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WIDEBAND SUBSTRATE-INTEGRATED WAVEGUIDE SIX-PORT POWER DIVIDER/COMBINER

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ABSTRACT: *A wideband six-port power divider/combiner with suitable coupling flatness is presented in substrate integrated waveguide (SIW) technology. The structure is composed of six ports that are connected to a common central region. By introducing resonating cavities in each port, the bandwidth and reflection of the SIW six-port device can be enlarged. Unsymmetrical apertures in lateral port arms are used to increase the isolation between the adjacent input and output ports. A six-port SIW prototype, operating at 12.5 GHz with 10 percent bandwidth, is designed and fabricated on RT/Duroid 5870 substrate to validate the design process and performance of the proposed power divider/combiner.* © 2013 Wiley Periodicals, Inc. Microwave Opt Technol Lett 55:2984–2986, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27997

Key words: *substrate-integrated waveguide; six port; power divider; power combiner; directional couplers*

1. INTRODUCTION

With the development of microwave and millimetre wave systems, demand for directional couplers that generate desired power splitting/combining with specification requirements such as bandwidth, structure, size, and insertion loss has increased considerably. Therefore, six-port circuits designed for direct communication receivers and radars are of specific interest [1,2]. These circuits can reduce system design, cost, and fabrication complexity and allow higher level of integration than conventional heterodyne receivers [3,4].

Rectangular waveguide couplers, due to their high manufacturing cost in the millimetre-wave range, bulky three-dimensional geometry, and difficult connection with planar structures, have been limited from being used in microwave integrated circuits. Moreover, microstrip circuits may suffer from high radiation loss and dispersion at millimetre-wave frequencies [5–7]. Substrate integrated waveguide (SIW) is a promising technique that combines relatively high Q-factor and low insertion loss merits of traditional rectangular waveguides with the simplicity of fabrication and low-cost integration of planar technology [8–10].

In this article, we present a directional six-port power divider/combiner for wide-band applications. Using SIW technology, the proposed design allows achieving high performance with respect to low cost, small size, and planar integration. The measured results of a six-port prototype centered at 12.5 GHz are in a good agreement with CST simulations.

2. DESIGN

The layout of the 11.5–13.5-GHz SIW six-port power divider/combiner is shown in Figure 1 along with its geometric parameters. The SIW cavities are coupled by inductive irises to increase the overall bandwidth and improve selectivity. The common central region provides the coupling capability of the compact SIW six-port device [7,8]. A signal from one of the input ports on the left side is transferred to the three opposite output ports while the remaining two input ports are isolated. The lateral and central arms have two and three resonators, respectively. In the lateral arms, unsymmetrical apertures are used to separate input and output waveguides and hence increase the isolation between adjacent ports.

The design begins with finding the initial values for resonator filters in each arm centered at 12.5 GHz with 2-GHz bandwidth. To speed up the process of optimization, the circuit is first optimized in all dielectric rectangular waveguide using the μWaveWizard, which is based on an efficient mode matching technique. Then, all square walls and aperture thicknesses with the fixed width of $d_{\text{square}}=1.024$ mm are replaced by circular via holes separated by periodic distance $S = 1.6$ mm and circular vias of radius [11]

$$r_{\text{circular}} = d_{\text{square}} \Big/ \left(1+\frac{1}{\sqrt{2}}\right) \tag{1}$$

which lead to via diameters of 1.2 mm.

For the input and output walls as well as surrounding walls, the equivalent waveguide width W_{eff} is transferred to SIW width W by using the implicit equation of [12]

$$W_{\text{eff}} \cong \frac{W}{\sqrt{1+\left(\frac{2W-d}{S}\right)\left(\frac{d}{W-d}\right)^2}} \tag{2}$$

in which W, d, S resemble the width of the SIW, diameter of via holes, and via hole spacing, respectively. Finally, a linear

