FAST AND EFFICIENT MODE-MATCHING ANALYSIS OF RIDGED CIRCULAR WAVEGUIDE POLARIZERS

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Abstract

A fast and efficient mode-matching technique is applied to the analysis and design of polarizer components in ridged circular waveguide technology. Two different structures (the septum polarizer and the longitudinal-ridge polarizer) are investigated with respect to the validity of approximating the rectangular-cross-section septa by conically shaped ridges in theory. Measurements of two different prototypes demonstrate, first, that the axial ratio response is not potentially critical to this approximation and, second, that some differences occur with respect to return loss and isolation performance, but that these difference have only been encountered beyond the 25dB margin. A CPU time comparison with HFSS results in a ten-minutes-versus-three-hours advantange of the mode-matching technique.

I. INTRODUCTION

Polarizers in square or circular waveguide technologies play an essential role in modern satellite and terrestrial communication systems, e.g. [1]. Traditionally, such components have been constructed from rectangular/square waveguides. Recently, however, circular components have been employed in order to avoid square-to-circular waveguide transformers at the circular antenna port and maintain the circular cross-section throughout the front-end part of the feed system.

Since the publication of the circular waveguide septum polarizer by Behe and Brachat in 1991 [2], several research teams embarked on an effort to determine the mode spectra of ridged circular waveguides for computer-aided design procedures, e.g. [3]-[7]. Moreover, several theoretical designs of entire components in ridged circular waveguide technology have been published, but only individual elements of the designs or structures without insertion-phase relevance have been verified experimentally [8]-[10].

Direct theory-practise comparisons for ridged circular waveguide components, in which the phase response is a critical parameter, are hardly available. Moreover, the influence of the approximation of the rectangular-cross-section ridges (practise) by conically shaped ones (theory) has not been determined for such components.

This paper closes this gap. Mode matching is applied to design and analyze two different ridged circular waveguide polarizer components, namely, the septum polarizer (Fig. 1a) and the longitudinal-ridge polarizer (Fig. 1b). Practical implementations utilize rectangular-cross-section septa, all of which are theoretically modeled by conically shaped ridges. The comparisons between theory and measurements show excellent agreement for the axial ratio but some degrees of difference in return loss values beyond the 25dB margin, especially for the septum polarizer, which we attributed to the conical-ridge approximation.

II. THEORY

Fig. 2 shows the different cross sections involved in the mode-matching analysis of the three polarizer configurations. The mode-spectra of the circular waveguide (Fig. 2a) and the sectoral waveguides (Figs. 2b, 2c) are well known [11].

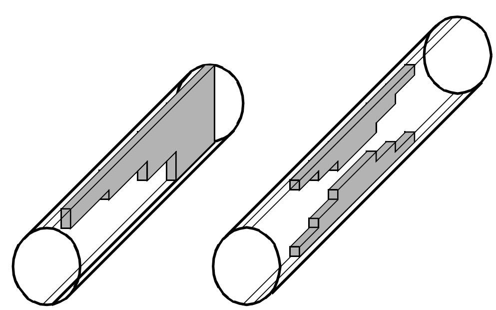

Fig. 1 *Ridged circular waveguide polarizers: (a) septum, (b) longitudinal-ridge.*

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The eigenfunctions of Figs. 2d, 2e, 2f are determined numerically. The individual expressions in subregions IIa, IIb are similar to those in [5]. However, the system matrix is formulated such that such a pole-free determinant function is obtained which significantly simplifies the search algorithm for the minimum singular values [12]. A coupled-integral-equation technique [13] has been used alternatively in order to verify the correct detection and order of the eigenmodes. Once the generalized scattering matrices of individual discontinuities or sections are computed, they are cascaded to form the scattering matrix for a specific polarization. Electric and magnetic walls in the plane of the ridges are utilized to form the overall scattering matrix [14]. For the component of Fig. 1b, this procedure is equivalent to a clockwise 45-degree rotation [15] of the structure. Standard optimization routines are employed for the design of a component according to specifications.

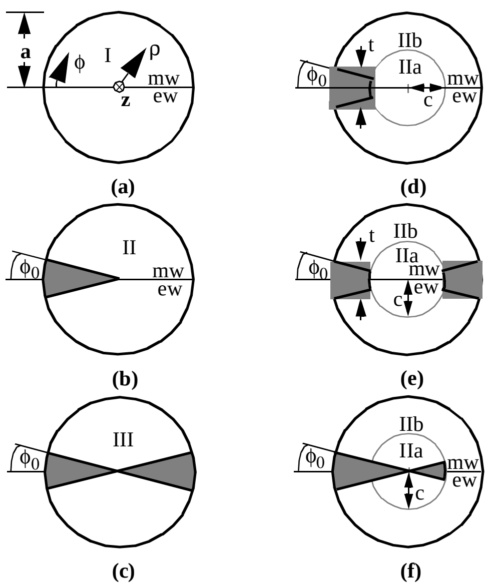

Fig. 2 *Cross sections involved in the mode-matching analysis of ridged circular waveguide polarizers.*

