Substrate Integrated Waveguide Right-Angled Power Divider Design Using Mode-Matching Techniques

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***Abstract*— Right-angled substrate integrated waveguide (SIW) power dividers are employed to obtain controllable phase distribution over the output ports. They are designed by varying the locations of via holes in an SIW corner via optimization techniques. In order to facilitate a fast and accurate numerical analysis method, mode-matching techniques are employed which use first, a square-to-circular via hole conversion and secondly, an S-matrix subtraction technique to model the corner. The method is demonstrated for two-way, three-way and four-way SIW power dividers with different degrees of phase variation over output ports. Excellent agreement with results obtained in CST validate the accuracy of the design approach.**

Keywords — substrate integrated waveguide; feed networks; power dividers; mode-matching techniques; computer-aided design.

I. INTRODUCTION

Antipodal tapered slot antennas (ATSAs) are compatible with substrate integrated waveguide (SIW) technology and, therefore, planar ATSAs arrays are often fed by a network of SIW power dividers [1] – [3]. First reported in [4], Y-junction, T-junction, coupler-type and backward SIW power dividers are proposed in [5] - [9].

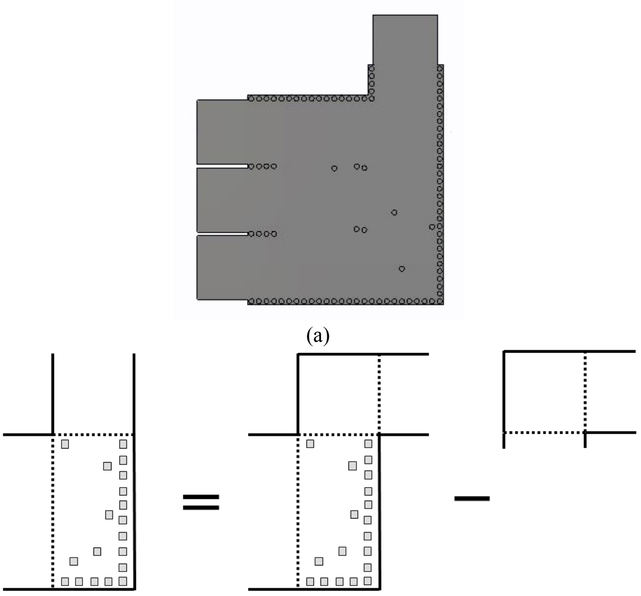
Most SIW and waveguide power dividers attempt to deliver the same phase to all outputs in order to obtain a broadside beam of the antenna array. However, several applications benefit from a different phase distribution over the radiating elements. For instance, a direction-finding operation requires a null at broadside, and beams in other than broadside directions are subject to different phase relationships at the antenna ports.

Therefore, this paper focuses on the design of right-angled SIW power dividers which allow the output phases to be changed by placing via holes in a right-angled SIW junction. It is based on an all-metal waveguide mode transducer principle [10], but the output phases are controllable.

Since the design of such power dividers requires extensive optimization of the locations of via holes in the right-angled junction, mode-matching techniques (MMTs) are employed to reduce computation time with respect to field-solvers such as CST and HFSS. Especially, a square-to-circular via hole conversion allows for fast processing times and accurate performance predictions [11].

II. THEORY

Fig. 1a shows a three-way SIW right-angled power divider with its input port on top and three output ports to the left. Any combination of via holes left of the corner region, as well as those at the input port are straightforwardly computed by an inline MMT algorithm, e.g. [9], [11]. The corner region (Fig. 1b) is analyzed by a scattering matrix subtraction technique where an offset yet inline MMT algorithm is used from whose result a waveguide corner is subtracted. (The reader is referred to [11], [12] for an in-depth coverage of the S-matrix subtraction technique.) Note that since the subtraction technique is vulnerable when too many modes are used in its process [12], [13], the corner is subtracted from the smallest dimension of the divider in Fig. 1a. In order to shorten simulation times, square vias are used in all MMT routines as they are easily converted to circular ones by a simple equivalence formula [11].



(a)

(b)

Fig. 1. Right-angled three-way SIW power divider (a) and computation of the SIW corner by S-matrix subtraction technique (b).

