FIELD THEORY DESIGN OF A CORRUGATED SEPTUM OMT

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ABSTRACT

This paper presents a rigorous design method for corrugated septum orthomode transducers (OMTs) which combine the advantage of the stepped septum structure compactness with that of the phase matching potential of corrugated waveguide polarizers. Based on the modal scattering matrix method, the design takes into account the influences of both, the finite septum thickness and the higher–order mode interaction at all discontinuities. Computer optimized design data are given for a Ku–band waveguide corrugated septum polarizer achieving a return loss of more than 20dB together with $90^\circ + 0^\circ/-3^\circ$ differential phase shift for about 10% bandwidth. The theory is verified by own measurements and those of other authors.

INTRODUCTION

Stepped–septum polarizers [1] – [4] have found many applications in phased array technology for satellite systems. The advantages of this polarizer circuit include compactness, low weight, relatively large bandwidth, and the fact that it inherently yields orthomode transducer (OMT) characteristics. An alternative septum polarizer design is a notched structure [5] which, however, shows less bandwidth. Although the return loss behavior for such septum polarizers can be matched for a desired band within a wide frequency range for both the TE_{10} and TE_{01} input modes [1] – [5], additional phase adjustment by dielectric slabs or by side wall dimension reduction [1] – [3] is often required in order to achieve also the desired phase orthogonality for this band.

In this paper we propose an alternative design, the corrugated septum polarizer (Fig. 1a), which combines the advantages of the compactness and the inherent OMT feature of the septum structure with the broadband phase shifting properties of corrugated waveguide sections [6]. Moreover, as the orthogonal mode differential phase curves vs. frequency of the septum and the corrugated structure, if adequately designed, may show opposite behavior, their compensation effect for the composite structure can be advantageously utilized for a nearly constant phase characteristic.

The theory given in this paper, which includes higher order mode coupling effects as well as the finite septum width, is based on modal field expansion into orthogonal eigenmodes [6] – [8]. The structure under investigation is composed by appropriate key–building blocks, the double–step discontinuity, the waveguide–to–ridged–waveguide transition, and the transition waveguide to septated waveguide. For the critical asymmetrical ridged waveguide eigenvalue problem (Fig. 1b), a fast Y–/H–matrix–type transverse resonance technique is applied together with the singular value decomposition method [9]. The generalized scattering matrix technique is utilized for calculating the composite circuit. Computer optimized design data are given for a Ku–band waveguide corrugated septum OMT achieving a return loss of more than 20dB together with nearly constant differential phase shift for about 10% bandwidth. The theory is verified by comparison of the results with those for the stepped and notched septum polarizer which are available in the literature as well as with own measurements.

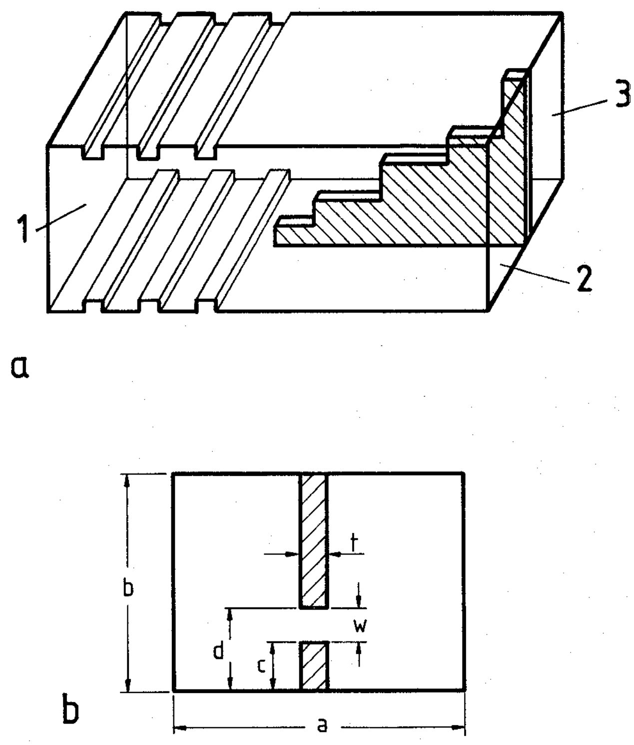

Fig. 1:
Corrugated Septum polarizer/OMT
a) Basic geometry and port designations
b) General asymmetric ridged waveguide structure

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THEORY

For the computer–aided design of the corrugated septum polarizer/OMT (Fig. 1a), the modal S–matrix method [6] – [11] is applied. The structure is decomposed into two key building blocks: double–plane waveguide step discontinuity [10], transition waveguide to asymmetrical ridged–waveguide (Fig. 1b) which includes the case with c = 0, and the transition waveguide to septated waveguide [11]. Combination with the modal scattering matrices of the corresponding intermediate homogeneous waveguide sections of finite or zero lengths, respectively, yields the total scattering matrix of the overall polarizer/OMT structure.

