

Two Numerical Techniques for Analysis of Pyramidal Horn Antennas with Continuous Metallic Ridges

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1. Introduction

By inserting continuous metallic ridges inside a standard pyramidal horn antenna, along the waveguide feed and the horn flare, it is possible to design horns with extremely large operating bandwidths. There is a lack of information in the literature on the numerical analysis of pyramidal horn antennas with metallic ridges, in spite of their many applications. This paper presents two independent computational techniques for the analysis of ridged pyramidal horn antennas. The first technique is a combined analytical/numerical technique based on the modal analysis and mode-matching procedure. The second technique is a fully numerical technique based on the integral-equation formulation and the method of moments as a solution procedure.

Pyramidal horn antennas with exponential and pole double ridges are fabricated for the operation in a frequency range 2-6 GHz. Fig.1 shows the geometry of antennas. The ridges are uniform along the waveguide feed and are tapered according to a continuous generating function (exponential or pole) in the z -coordinate along the horn flare. Propagating fields are excited in the waveguide by a coaxial probe. A very precise and reliable experimental setup in a 35-foot anechoic chamber is used for radiation pattern measurements. Being completely different and independent, the two modeling techniques serve to cross-check and cross-validate each other. Excellent agreement between the results obtained by the two theoretical approaches is observed, along with an excellent agreement with experimental results.

2. Mode-Matching Analysis of Ridged Pyramidal Horn Antennas

The first computational technique for the analysis of ridged horn antennas belongs to the class of combined analytical/numerical methods based on modal analysis and mode-matching procedures (e.g., [1]). According to this technique [2], the horn flare is approximated by a multi-stepped ridged waveguide structure (Fig.2), modal analysis is performed for each ridged waveguide step, and mode matching is progressively applied at each step interface. Mode fields for the gap region (region between the ridges) and the trough region (the remaining part of the waveguide cross section) are derived from the 2D Helmholtz equation for the appropriate scalar potential function and boundary conditions at waveguide walls and boundaries of ridges. Quasi-static approximation for the electric field near the ridge corner is incorporated in the solution. The waveguide cut-off number for each ridged waveguide section is obtained from the eigenvalue analysis. By matching the tangential components of the electric and magnetic field vectors at interfaces between adjacent elementary waveguide sections along the horn flare, mode by mode, for both the gap and trough regions, a generalized scattering matrix is obtained for

forward and backward wave coefficients at each step. Finally, a generalized transmission matrix is constructed that relates fields at the aperture to fields at the flare throat. The mode-matching procedure is initiated by forward wave coefficients in the throat, which are obtained by a modal expansion of fields excited by a coaxial probe in the feeding ridged waveguide, with backward wave coefficients assumed to be zero in the throat. The radiation field is computed directly from the field distribution over the horn aperture by applying the Huygens' equivalence principle.

3. Integral-Equation Modeling of Ridged Pyramidal Horn Antennas

The second technique used for the analysis of ridged horn antennas in this paper belongs to the class of fully numerical methods based on a "general purpose" analysis of a waveguide structure as a general 3D electromagnetic radiation/scattering problem [3-5]. This technique is based on the integral equation formulation in frequency domain and the method of moments as a solution procedure [6, 7]. The horn antenna as a whole is modeled by a system of bilinear quadrilateral surface elements (Fig.3) in conjunction with the polynomial approximation of the surface current density vector over the elements. Current expansion functions satisfy automatically the current continuity condition along edges shared by surface elements. Polynomial degrees can be high, enabling electrically large elements to be used (large-domain method). The scattered electric field is expressed in terms of currents, with unknown current-distribution coefficients to be determined. The coaxial-line excitation of the waveguide is modeled by the impressed electric field due to a point generator at the base of the wire probe. Boundary condition for the tangential component of the total (impressed plus scattered) electric field vector is enforced to be satisfied over all surfaces in the model, which results in a surface integral equation with the current density vector as unknown. The integral equation is transformed into a matrix equation by the Galerkin-type version of the method of moments. The matrix equation is finally solved for current distribution coefficients by Gaussian elimination.

