DESIGN OF MILLIMETER-WAVE EXTRACTED-POLE FILTERS WITH ASYMMETRICAL FREQUENCY CHARACTERISTICS

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ABSTRACT

In this paper, we present a rigorous field theory analysis for iris-type extracted-pole filters. The design and performance of two extracted-pole filters with asymmetrical frequency characteristics designed at 60 GHz are described. The accuracy of the computed results is checked by comparison with the measured data.

INTRODUCTION

In most diplexer applications, a steep cutoff is needed on one side of each filter, with a relatively low selectivity requirements on the other side. Although dual-mode elliptic filters are effective in meeting these requirements, their use is limited to narrowband applications. Moreover, the necessity of using coupling and tuning screws imposes additional limitations on their utilization in millimeter-wave applications.

More recently, it has been shown in [1], [2] that the selectivity of conventional E-plane filters can be improved by using inductively coupled stopband cavities mounted on the top of the waveguide housing. However, in the design procedure used in [1], [2] the dimensions of the E-plane filter and the stopband cavities are preoptimized separately, leading to an overall filter with unnecessarily longer length.

On the other hand, the advantages of the extracted-pole technique has been demonstrated in the design of a six-pole cylindrical TE_{011} mode filter in [3]. In conventional Chebyshev bandpass filters, the transmission zerios exist at infinity, there providing infinite attenuation. In view of [3] and [4], if some of these zeros are brought to finite location in the argand diagram, features such as very high cut-off slopes and in-band group delay equalization may be achieved. A generalized circuit theory synthesis procedure has been presented in [4] for extracted-pole filters with symmetrical and asymmetrical frequency characteristics. it is desirable, however, that the design procedures of millimeter-wave filters be based on highly accurate analysis.

In this paper, we present a rigorous field theory analysis for the extracted-pole iris-type filter shown in Figure 1. The analysis is based on the mode matching fomulation allowing the effect of the higher order modes to be taken into account. In contrast to the filter configuration considered in [1] and [2], which can be only used in narrowband applications, the filter structure described in this paper is useful in narrowband and wideband applications. The performance of two extracted-pole filters (transmit and receive) designed at V-band is presented and compared with theory.

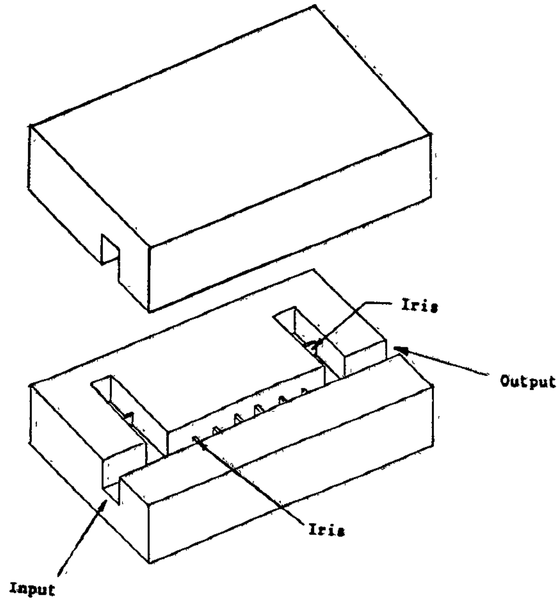

Figure 1: Iris-Type Extracted-Pole Filter

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ANALYSIS AND NUMERICAL RESULTS

Figure 1.0 illustrates the extracted-pole filter configuration considered in this paper. A set of irises are machined in two blocks which are bolted together to form the filter. The two key elements in the filter structure are the inductive iris and the E-plane waveguide T-junction. A method for analyzing the inductive iris has been described in [5], [6]. In this paper, we present a simplified formulation for evaluating the scattering parameters of the waveguide T-junction. The formulation is an extension of the technique used in [7] for analyzing right-angle waveguide corners. However, unlike the approach used in [7], which only yields the scattering parameters of the dominant mode, the formulation presented in this paper provides the scattering parameters of the dominant as well as the higher order modes.