The motivation for using conically shaped ridges in the analysis instead of the actual shapes (c.f. Figs. 2d, 2e) lies in the fact that the circular-cylindrical cordinate system can be maintained throughout. Therefore, a critical point in the entire analysis is the translation of the actual thickness t into the semi-angle ϕ_0. Our investigations have led to the following conclusions: The components are efficiently calculated by using a constant angle

$$\phi_0 = arc\sin\left(\frac{t}{2a}\right) \qquad (1)$$

where a is the radius of the circular waveguide.

A particularly critical case occurs if the ridge penetration falls close to the radius of the circular waveguide. This renders subregion IIa in Figs. 2d - 2f extremely small and usually creates numerical difficulties. Therefore, if c/a<0.02, the ridge is replaced by the sectoral guide of Fig. 2b.

The main advantage of this mode-matching analysis and design compared to other methods is its speed. For instance, the finite-element-based software package HFSS requires approximately three hours for an analysis of a three-section septum polarizer with fifteen frequency points on a Sparc20 station. The mode-matching software performs the same task within ten minutes on a Pentium 90 PC.

III. RESULTS

In order to verify the mode-matching septum polarizer software, results are compared with measurements of prototypes in C-band and K-band. Figs.3 show a comparison between measured and calculated results for a four-section C-band polarizer with a thickness-to-radius ratio of t/d=0.04. Excellent agreement for return loss, isolation (top) and axial ratio (bottom) can be observed.

A slightly thicker septum with t/a=0.06 has been used in a four-section 25 GHz design. The comparison between measurements and results of the mode-matching design is shown in Figs. 4. Although the general tendency of the return loss curve seems to be reversed, the software correctly predicts more than 30 dB return loss (top). Moreover, the axial ratio computations show very good agreement with the measured values (bottom) and thus validate the mode-matching analysis. The discrepancies in return loss are believed to be caused by those polarizer sections whose ridges penetrate the circular waveguide to approximately the waveguide center. In this case, the field singularities at the corners of the conically shaped ridges (theory) deviate markedly from those of the rectangular ridges used in the prototypes. Several other comparisons with a commercial field solver (HFSS, not shown here) have lent support to this assumption. Whereas mode-matching usually predicts a smoothly curved return loss (e.g. Fig. 4, top), the rectangular ridge is more likely to produce a more pronounced peak.

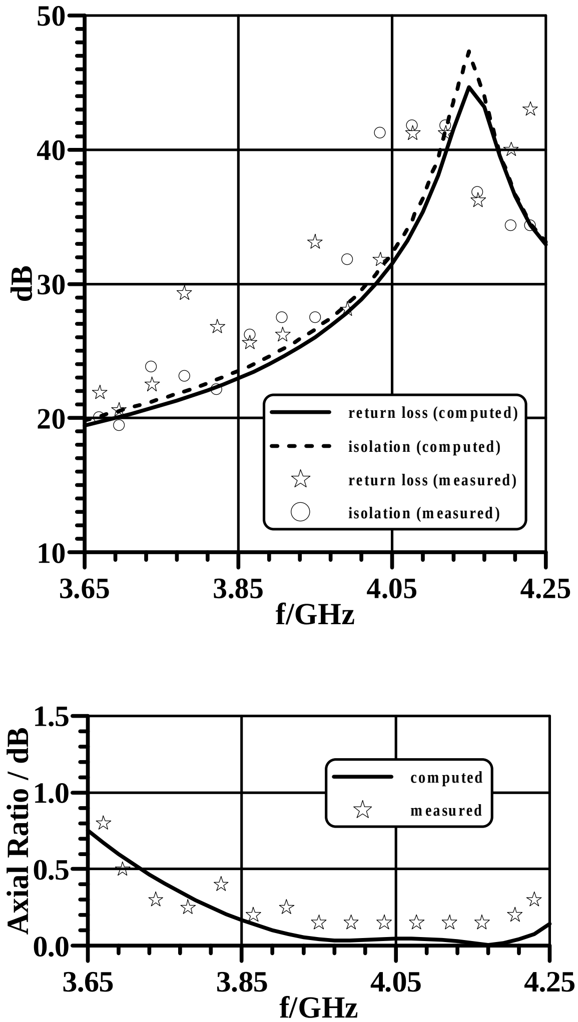

Fig. 3 *Measured and computed performance of a four-section C-band septum polarizer (c.f. Fig. 1a).*

The permormance of a longitudinal-ridge polarizer design is shown in Fig. 5. Design specifications called for 25dB return loss and 0.3dB axial ratio between 23.2 and 25.7 GHz. The ridge thickness is t/a=0.07. Note that the isolation shown here is that between the two linear polarizations of the -45-degree counterclockwise rotated input signal (c.f. Fig. 1b). The isolation between the LHCP and RHCP components at the output is estimated to be 35dB for the given axial-ratio specification [1].

