A Novel Compact Millimeter Wave Diplexer

Erdem Ofli and Rüdiger Vahldieck

Swiss Federal Institute of Technology, Laboratory for Electromagnetic Fields and Microwave Electronics (IFH), Gloriastrasse 35, CH-8092, Zurich, Switzerland
ofli@ifh.ee.ethz.ch

Abstract — **A novel compact millimeter wave diplexer is presented. The structure is composed of an H-plane transformer section and two cross-coupled folded E-plane metal-insert filters. The design is based on the generalized scattering matrices of the key building blocks of the diplexer which are computed using standard Mode Matching Technique (MMT). The new diplexer requires half the number of resonators of a conventional E-plane diplexer with T-section power dividers, is thus much shorter and shows less insertion loss. At the same time the ease of manufacturing known from typical E-plane filters is maintained.**

I. Introduction

Modern broadband millimeter wave communication systems require low-cost, mass-producible diplexers which satisfy relatively tight electrical specifications. However, tight electrical specifications and low-cost fabrication are usually a contradiction in terms and only few solutions are known to date that simultaneously satisfy these requirements. Most prominent among them are direct-coupled E-plane metal-insert filters which are inserted in both waveguide arms and fed by a common port consisting of an H-plane T-junction. The advantages of E-plane metal-insert filters for low-cost mass-fabrication are well known as this type of filter combines low-cost etching technique with straight forward milling of split-block waveguide housings. For very tight electrical specifications, however, the accuracy of etching techniques (+/- 20μm) for the metal inserts may not be sufficient. For this case a specialised electroforming technique has been adopted so that the shape of the metal inserts of the E-plane filter can now be fabricated with a routine accuracy of about 3μm on a 50μm thick silverized nickel sheet. For large quantities (>1000 pieces) the price for the inserts is comparable to those obtained from chemical etching. With these low manufacturing tolerances it was possible to achieve a consistent diplexer return loss of less than −18dB at 39GHz with very little frequency shift (+/- 15MHz).

Besides the many advantages of E-plane filters for millimeter wave applications, they show poor performance as diplexers when a high isolation between closely spaced passbands is required. In this case isolation can only be improved by using a larger number of resonators which also increases insertion loss as well as the size of the diplexer.

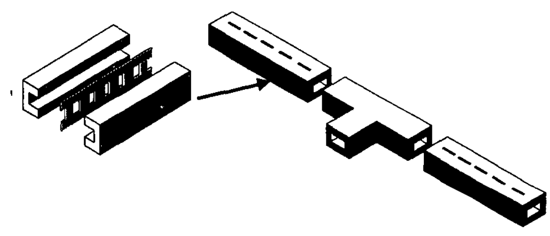

Fig. 1. Millimeter wave diplexer with direct-coupled E-plane metal-insert filters and T-section power divider.

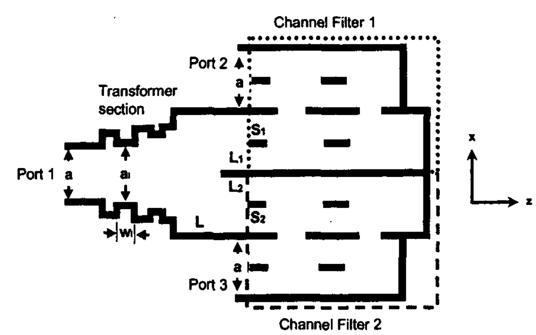

Fig. 2. Top view of the new diplexer structure with cross-coupled folded E-plane metal-insert filters.

To eliminate these problems and at the same time maintain the advantages of E-plane filters, a novel millimeter wave diplexer is introduced utilizing cross-

0-7803-7239-5/02/$10.00 © 2002 IEEE

2002 IEEE MTT-S Digest

coupled folded E-plane metal-insert filters as shown in Fig.2. The new diplexer is designed to operate in Q-band. The performance is compared with that of a standard E-plane diplexer shown in Fig.1.

II. Diplexer Design

Analysis and design of the new diplexer structure shown in Fig.2 is based on the mode matching technique (MMT). The structure consists of H-plane transformer sections optimized for the frequency range of both passbands and two cross-coupled folded E-plane single metal-insert filters.

