Substrate Integrated Waveguide Diplexer with Dual-Mode Junction Cavity

Zamzam Kordiboroujeni and Jens Bornemann
Department of Electrical and Computer Engineering
University of Victoria
Victoria, BC, V8W 2Y2, Canada
zkordi@ece.uvic.ca

***Abstract*—A compact inline K-band diplexer with dual-mode junction cavity in substrate integrated waveguide (SIW) technology is presented. The dual-mode cavity provides a transition between the input port and the two channels of the diplexer, as well as one pole for each channel filter which results in a reduced size compared to other inline diplexer topologies. The diplexer design is carried out using an efficient mode-matching technique (MMT), and its performance is validated by simulated and measured results. The diplexer channels are located at 23.7 GHz and 25.7 GHz, with 5.9 and 5.4 percent fractional bandwidths, respectively. Inband return loss measurements are better than 17.43 dB and 17.24 dB, and the insertion losses are 1.64 dB and 2.2 dB, in the lower and higher bands, respectively.**

Keywords—Diplexer; substrate integrated waveguide; dual-mode cavity; inline topology; mode-matching techniqes; coupling matrix.

I. INTRODUCTION

The evolution of substrate integrated waveguide (SIW) technology during the past few years has resulted in increasing interest from the microwave engineering industry towards this promising technology. As a result, and in order to respond to the demand for more compact and low profile designs in communication systems, compact SIW component designs are advantageous and in demand.

Diplexers and multiplexers are essential components in front-end systems because they provide desired isolation between Rx/Tx or individual frequency bands. SIW diplexer designs, mostly inline diplexers, with different topologies and at different frequency bands are reported in the literature. However, inline diplexers require junctions between the input port and the two channel filters. This junction can be in the form of a taper, as presented in [1, 2], or compensated T-junctions [3, 4]. In order to avoid these junctions in inline diplexers, dual-mode cavities can be used which lead to more compact designs [5].

In this paper, an inline K-band diplexer with dual-mode cavity junction, which adds one pole to each of the channel filters, is presented. The key advantage of this diplexer compared to the one presented in [1] is a more compact design. The diplexer is first designed in waveguide technology, considering the fact that one pole will be added to each channel filter by the dual-mode cavity. The dimensions of the square via holes, as derived in [6] for a given via diameter, can be incorporated from the onset in the all-dielectric waveguide design as, e.g., aperture thickness. The next step is translating the design in SIW technology using relations between the SIW width and its effective waveguide width as presented in [7]. Optimization of the diplexer design with square via holes is carried out using an efficient mode-matching technique (MMT) [8]. Comparison between MMT data and simulation data obtained from CST Microwave Studio and μWave Wizard, and also measurement data validates the design approach.

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II. DESIGN

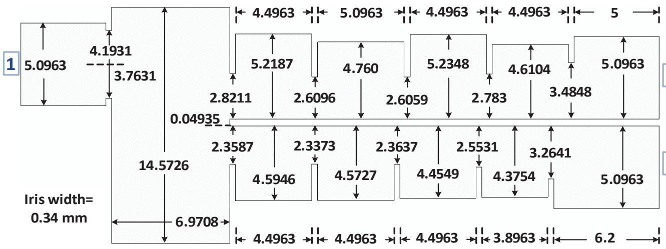
The diplexer is designed on RT/duroid 6002 substrate with relative permittivity ε_r=2.94 and thickness 0.508 mm, for operation at 23.7 GHz and 25.7 GHz with bandwidths of 1.4 GHz. The metallization thickness is 17μm. The loss factors are $\tan\delta$=0.0012 for the dielectric and σ=5.8×10^7 S/m for the copper layers and vias. The SIW widths at the Rx/Tx ports are 5.4 mm, which results in an effective waveguide width of 5.0963 mm according to [7]. The via diameter is 1/64", and the via pitch is 0.6 mm. The side length of the equivalent square vias in the MMT analysis, i.e., the aperture thickness in the waveguide design, is 0.34 mm.

The diplexer is first designed in waveguide technology with the MMT approach. Having established the fact that 5th-order filters are required, the first step is to design 4th-order inductive-iris-type Chebyshev channel filters, keeping in mind that the fifth-pole will be added by the dual-mode cavity, e.g. [5], that forms the junction between channel filters and input port. Once the dual-mode cavity is initially designed to support both TE_{102} and TE_{201} modes, e.g., as in [9], the diplexer is optimized in the MMT for 5th-order channel characteristics. It should be noted that the widths of resonators, rather than the lengths, are varied because it fits better with the MMT routine for SIW.

