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A Design of Compact Microwave Six-Port Device for Ultra-Wideband Applications

Hongyan Li[1, *], Jun Zhu[2], and En Li[2]

Abstract—A compact fully integrated wideband six-port device composed of a suspended stripline Wilkinson power divider and three bias stripline of 3-dB quadrature directional couplers is presented. In order to integrate a six-port circuit, a multilayer circuit structure has been adopted by the via hole interconnection at the output port of the divider. The 3-dB quadrature directional coupler is composed of two 8.34-dB quadrature directional couplers by series connection. In this way, the six-port circuit structure is simplified and reduced. A multisection impedance match structure has been adopted in the suspended stripline Wilkinson power divider to achieve ultra-wide frequency band. In the experiment, the fully integrated six-port device has obtained good measurement result. It is superior to other present six-port networks in microwave performance with the same dimension.

1. INTRODUCTION

Six-port is an important passive microwave device, which is widely utilized in microwave measurement systems. It plays a very important role in measuring voltage, current, power, impedance, and phase, as discussed in [1]. The characteristics of a complex signal can also be detected by a six-port coupler [2]. As known to all, six-port devices are widely adopted in microwave vector device analyzer (VNA), in which six-port devices are compact and fully integrated for ultra-wideband applications [3]. An obvious advantage of the device is that magnitude and phase of two complex signals can be measured accurately by heterodyning receiver technology. It is applied not only to the measurement of S-parameter of high-power transistors [4], but also to designing microwave receivers [5] and vector voltmeters. In the field of microwave measurement, a six-port device can be employed in broadband nonlinear system measurement. It is the core module in AM-AM and AM-PM test. In the medical field, six-port measurement technology can be found in remote respiration and heartbeat monitoring sensor [6], as well as in absorption measurements of biological sample [7].

In this article, a wideband six-port device is designed with a novel and compact structure which makes good contribution to reducing the circuit size. In the past, wideband six-port devices were assembled utilizing commercially available 90° and 180° couplers and power dividers in stripline, microstrip, and waveguide technology. In [3], the system was made up of a UWB 3-dB microstrip/slotline coupler, a power divider with a parallel strip input port and two microstrip output ports and a power divider with three microstrip ports. However, the connections of these components brought many drawbacks such as large volume, high cost, and difference phase of the connecting line. Two compact and fully integrated six-port devices were investigated for scalar power measurements to test the ratio of two complex voltages or two complex wave amplifiers [3]. Full integration was realized by the two promotions: multisection in-phase Wilkinson power by suspended stripline technology and multisection 3-dB quadrature directional couplers by two 8.43-dB quadrature directional couplers with series connection. A schematic diagram of the structure is shown in Fig. 1. Q denotes a 3-dB quadrature directional coupler, and D represents an in-phase power divider.

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* Corresponding author: Hongyan Li (gor_lee@163.com).

[1] Southwest China Research Institute of Electronic Equipment, China. [2] University of Electronic Science and Technology of China, China.

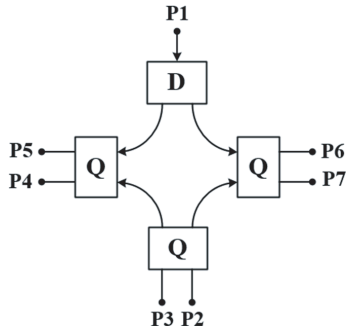

Figure 1. Constitution of a six-port network.

2. DESIGN OF SIX-PORT DEVICES

As shown in [8], a six-port device is composed of three 3-dB couplers and in-phase or out-of-phase power divider. In this paper, the design of a wideband six-port network that features a fully integrated device on the planar microstrip is proposed. In order to improve the bandwidth and directivity factor, 8.34-dB quadrature directional couplers by series connection are adopted. A multilayer circuit structure consists of three conductor layers interleaved by two dielectric layers. A suspended stripline Wilkinson power divider on medial layer connects directional couplers by a via hole. In order to integrate the power divider and directional couplers, transitions are employed by suspended striplines. Many microwave devices such as directional coupler [9], power Combiner [10], filter [11, 12] were designed using suspended striplines which with low dissipation, temperature performance, as well as good batch consistency, is very suitable for broadband microwave components design.