Design and optimization of the H-plane transformer sections (Fig.3) is known from [1]. Initially the response of the H-plane power divider with the quarter-wave transformer sections is poor. However, after optimization of the transformer section the performance is quite acceptable [1] and will even become better after connection to the channel filters. Compared to the T-section power divider the H-plane transformer does not require additional compensation elements such as irises [2] or posts [3]. The latter are quite sensitive to manufacturing tolerances.

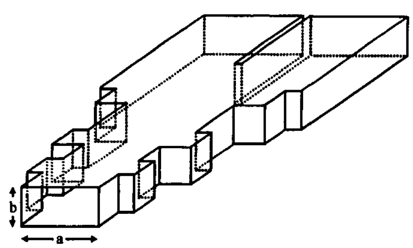

Fig. 3. 3D-view of the H-plane power divider [1].

The geometry of a cross-coupled folded E-plane filter used as channel filter is shown in Fig.4. This structure has been introduced recently to improve the slope selectivity [4] of E-plane filters. The four cavities used in this example are directly coupled through evanescent waveguide sections (metal septa). Cross coupling is accomplished by a full height opening in the separating wall between the 1st and the 4th resonator (producing finite transmission zeros).

Note that the 2nd and the 3rd resonators are also coupled through a full height wall opening and that the second resonator is double the length of the other resonators. This is necessary to achieve negative coupling. If the source is coupled only to resonator 1 and the load only to resonator 4, the coupling between resonators 1 and 4 must be negative to generate two transmission zeros [5]. To get a negative coupling, the next resonance is used, i.e. (TE_{102}), in resonator 3 instead of the fundamental resonance (TE_{101}). The coupling slot between resonators 2 and 3 is located in the second half of resonator 3 to force a negative coupling between 1 and 4. By placing the so obtained finite transmission zeros close to the passband improves the transfer characteristics of E-plane filters significantly.

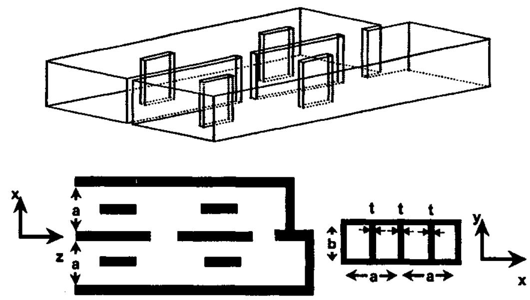

Fig. 4. Cross-coupled folded E-plane single metal-insert filter structure [4].

Since only TE_{mo}-modes are excited in the entire structure, the analysis by MMT is straightforward and very fast. The generalized scattering matrices of each discontinuity are cascaded appropriately to obtain the overall frequency response of the diplexer configuration as shown in Fig.5. The overall S-matrix of the taper is obtained by cascading the S-matrices of each taper section. Connecting this matrix to the bifurcation, which is a three-port S-matrix, and finally to the S-matrices of the individual filter S-matrices, provides the S-matrix of the entire diplexer.

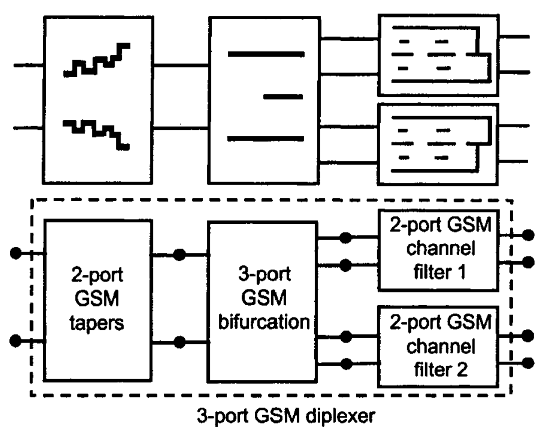

Fig. 5. Generalized scattering matrix (GSM) representation of the discontinuities involved in the diplexer structure.

