FIELD THEORY CAD OF L–SHAPED IRIS COUPLED MODE LAUNCHERS AND DUAL–MODE FILTERS

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ABSTRACT

A rigorous field theory design method for L–shaped iris coupled TE_{10}–to–TE_{01}–mode launchers and dual–mode filters is presented. The theory is based on the full–wave mode–matching key–building block S–parameter description of the L–shaped iris in rectangular waveguides and allows, associated with the generalized S–matrix technique, the complete three–dimensional modeling of L–shaped structures and cascaded discontinuities. Arbitrary obstacle location and finite thickness are rigorously taken into account. An optimized design example of a very compact Ku–band (12–18 GHz) mode–launcher achieves 5% bandwidth with more than 20 dB return loss at the 90°–twisted WR62 in– and output waveguides. The computer optimized design of a Ku–band L–shaped iris coupled 4–pole dual–mode filter demonstrates good elliptic function behavior. The theory is verified by measurements.

INTRODUCTION

Dual–mode resonator filters require an adequate coupling mechanism between the orthogonal modes of operation which is traditionally realized by 45°–coupling screws [1], [2]. Although screws may be considered to be a flexible means for adjusting the filter performance, the low–cost and mass–production requirements of modern filter design has created the need for alternative solutions which allow the accurate electromagnetic overall CAD of such filters without the necessity for post assembly fine tuning elements.

More recently, L–shaped rectangular waveguide sections have been utilized [3], [4] for providing the required coupling between the TE_{10}– and TE_{01}–modes for mode–launcher [3] and for dual–mode filter applications [4]. However, the L–shaped mode–launcher was designed experimentally [3], and the investigation of the L–resonator properties in the dual–mode filter design [4] was restricted to a two–dimensional eigenvalue mode–matching solution. The rigorous full design potential of a complete three–dimensional field theory CAD method for designing such components which are built by L–shaped elements, therefore, has not yet been applied so far. Moreover, for compact and improved components it may be desirable to utilize the mutual compensation effects inherent in the individual structures by taking the overall performance of the filter or launcher component directly into account for the optimization process.

The purpose of this paper is to present a rigorous three–dimensional field–theory method for the design of L–shaped iris coupled rectangular waveguide structures (Fig. 1) suitable for providing adequate TE_{10}–and TE_{01}–mode coupling, and for the design of related cascaded structures, such as mode–launchers (Fig. 1a) and dual–mode filters (Fig. 1b). The theory is based on the full–wave mode–matching method for calculation the key–building block discontinuity rectangular waveguide to the L–shaped waveguide associated with the generalized technique [5] – [7]. The combination with the already known key–building block asymmetrical rectangular waveguide double plane step [5] achieves the efficient analysis of the L–shaped iris of finite thickness within rectangular resonators. Moreover, the composite structures may be rigorously analyzed including all higher–order modes including the mode conversion effect between the orthogonal TE_{10}– and TE_{01}–modes. The efficiency of the

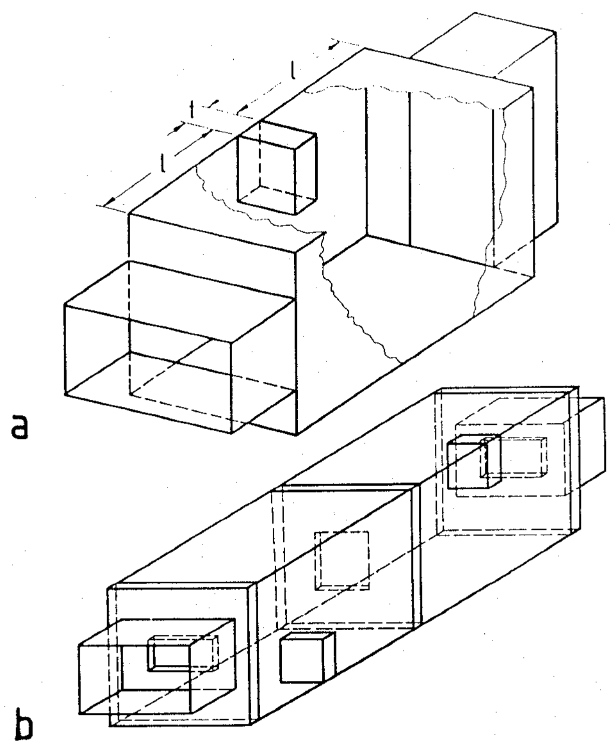

Fig. 1:
L–shaped iris coupled structures
a) TE_{10}–to–TE_{01} mode launcher
b) Dual–mode filter

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method is demonstrated by designing an optimum short Ku–band two–resonator mode launcher between 90°–twisted WR62 in– and output waveguides, and by designing a Ku–band 4–pole dual–mode filter which demonstrates good elliptic function behavior. The theory is verified by measurements.