Consider the T-junction shown in Figure 2, the fields in regions I, II, and III can be expanded in terms of TE and TM modes which are readily obtained using the electric and magnetic Hertzian potentials derived in [9]. In view of [7], the fields in region IV can be written in terms of three standing wave solutions as.

$$E_{IV} = \Sigma C_{1n}\Phi_{1n} + \Sigma C_{2n}\Phi_{2n} + \Sigma C_{3n}\Phi_{3n} \quad (1)$$

$$H_{IV} = \Sigma C_{1n}\Psi_{1n} + \Sigma C_{2n}\Psi_{2n} + \Sigma C_{3n}\Psi_{3n} \quad (2)$$

Matching the components of the electric fields and magnetic fields at the cross sections, S_1, S_2 and S_3 defined in Figure 3 gives.

$$\begin{bmatrix} A_I + B_I \\ A_{II} + B_{II} \\ A_{III} + B_{III} \end{bmatrix} = \begin{bmatrix} H_1 & 0 & 0 \\ 0 & H_2 & 0 \\ 0 & 0 & H_3 \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} A_I - B_I \\ A_{II} - B_{II} \\ A_{III} - B_{III} \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{22} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \quad (4)$$

where A_i, B_i are the E-field incident and reflected amplitude vectors, H_i, $i=1,2,3$ are diagonal matrices. M_{ij} are the H-field mode matching matrices whose elements represent the coupling between the various modes. After some manipulations the scattering matrix of the T-junction can be written as:

$$[S] = 2.0 \begin{bmatrix} H_1 & 0 & 0 \\ 0 & H_2 & 0 \\ 0 & 0 & H_3 \end{bmatrix} \times \begin{bmatrix} H_1 + M_{11} & M_{12} & M_{13} \\ M_{21} & H_2 + M_{22} & M_{23} \\ M_{31} & M_{32} & H_3 + M_{33} \end{bmatrix}^{-1} - [I] \quad (5)$$

To verify the validity of the formulation presented in this paper, we compare in Figure 3 our results for E-plane and H-plane T-junctions with experimental data. The results are computed using 42 expansion terms in region IV and 7 TE and 7 TM modes in each of the three regions I, II and III. It is observed that the measured data agree well with the computed results.

Having determined the scattering matrix of the E-plane waveguide T-junction, the overall scattering matrix of extracted-pole filter can be determined using the generalized scattering matrix technique [5]. The filter is then designed using a CAD algorithm consisting of an analysis routine and an optimization routine which in turn tunes the filter dimensions to achieve the desired performance. The optimization routine is based on the minimax optimization approach [8]. The advantage of this approach is that, a fast convergent solution can be achieved by carefully selecting the frequency sampling points.

In the design procedures, the circuit theory model presented in [3], [4] for extracted-pole filters is first used to calculate the iris susceptances and resonator lengths. This model does not take into account the effects of the T-junction discontinuity, the finite thickness of the irises and the higher order mode interactions. However, it provides a reasonable initial solution for the optimization process.

Two extracted-pole filters with asymmetric frequency characteristics have been designed and tested at V-band. A receive filter with a passband of 59.54-60.04 GHz and a transmit filter with passband of 63.5-64.0 GHz. Each filter is required to provide a 70 dB rejection at the passband of the other, with stringent insertion loss and group delay specifications. The filters are designed for a bandwidth of approximately 3.5 GHz to meet the required insertion loss performance. Figures 4 and 5 show a comparison between the field theory optimized computer results and the measured results for the two filters. It is noted that the measured results are in excellent agreement with the theoretical calculations.

CONCLUSIONS

A field theory analysis has been presented for extracted-pole filters. The numerical results obtained have been compared with experimental data. The feasibility of designing extracted-pole filters having asymmetrical frequency characteristics at the millimeter-wave range has been demonstrated. The filter structure considered in this paper promises to be useful in microwave and millimetre-wave diplexer applications.

ACKNOWLEDGEMENT

This work was supported in part by FIAR Space Division and the European Space Agency.

