A Transverse Slot in the Broad Wall of Inhomogeneously Loaded Rectangular Waveguide for Array Applications

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Abstract—**The self-properties of transverse slots in the broad wall of inhomogeneously loaded rectangular waveguide are computed using an integral equation moment method formulation, and compared to measured values. Results are also presented which show that transverse slots in inhomogeneously loaded rectangular waveguide can be used for antenna arrays which will not have grating lobes in their radiation patterns, and will not suffer from the same distribution taper limitations as similar arrays of homogeneous waveguide transverse slots.**

I. Introduction

TRANSVERSE slots in the broad wall of homogeneous rectangular waveguide are not commonly used as radiating elements in resonant slotted waveguide arrays because of two reasons [1]: 1) the required slot spacing of λ_g (which is substantially larger than λ_0 for a homogeneous air-filled waveguide) in resonant arrays has the result that grating lobes in the radiation pattern cannot be avoided, and 2) low sidelobes in the radiation pattern are impossible to realize because of the limited range of coupling versus slot-offset which can be achieved with a transverse slot in the broad wall of homogeneous waveguide.

Some possible solutions for the 'slot spacing'-problem are to fill the waveguide homogeneously with a dielectric (to reduce λ_g of the waveguide), or by using a spatial filter to suppress the grating lobes, as was suggested by Josefsson [2]. To the author's knowledge no solution has yet been suggested in the literature for the 'limited coupling versus offset problem. This paper will show how both these problems can be overcome simultaneously, by using transverse slots in the broad wall of inhomogeneously loaded rectangular waveguide (with the dielectric against one of the waveguide sidewalls, as shown in Fig. 1) as radiating elements. This becomes possible because of the additional design variables (namely the width and relative permittivity of the dielectric slab) offered by such a waveguide. An integral equation moment method formulation was used to analyze such a transverse slot. The analysis used was adapted from that in [3], where transverse slots in inhomogeneously loaded waveguide of the type where the dielectric slab is situated in the *center* of the waveguide, were analyzed. The validity of the theory was verified through comparison of computed data with carefully measured data of the self-properties of such a transverse slot.

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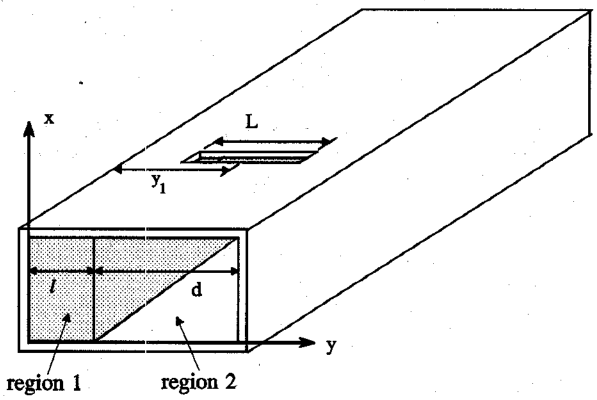

Fig. 1. A transverse slot with offset y_1 in the broad wall of an inhomogeneously loaded rectangular waveguide.

II. Analysis

The analysis of the transverse slot (Fig. 1) was done using the same formulation as described in some detail in [3]. The main difference was that a new waveguide Green's function had to be determined because the dielectric slab was now situated against one of the waveguide sidewalls. The waveguide interior is divided into regions 1 and 2, as shown in Fig. 1. Region 2 is air-filled, and region 1 is a dielectric medium with relative dielectric constant ϵ_r. The waveguide Green's function (only the *yy*-component is needed in the analysis) for this type of inhomogeneously loaded waveguide is of the form

$$\tilde{\tilde{G}}_{yy}(\mathbf{r},\mathbf{r_0}) = \frac{1}{j\omega\epsilon_0\epsilon_i}\left\{\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}\frac{-1}{2\mathbf{Y}^h_{\mathrm{mn}}}\mathbf{h}^h_{ymn}(x,y)\, \mathbf{h}^h_{ymn}(x_0,y_0)\mathrm{e}^{-\gamma^h{}_{zmn}|z-z_0|}\right\}$$

with the magnetic vector of the TE mode given by

$$\mathbf{h}^h_{ymn}(x,y) = \frac{\left((\gamma^h_{zmn})^2-(m\pi/b)^2\right)\hat{a}_y}{j\omega\mu_0\gamma^h_{zmn}\sqrt{\frac{b\mathbf{W}}{\epsilon_{0m}}}} \times \begin{cases}\sinh(\gamma^h_{y\mathrm{1n}}y)\cos\left[\dfrac{m\pi x}{b}\right]; & y\in \text{region 1}\\ C_h\sinh\left[\gamma^h_{y2n}(l+d-y)\right]\cos\left[\dfrac{m\pi x}{b}\right]; & y\in\text{region 2}\end{cases}$$