The electromagnetic field in the subregions of the key–building blocks

$$\vec{E}^i = \nabla \times \vec{A}_H^i + \frac{1}{j\omega\epsilon} \nabla \times \nabla \times \vec{A}_E^i$$
$$\vec{H}^i = \nabla \times \vec{A}_E^i - \frac{1}{j\omega\mu} \nabla \times \nabla \times \vec{A}_H^i \qquad (1)$$

is derived from the z–components of two vector potentials

$$A_{Hz}^i = \sum_{q=0}^{Q} (\sqrt{Z_{hq}^i}) \cdot T_{Hq}^i \cdot [V_{Hq}^i e^{-jk_{zHq}^i} + R_{Hq}^i e^{+jk_{zhq}^i}]$$
$$A_{Ez}^i = \sum_{p=0}^{P} (\sqrt{Y_{Ep}^i}) \cdot T_{Ep}^i \cdot [V_{Ep}^i e^{-jk_{zHq}^i} - R_{Ep}^i e^{+jk_{zhq}^i}] \qquad (2)$$

with the wave impedances $Z_{Hq}^i = 1/Y_{Hq}^i$, $Z_{Ep}^i = 1/Y_{Ep}^i$, and the wavenumbers k_z.

V and R are the TE– and TM–mode wave amplitudes of the forward and backward waves, respectively, which have to be related to each other at the corresponding discontinuity. This will yield the corresponding scattering matrix relations. T_H, T_E are the cross–section eigenfunctions of the corresponding waveguide structures under consideration [6] – [8].

For the general asymmetrical E–plane finned or ridged waveguide eigenvalue problem (Fig. 1b), a Y–/H–matrix–type transverse resonance method is used together with the singular value decomposition technique [9]. This reliable procedure reduces the computational requirements significantly.

Matching the tangential field components of the regions involved at the common interface yields the modal scattering matrix (S) of the related discontinuity [6] – [8]. The series of step discontinuities, for a complete polarizer structure, is calculated by direct combination of the single modal scattering matrices.

The computer–aided design is carried out step by step in order to reduce the requirements for the optimization process: First, the stepped septum design data of [1] are taken for the initial optimization parameters. Second, a suitable corrugated polarizer structure is optimized for compensating the phase deviation. Finally, the optimization program utilizing the evolution strategy method [6] is applied for the overall structure. An error function is minimized with respect to a parameter vector which contains the septum and corrugated geometries, until a specific return loss and phase difference value is achieved over the desired frequency range.

The number of TE–modes, TM–modes, and cross–sectional expansion terms [8] are chosen to be 30, 18, 30, for the septum sections, and 30, 18, for the corrugated waveguide sections, respectively. The numbers have been obtained by checking the convergence behavior against measurements, cf. Figs. 2, 3 and 4.