The design process proceeds in three steps:

1. For given substrate permittivity ε_r, frequency range, i.e. cutoff frequency f_c, via diameter d, and via pitch p, input and output ports are specified, both in terms of their actual SIW width a and the equivalent waveguide width a_{eq}, as [14]

$$f_c = \frac{c}{2a_{eq}\sqrt{\varepsilon_r}} \tag{1}$$

$$a = a_{eq} + p\left(0.766e^{0.4482d/p} - 1.176e^{-1.214d/p}\right) \tag{2}$$

2. A starting-position via configuration is chosen which usually starts with a diagonal line of vias across the corner region and adjacent multi-mode area towards the output ports.

3. The positions of the diagonal-line vias are optimized for given divider ratio and phase distribution. A minimax-based

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optimization strategy [15] is linked to the MMT analysis technique to Facilitate a speedy convergence. If a via overlaps with the straight boundaries or port dividing vias during optimization, it is removed from the circuit.

The numerical analysis and design process is applied to two-way, three-way and four-way SIW power dividers with different degrees of phase variation over output ports.

III. RESULTS

The following design examples use RT/duroid 6002 substrate with $\varepsilon_r = 2.94$ and height $h = 508$ µm. The width of all SIW waveguide ports is set to $a = 5.4$ mm, the via diameter is $d = 1/64" \approx 0.3969$ mm, and the pitch distance is $p = 0.6$ mm. The resulting cutoff frequency is 17.15 GHz [14]. Designs are verified by comparison with results obtained from CST Microwave Studio.

Fig. 2 shows the performance of a two-way SIW power divider with 140-degree phase difference between output ports. The divider bandwidth extends from 20 GHz to 26 GHz over which the output phase difference varies between 137 and 147 degrees. Note that all phases are normalized to that at port 2.

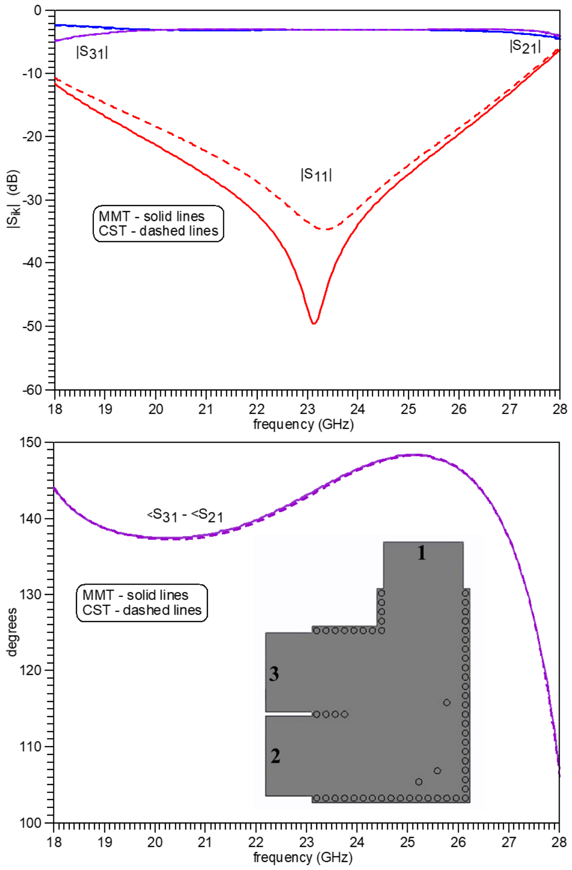

Fig. 2. Performance comparison between MMT and CST at the example of a two-way right-angled SIW power divider with 140-degree phase difference.

