ANALYSIS OF THE "MICROSTRIP-LOADED INSET DIELECTRIC WAVEGUIDE"

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Abstract

Strip-loaded inset dielectric guide antennas have shown considerable potential in the millimeter wave range. For the purpose of signal feeding and processing, it would be useful to employ microstrip-type circuitry.

In this contribution we describe the properties of microstrip-loaded inset guide and its application to a strip-loaded antenna with horizontal polarization.

I. Introduction

THE PRINCIPAL characteristics of the inset guide (fig.1) (1,2) consist in its excellent confinement of the E.M. field, its low loss and low fabrication cost, the structure being not too sensitive to fabrication tolerances.

Moreover, inset guide presents an interface where it is possible to place metallic strips with a view to realizing a leaky wave antenna.

The polarization of the antenna is determined by the excitation, the shape and position of the strip as well as the geometry of the IDG.

In previous work, we examined an antenna application with E_x polarization, starting from a LSE-polarized IDG (3). The horizontal polarization is obtained by placing longitudinal strips on an IDG suitable for LSM polarization. For the geometry of fig. 1, the electric field has three components; in particular, E_z is symmetric w.r.t. the x-axis and E_x is antisymmetric. This ensures pure horizontal polarization properties for the array.

In order to synthesize the the array , $\lambda_g/2$ -long strips, are spaced λ_g apart (fig.2). A desidered current profile is obtained by varying the strip width or by placing the strips to the side of the median line. The presence of the strips modifies considerably the characteristic of the structure. The array of strips can be designed as a cascade of sections of IDG (waveguide length λ') alternate with sections of Microstrip-Loaded Inset Dielectric Guide (MSLIDG, waveguide length λ'') (fig. 2). For this purpose it is essential to determine the characteristic of MSLIDG. Unlike general dielectric antennas, the feeding arrangement does not constitute a problem for either polarization. In the present case, in particular, it is natural to use a microstrip circuit in the antenna feed which matches the geometric configuration of the antenna itself.

In conclusion MSLIDG presents the following applications:

1) Array design.

2) Direct feeding arrangement for the antenna and antenna circuitry.

3) A possible alternative to microstrip for millimetric circuits. In particular, it would seem that this type of waveguide can operate in a mode not far different from that of microstrip as well as in a dielectric mode similar to that of IDG.

II. Analysis

The mode structure of MSLIDG is essentially hybrid and a full six field analysis is required. However, physical considerations allow some insight. Propagation modes are of two kinds: a "microstrip-like mode", due to the presence of two conductors (fig. 3), and dielectric modes, similar to IDG's modes (1).

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We introduce two y-directed hertzian potentials . By Transverse Resonance Diffraction in the space domain (TRD), we obtain two coupled integral equations for E_x , $\partial_x E_z$, to be solved by Galerkin's method.

$$\Pi_e^{\pm}=\vec{y}\psi_e^{\pm}(x,y)e^{-j\beta z} \quad (1a)$$

$$\Pi_h^{\pm}=\vec{y}\psi_h^{\pm}(x,y)e^{-j\beta z} \quad (1b)$$

where,considering only odd modes because of symmetry considerations, we have:

$$\psi_e^{+}(x,y)=\int_0^{\infty} I(\rho)\phi_e(x,\rho)e^{-jk_y y}d\rho \quad (2a)$$

$$\psi_e^{-}(x,y)=\sum_{1,3}^{\infty} I_n\phi_{en}(x)\frac{\cos q_n(y+h)}{\cos q_n h} \quad (2b)$$

$$\psi_h^{+}(x,y)=\int_0^{\infty} V(\rho)\phi_h(x,\rho)e^{-jk_y y}d\rho \quad (3a)$$

$$\psi_h^{-}(x,y)=\sum_{1,3}^{\infty} V_n\phi_{hn}(x)\frac{\sin q_n(y+h)}{\sin q_n h} \quad (3b)$$

where:

$$q_n=\sqrt{\varepsilon_r k_0^2-(\frac{n\pi}{a})^2-\beta^2}$$

$$k_y=\sqrt{k_0^2\rho^2-\beta^2}$$

$$\phi_{en}(x)=\frac{2}{\sqrt{a}}\cos\frac{n\pi}{a}x \qquad \phi_e(x,\rho)=\sqrt{\frac{2}{\pi}}\cos\rho x$$

$$\phi_{hn}(x)=\frac{2}{\sqrt{a}}\sin\frac{n\pi}{a}x \qquad \phi_h(x,\rho)=\sqrt{\frac{2}{\pi}}\sin\rho x$$