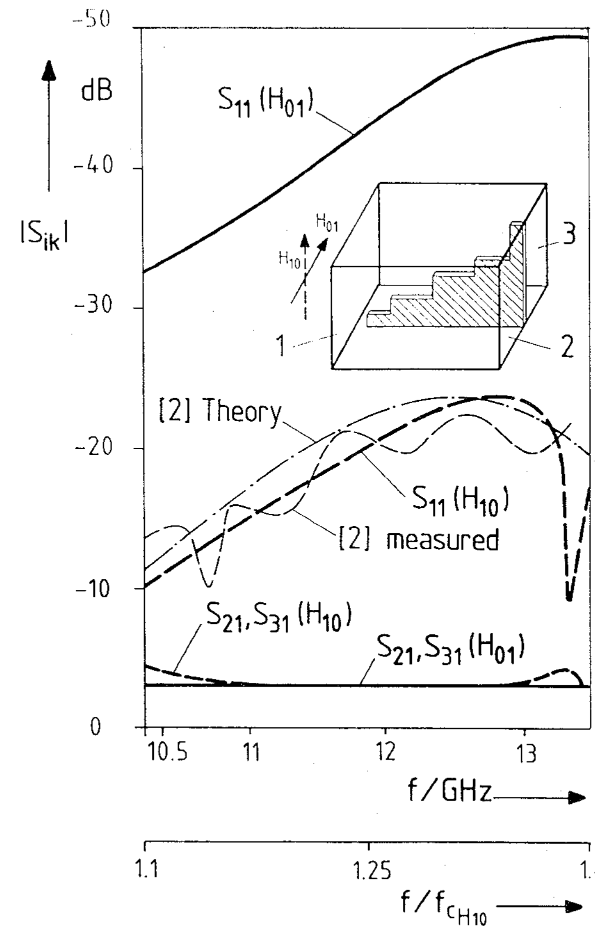

Fig. 2:
Septum polarizer design according to [1]
Ku–band (WR75–R120–output–waveguide housings, 15.8mm x 7.9mm; 15.8mm square input waveguide), analyzed by our method

RESULTS

For a first verification of the theory, the septum polarizer design of [1] has been scaled up into the waveguide Ku–band (WR75–, R120–output–waveguide housings, 15.8mm x 7.9mm; 15.8mm square input waveguide) and has been analyzed by our method. Fig. 2 shows the results for the scattering parameters for H_{10}–(TE_{10}–) and H_{01}–(TE_{01}–) mode incidence. Good agreement with $S_{11}(H_{10})$ measurements reported in [2] may be stated. The differential phase shift $\Delta\varphi = [\measuredangle S_{21}(H_{10}) - \measuredangle S_{21}(H_{01})]$ of about 105° for this design (not shown in the Fig.2), however, does not provide the desired orthogonal behavior.

For a second verification, the notched septum polarizer type (Figs. 3, 4) is taken into account. Fig. 3 shows the field theory analysis of the notched septum polarizer design according to [5]. Merely fair agreement with the measurements of [5] can be stated. An own notched septum polarizer has been built (Fig. 4), therefore. Although this design is not optimum concerning both the H_{10} return loss and the differential phase shift, and a relatively thick septum (t = 1mm) has been used, good agreement between measurements and the theory may be demonstrated (Fig. 4) which holds also for the scattering parameters (not shown).

Figs. 5 present the results for a field theory optimized Ku–band waveguide corrugated septum OMT achieving a return loss of more than 20dB (Fig. 5a) together with nearly constant differential phase shift of about 90° (Fig. 5b) for about 10% bandwidth.

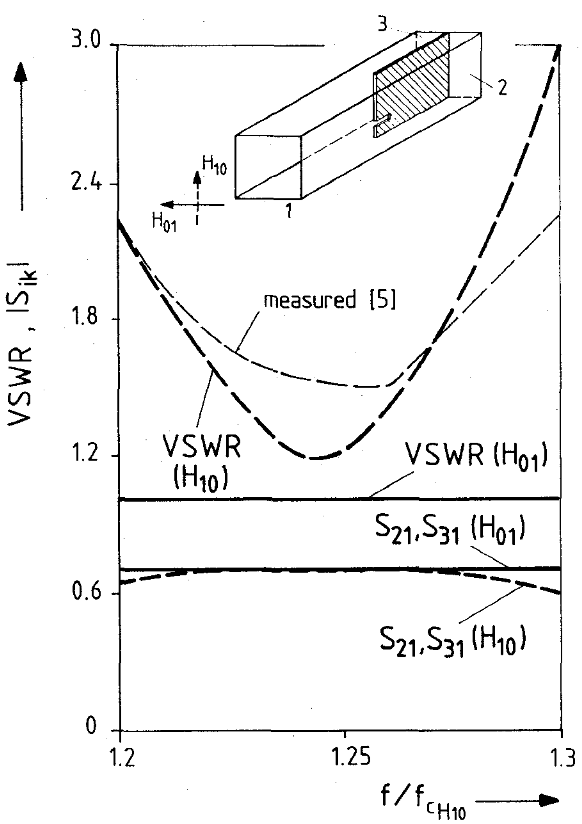

Fig. 3:
Field theory analysis of the notched septum polarizer according to [5].

