AN INTEGRATED T-SEPTUM WAVEGUIDE DIPLEXER FOR COMPACT FRONT-END APPLICATIONS

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ABSTRACT

This paper introduces a new T-septum waveguide diplexer for compact integrated front-end applications in modern communication systems. The 8.74/10.14 GHz X-band design for four-percent channel bandwidths is one of the most compact waveguide diplexers ever presented. The size reduction is predominantly achieved by utilizing T-septum filter technology which reduces the dimensions of a typical waveguide filter by a factor of four to five. Moreover, a considerably improved stopband behavior towards figher frequencies is obtained. Together with a height-reduced waveguide E-plane T-junction, the overall diplexer dimensions are less than $(30mm)^3$. The computer-aided analysis and design are based on mode-matching techniques and optimization procedures, respectively. The channel filters are separately synthesized and fine-tuned by a final optimization to meet diplexer specifications. The design can be scaled to other waveguide bands. The theory is verified by measurements at the example of an X-band T-septum filter configuration.

I. INTRODUCTION

The advent of integrated waveguide E-plane technology placed an increasing demand on millimeter-wave diplexing units for transmit-receive channel separation, e.g. [1-3]. Since then, a number of different multiplexer components based on field-theory designs have been proposed. While the physical channel separation is commonly accomplished by waveguide N-furcations or T-junctions, the filter configurations and their performance distinguish the different designs. Most components employ E-plane filters [4-9], others use elliptic function filters [10], or lowpass-highpass arrangements for diplexer applications [11]. Although the numerical models have been improved to include, e.g., discontinuity-compensating irises and steps, no attempts have been made to reduce the physical size of the components in order to make these designs attractive for modern integrated microwave communication systems. Since the space requirements are dominantly determined by the resonance wavelengths of the channel filters, smaller filter configurations will automatically contribute to low-weight, small-size and compact multiplexer designs.

Therefore, this paper focuses on a novel integrated waveguide diplexer based on T-septum filter technology (Fig. 1). By utilizing the wideband properties of T-septum waveguides [12] and rigorous numerical models for the filter design [13], both the channel filters and the connecting T-junction can be significantly reduced in size. Consequently, the overall dimensions of an X-band waveguide diplexer with three-resonator channel filters are less than 30mm x 30mm x 30mm. The component is suitable for split-block housing fabrication by numerical controlled milling facilities.

II. DESIGN

The design of the integrated T-septum waveguide diplexer is primarily based on mode-matching techniques. Except for the waveguide E-plane T-junction, which is solved according to [9], the discontinuities involved are an H-plane step and a waveguide-to-T-septum discontinuity as shown in Fig. 2. The numerical analysis follows that of [13]. However, the T-septum cross-section functions need to be slightly modified due to the fact that only single T-septums are used here for compactness.

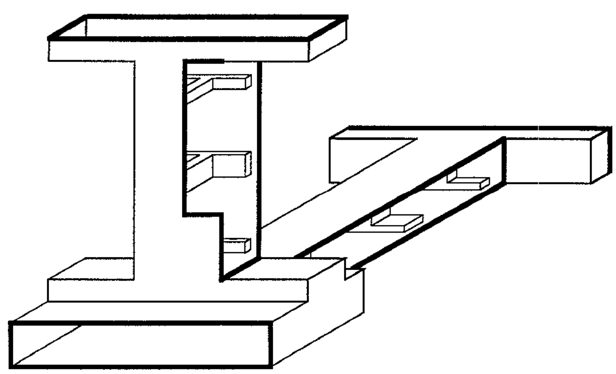

Fig. 1 Integrated T-septum waveguide diplexer for compact front-end applications.

