Substrate Integrated Waveguide Crossover Formed By Orthogonal TE_{102} Resonators

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***Abstract*—A simple yet efficient substrate integrated waveguide (SIW) crossover circuit is presented. It is formed by excitation of two orthogonal full-wavelength (TE_{102}-mode) resonators whose centers coincide with that of the symmetric SIW cross junction. Half-wavelength (TE_{101}-mode) resonators are added in all four ports to increase bandwidth. The SIW crossover is designed to operate at 24.75 GHz with a bandwidth of 3 GHz. A prototype is fabricated on RT/duroid 6002, and measurements agree well with simulations. The minimum measured return loss is better than 17 dB, maximum insertion loss is 1.1 dB, and isolation between the channels is better than 12 dB. Based on these results, two other crossovers with isolation better than 23 dB are proposed.**

Keywords— Substrate integrated waveguide, crossover, full-wavelength resonator, filter design.

I. Introduction

Transmission line crossovers are frequently required in microwave integrated circuits, and traditional approaches employ dual-layered topologies [1] or ground-plane etching [2] in microstrip technology, dual-layer substrate integrated waveguide (SIW) couplers [3], or air bridges in coplanar waveguide [4]. Single-layer microstrip crossovers require 0-dB couplers as ring [5] or branch-line [6] components. Alternatively, filtering capabilities can be incorporated which is demonstrated for three intersecting microstrip channels in [7] and an H-plane waveguide intersection in [8].

SIW crossover structures have mostly been used in cruciform 3-dB directional couplers [9] – [11]. The only 0-dB crossover SIW coupler is presented in [12], but its fabrication requires rectangular and ring-sector-shaped via holes which cannot be produced in regular commercial printed-circuit facilities.

Therefore, this paper presents an easy-to-fabricate SIW crossover. It is based on the excitation of two orthogonal full-wavelength resonators that have their respective zero-E-field locations in the center of the cross junction. Since this arrangement leads to a relatively narrowband crossover, adding additional half-wave resonators increases bandwidth and still provides sufficient isolation between the crossing channels. To the best of the authors' knowledge, this is the first 90-degree waveguide/SIW crossover that is neither based on coupling theory nor requires offset waveguide ports.

II. Design

The substrate chosen for this application is RT/duroid 6002 with ε_r=2.94 and height h=508 μm. The via diameter d is selected as 1/64" (0.3969 mm) which is a standard drill size and thus aids to fabrication simplicity. The via pitch p (center-to-center spacing) is 0.6 mm, resulting in a d/p ratio of 0.661. The center-to-center channel width is 5.4 mm and its cutoff frequency is 17.2 GHz according to [13]. Simulations are initially performed without including losses. Fig. 1 shows the basic crossover SIW circuit including port numbering. The two via holes in each of the four symmetric channels act as irises and are chosen such that a full-wave resonance is excited between two opposite iris pairs. Consequently, the electric field vectors in the branching ports point in opposite directions from their centers, thus trying to excite a TE_{20} mode which is below cutoff in the branching SIW ports. The three-dimensional field plot in Fig. 2 depicts the basic operation.

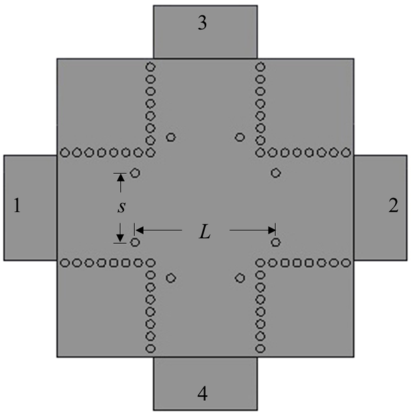


Fig. 1. Substrate integrated waveguide crossover based on full-wavelength resonator, including port numering used in this paper.