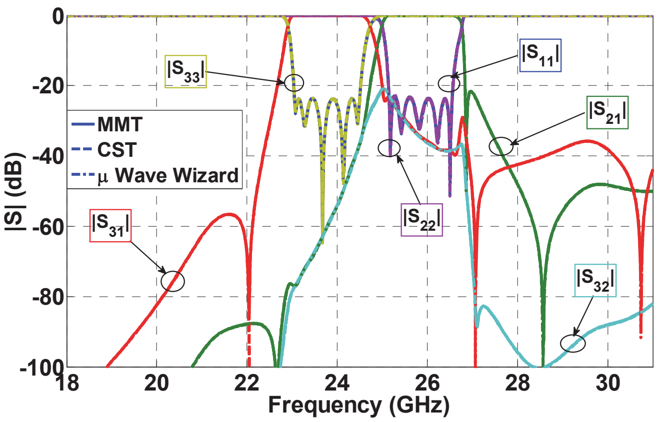
The diplexer is then translated into SIW technology with square via holes [7]. Optimization steps in the SIW diplexer design are carried out using the MMT approach presented in [8]. Microstrip transitions and bends are also designed in order to provide means for measuring the structure. The performance of the designed diplexer with square via holes is validated by comparing the MMT design with simulated and measured data for the diplexer with circular vias.

III. RESULTS

Fig. 1a shows the layout of the designed diplexer in all-dielectric waveguide technology, and its S-parameters are presented in Fig. 1b. All dimensions presented in the layout in Fig. 1a are in millimeters. As it is shown in Fig. 1b, return losses better than 23.7 dB at the lower band and 23.3 dB at the higher band are achieved. The minimum isolation between two channels is 21.5 dB. The diplexer shows high selectivity and low inband return loss. It is designed with the MMT approach, and its performance is validated with simulation data achieved from CST Microwave Studio and μWave Wizard. Excellent agreement between three sets of data is observed.



(a)



(b)

Fig. 1. All-dielectric waveguide diplexer with dual-mode cavity junction (a), and comparison between its S-parameter data obtained by MMT (solid lines), CST (dashed lines), and μWave Wizard (dash-dotted lines) (b).

It should be mentioned that the transmission zeros observed in $|S_{31}|$ right before the lower pass-band and in $|S_{21}|$ right after the higher pass-band (c.f. Fig. 1b) originate from the direct routes between the input port and channel filters. In each band, the nonresonating mode of the dual-mode cavity creates bypass coupling, which results in one transmission zero for each band. Other observed transmission zeros are caused by higher order modes, which are commonly observed in waveguide diplexers.

The coupling matrix of the all-dielectric diplexer is extracted following the reasoning presented above and based on the method in [10]. The channel filter coupling matrices are designed separately, and that of the diplexer is obtained by optimization. The routing scheme is depicted in Fig. 2. The return losses of 23.75 dB in the lower band, and 23.45 dB in the higher band are achieved at slightly wider bandwidths (1.45 GHz).

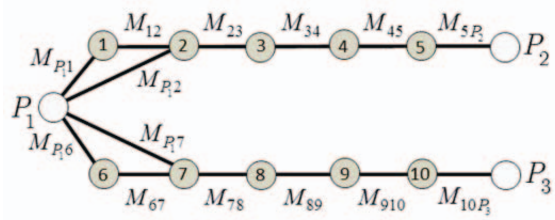


Fig. 2. Coupling scheme for the all-dielectric waveguide diplexer with dual-mode cavity junction.

A comparison between the MMT data of Fig. 1b and the results using the coupling matrix is presented in Fig. 3. It is observed that all return loss poles as well as the two transmission zeros at 22 GHz and 26.8 GHz are well represented.

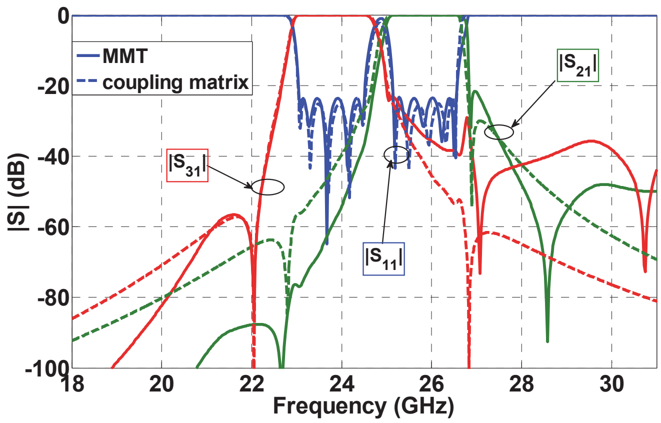
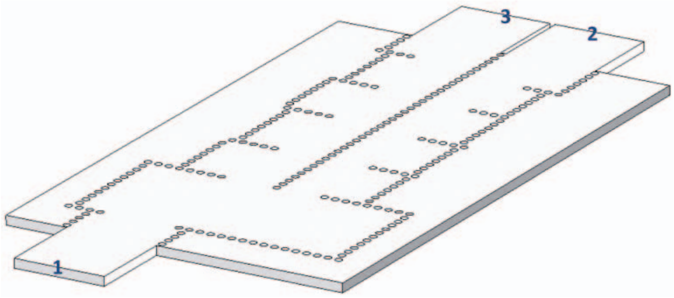


Fig. 3. Comparison between S-parameter data obtained by MMT (solid lines) and coupling matrix (dashed lines) for the waveguide diplexer with dual-mode cavity junction.

