K-Band Substrate Integrated Waveguide T-junction Diplexer Design by Mode-Matching Techniques

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***Abstract* — The Mode-Matching Technique (MMT) is deployed to analyze and design a Substrate Integrated Waveguide (SIW) T-junction diplexer in K-band. The diplexer has bandwidths of 2.75 percent and 2.63 percent at 18.15 GHz and 19 GHz, respectively. The MMT results are compared with simulated data obtained from commercially available field solvers such as CST Microwave Studio, µWave Wizard and ANSYS HFSS. Excellent agreement between MMT and simulated data is achieved. Measured data obtained from a fabricated prototype diplexer agree well with simulated and MMT results.**

Index Terms — Substrate integrated waveguide, mode-matching techniques, diplexer, T-junction.

I. INTRODUCTION

Designing microwave and millimeter-wave components based on Substrate Integrated Waveguide (SIW) technology is an ongoing trend among microwave engineers. The high Q-factor, high power handling and low loss characteristics of these structures are inherited from conventional waveguide technology. In addition, the ability of being mass-producible and integrable with other planar technologies at a lower cost and in a compact layout, which is inherited from planar topologies, has made SIW a promising technology for implementation and integration of microwave and millimeter-wave devices. Among numerous other passive components designed based on this technology are diplexers.

Diplexers, as the simplest form of multiplexers, provide needed frequency separations between transmit and receive channels in microwave circuitry. Attempts to design SIW diplexers have been carried out at different frequency bands, ranging from C-band up to 60 GHz, and with different structural configurations. A C-band SIW diplexer using single-mode iris filters in a branching-port configuration is proposed in [1]. Also in C-band, a T-junction SIW diplexer presented in [2] uses complementary split-ring resonators. In [3], a similar configuration to that of [1], using asymmetric dual-mode iris filters is proposed in X-band. Another diplexer design in X-band uses triplet technology [4]. It has input and output ports on opposite sides of the substrate and uses iris filters including a tri-section [4]. An X-band multi-layered SIW diplexer with dual-mode resonators is presented in [5]. In [6], a diplexer operating at K-band employs dual-mode SIW filters with circular and elliptic cavities. A K-band SIW diplexer is presented in [7]. This diplexer has input and output ports on opposite sides of the board and is designed using an efficient Mode-Matching Technique (MMT) [7]. A Ka-band SIW diplexer using two filters and a circulator is presented in [8]. Finally at 60 GHz, a T-junction diplexer with iris filters is presented in [9].

In all diplexers mentioned above, except for the one in [7], the final steps of the design and optimization of the diplexers are carried out using full-wave simulators. Considering the large number of optimization parameters in an SIW diplexer design, this approach is tedious and cumbersome. In [7], the MMT approach presented in [10], [11] is adopted to analyze and design the diplexer, which is an order of magnitude faster than commercially available field solvers. At that time, however, the method could not be deployed for the analysis of SIW T-junctions.

In this paper, an MMT approach, which includes the rigorous treatment of SIW T-junctions, is adopted. After validating the numerical method for a single T-junction, a T-junction SIW diplexer at K-band is designed, fabricated and measured. The MMT data is verified by measurements as well as simulated data obtained from CST Microwave Studio, µWave Wizard and ANSYS HFSS.

II. THEORY

The MMT approach presented in [10], [11] for analyzing SIW structures cannot directly be applied for the analysis of SIW T-junctions. Therefore, in this paper, the method is modified by employing the S-parameter separation technique [12] as follows. The approach presented in [11] is used first to compute the modal *S* matrix of an asymmetric SIW/waveguide bifurcation. In the second step, the *S* matrix of a waveguide corner is subtracted to obtain the modal *S* matrix of the SIW T-junction. Thus this procedure allows us to include the analysis and design of SIW components involving T-junctions.

Fig. 1 presents the layout and S-parameters results of the designed SIW T-junction in K-band. In this paper, the substrate is selected as RT/duroid 6002 with $\varepsilon_r=2.94$, substrate height $h=0.508$ *mm* and metallization thickness $t=17.5$ *µm*. The diameters of the circular vias are chosen as $d=0.644$ *mm* so that the side lengths of the equivalent square vias in the MMT analysis becomes $l_{square}=0.55\ mm$ according to [11]. The equivalent waveguide width of the SIW, W_{equi}, is $W_{equi}=7.015\ mm$ when the cut-off frequency is chosen as $f_c=12.46\ GHz$. When selecting a via pitch of $p=1\ mm$, which yields a d/p ratio in the applicable range of SIW [13], the SIW width, a_{SIW}, is calculated from the formula presented in [14] as $a_{SIW}=7.5\ mm$.