THEORY

The L–shaped iris problem is decomposed into two key building blocks: transition rectangular waveguide to L–shaped waveguide (Fig. 2a) and the double–step junction discontinuity [5]. Combination with the modal scattering matrices of the corresponding intermediate homogeneous waveguide sections of finite lengths yields the total scattering matrix of the composed structure.

The electromagnetic field in the regions i = I, II (I: rectangular waveguide, II: L–shaped waveguide, Fig. 2a)

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

is derived from the z–components of two vector potentials

$$A^i_{Hz} = \sum_{q=0}^{Q} (\sqrt{Z^i_{hq}}) \cdot T^i_{Hq} \cdot [V^i_{Hq} e^{-jk^i_{zHq}} + R^i_{Hq} e^{+jk^i_{zhq}}]$$
$$A^i_{Ez} = \sum_{p=0}^{P} (\sqrt{Y^i_{Ep}}) \cdot T^i_{Ep} \cdot [V^i_{Ep} e^{-jk^i_{zHq}} - R^i_{Ep} e^{+jk^i_{zhq}}] \qquad (2)$$

with the wave impedances

$$Z^i_{Hq} = (\omega\mu)/(k^i_{zHq}) = 1/Y^i_{Hq},\ Y^i_{Ep} = (\omega\epsilon)/(k^i_{zEp}) = 1/Z^i_{Ep}, \qquad (3)$$

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 at the corresponding discontinuity. This will yield the corresponding scattering matrix relations. T^i_{Hq}, T^i_{Ep} are the the cross–section eigenfunctions of the corresponding waveguide structures under consideration, i.e. L–shaped guide (i=II), and rectangular waveguide (i=I).

The cross–section eigenvalue problem, like in [4], [7], [8], for the homogeneous L–shaped waveguide (Fig. 2) can be solved separately for TE– and TM–modes. For the eigenvalue problem, the transverse resonance method is used [7], [8]. This procedure reduces the size of the characteristic matrix equation to a quarter of the original size. The results for the normalized propagation constant of the example of a quadratic L–shaped structure ($x_1=y_1$, $x_2=y_2$) are plotted in Fig. 2 and compared to available results of [4]. Good agreement may be stated.

In order to calculate the modal scattering matrix of the key–building block discontinuity rectangular waveguide to L–shaped waveguide directly by the corresponding field matching relations of the wave amplitude coefficients according to (2), the cross–section eigenfunctions are suitably normalized [7].

Matching the tangential field components at the common interface yields the modal scattering matrix of the step discontinuity waveguide to L–shaped waveguide in the form:

$$\begin{bmatrix} (R^I) \\ (V^{II}) \end{bmatrix} = (S) \begin{bmatrix} (V^I) \\ (R^{II}) \end{bmatrix} . \qquad (4)$$

The modal scattering matrix of the rectangular waveguide double–step discontinuity is already given in [5]. The series of step discontinuities, for a L–shaped obstacle of finite length or a complete mode launcher structure, is calculated by direct combination of the single modal scattering matrices [5] – [7].