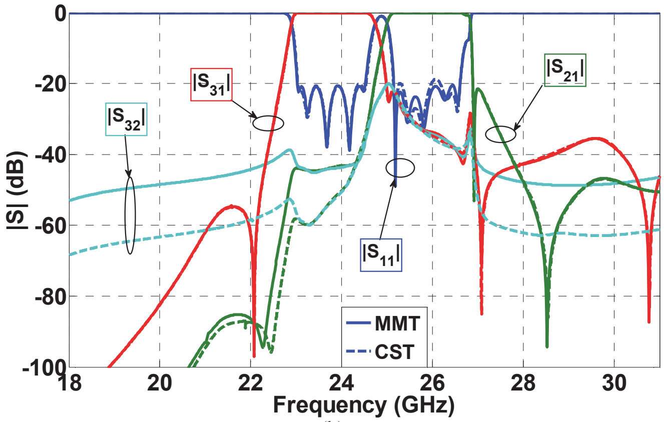
The all-dielectric waveguide diplexer is then translated to SIW technology with square vias, and the MMT approach is deployed to fine optimize the structure as described in Section II.

Fig. 4a shows the layout of the SIW diplexer with dual-mode cavity junction excited with waveguide ports. The S-parameters of the SIW diplexer are presented in Fig. 4b. Return losses better than 20.6 dB in the lower band and 20.25 dB in the higher band are achieved for the SIW diplexer. The isolation between the two channels is better than 21 dB. Note that all five poles for each band of the diplexer are perfectly shown in the SIW design as well. The MMT data from the analysis of the SIW diplexer with square via holes is compared with the simulation data for the diplexer with circular via holes obtained from CST. Despite some discrepancies below -40 dB, the agreement between the different sets of data is very good.

Electric field patterns inside the SIW diplexer at the lower (f =24 GHz) and higher (f =26 GHz) frequency bands of the diplexer are shown in Fig. 5a and Fig. 5b, respectively. Note that all resonators are perfectly resonating at the respective frequency bands, which proves the robustness of the design.

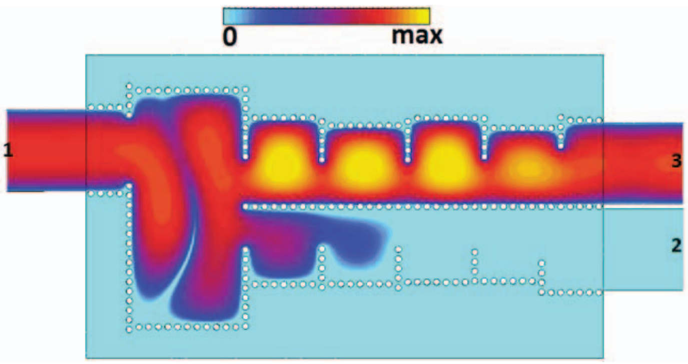


(a)

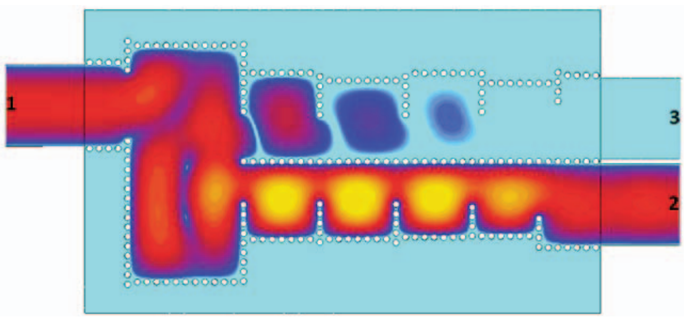


(b)

Fig. 4. SIW diplexer with dual-mode cavity junction with waveguide ports (a), and comparison between its S-parameter data obtained by MMT (square vias, solid lines) and CST (circular vias, dashed lines) (b).



(a) f=24 GHz.



(b) f=26 GHz.

Fig. 5. Electric field patterns inside the SIW diplexer in the lower (f=24 GHz (a)) and higher (f=26 GHz (b)) frequency bands.