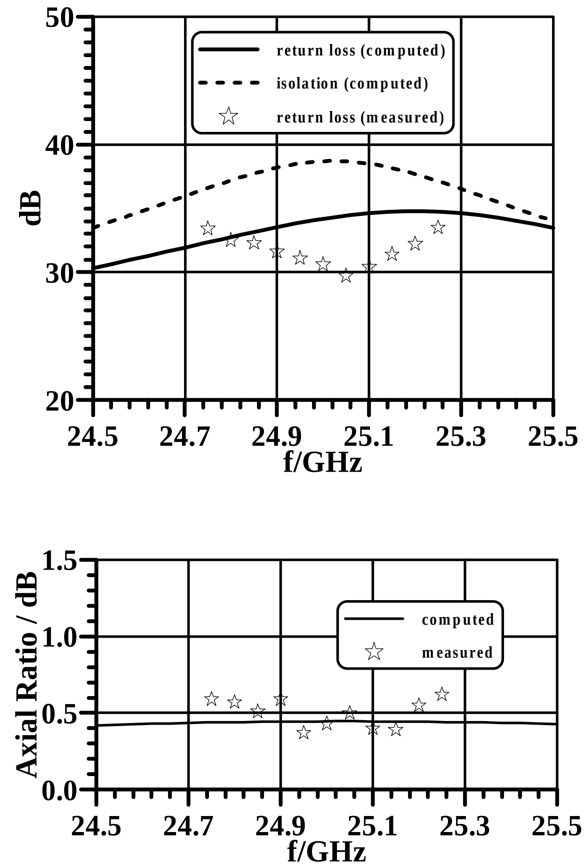

Fig. 4 *Measured and computed performance of a four-section K-band septum polarizer (c.f. Fig. 1a).*

IV. CONCLUSIONS

Measurements of two different polarizers in ridged circular waveguide technology demonstrate that a mode-matching technique, which approximates rectangular-cross-section septa by conically shaped ridges, can be used efficiently in design procedures for front-end components. It is found that the axial ratio response is not particularly sensitive to the shape approximation, but some differences - usually beyond 25dB - are observed in the return loss and isolation behaviour. Therefore, and in light of the CPU time advantage against commercial fields solvers, the mode-matching technique offers a fast and efficient alternative for ridged circular waveguide polarizer design.

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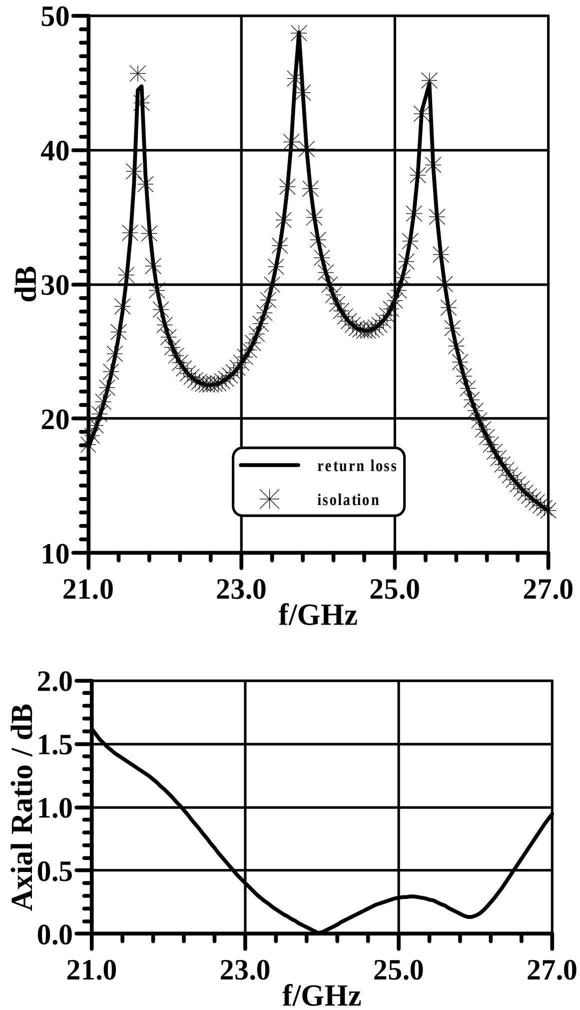

Fig. 5 *Performance of optimized longitudinal-ridge polarizer (c.f. Fig. 1b).*