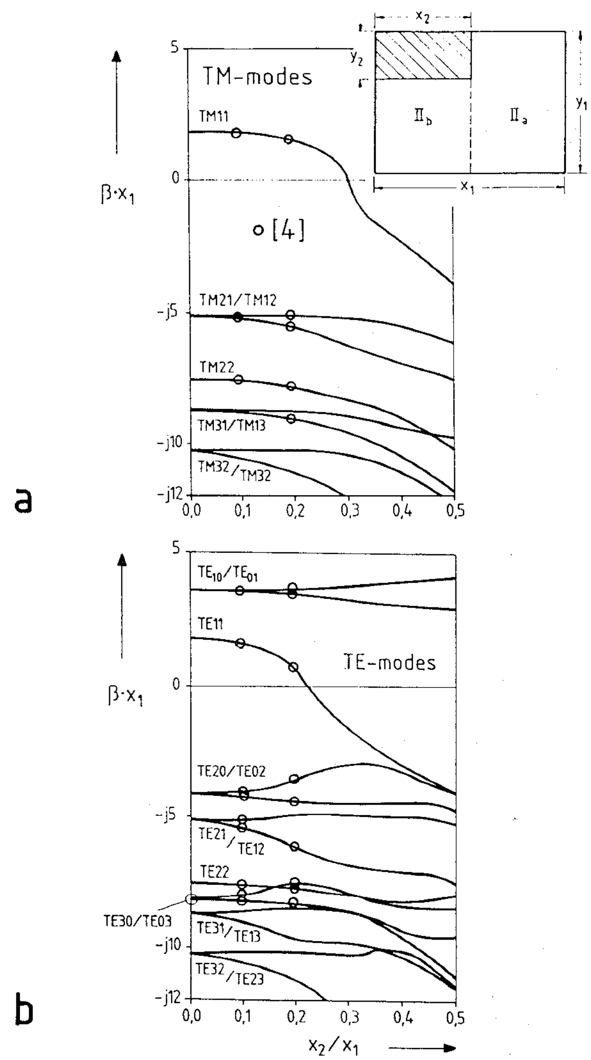

Fig. 2:
Normalized propagation factors of the square L–shaped waveguide ($x_1=x_2$, $y_1=y_2$)

The number of TE–modes, TM–modes, and cross–sectional expansion terms [6] are chosen to be 27, 17, 25, respectively. For better convergence, the numbers of the expansion terms for matching the subregions IIb and IIa (Fig. 2) are chosen so that the values relate to the ratio of the corresponding y dimensions, for instance 5:25 if the ratio of the y dimensions is 1:5. The choice of the numbers of the modes and expansion terms has been verified by checking the convergence behavior against the already available propagation constants [9], [4] as well as against the results of own measurements.

RESULTS

For the verification of the theory for calculating a three–dimensional structure, Fig. 3a shows the computed and measured (TE_{10}–to–TE_{10}) return and (TE_{10}–to–TE_{01}) insertion losses versus frequency of a nonoptimized L–shaped iris coupled dual–mode resonator mode launcher designed for operation in the waveguide Ku–band (WR 62 waveguide in– and output ports: 15.799mm x 7.899mm). The mode launcher with the 1 mm thick L–shaped iris has been fabricated by using simple filing and soldering techniques. Excellent agreement between the measurements and the theoretically predicted values may be observed.

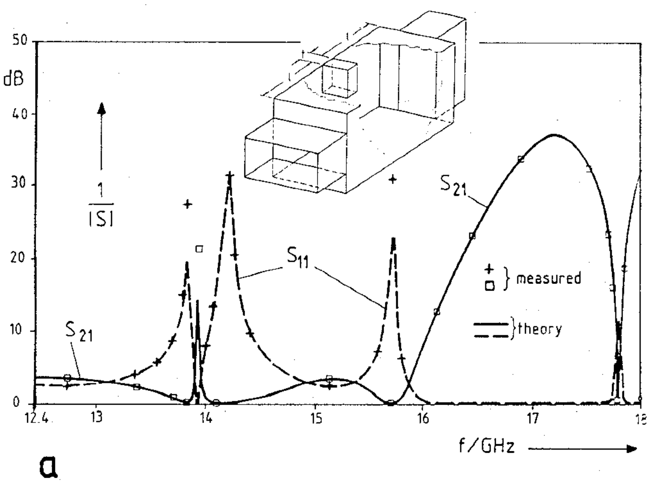

Fig. 3:
TE_{10}–to–TE_{10} return (– – –) and TE_{10}–to–TE_{01} insertion loss (———) curves versus frequency of an L–shaped iris coupled resonator mode launcher in the waveguide Ku–band (WR 62 waveguide in– and output ports: 15.799mm x 7.899mm).
a) Nonoptimized structure $x_1 = y_1 = 15.799$ mm, $x_2 = y_2 = 7.00$ mm (cf. Fig. 2), t = 1.00 mm, l = 7.00 mm. (ooo, +++ measured values).