4. Numerical and Experimental Results

Figures 4 and 5 show measured and computed radiation patterns of the horn antenna without ridges, horn with exponential ridges, and horn with pole ridges in the E-plane and H-plane at 4GHz. Dimensions of the antenna with regards to Fig.1 are: $a = 2.29''$, $b = 1.145''$, $A = 10.25''$, $B = 7.5''$, $t = 0.5''$, $L = 12''$, $l_1 = 0.75''$, and $l_2 = 1.5''$ ($l'' = 2.54$ cm). The exponential ridge taper is described as

$$s_{\text{exp}}(z) = s_{\text{exp}}(0)e^{pz}, \quad p = \frac{1}{L} \ln \frac{s_{\text{exp}}(L)}{s_{\text{exp}}(0)}, \quad 0 \leq z \leq L, \quad (1)$$

while the function describing the pole ridge taper is

$$s_{\text{pole}}(z) = \frac{s_{\text{pole}}(0)L}{L - qz}, \quad q = 1 - \frac{s_{\text{pole}}(0)}{s_{\text{pole}}(L)}, \quad 0 \leq z \leq L. \quad (2)$$

Here, $s_{\text{exp}}(0) = s_{\text{pole}}(0) = 0.25''$ and $s_{\text{exp}}(L) = s_{\text{pole}}(L) = B$. In the modal analysis, number of sections along the flare is 128, number of modes 16, and number of basis functions in the cross-section 16. The mode-matching code is implemented in *MatLab*. The CPU time is 79 minutes with a very modest PC (Pentium 166 MHz with 16 MB RAM memory). In the integral-equation analysis, the polynomial orders range from 1 to 10, and the total number of unknowns is 498. The integral-equation code is implemented

in *FORTRAN*. The CPU time is 81 seconds on a PC Pentium 166 MHz. We observe an excellent agreement of the three sets of results.

References

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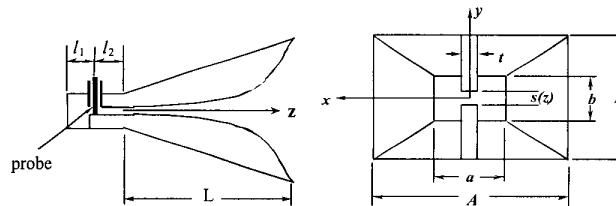


Fig.1. Geometry of a pyramidal horn antenna with double continuous ridges.

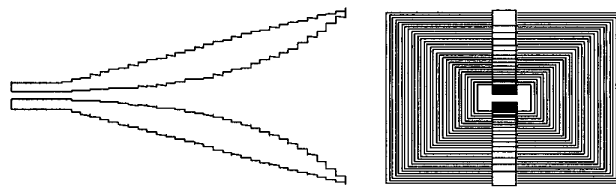


Fig.2. Geometrical model of a ridged horn antenna used for the mode-matching analysis.

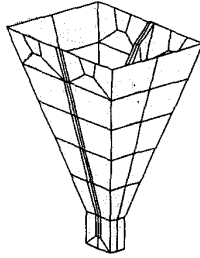


Fig.3. Geometrical model of a double-ridged pyramidal horn antenna used for the integral-equation analysis.

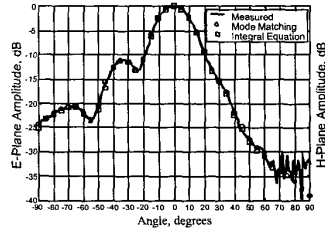


Fig.4. Measured and computed radiation patterns of the horn antenna without ridges in the E-plane and H-plane at 4 GHz.

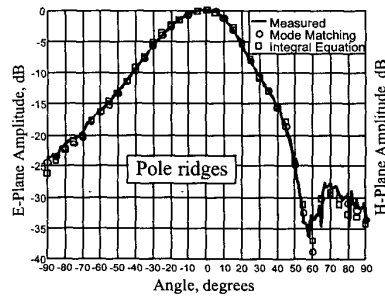
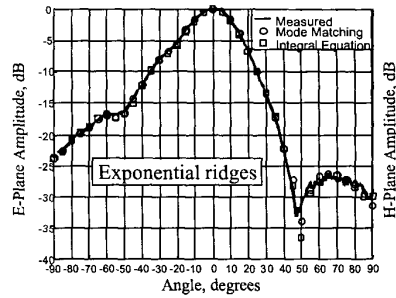


Fig.5. Measured and computed radiation patterns of the horn antenna with exponential and pole ridges in the E-plane and H-plane at 4 GHz.