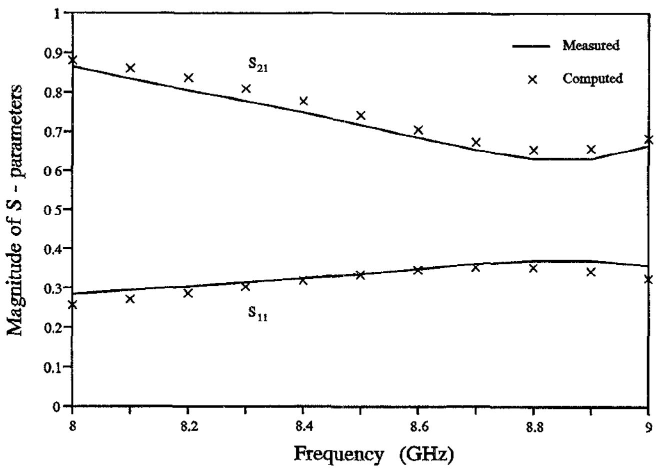

Fig. 2. Measured and computed magnitude of the scattering parameters for a transverse slot in an inhomogeneously loaded rectangular waveguide.

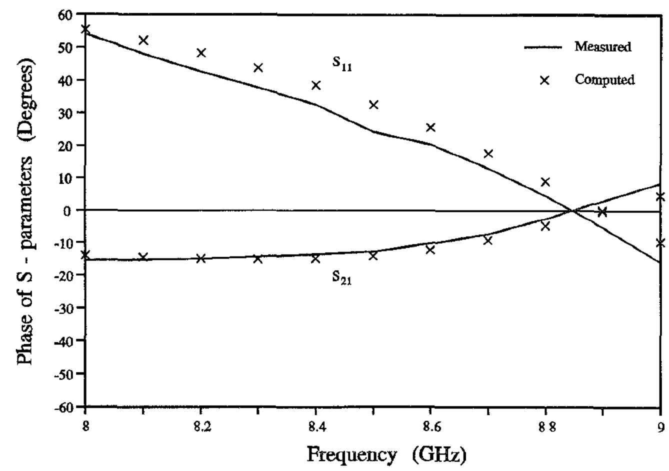

Fig. 3. Measured and computed phase of the scattering parameters for a transverse slot in an inhomogeneously loaded rectangular waveguide.

with

$$\mathbf{Y}^h_{mn} = \frac{(\gamma^h_{zmn})^2 - (m\pi/b)^2}{j\omega\mu_0\gamma^h_{zmn}}$$

$$W = \left\{\frac{\sinh(\gamma^h_{y1n}l)\cosh(\gamma^h_{y1n}l)}{2\gamma^h_{y1n}} - \frac{l}{2}\right\} + C_h^2\left\{\frac{\sinh(\gamma^h_{y2n}d)\cosh(\gamma^h_{y2n}d)}{2\gamma^h_{y2n}} - \frac{d}{2}\right\}$$

and

$$C_h = \frac{\sinh(\gamma^h_{y1n}l)}{\sinh(\gamma^h_{y2n}d)}$$

In the expressions above, γ_{y1n} and γ_{y2n} are the modal propagation constants in the y-direction for regions 1 and 2 of the waveguide, and γ_{zmn} the modal propagation constant in the z-direction. γ_{y1n} and γ_{y2n} are solutions of a transcendental equation [4], [5]. Using this Green's function and the analysis procedure described in [3], software was developed to analyse transverse slots in the broad wall of an inhomogeneously loaded waveguide. In order to verify the theoretical analysis results a transverse slot in such an inhomogeneously loaded X-band waveguide section was manufactured and the scattering parameters measured on a vector network analyzer. The length of the slot was 15.75 mm, the offset from the edge of the waveguide was 11.43 mm, and the dielectric slab (of relative permitivity 5.0) was 6.0 mm wide. A comparison between the computed and measured results is shown in Figs. 2 and 3. Agreement was found to be good.