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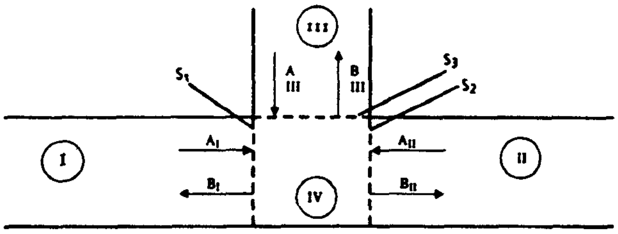

Figure 2: Waveguide T-junction

(a)

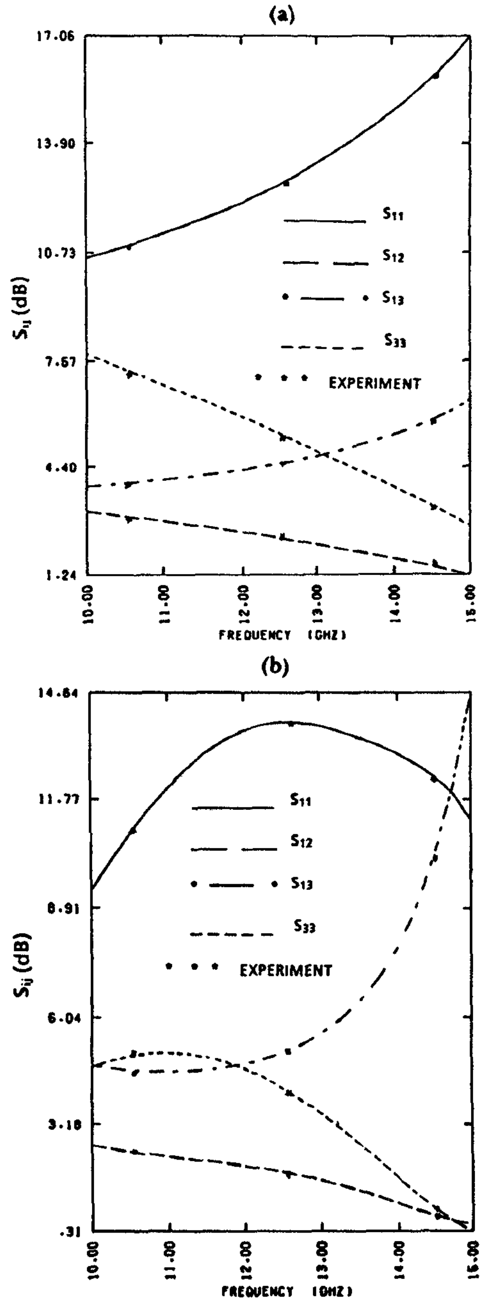

Figure 3: Scattering Parameters of WR75 T-Junction
a) E-plane T-Junction
b) H-plane T-Junction