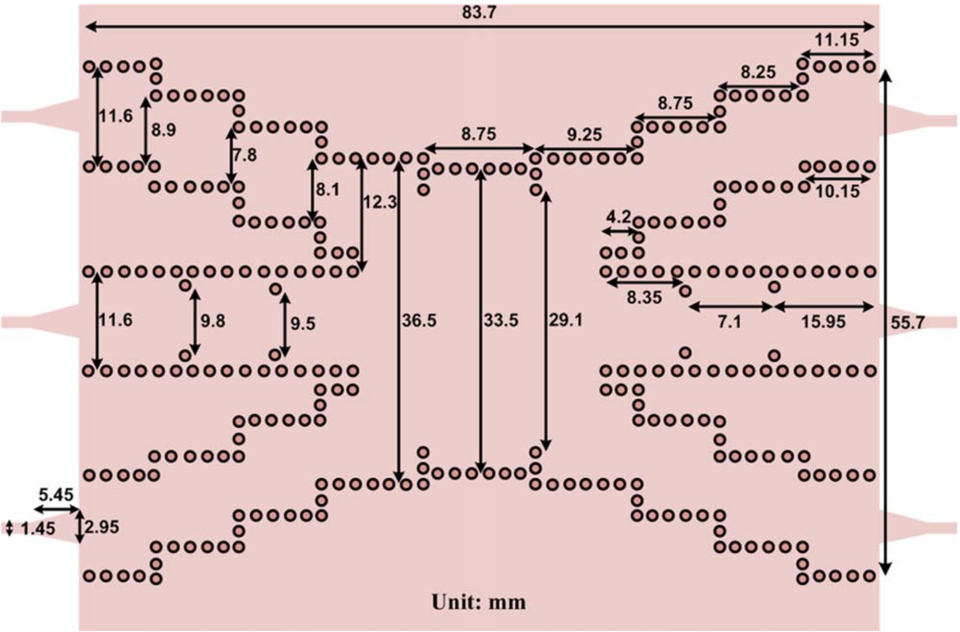

Figure 1 Layout and dimensional parameters of the symmetrical SIW six-port power divider/combiner. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

microstrip taper is designed to transform the fundamental SIW mode to 50-Ohm microstrip lines [13]. Then, the SIW coupler is optimized within HFSS and verified by CST.

3. RESULTS

The designed six-port SIW coupler is prototyped on 0.508-mm RT/Duroid 5870 substrate with relative permittivity of 2.33 ± 0.02, conductor thickness of 17.5 μm, and loss tangent of 0.0012. The diameter of all via holes is 1.2 mm with center to centre spacing of $S = 1.6$ mm. The circuit is optimized to meet the requirements of ±0.2 dB ripple for the coupling parameters and better than 25-dB isolation and return loss in a 10 percent bandwidth at 12.5 GHz. Figure 2 shows a photograph of the fabricated prototype circuit. Simulated results with CST and measured frequency responses of the proposed coupler topology are compared in Figure 3. The return loss and isolation in the passband, and the resonator cavities are well-reproduced in simulations as well as measurements. A slight shift toward lower frequencies is observed which is well within the tolerance scheme of the substrate material used (c.f. above). This fact together with port mismatches during measurements (see below) also explains the increased return loss and isolation in the passband. In the frequency range between 11.8 and 13.2 GHz, the measured return loss ($|S_{11}|$) and isolation ($|S_{21}|$) are below -22 dB. The measured return loss ($|S_{22}|$) and isolation ($|S_{31}|$) are below -19 dB in the range between 11.7 and 12.7 GHz with ±0.3 dB flatness in the passband. The insertion losses are measured as 1.33 dB [$|S_{41}|$ in Fig. 3(a) and $|S_{51}|$ in Fig. 3(c)], and 1.63 dB [$|S_{52}|$ in Fig. 3(d) and $|S_{61}|$ in Fig. 3(b)], down from the theoretical value of 4.77 dB.

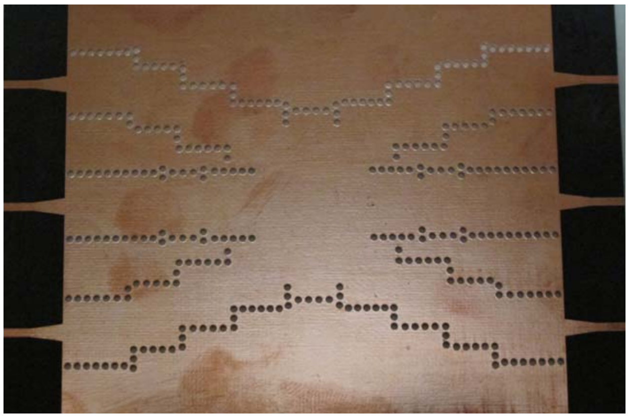

Figure 2 Photograph of the fabricated SIW six-port prototype. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

For measurement purposes, the microstrip ports are equipped with coaxial connector terminations. Although the coax connectors and microstrip-to-SIW transitions are deembedded from measurements using standard transmission, reflection, line calibration, this process applies only to the two measured ports while the reflections of the remaining four ports, due to microstrip-to-SIW transitions and 50-Ohm coaxial terminations, influence the measurements.