If the structure dimensions, e.g. the resonator length and the thickness of the L–shaped iris, are suitably optimized, improved results are achieved. This is demonstrated in Fig. 3b where 22dB return loss and less

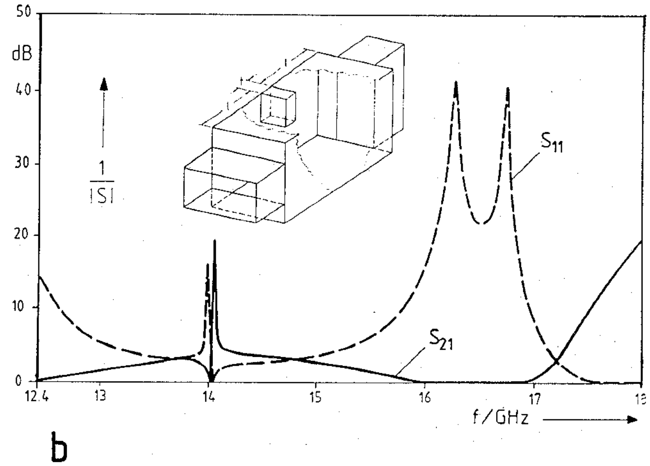

Fig. 3:
b) Optimized structure, $x_2 = y_2 = 7.00$ mm
t = 0.210 mm, l = 5.50 mm.

than 0.1 dB insertion loss are attained within the range of about 16.1 GHz and 16.8 GHz. The overall length of the mode launcher is only about 11.2 mm; the 0.210 mm thick L–shaped obstacle may be fabricated by metal etching techniques.

As a second example, a Ku–band 4–pole dual–mode filter with two square waveguide resonators and two L–shaped iris coupling elements has been computer optimized. The two L–shaped iris elements are twisted by 90° in the longitudinal direction to produce the necessary negative 1–4 resonator coupling for elliptic filter response. Fig. 4 demonstrates the good elliptic function and return loss behavior of the filter.

CONCLUSION

A rigorous three–dimensional field theory method is presented for the design of L–shaped iris coupled rectangular waveguide structures which may be used as adequate TE_{10}–to–TE_{01} mode coupling elements for mode–launchers and dual–mode filters. The theory is based on the full–wave mode–matching method for calculating the key–building block discontinuity rectangular waveguide to the L–shaped waveguide associated with the generalized S–matrix technique. The combination with the already known key–building block asymmetrical rectangular waveguide double plane step achieves the efficient modeling of the L–shaped iris of finite thickness within rectangular resonators. Moreover, the composite structures may be rigorously analyzed including all higher–order modes including the mode conversion effect between the orthogonal modes. The efficiency of the method is demonstrated by designing an optimum short Ku–band two–resonator mode launcher between 90°–twisted W62 in– and output waveguides and by a Ku–band elliptic function 4–pole dual–mode filter. The theory is verified by measurements.

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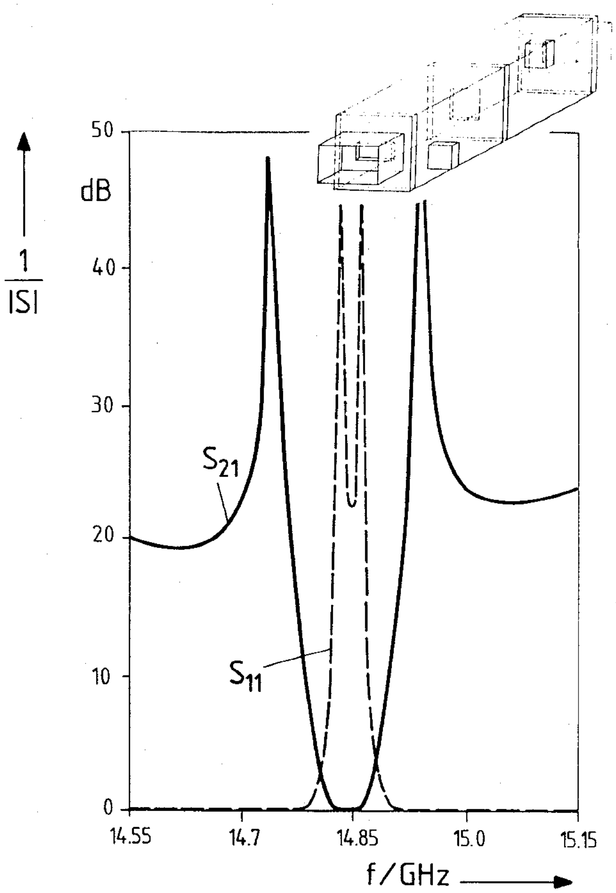

Fig. 4:
4–pole L–shaped iris coupled elliptic function dual–mode filter designed for the waveguide Ku–band

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