In order to make ports accessible for measurements using a test fixture, microstrip ports and transition tapers from microstrip to SIW are designed as well. The initial parameters of the taper are chosen as in [11] and are then optimized to reach satisfactory performance. The width of the 50 Ω microstrip ports is w_m=1.2684 mm, and the width and length of the microstrip taper transition after optimization are 1.8217 mm and 1.7729 mm, respectively.

As the two output ports of the diplexer are located close to each other, two separate structures are built. In each of the two structures, one of the output ports is curved in order to provide access with the test fixture. The parameters of the bent microstrip ports, $R_c=2w_m$, $\alpha=\pi/2$, are based on the data presented in [12], where R_c is the radius of the bend, and α the curve angle. The fabricated structures along with the measurement data are presented in the next section.

IV. Measurements

Fig. 6 shows the fabricated prototypes of the SIW diplexer with dual-mode cavity junction. In each of the prototypes, one of the two output ports is bent in order to make the measurement feasible by using the test fixture. The bottom layers of the diplexers are solid ground metallization.

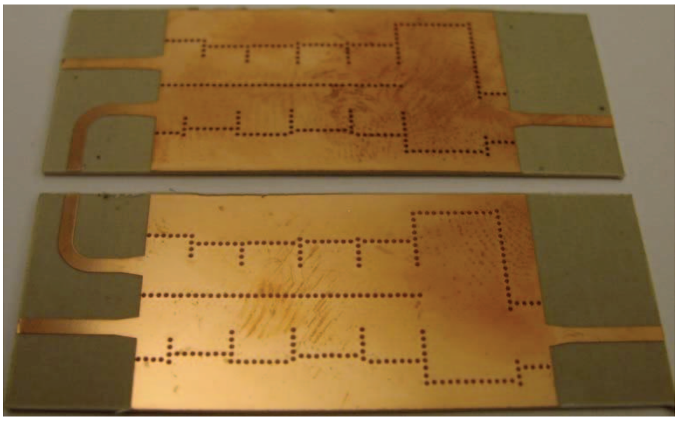


Fig. 6. Photograph of the two fabricated SIW diplexers with dual-mode cavity junction. In each structure, one of the output ports is bent.

The comparison between S-parameters obtained from measurements, simulations in CST and the MMT analysis is presented in Fig. 7. Measured inband return losses are 17.43 dB and 17.24 dB compared with 20.4 dB and 19.85 dB, respectively, in the CST simulations. The minimum measured insertion loss in the lower and higher bands is 1.64 dB and 2.2 dB, respectively, compared to about 1.49 dB and 1.7 dB in the CST and MMT simulations. The minimum measured isolation is 23 dB, compared with 21 dB from simulations. These differences are explained by the absorbing material used for the curved ports in the measurements (Fig. 6). This material, when placed on the curved microstrip port, does not fully represent a matched load. Moreover, these ports could not be deembedded from the measurements so that the SIW-to-microstrip taper contributes to the reflection at such ports.

The general transmission curves are also reproduced but differences in the slopes of the respective passbands are observed. These discrepancies can be attributed to the measurement procedure and limitations in the measurement setup. However, the overall agreement between these sets of data is good. The diplexer shows acceptable performance in terms of return loss (return losses better that 17.25 dB in both bands), and provides enough isolation between the two channels.

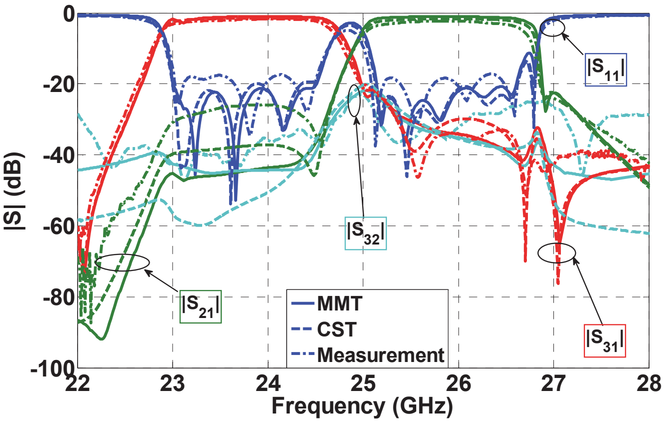


Fig. 7. S-parameter comparison for the SIW diplexer with microstrip ports between data obtained by MMT (square vias, solid lines), CST (circular vias, dashed lines) and measurement (circular vias, dash-dotted lines).

V. Conclusion

An SIW diplexer with dual-mode cavity junction in K-band is efficiently analyzed and designed using an MMT approach. The dual-mode cavity junction provides one pole for each channel filter, thus reducing the size of the diplexer compared to other inline diplexer designs. In addition, the diplexer has high selectivity and low insertion loss. The results from the theory for square vias are validated by data obtained from full-wave simulations for circular vias. Moreover, the results of the analytical approach are verified by measured data.

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