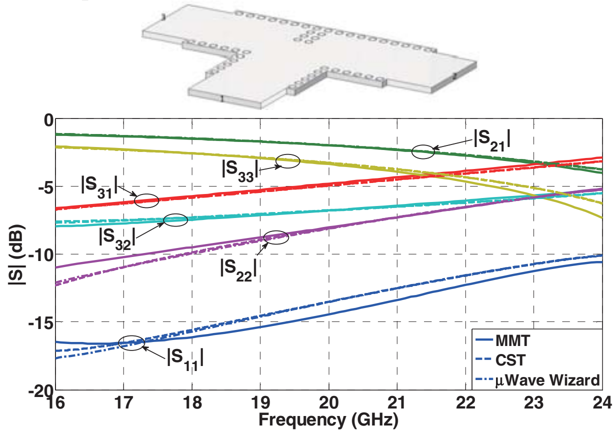

Fig. 1. Layout and performance comparison between MMT (square via holes – solid lines), CST (circular via holes – dashed lines) and µWave Wizard (circular via holes – dash-dotted lines) for an SIW T-junction.

The SIW T-junction is analyzed and designed with the MMT with square vias and is also simulated using CST Microwave Studio and µWave Wizard with circular vias. As it can be seen in Fig. 1, the modified MMT approach can accurately model the behavior of the SIW T-junction, and excellent agreement is observed between MMT and simulation results. The modified MMT approach can now be used to design a K-band T-junction diplexer.

III. Diplexer Design

The diplexer design starts with the design of the two channel filters. In both channels, five-pole SIW Chebyshev filters are designed with the goal of having $|S_{11}|<-25dB$ in the pass-band. The bandwidths of both filters are *0.5 GHz*.

The layout and S-parameters of the channel filter for the lower band are presented in Fig. 2. This filter has *2.75* percent bandwidth at *18.15 GHz*. Also, the layout and S-parameters of the channel filter for the higher band are presented in Fig. 3. This filter is designed for *2.63* percent bandwidth at *19 GHz*. For both filters, the MMT results of the SIW structures with square vias are verified by simulation data for the same structures with circular vias.

After designing two channel filters, the final T-junction diplexer is designed and analyzed. The optimization steps in the design of the SIW T-junction diplexer are carried out by employing the MMT approach, which saves a tremendous amount of time as the proposed MMT technique is faster than commercially available field solvers by an order of magnitude [10].

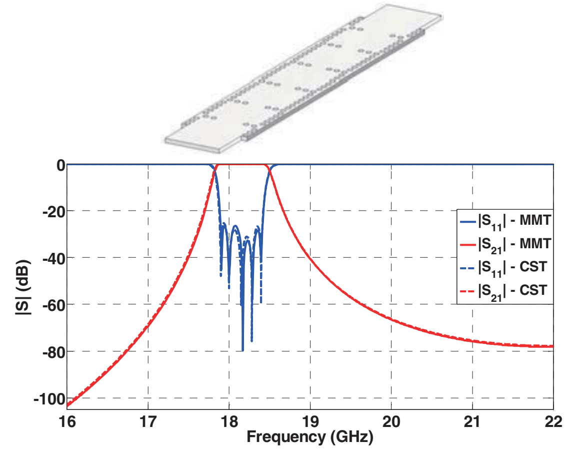

Fig. 2. Layout and performance comparison between MMT (square via holes – solid lines) and CST (circular via holes – dashed lines) for the channel filter in the lower band.

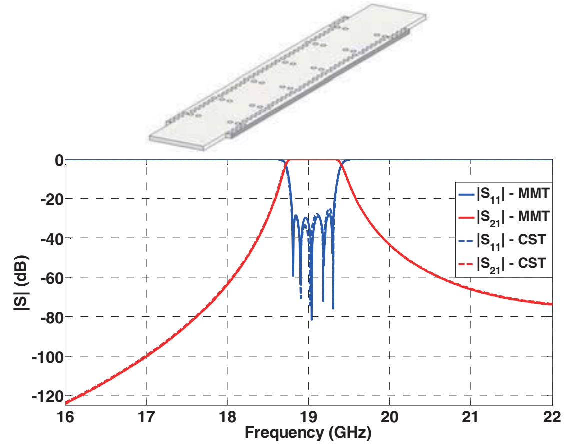

Fig. 3. Layout and performance comparison between MMT (square via holes – solid lines) and CST (circular via holes – dashed lines) for the channel filter in the upper band.