$$T_h(x,y) = \sum_{j=0}^{J-1} A_j^I \frac{\sin\left[k_{xj}^I (x - \frac{a}{2})\right]}{k_{xj}^I} \frac{\cos\left[\frac{j\pi}{b_1} y\right]}{\sqrt{1+\delta_{0j}}} + \sum_{m=0}^{M-1} A_m^{II} \cos\left[k_{xm}^{II} x\right] \frac{\cos\left[\frac{m\pi}{b} y\right]}{\sqrt{1+\delta_{0m}}} + \sum_{n=0}^{N-1} A_n^{III} \cos\left[k_{xn}^{III}(x-a_2)\right] \frac{\cos\left[\frac{n\pi}{b-b_2}(y-b_2)\right]}{\sqrt{1+\delta_{0n}}} \quad (1)$$

$$T_e(x,y) = \sum_{j=1}^{J-1} D_j^I \cos\left[k_{xj}^I (x - \frac{a}{2})\right] \sin\left[\frac{j\pi}{b_1} y\right] + \sum_{m=1}^{M-1} D_m^{II} \frac{\sin\left[k_{xm}^{II} x\right]}{k_{xm}^{II}} \sin\left[\frac{m\pi}{b} y\right] + \sum_{n=1}^{N-1} D_n^{III} \frac{\sin\left[k_{xn}^{III}(x-a_2)\right]}{k_{xn}^{III}} \sin\left[\frac{n\pi}{b-b_2}(y-b_2)\right] \quad (2)$$

The design of the diplexer is carried out in two steps. First, the evanescent-mode T-septum channel filters are designed using the procedure outlined in [14]. Emphasis is placed on the fact that the filter for the lower frequency band is not increased in length compared to that for the upper band. Instead the T-septum dimensions are slightly modified which contributes to the compactness of the design. In the second step, the filters are connected to the waveguide T-junction, and only the lengths between the T-junction and the H-plane steps are optimized. Finally, an overall optimization, e.g. [15], fine-tunes the lengths involved in the second step and, addidionally, the section lengths of both channel filters. This contributes to an improved return loss behavior in the diplexer passbands.

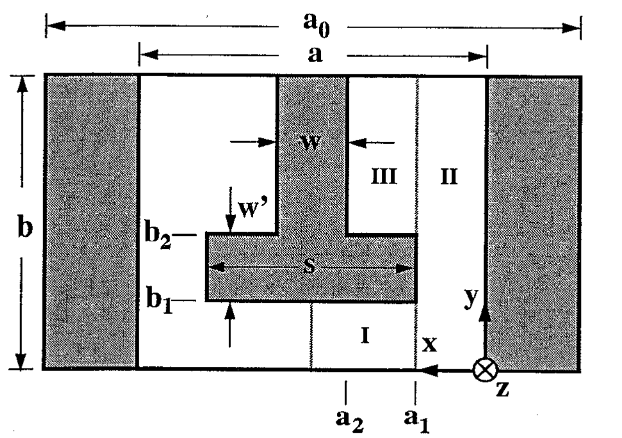

Fig. 2 Cross-section of discontinuities for diplexer analysis.

III. RESULTS

The initial investigation is concerned with the performance of the channel filters. Fig. 3 shows the response of a T-septum evanescent-mode waveguide filter with a double-plane step discontinuity between the connecting and the below-cutoff guides. Although the agreement between theory and measurements is fairly close, some problems in the prototype component are encountered regarding the precise axial alignment of the filter to the connected X-band waveguides of the measurement setup. This results in the insertion and return loss values shown in Fig. 3 which require improvement before implementation in a diplexer circuit.