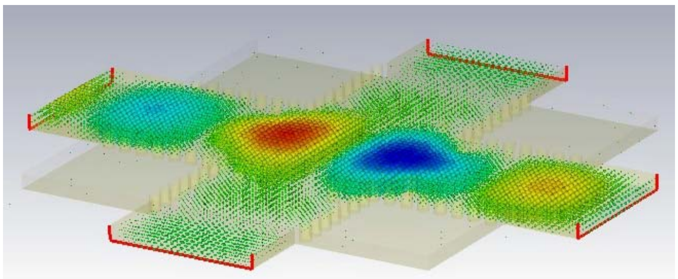


Fig. 2. Electric field within the SIW crossover displaying the full-wave (TE_{102}-mode) resonance.

The performance of such a crossover is presented in Fig. 3 for a full-wave resonance of 26.2 GHz. It was designed in CST and verified with a code based on the mode-matching technique (MMT) recently proposed in [14]. The iris vias are separated by *s*=3.4 mm, and two opposite via pairs are *L*=6.9 mm apart (c.f. Fig. 1). The locations of all other vias are based on symmetry, and so are the scattering parameters omitted in Fig. 3. This circuit provides a 10-dB return loss bandwidth of 1.3 GHz and an isolation of better than 15 dB between the crossing channels.

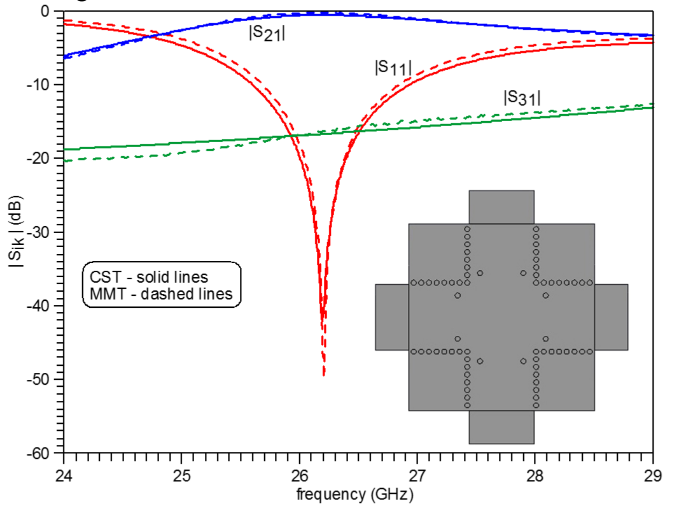


Fig. 3. Performance of the SIW crossover for a full-wave resonance of 26.2 GHz (s = 3.4 mm, L = 6.9 mm); comparison between CST and MMT.

Since the distance L is determined by a TE_{102} cavity, the resonance frequency is easily changed by maintaining the iris dimensions and varying the distance between two opposite iris pairs. This is demonstrated in Fig. 4.

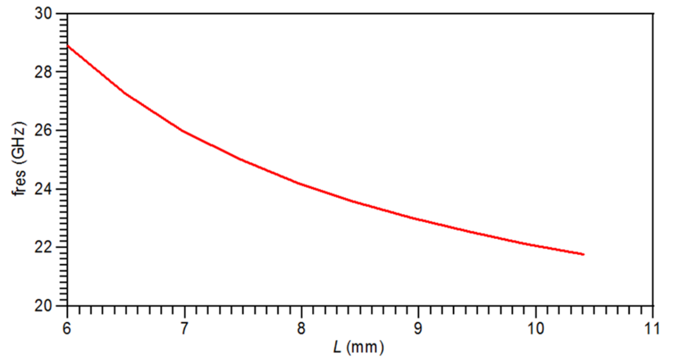


Fig. 4. Variation of full-wavelength resonance frequency, f_{res}, with distance L between two opposite via pairs (s = 3.4 mm).

In order to increase the bandwidth of the crossover without enlarging the cross junction, regular SIW half-wave (TE_{101}-mode) resonators can be added to all four ports.