Four sections model is established on the basis of the wide-band impedance match theory when the power divider is designed. Schematic of the proposed Wilkinson power divider is shown in Fig. 2(a). The input port impedance matching is achieved by transforming sections in output lines 2 and 3 which are symmetry. The simulation analysis shows that the impedance matching and isolation can be improved by reducing the equivalent permittivity. Therefore, lower equivalent permittivity is chosen in the design to get better performance. The simulated results of the new power divider is shown in Fig. 3.

Directional coupler design can be divided into two phases. First step is an 8.34-dB directional coupler designing at the operating frequency band from 2 to 8 GHz; secondly, series connection realizing between couplers. A schematic diagram of the proposed couplers is shown in Fig. 2(a). In the model of the proposed directional couplers, 7-section quarter-wave transformers are chosen for wide-band matching. When three couplers connect in series, the performance of the directional couplers is deteriorated. The isolation and return loss are obviously worse. The phenomenon can be explained by the parasitic reactance connection parts. In order to improve microwave performance, continuous zigzag capacitive compensation technology is adopted in the design. The zigzag which plays the same role of shunt capacity can degrade the effect of discontinuity regions on odd characteristic impedance. Fig. 4 shows the simulation results of the coupler. The S-parameter results of the 3-dB directional couplers can reach a good performance by zigzag compensation.

The coupled line section and the proposed power divider are built on a Rogers RT 5880 substrate, whose the thickness is 0.254 mm. However, the thickness of the medial layer of directional couplers has a great influence on the performance of the six-port device, on which the traces of coupled lines are etched and placed between two 0.787 mm thick laminate layers. The coupled line includes 18 µm of conductive coating; the relative permittivity = 2.2. The center frequency of the coupler is designed at 5 GHz. Compatibility of the circuit structure should be considered basically before six-port device is fully integrated. In order to realize good signal transmission of suspended stripline and stripline, the via hole simulation is taken a good care of. Phase deviation has also accompanied with employing the via hole. Therefore, it is necessary for the power divider to increase length of the other ports. The accurate length depending on the phase can be simulating by HFSS.

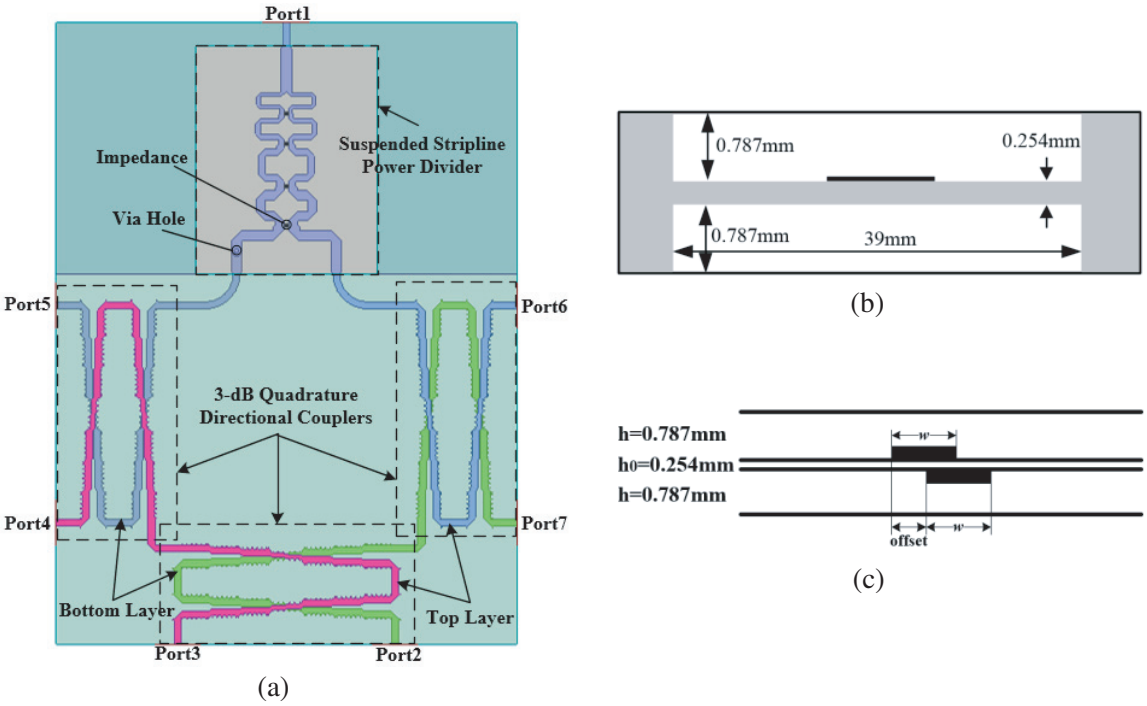

Figure 2. Schematic diagram of the fully integrated six-port device. (a) The simulation model; (b) possible configuration for implementation into a large circuit; (c) cross-section view of the stripline coupled-line.