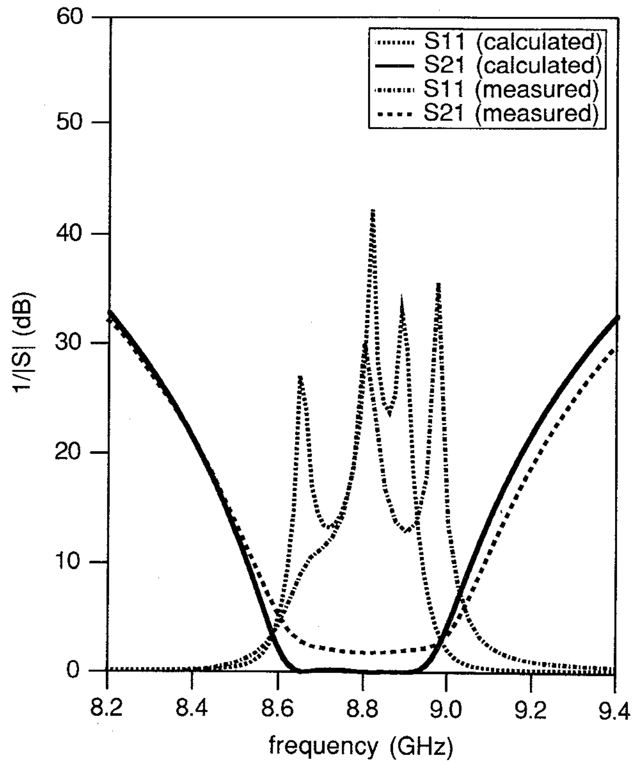

Fig. 3 Calculated and measured response of T-septum waveguide channel filter with double-plane step discontinuity to evanescent-mode guide.

Since the double-plane step discontinuity appears to be the most critical part of the filter component, the diplexer arrangement of Fig. 1 is designed with H-plane steps only. While the below-cutoff operation for the evanescent-mode filters is maintained, an additional advantage of solely using H-plane steps is the reduced waveguide height of the overall component - a technique which is frequently used in integrated satellite front ends.

Figs. 4 presents the transmission and input return loss responses of the X-band integrated T-septum waveguide diplexer for 8.74/10.14 GHz with bandwidths of approximately four percent. The cross-sections of the waveguide ports are 22.86mm x 3.5mm, those of the evanescent-mode sections are 7.112mm x 3.5mm. Both filters are only 18mm long with typically less than 3mm connecting lengths to the T-junction. These dimensions make the diplexer manufacturable in a cubicle of less than 30mm x 30mm x 30mm.

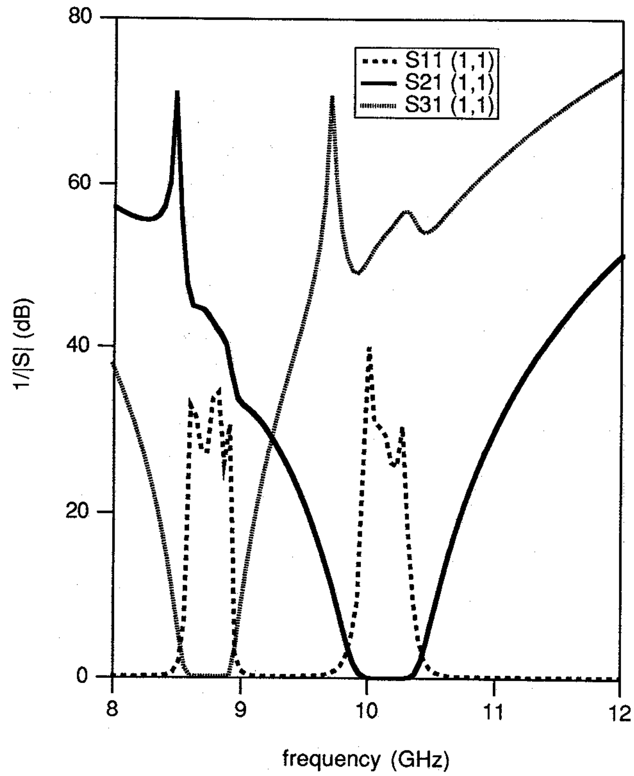

Fig. 4a Transmission and input reflection behavior of integrated T-septum X-band waveguide diplexer.