Now, we express the coefficients $I(\rho), I_n, V(\rho), V_n$ as combinations of transverse E components. Substituting these expressions in the equation of magnetic field, we obtain:

$$\begin{bmatrix} H_z^{\pm}(x,0) \\ \int H_x^{\pm}dx \end{bmatrix} = \mp \begin{bmatrix} \tilde{Y}_{11}^{\pm} & \tilde{Y}_{12}^{\pm} \\ \tilde{Y}_{21}^{\pm} & \tilde{Y}_{22}^{\pm} \end{bmatrix} \begin{bmatrix} E_x^{\pm}(x',0) \\ \partial_x E_z^{\pm}(x',0) \end{bmatrix} \quad (4)$$

Where the expressions for the admittance integral operators can be found in (1).

By imposing the continuity of transverse E.M. field across the interface slot-air we get the integral equation :

$$\begin{bmatrix} (\tilde{Y}_{11}^{+}+\tilde{Y}_{11}^{-}) & (\tilde{Y}_{12}^{+}+\tilde{Y}_{11}^{-}) \\ (\tilde{Y}_{21}^{+}+\tilde{Y}_{21}^{-}) & (\tilde{Y}_{22}^{+}+\tilde{Y}_{22}^{-}) \end{bmatrix} \begin{bmatrix} E_x(x',0) \\ \partial_x E_z(x',0) \end{bmatrix} = 0 \quad (5)$$

$$l/2 < x < a/2$$

The variational solution of the integral equation (5) in the Ritz-Galerkin formulation rests on th finite discrete expansion of the unknown interface field $E_x(x,0)$,$\partial_x E_z(x,0)$ in terms of known functions.

In order to achieve a rapid convergence, the edge conditions need to be satisfied 'a priori' by the set of expanding functions. In particular,the boundary conditions at the 90°-edge are of the type $r^{-1/3}$ and at the 0°-edge are of the type $r^{-1/2}$.

Consequently, if we choose a weight function $W(x) = (x-l/2)^{-1/2}(a/2-x)^{-1/3}$ (in the l/2--a/2 range), we automatically satisfy the edge conditions. The latter choice, in turn, leads naturally to the choice of the Jacobi's polynomials $G_k(1/6,1/2,x)$ (k=0,1,...), for the expression of the E-field which are orthonormal w.r.t. the above weight function, i.e.:

$$\langle f_k,f_j\rangle=\int_{l/2}^{a/2} W(x)f_k(x)f_j(x)dx = \delta_{kj} \quad (6)$$

$$f_k(x)= G_k[(2x-l)/(a-l)]/N_k$$

Where N_k is the normalization factor of the k-th polynomial. We can now expand all quantities appearing in the integral equation in terms of finite number (k=0,1,..,N-1) of the above functions.

Namely:

$$E_x(x,0) = W(x)\sum_{0,1}^{N-1} X_k f_k(x) \quad (7a)$$

$$\partial_x E_z(x,0) = W(x)\sum_{0,1}^{M-1} Z_k f_k(x) \quad (7b)$$

$$\phi_{hn}(x)=\sum_{0,1}^{N}P_{kn}f_k(x) \qquad \phi_h(x,\rho)=\sum_{0,1}^{N}P_k(\rho)f_k(x)$$

$$P_{kn}=\langle\phi_{hk},f_n\rangle \qquad P_k(\rho)=\langle\phi_h,f_k\rangle$$

By substituting (6) into the integral equation (4), we can recast the latter as a standard matrix equation of order NxN:

$$\begin{bmatrix}[Y_{11}] & [Y_{12}] \\ [Y_{21}] & [Y_{22}]\end{bmatrix}\begin{bmatrix}\underline{X} \\ \underline{Z}\end{bmatrix}=\underline{0} \qquad (8)$$

where :

$$[Y_{nm}]_{ij}=\langle f_i,\tilde{Y}_{nm},f_j\rangle$$

non trivial solutions of (8) are obtained by setting:

$$\det\underline{Y}(\beta)=0 \qquad (9)$$

Which is the dispersion equation for the discrete modes of the guide .

III. Experiment

III.1 Dispersion curves

Assuming just a single function expansion for E_x and E'_z gives accurate dispersion curves. In figure 4 we report the characteristics β/k_0 for the microstrip-like mode for a MSLIDG with a=22.84 mm, h=10.16 mm, l=2mm and compare the theoretical values of λ_g with the values measured in the range of single mode operation.

The onset of the dielectric waveguide mode at around 8.5 GHz it is noted on the right hand corner of the figure. Even closer quantitative agreement seems obtainable with just a second order expansion .