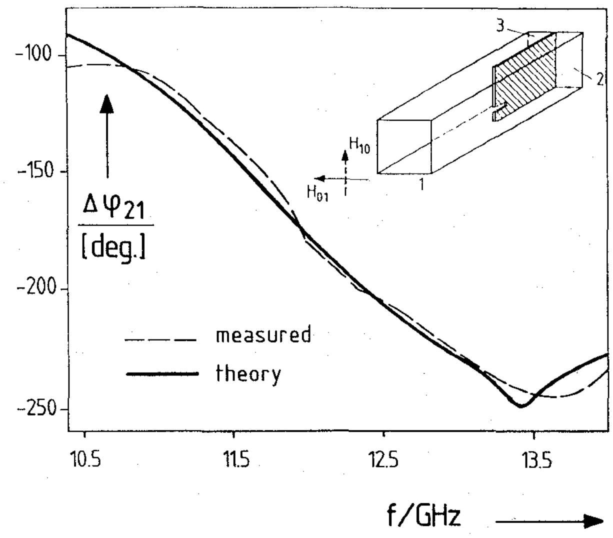

Fig. 4:
Notched septum polarizer with a relatively thick septum (t = 1mm). Differential phase shift.

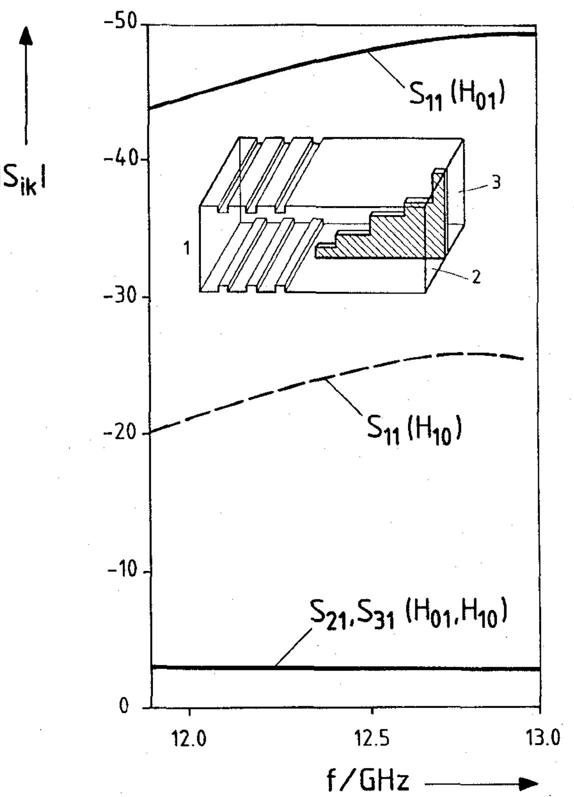

Fig. 5:
Field theory optimized Ku–band waveguide corrugated septum polarizer/OMT
a) S–parameters

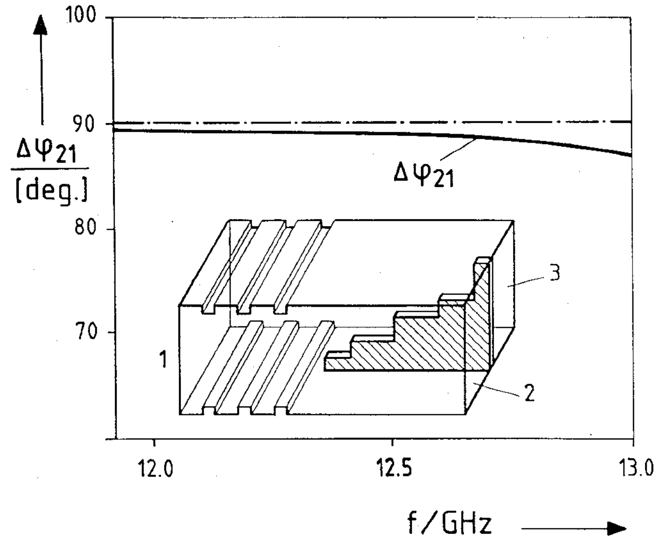

Fig. 5:
b) Differential phase shift

CONCLUSION

The rigorous modal S–matrix method presented in this paper achieves the accurate computer–aided design of corrugated septum polarizers/OMTs which combine the advantages of the compactness and the OMT feature of the septum structure with the broadband phase shifting properties of corrugated waveguide sections. The structure under investigation is composed by standard field theory key–building blocks, the double–step discontinuity, the waveguide–to–ridged–waveguide transition, and the transition waveguide to septated waveguide. Therefore, the finite thickness of the septum and the corrugations as well as the higher order mode interaction at all discontinuities are rigorously taken into account. The theory is verified by measurements.

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