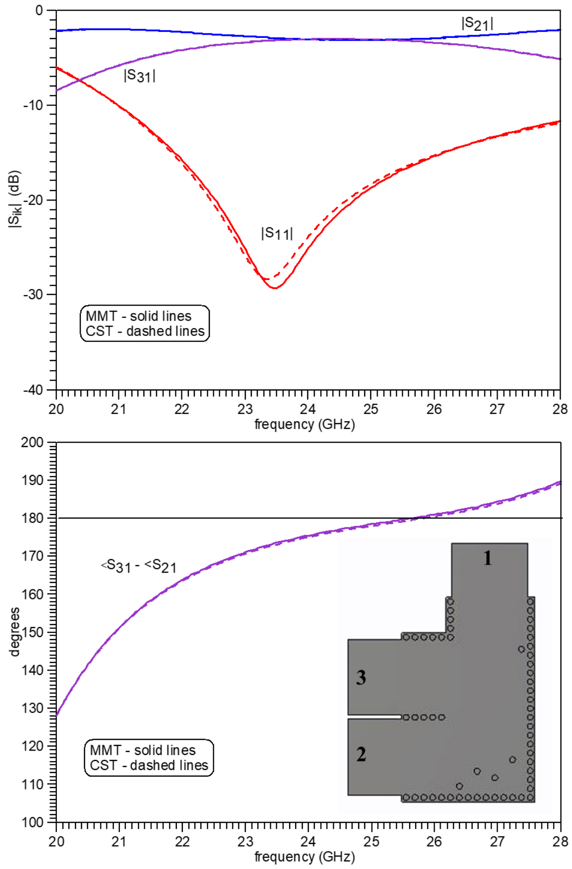

Fig. 3. Performance comparison between MMT and CST at the example of a two-way right-angled SIW power divider with 180-degree phase difference.

The performance of a two-way divider with about 180-degree phase difference is depicted in Fig. 3. The divider bandwidth is 2.2 GHz centered at 24.6 GHz. The phase variation over this bandwidth is 174 to 180 degrees which is acceptable, for instance, in direction-finding applications.

Our next example is a three-way divider with signals that are 4.77 dB down in the output ports as shown in Fig. 4. The divider bandwidth of 3.8 GHz is centered at 24.1 GHz. The phase variation between ports 3 and 2 is between 161 and 194 degrees, that between ports 4 and 2 is between -58 and +7 degrees.

In comparison with Fig. 4, Fig. 5 shows an inline 3-way divider. The 20-dB return loss bandwidth of 4.77 dB power division is 3.8 GHz centered at 24.7 GHz. Due to the symmetry of the inline divider, the phases at ports 2 and 4 are identical. However, the phase at the center output port 3 shows a difference with respect to those at ports 2 and 4. Over the bandwidth of the divider, that phase difference varies between 27 and 52 degrees.

The performance of a four-way right-angled SIW power divider is shown in Fig. 6. The 6 dB divider bandwidth is narrow and extends from 25.8 GHz to 26.4 GHz. Over this bandwidth, the phase variations are 72–55 degrees (ports 3 and 2), 14–16 degrees (ports 4 and 2), and 210–221 degrees (ports 5 and 2).

Note that all design examples are verified in magnitude and phase by CST simulations, and very good agreement is obtained. In examples presented here, as well as in previous

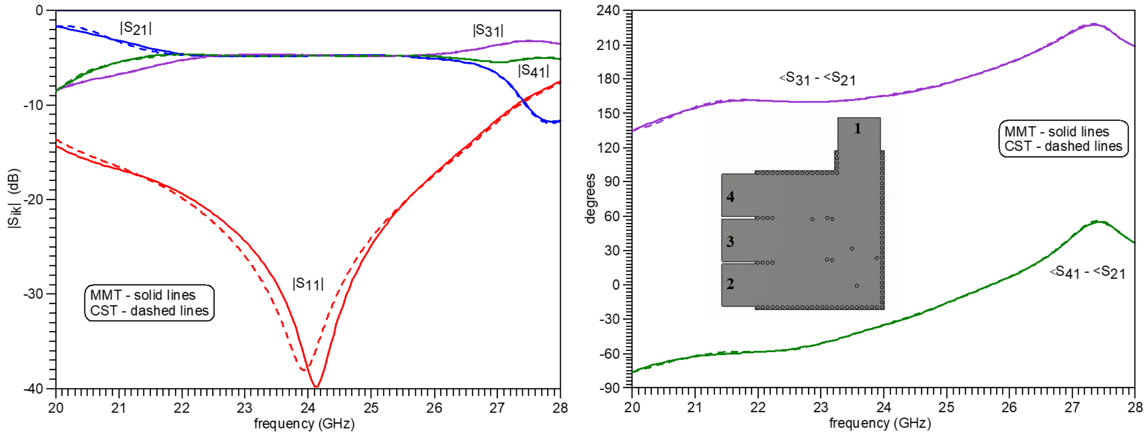

Fig. 4. Performance comparison between MMT and CST at the example of a three-way right-angled SIW power divider with phase differences of 165 and -30 degrees.