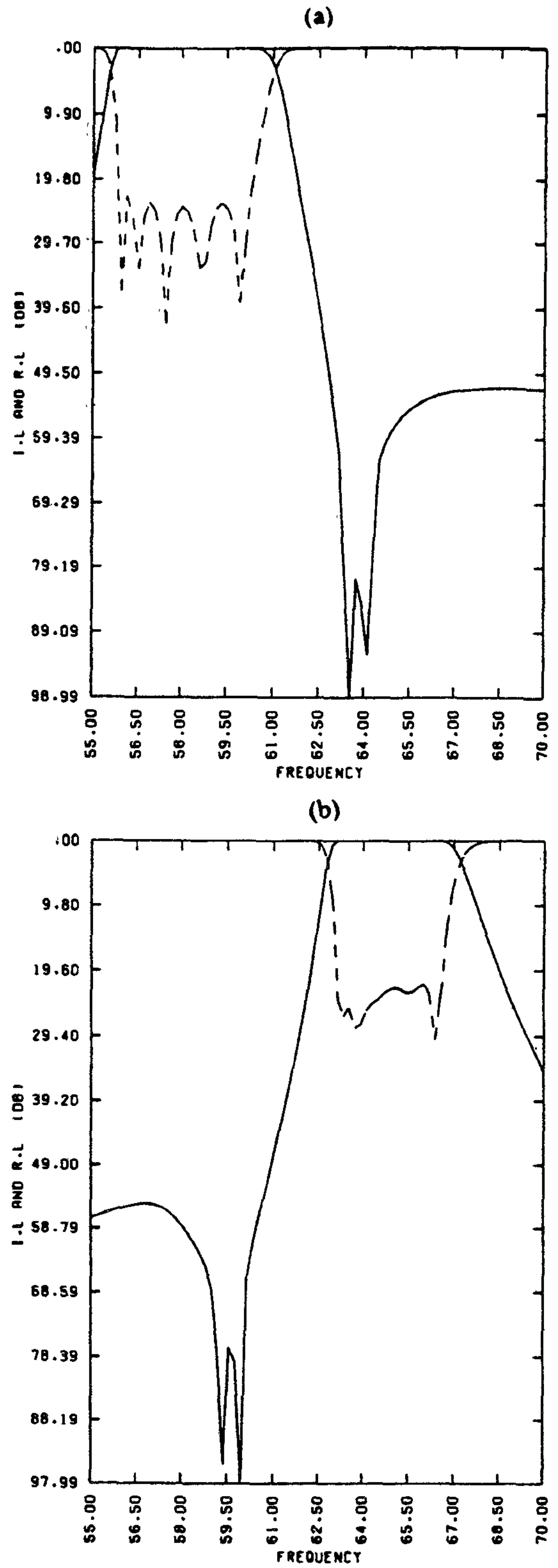

Figure 4: The Field Theory Optimized Computer Performance for a) A receive filter, b) A transmit filter

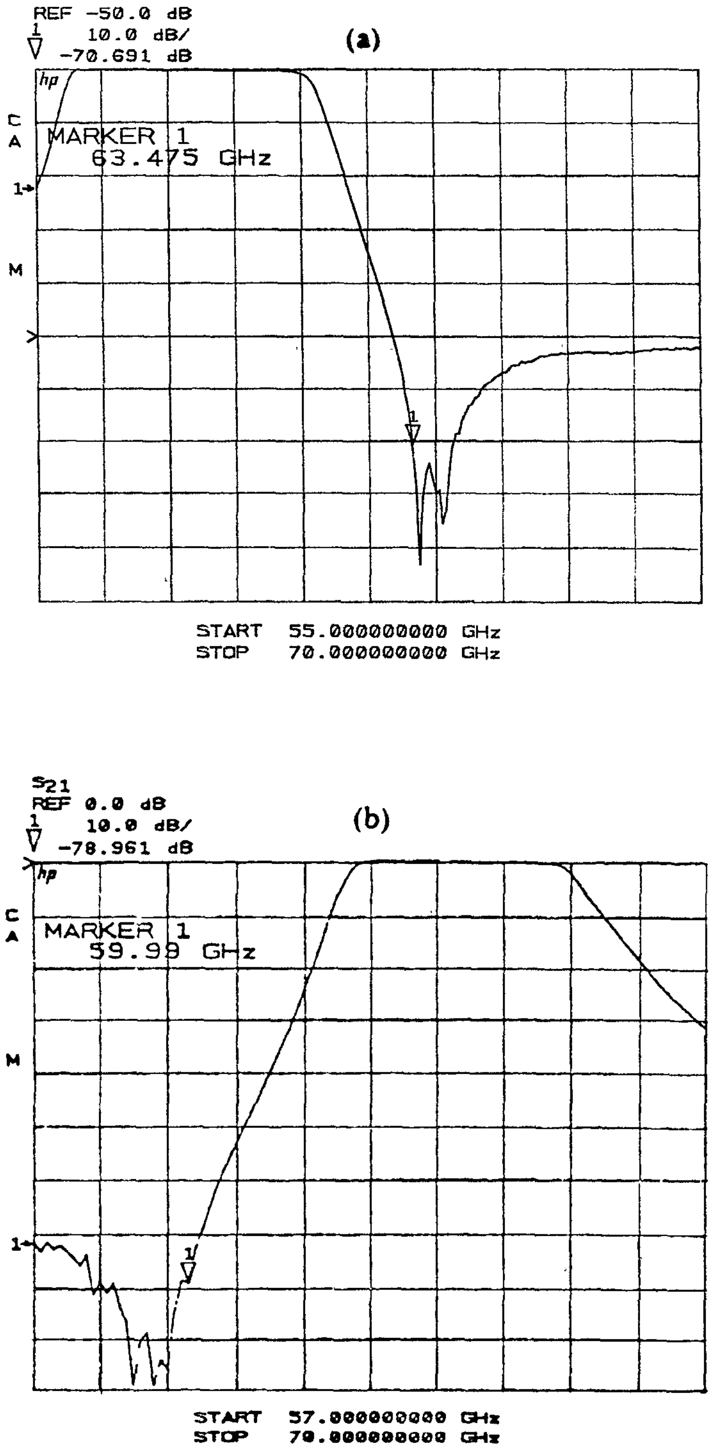

Figure 5: The Measured Performance of the Two Filters Simulated in Figure 4 a) A receive filter, b) A transmit filter