III. RESULTS

Two cross-coupled folded E-plane filters are designed individually at center frequencies of 38.8GHz for Channel 1 and 39.8GHz for Channel 2, respectively, with a 500MHz guard band in between. Both filters and the taper section were initially optimized separately. Subsequently they were connected and in a final optimization run the following parameters are fine tuned: The taper dimensions like the individual waveguide widths (a_i) and lengths (w_i); the distance between the bifurcation (L, Fig.2) and the taper; the distance between the filters and the start of the bifurcation (L_1,L_2, Fig.2); the first septa of the individual filters (S_1, S_2, Fig.2). This fine tuning was necessary to compensate for the mutual coupling between the taper and the bifurcation as well as the filters and the bifurcation [6]. Other dimensions of the filters are not changed through the optimization.

Results for the 3-section H-plane transformer with bifurcation are shown in Fig.6. The computed return loss of the power divider is better than –16dB in the passband of both filters. Finally, the optimized structure reveals that the overall return loss of the diplexer is better than the return loss of the power divider alone. If one had optimized the power divider separately, i.e. without filters, the return loss in the frequency range of interest would have been better than –20dB. But, since the filter interacts with the power divider, it is better to do a fine optimization after all components are added to avoid unnecessary work beforehand. As seen in Fig.8, the overall return loss of the diplexer in the passband after fine optimization is –20dB.

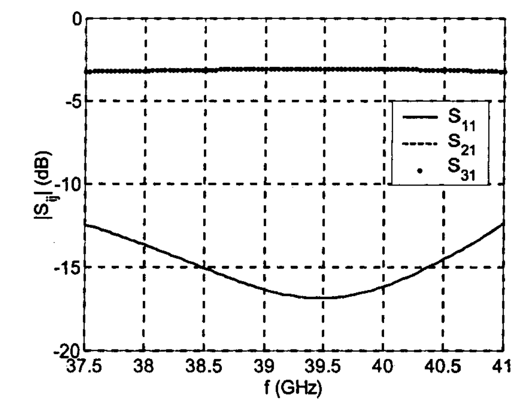

Fig. 6. Frequency response of the power divider (3-section taper with bifurcation).

The computed frequency response of the lower one of the two cross-coupled E-plane metal insert filters is shown in Fig.7. Four resonators have been used in both filters. For both filters the transmission zero at the higher, respectively, lower stopband slope improves the isolation between both filters. Like in the case of the taper, the initial optimization of the filters (Fig.7) gives not as good a response as after the fine optimization of the entire diplexer (Fig.9). In the final optimization mainly the first septa of the filters are optimized as well as the distance to the bifurcation. Fig.8 illustrates the insertion loss performance of the entire diplexer. Characteristic for diplexers is their stopband interaction at about the 3dB point of the respective other filter which is also seen in Fig.8. For verification of the MMT results an HFSS analysis shows very good agreement. Fig.9 shows the return loss of the diplexer. Except for the slight differences in the return loss (MMT provides better than –20dB, while HFSS calculates only –17dB) also here the agreement is very good. The MMT computations were based on 55 number of modes while for HFSS the discontinuities were resolved with a mesh of 93529 tetrahedras. This was a compromise between accuracy and computation time. It should be noted that the optimization of the overall structure with MMT is very fast and -for CPU-time reasons- could not be done with HFSS.

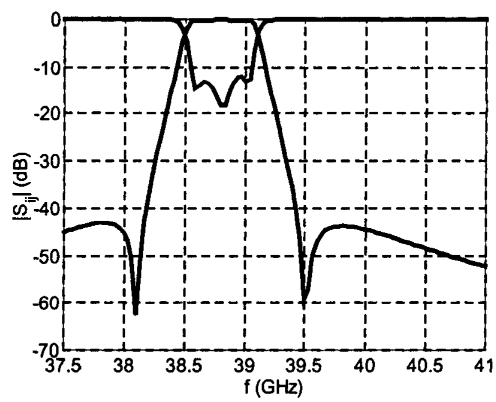

Fig. 7. Frequency response of the lower one of the folded cross-coupled 4-resonator E-plane metal-insert filters computed with the MMT.

Finally, Fig.10 shows a comparison between the new diplexer structure with the two four-resonator cross-coupled E-plane filters and a conventional design using two 9-resonator direct-coupled E-plane filters. Almost the same performance is achieved except that the measured insertion loss of the 9-resonator design is about 2dB while that of the 4-resonator cross-coupled design is about 1dB. Furthermore, since the performance of the cross-coupled E-plane filter is achieved with only 4 resonators in folded geometry, the overall length is significantly decreased compared to the traditional diplexer arrangement.