III.2 Array design

We designed a 22 element horizontal array, operating at 10.2 GHz. The lengths and spacings of the array elements were chosen as described in the introduction. Although, at this frequency, the MSLIDG operates in two modes, neglecting the second mode is unimportant for the design of the array. In figure 5 we report the radiation pattern of the antenna in the E-plane. It is noted that difference between main lobe and side lobes is 18 dB. Although no special precautions were taken, input reflection was below-13dB at the center frequency. We are currently improving the accuracy of the variational solution and further details will be presented later.

References

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(3) T.E. Rozzi, R.De Leo, L. Ma, A. Morini, 'Equivalent network of transverse dipoles on Inset Dielectric Guide : application to linear arrays.' to appear in IEEE Trans. on A.P, 1989.

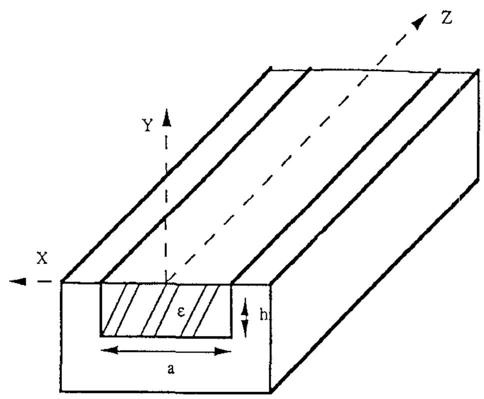

fig 1 Inset dielectric guide

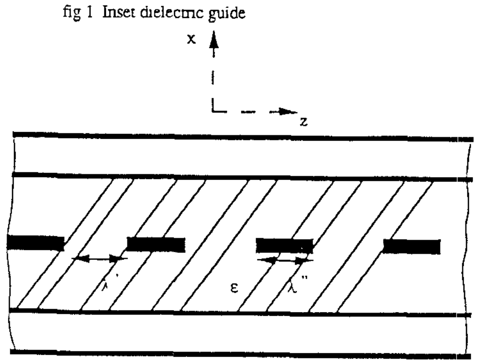

fig. 2 Horizontally polarized array

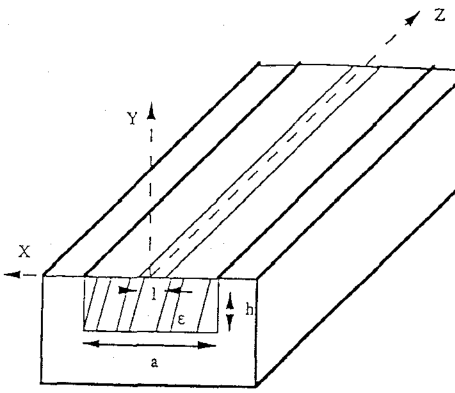

fig. 3 Microstrip loaded IDG

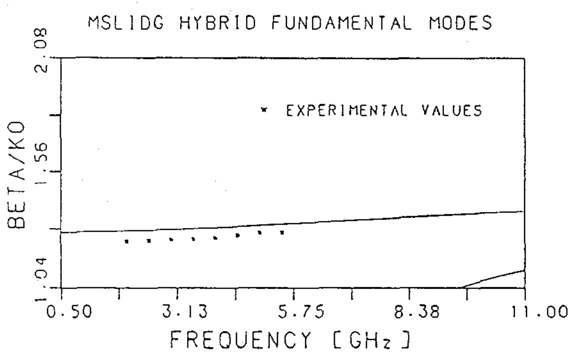

fig.4
Theoretical and experimental dispersion curves for the MSLIDG

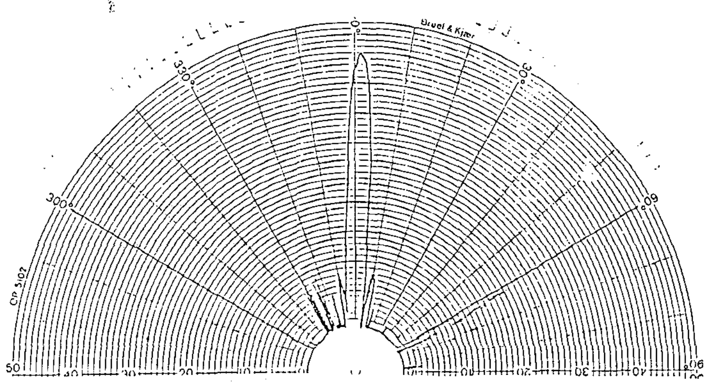

fig.5
Experimental radiation pattern (E plane) of 22 elements array .