4. CONCLUSION

A simple design of a six-port power divider/combiner with wide bandwidth, which is new in SIW technology, is presented. The coupling between resonator cavities is used in the symmetric structure to increase the bandwidth. The coupler is designed and fabricated on 0.508-mm RT/Duroid 5870 substrate. Good agreement between experiments and simulations is observed, demonstrating 10 percent reflection bandwidth below -19 dB and 10 percent isolation bandwidth below -20 dB with flatness of ±0.3 dB and insertion losses better than 1.63 dB. The proposed circuit is well-suited for low-cost, wideband, and compact-size wireless and microwave applications.

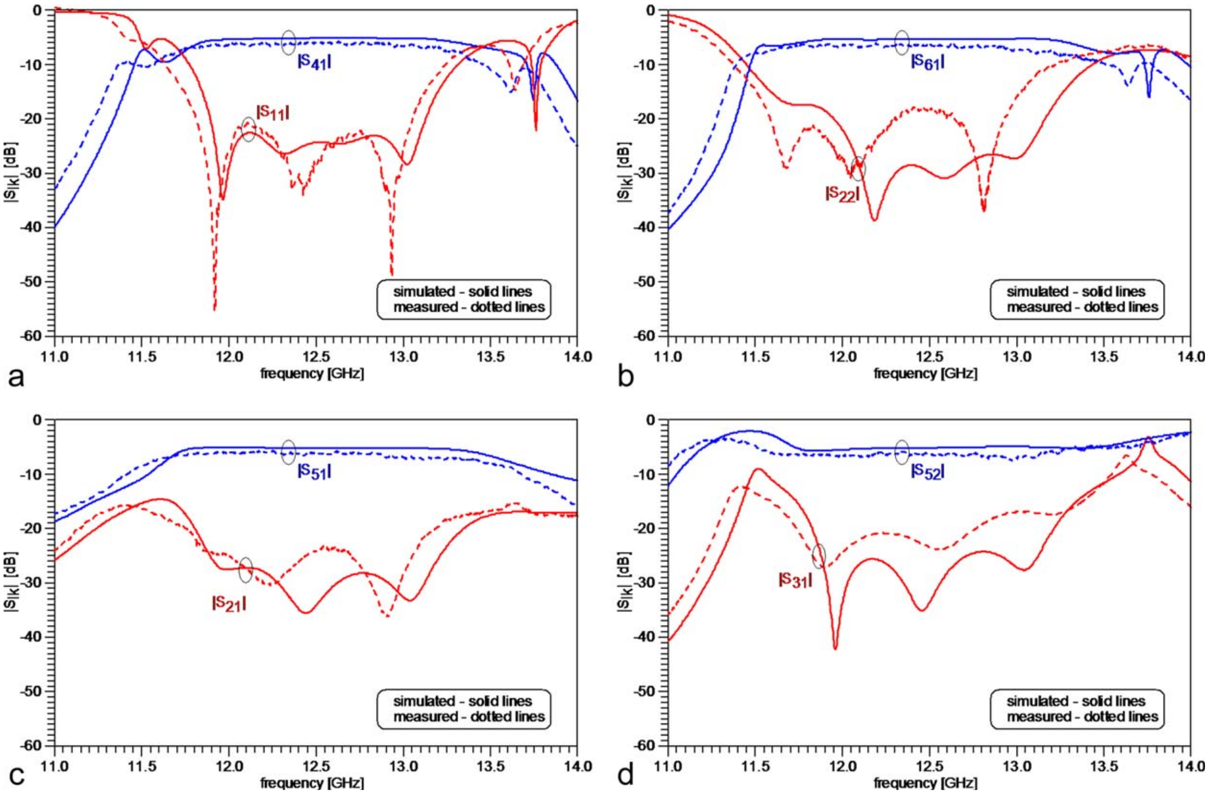

Figure 3 Comparison between simulated (solid lines) and measured (dotted lines) scattering parameters of SIW six-port power divider/combiner; (a) S_{11} and S_{41}, (b) S_{22} and S_{61}, (c) S_{21} and S_{51}, and (d) S_{31} and S_{52}. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

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A NEW NARROW BAND FREQUENCY SELECTIVE SURFACE GEOMETRY DESIGN AT THE UNLICENSED 2.4-GHz ISM BAND

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ABSTRACT: *Wireless devices in the unlicensed instruments, scientific, and measurements (ISM) bands cause mutual interference in indoor environments. This interference degrades the system performance and compromises security. Transforming existing building walls to a band stop frequency selective surface (FSS) can be an efficient solution for*