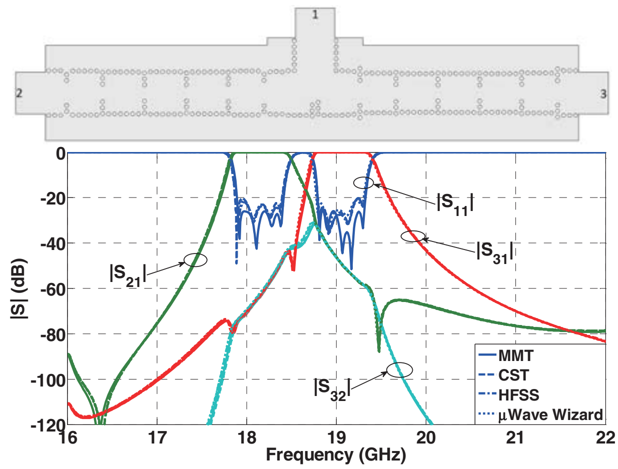

Fig. 4. Layout of the simulated K-band SIW T-junction diplexer with waveguide ports and performance comparison between MMT (square via holes – solid lines), CST (circular via holes – dashed lines), µWave Wizard (circular via holes – dotted lines) and HFSS (circular via holes – dash-dotted lines).

Fig. 4 depicts the layout and performance of the final diplexer with waveguide ports. The MMT data for the structure with square vias are compared with simulated data obtained from CST, µWave Wizard and HFSS. Excellent agreement is again observed between the MMT results with square vias and simulated responses with circular vias.

IV. Measurement

Fig. 5 shows the fabricated prototype of the diplexer along with the S-parameter results from measurements, simulations, and also MMT. Measured in-band insertion losses are *3.88 dB* and *4.28 dB* compared with *2.39 dB* and *2.46 dB*, respectively, in the CST simulations. The minimum measured return loss in the two bands is *18.13 dB* and *16.9 dB*, respectively, compared to *23.4 dB* and *21.3 dB* in the simulation. Due to fabrication restrictions, the via diameter has been changed to $d=0.65$ *mm*, which causes the measured data to have a slight frequency shift towards higher frequencies compared to the MMT and simulated data. Otherwise, the measured data confirms the validity of the proposed MMT approach for the analysis and design of SIW components involving T-junctions.

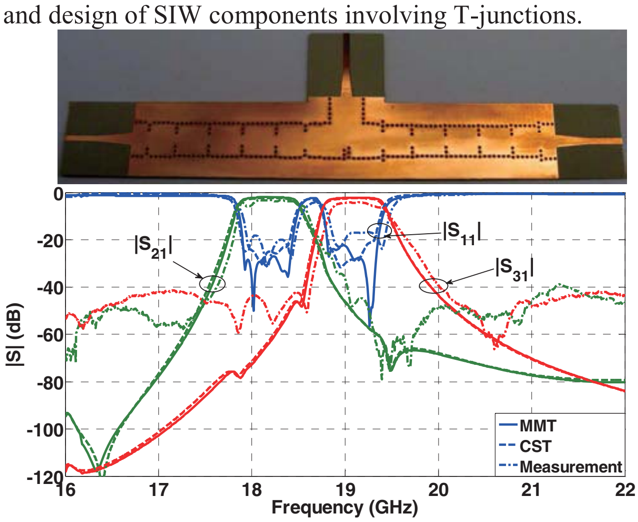

Fig. 5. Layout of the fabricated K-band SIW T-junction diplexer and performance comparison between MMT (square via holes – solid lines), CST (circular via holes – dashed lines) and measurements (circular via holes – dash-dotted lines).

V. Conclusion

An SIW T-junction diplexer in K-band is efficiently analyzed and designed using a modified MMT approach. The results from the theory for square vias are validated by data obtained from full-wave simulations for circular vias. It is demonstrated that the proposed analytical approach accurately models the SIW T-junctions, and results are in excellent agreement with those obtained by full-wave commercially available field solvers. Moreover, the results of the proposed technique are verified by measured data of an SIW T-junction diplexer prototype.

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