The design of such a circuit commences, first, with a standard rectangular, dielectric-filled waveguide filter synthesis for three resonators, e.g. [15], for given equivalent waveguide width [13] and post dimensions. Secondly, the center resonator is extended to form a TE_{102}-mode resonance. Finally, the design is transferred to SIW technology in CST and fine-optimized using Powell's method.

Fig. 5 shows such an example for a bandwidth of more than 3 GHz that was optimized for 20 dB return loss in CST. The isolation between crossing channels is better than 11 dB.

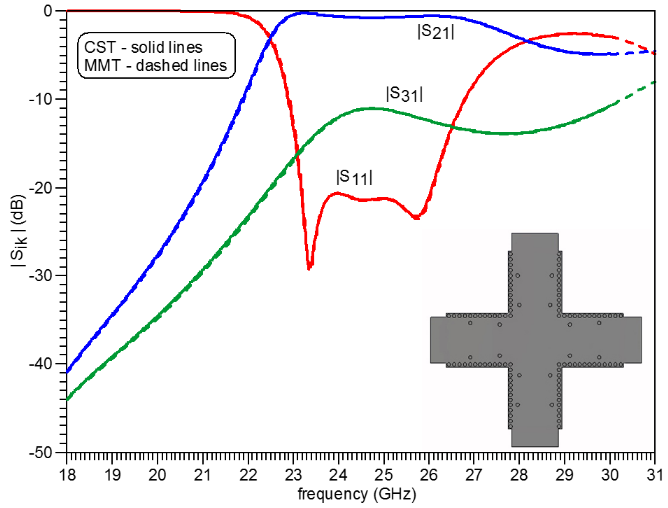


Fig. 5. Bandwidth enhancement of the SIW crossover with additional half-wave resonators at each port; comparison between CST and MMT.

For specifications where one of the crossing channels requires a narrower bandwidth within a wider band of the other channel, additional resonators need to be added only to the path with wider bandwidth. This is demonstrated in Fig. 6 where the two vertical half-wave resonators of the crossover structure in the inset of Fig. 5 have been removed.

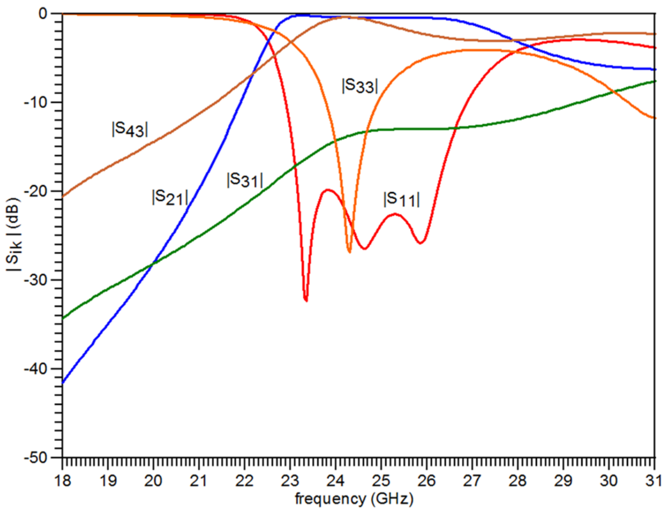


Fig. 6. Unequal bandwidths of the two crossing channels; vertical half-wave resonators in Fig. 5 removed.

III. RESULTS

The SIW crossover in Fig. 5 is prototyped on RT/duroid 6002 substrate. SIW-to-microstrip transitions with long microstrip sections are added for access with test fixture equipment as shown in Fig. 7. All coax-to-test fixture-to-microstrip-to-SIW transitions are deembedded using custom-made TRL calibration standards. Absorber material is added to terminate those ports that are not included in respective measurements.