III. Overcoming the Grating Lobe Limitations

Possible solutions to overcome the interslot spacing problem for slot arrays are loading the waveguide homogeneously with dielectric [6], [7], or using grating lobe spatial filters [1], [2]. A rectangular waveguide partly loaded with dielectric as shown in Fig. 1 has the advantage that λ_g of the dominant mode can be adjusted by two variables, the width and relative permittivity of the dielectric loading in the waveguide. Fig. 4 shows computed values of λ_g for partly-filled waveguide as a function of relative permittivity for two different widths of dielectric. The computations were done at 9 GHz in standard X-band rectangular waveguide. For the case $l = 5$ mm it can be seen that for all values of ϵ_r larger than 4.5, λ_g will be smaller than λ_0, which satisfies the requirement for element spacing to avoid grating lobes in the radiation pattern of a linear array. For $l = 10$ mm, λ_g will be smaller than λ_0 for all values of ϵ_r larger than 2.1.

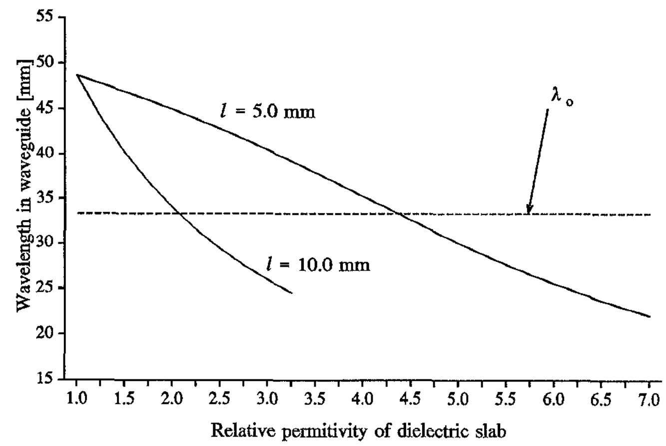

Fig 4 Computed guide-wavelength for the dominant mode in an inhomogeneously loaded rectangular X-band waveguide at a frequency of 9 GHz as a function of the relative permittivity of the dielectric slab

IV. Overcoming the Distribution Taper Limitations

The scattering and equivalent network parameters of transverse slots in inhomogeneously loaded waveguide were investigated for a range of slot offsets, slab widths and dielectric constants. The equivalent network for a transverse slot in the broad wall of a rectangular waveguide is a series impedance [2]. With a careful choice of the additional design parameters a much wider range of coupling (or resonant series equivalent

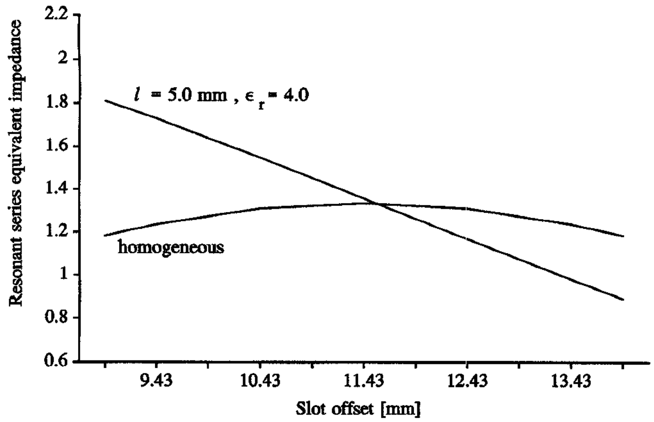

Fig. 5. Computed resonant series equivalent network impedance (normalized) of a transverse slot in a homogeneous and an inhomogeneous waveguide as a function of the offset from the side of the waveguide.

network impedance) versus slot offset can be achieved in inhomogeneous waveguide than is possible in homogeneous waveguide. To illustrate this, Fig. 5 shows computed values of the resonant series equivalent network impedance of a transverse slot in homogeneous and inhomogeneous (for the case $l = 5$ mm, $\epsilon_r = 4.0$) waveguide versus slot offset. It is clearly seen that the inhomogeneous waveguide slot has a much larger coupling range, allowing the design of arrays with the necessary distribution taper to obtain low sidelobes in the radiation pattern.

V. Conclusion

Computed and measured results for the self-properties of transverse slots in inhomogeneously loaded waveguide have been presented. Such results do not appear to have been published by other authors. It was also shown how existing limitations in the design of transverse slot arrays can be overcome by using inhomogeneously loaded waveguide of the type where the dielectric slab is situated against one of the sidewalls of the waveguide.

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