf{r}) = \frac{j}{8\pi} \sum_{n=0}^{\infty} e^{-jn(\varphi-\varphi')} \int\limits_{k_z} \sqrt{\rho_i} V^n_l(\rho, k_z) e^{-jk_z(z-z')} \mathrm{d}k_z \tag{4}$$

since for a Hertzian dipole $J^i_z(k_z) = 1$. Assuming the antenna in the transmitting mode, in the outermost layer M, the generalized voltage is described only by outgoing cylindrical waves in ρ directions as follows

$$V^n_l(\rho) = \frac{k^2_\rho}{j\omega\varepsilon\sqrt{\rho_i}} D^M_n H^{(2)}_n(k_{\rho_M}\rho) \tag{5}$$

$$E^i_z(\mathbf{r}) = \frac{j}{8\pi} \sum_{n=0}^{\infty} e^{-jn(\varphi-\varphi')} \int\limits_{k_z} \frac{k^2_\rho}{j\omega\varepsilon} D^M_n H^{(2)}_n(k_{\rho_M}\rho) e^{-jk_z(z-z')} \mathrm{d}k_z \tag{6}$$

For $\rho \to +\infty$ the integral (3) is solved in the following way [12]

$$E_z = \frac{(1+j)}{j\omega\varepsilon_M} k^2_{\rho_0} \frac{e^{-jkr}}{r} \sum_{n=0}^{+\infty} j^n D^M_n(k_{z_0}) e^{-jn(\varphi-\varphi')} \tag{7}$$

where $k_{z_0} = -k\sin\theta$, $k_{\rho,0} = k\cos\theta$, $k^2 = k^2_z + k^2_\rho = k^2_{z,0} + k^2_{\rho,0}$, $r = \rho\sqrt{1+\tan^2\theta}$ and $z = \rho\tan\theta$ with $\theta\epsilon[-\pi/2, \pi/2]$. We may note that the radiation pattern of the small dipole antenna depends directly on the characteristic of the GTL parameters as layers thickness, permeability and permittivity, by the amplitudes $D^M_n(-k\sin\theta)$.

3 Examples and Validation

As an application we consider a conformal dipole confined in one-layer cylindrical radome and placed near a cylindrical reflector. For designing the pattern we start with the spectral domain representation of the problem and describe the coupling of the modes by the equivalent circuit depicted in Figure 2. Our design goal is to compensate the influence of the radome on the vertical far field pattern (VP).

For a given azimuth angle φ, the VP is described in terms of voltage amplitudes, $D^M_n(-k\sin\theta)$, as shown in (7) for any θ. Therefore the VP can be shaped choosing a set of reference complex voltage amplitudes $(D^M_{n_d}(-k\sin\theta))$. For this purpose a reference simulation is performed considering the cylindrical reflector without the radome. In this case reference voltages amplitudes are computed solving the equations for the GTL composed of the layer 1 and 3, Figure 2. The obtained voltage amplitudes are stored and used as a reference.

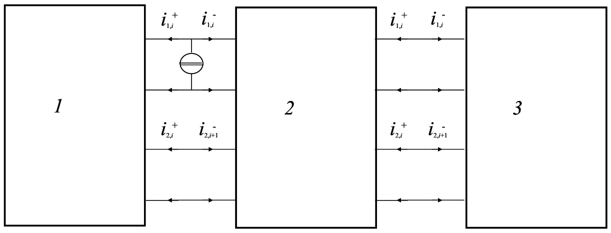
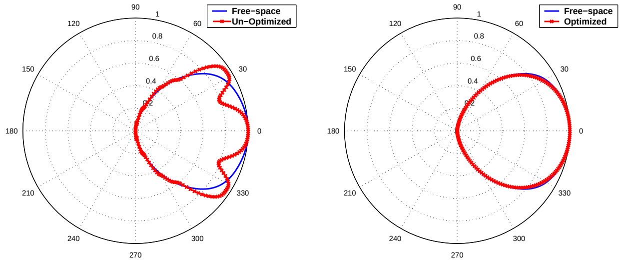


Figure 2: Designed Structure in SD. The GTL 1 models the cylindrical reflector the GTL 2 radome and 3 the free space in SD.



(a) Un-optimized pattern vs Desired pattern at 2.0GHz

(b) Optimized pattern vs Desired pattern at 2.0GHz

Figure 3: Comparison between Desired, Un-optimized and optimized Vertical Pattern of a small dipole at 3.8cm from the cylindrical reflector.

In the next step the voltage amplitudes are calculated for the antenna with the radome for any angle θ. The coefficients in this case are obtained by solving the GTL equations for the layers 1, 2 and 3, Figure 2. All coefficients are normalized to the coefficient of the lowest angular mode ($n = 0$). The error value for the optimization procedure was derived from the norm of the difference vector of optimum voltages amplitudes ($D_{n_d}^M(-k \sin\theta)$) and the $D_n^M(-k \sin\theta)$ computed with radome.

The optimization routine is based on steepest-descent algorithm in which the optimal thickness, the permittivity of the radome and the position of the source with respect to the cylindrical reflector are found. The results are shown in Figure 3.

The optimized structure is then used to compute the Green's function. With this Green's function the current density distribution of a conformal half-wave dipole antenna is computed. The conformal dipole width over the circumference is $w = 0.01m$ and the height is $L = \lambda/2$ at 2 GHz. The gap width at the feeding point is $h = 0.001m$. Since $w/\lambda = 0.0667$ the current can be considered to flow in axial direction. For the computation of the axial current distribution the MoM is applied in spectral domain using subsectional basis functions of rectangular shape.

The influence of the w is accounted by modelling the angular φ dependence of the current in one subsection with a triangular shape. We may observe that the influence of w is relevant for the input impendence computation and the radiation pattern.

The optimization routine and the MoM are both intergraded in a computer code written in Matlab. To validate the code and the method the field computations are compared in terms of far field pattern with a popular commercial tool HFSS and with measurements. HFSS is based on Finite Element Method [5]. The comparison is performed at 2GHz using the optimized structure and results are shown in Figure 4.

Having developed a semianalytical technique we expect a significatively improvements also in terms of time computation and memory requirement. To verify it, we have chosen a desktop computer with processor 2.4 GHz Intel Pentium 4 processor and 1 GB fast DDR RAM and performed the simulation with HFSS and the IEM implemented in Matlab. In this case the we have observed a running time for the Matlab code approximately 500 times faster and for the memory allocation 50 times less.

4 Summary

A computer program for conformal multilayered cylindrical antennas has been presented. The program based on IEM method, exploits the GTL model to integrate analysis and optimization of conformal cylindrical radiating structures. It

(a) HP simulated with IEM, HFSS and Measured without radome.

(b) HP simulated with IEM, HFSS and Measured with radome.

Figure 4: Comparison between simulated with IEM, HFSS and measured Horizontal (HP) and Vertical Pattern (VP) of the conformal finite length dipole at 2GHz.

has been shown that a multilayered cylindrical antennas can be designed and optimized accurately using the GTL model. It was shown that the radiation pattern can be optimized using the GTL approach. The results have been validated with a commercial tool and measurements and very good agreement has been observed.

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