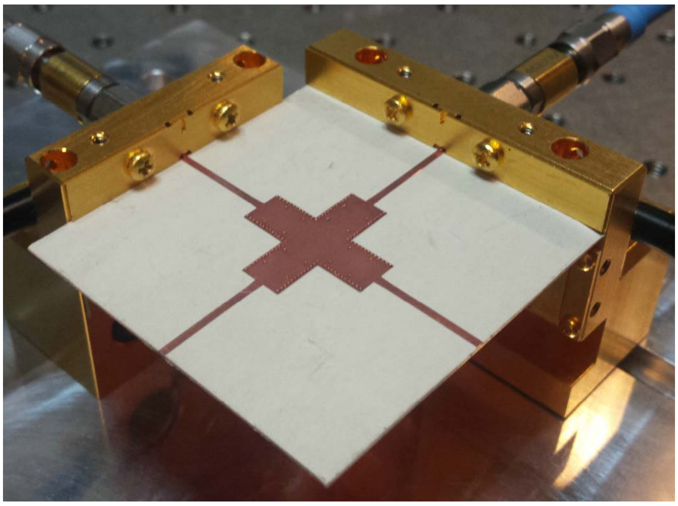


Fig. 7. SIW crossover circuit in test fixture.

A comparison between measured and simulated results (using tanδ = 0.0012 and 35 µm copper layers) is depicted in Fig. 8. Agreement is generally good, except for a slight hump in the return loss that we attribute to a detuned resonator which also explains the slight shift towards higher frequencies.

Over the three GHz bandwidth between 23.25 GHz and 26.25 GHz, the measured minimum return loss (due to the detuned resonator) is 17.1 dB compared to 20.8 dB in CST. The maximum measured insertion loss is 1.1 dB which matches the simulated value down to 0.03 dB. The measured isolation of 12.4 dB is slightly better than that predicted in CST (11.4 dB).

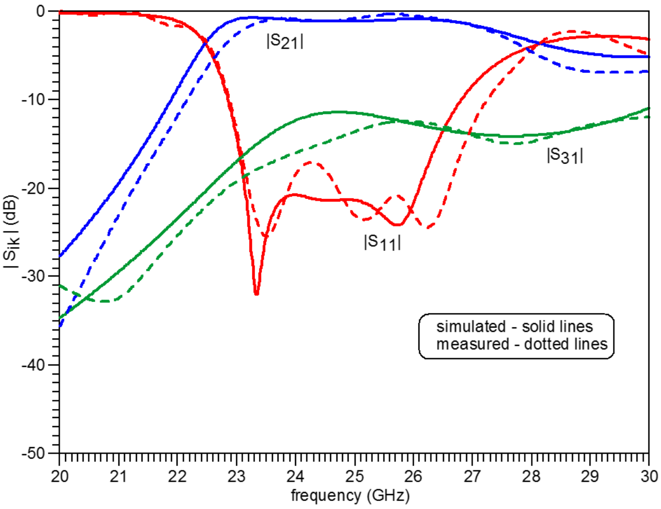


Fig. 8. Comparison between measured and simulated results of the SIW crossover.

When this SIW crossover was modeled in typical crossover applications, it was found that depending on specifications, isolation values of 10 dB to 15 dB might not be sufficient. In a subsequent investigation, it was determined that higher isolation values can be obtained if the TE_{102}-mode resonators are coupled by employing centered vias instead of iris-type vias. Such a design, using the same three design steps as before, is shown in Fig. 9. However, such a measure comes with a reduction in bandwidth. This is demonstrated in Fig. 9 for a crossover that achieves 23 dB isolation and a 10 dB return loss bandwidth of 0.83 GHz at 25.4 GHz.