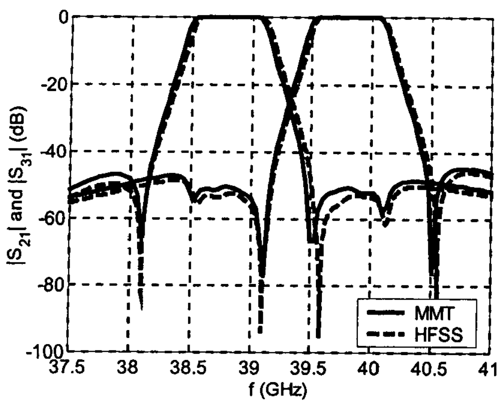

Fig. 8. Insertion loss of the diplexer computed with the MMT (solid line) and verified by HFSS (dashed line).

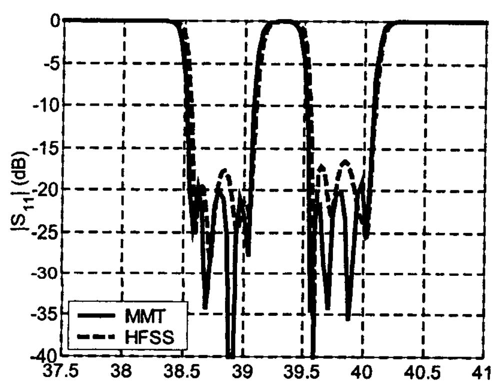

Fig. 9. Return loss of the diplexer computed with the MMT (solid line) and verified by HFSS (dashed line).

IV. Conclusion

A new compact H-plane diplexer with cross-coupled E-plane filters for millimeter wave applications has been developed. The resulting diplexer requires less than half the number of resonators of conventional E-plane diplexers to achieve comparable performance. The new design offers lower insertion loss, is much shorter than the conventional design and maintains the manufacturing advantages known from E-plane technology. The complete structure is analyzed and optimized using the MMT. Verification with HFSS shows excellent agreement.

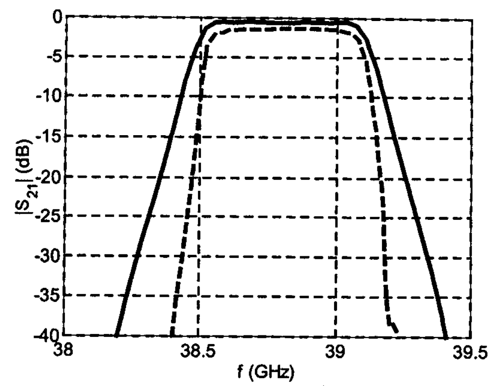

Fig. 10. Performance comparison between the diplexer with two 4-resonator cross-coupled E-plane filters (solid line) and the diplexer with two 9-resonator direct-coupled E-plane filters (dashed line).

Acknowledgment

This work was supported by Huber+Suhner AG under a Grant from the Kommission für Technik und Innovation, Government of Switzerland.

References

[1] J. Bornemann, "Design of millimeter-wave diplexers with optimized H-plane transformer sections", *Can. J. Elect. & Comp. Eng.*, vol. 15, 1990, pp. 5-8.

[2] J. Dittloff and F. Arndt, "Computer-aided design of slit-coupled H-plane T-junction diplexers with E-plane metal-insert filters", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-36, pp. 1833-1840, Dec. 1988.

[3] Y. Rong, H. Yao, K.A. Zaki and T. Dolan, "Millimeter-wave Ka-band H-plane diplexers and multiplexers", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-47, pp. 2325-2330, Dec. 1999.

[4] E. Ofli, R. Vahldieck, and S. Amari, "Analysis and design of mass-producible cross-coupled, folded E-plane filters", *IEEE MTT-S Int. Symp. Dig.*, 2001, pp. 1775-1778.

[5] A.E. Williams, "A four-cavity elliptic waveguide filter", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 1109-1114, Dec. 1970.

[6] R. Vahldieck and B.V. de la Filolie, "Computer-aided design of parallel-connected millimeter-wave diplexer/ multiplexers", *IEEE MTT-S Int. Symp. Dig.*, 1988, pp. 435-438.