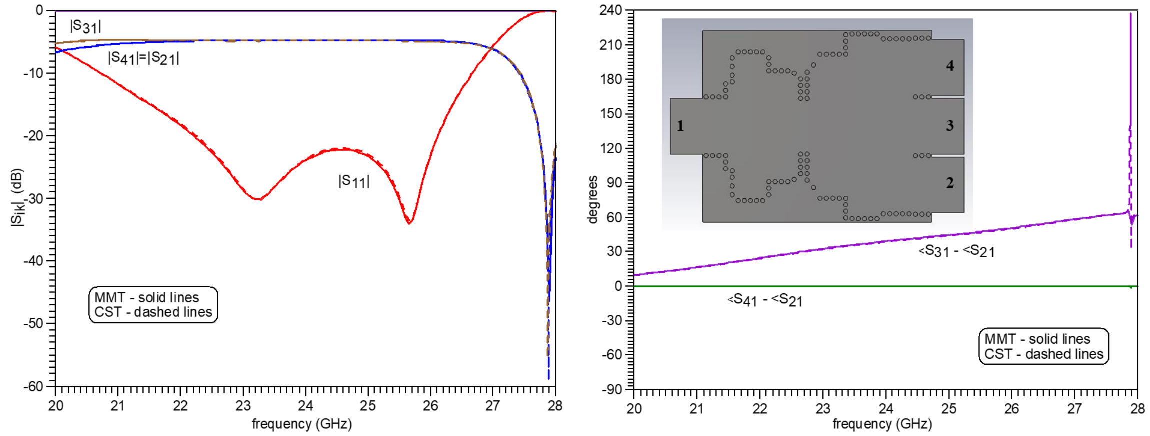

Fig. 5. Performance comparison between MMT and CST at the example of a symmetric inline three-way SIW power divider.

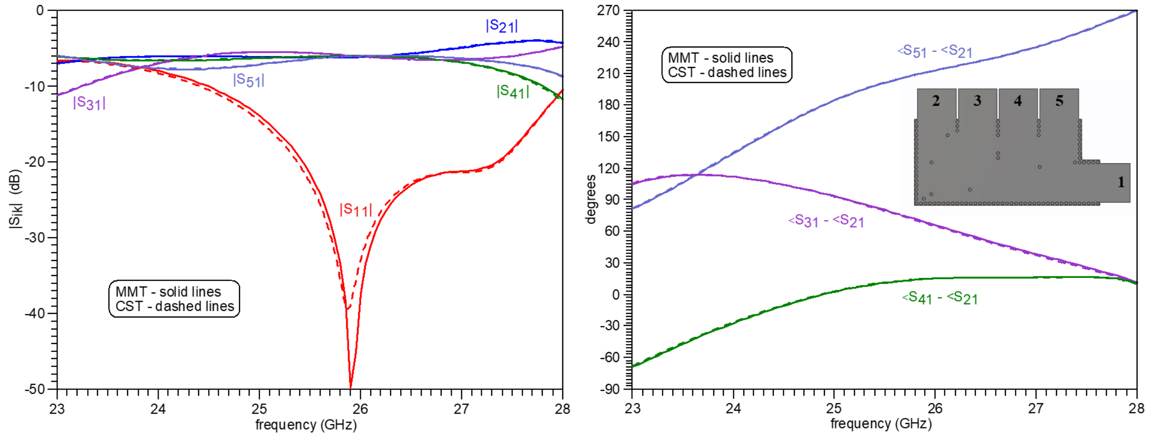

Fig. 6. Performance comparison between MMT and CST at the example of a four-way right-angled SIW power divider with phase differences of 65, 215 and 15 degrees.

comparisons (e.g. [9], [11], [12]) between MMT and CST, depending on implementation, the MMT code is at least one order of magnitude faster than CST.

IV. CONCLUSION

Substrate integrated waveguide right-angled power dividers offer attractive solutions when different phase distributions at the output ports are desired. They are designed by a computationally efficient mode-matching technique which allows a fast optimization of the positions of all via holes involved. Designs are for two-way, three-way and four-way SIW power dividers with different degrees of phase variation over their output ports. Note that a three-way inline divider also shows different phases over the output ports which supports the fact that equal phases are only obtained with binary dividers. All components are validated by simulations in CST, and excellent agreement between CST and mode-matching results is obtained.

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