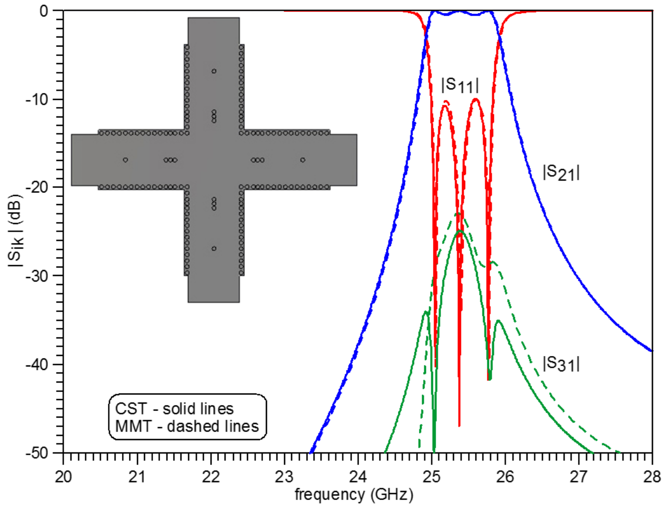


Fig. 9. Performance of SIW crossover using resonators with center-via coupling elements.

Moreover, the coupling around the single center via is too low to allow for reasonable filter performance at lower frequencies. Therefore, the first coupling element is converted back to an SIW iris and the filter redesigned for 23.85 GHz. Fig. 10 shows the layout and Fig. 11 its performance. This SIW crossover achieves an isolation of better than 24 dB and a 20 dB return loss bandwidth of 0.55 GHz at 23.85 GHz.

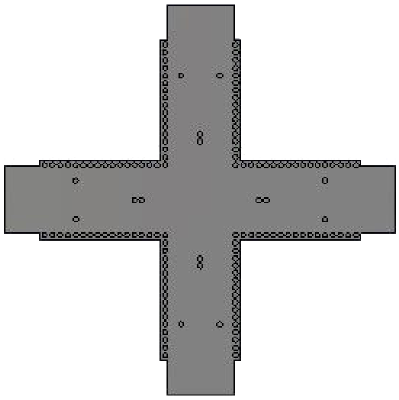
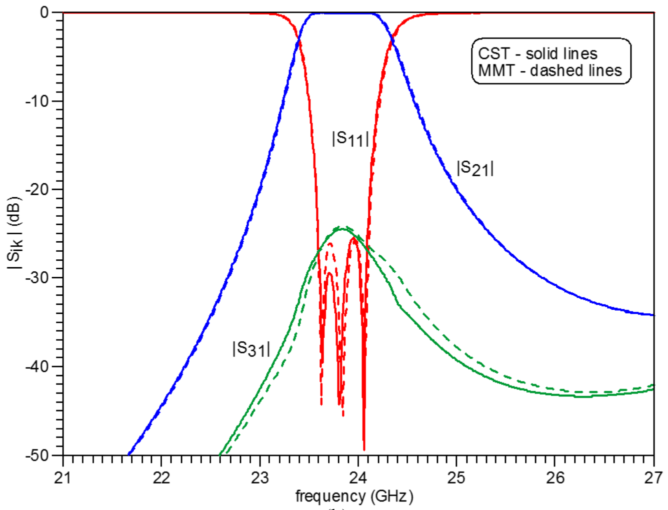


Fig. 10. Layout of SIW crossover employing TE_{102}-mode and TE_{101}-mode resonators with center-via and iris-type coupling elements.

IV. Conclusion

The circuits presented in this paper provide a simple solution for band-limited substrate integrated waveguide crossover applications. The center full-wave TE_{102}-mode resonators provide isolation while added half-wave TE_{101}-mode resonators increase bandwidth. The design follows straightforwardly from direct-coupled filter synthesis. Good agreement between measured and simulated data validate the principle design operation and the viability of these crossovers in SIW circuitry. The crossovers provide flexibility with respect to different bandwidths of the crossing channels as well as increased isolation over a narrower bandwidth.



(b)

Fig. 11. Performance of SIW crossover employing TE_{102}-mode and TE_{101}-mode resonators with center-via and iris-type coupling elements; performance comparison between CST and MMT.

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