Modelling vertical antennas in a horizontally stratified dielectric medium for radio astronomy study

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Summary

Subtracting poles relating to the surface wave effects of horizontal interfaces just above and below a vertical antenna in a horizontally stratified dielectric medium, Moment method together with Generalized-pencil-of-function (GPOF) method has been efficiently used for numerical modelling of the antenna. Using a delta-gap exciting current, input impedances of an antenna covered by a radome and backed by a ground plane are computed which nearly agree with those computed using commercial packages. It is observed that small variations occur in the computed input impedance (in a frequency range) of a vertical antenna (implying increased bandwidth) covered by a low permittivity radome and backed by a ground plane. Effects of permittivity and separation of a radome from the antenna are presented.

Introduction

ASTRON, The Netherlands Foundation for Research in Astronomy has been developing the aperture array concept for the Square Kilometer Array (SKA) where vertical array elements on ground would be protected from environment by radomes. Modelling of antennas is being carried out to study the radome material properties and its effect on the antenna impedances.

Computational procedure

Electric field $\bar{E}(\bar{r})$ at a field point $\bar{r}$ due to a source current $\bar{J}(\bar{r}')$ at $\bar{r}' \in S'$ (surface distributed source) is given by:

$$\bar{E}(\bar{r}) = \int_{S'} (\kappa^2 \bar{\bar{I}} + \nabla\nabla) \cdot \bar{\bar{G}}(\bar{r}, \bar{r}') \cdot \bar{J}(\bar{r}') \mathrm{d}S'. \tag{1}$$

Moment method together with triangular basis and testing functions is used to compute the unknown current $\bar{J}(\bar{r}')$. In equation (1), a component $G(\bar{r}, \bar{r}')$ of the dyadic Green's function $\bar{\bar{G}}(\bar{r}, \bar{r}')$ assumes the following form:

$$G(\bar{r}, \bar{r}') = \frac{1}{2\pi} \int_0^\infty [\lambda(\tilde{\pi}_{(x', z')}(\bar{r}, \bar{r}') - \tilde{\pi}(\text{half})] J_0(\lambda\rho) \mathrm{d}\lambda + I(\text{half}). \tag{2}$$

Subtracting $\tilde{\pi}(\text{half})$ from $\tilde{\pi}(\bar{r}, \bar{r}')$ pole singularities in the integral of equation (2) are reduced. The subtracted term is compensated by analytical solution $I(\text{half})$. Using the approximation $\lambda(\tilde{\pi}_{(x', z')}(\bar{r}, \bar{r}') - \tilde{\pi}(\text{half})) = \sum_{i=0}^{M} a_i \exp(\lambda b_i)$ in the integrand of equation (2), we obtain

$$G(\bar{r}, \bar{r}') = \frac{1}{2\pi} \sum_{i=0}^{M} \frac{a_i}{\sqrt{\rho_{m,n}^2 + b_i^2}} + I(\text{half}). \tag{3}$$

GPOF method for approximation determines M pairs of complex residues a_i and complex poles b_i. Using present method time consuming numerical integration of equation (2) is avoided, completely.

Numerical computation

The approximation for the term within the square brackets in equation (2), mentioned in the previous section, forms the core of the computation. An error of less than 0.5% was observed in GPOF approximation. For surface integration over the right-hand side of the equation (3) for Moment method implementation, integration in horizontal direction is carried out analytically while integration in vertical direction is carried out numerically. Exciting an antenna with a delta-gap current in a linearly tapered slot immediately above a cavity, resistance and reactance of input impedance of the antenna are computed. The results nearly agree with those computed with the commercial packages Zeland and HFSS. The impedance of the antenna under a low permittivity ($\varepsilon_r = 2$) radome layer and backed by a ground plane shows small variations at different frequencies.

Conclusion

GPOF method has been useful in developing an efficient numerical scheme for studying the behaviour of a vertical antenna embedded in a stratified dielectric medium. Pole singularities on the immediate interfaces in a microstrip source region have been implicitly included to numerically include the surface waves relating to the poles. A proper choice of radome material may result in small variations in input impedance implying an increased bandwidth of a vertical antenna.