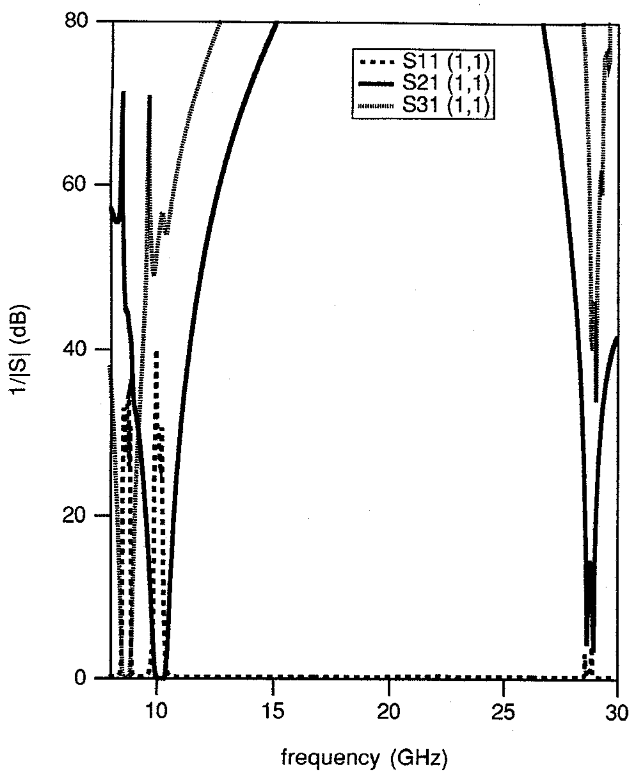

Fig. 4b Stopband behavior of X-band diplexer.

As shown in Fig. 4a, the crossover attenuation is 29 dB, and the input return loss is better than 25 dB. Fig. 4b displays the excellent stopband characteristics of the diplexer up to 28 GHz. This is a fundamental advantage of T-septum waveguide filter technology.

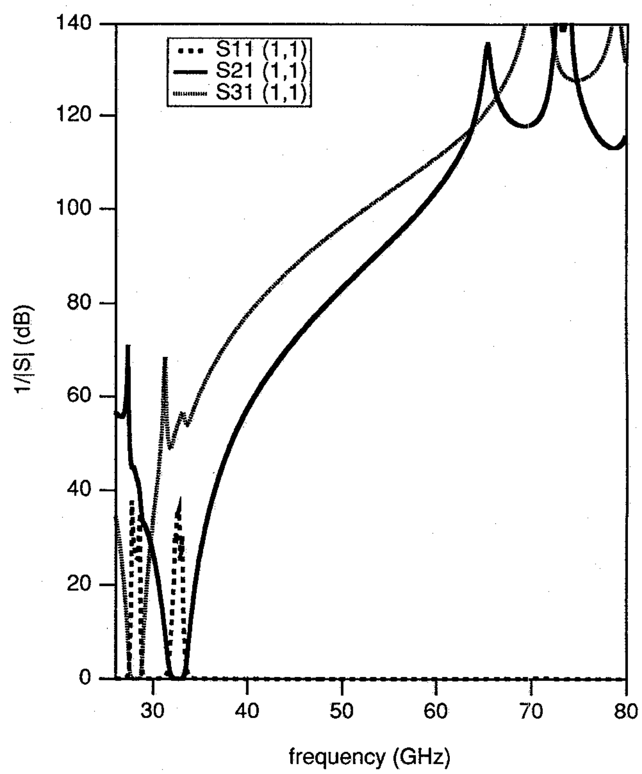

Fig. 5 Performance of diplexer scaled for Ka-band operation.

The diplexer design can be scaled to any other waveguide band with identical frequency behavior with respect to the fundamental-mode cutoff frequency of the input-port waveguide. This is demonstrated in Fig. 5 for operation in Ka-band. The channel passbands are centered at 28.2/32.7 GHz, and a stopband beyond 80 GHz is obtained.

IV. CONCLUSION

The design of an integrated T-septum waveguide diplexer is presented. By utilizing the advantages of T-septum evanescent-mode filter structures and reduced-height waveguide technology, an extremely small component is obtained which is idealy suited for compact integrated front-end applications. Excellent performance is obtained with respect to stopband characteristics towards higher frequencies. The analysis is based on rigorous field-theory techniques involving mode-matching methods. The design procedure is based on seperate channel filter design and a final optimization including all relevant parameters to improve the input return loss performance.

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