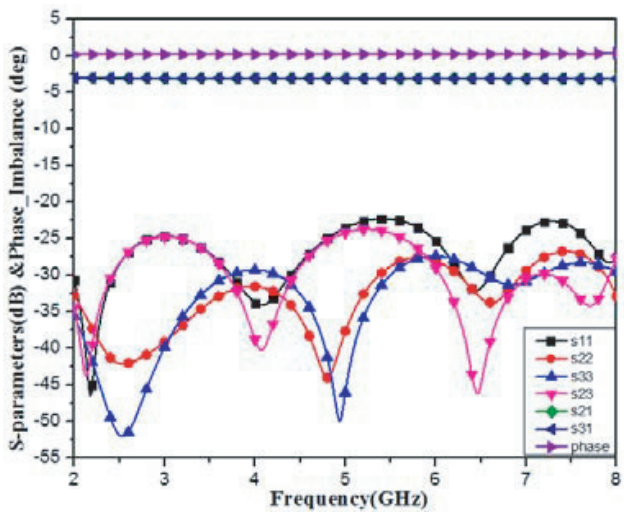

Figure 3. Simulation results for the S-parameters and phase imbalance of the new Wilkinson power divider.

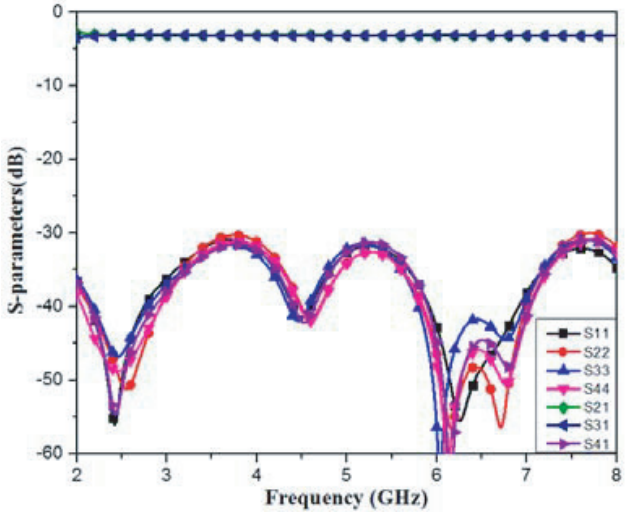

Figure 4. Simulation results for the S-parameters of the 3-dB quadrature directional couplers.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The presented design has been manufactured and measured. The performance of the fabricated six-port device is measured by Agilent E8363B VNA. Test result of the return loss is better than -15 dBm, identical to the simulation. S parameters deteriorate at a few points as the influence of uncontinuity between the SMA inner conductor and the stripline. The measured isolation between port 1 and port 2

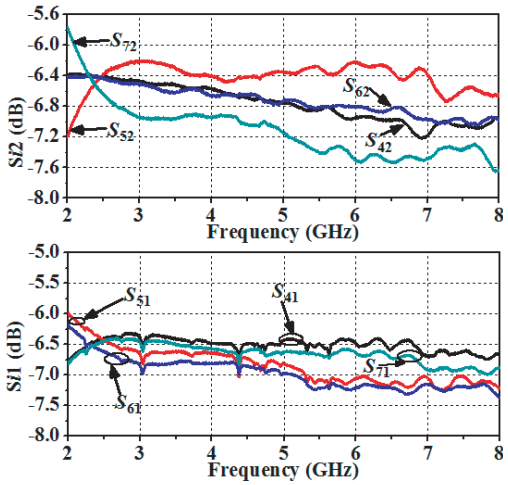

Figure 5. Measured results for the S-parameter of the six-port device.

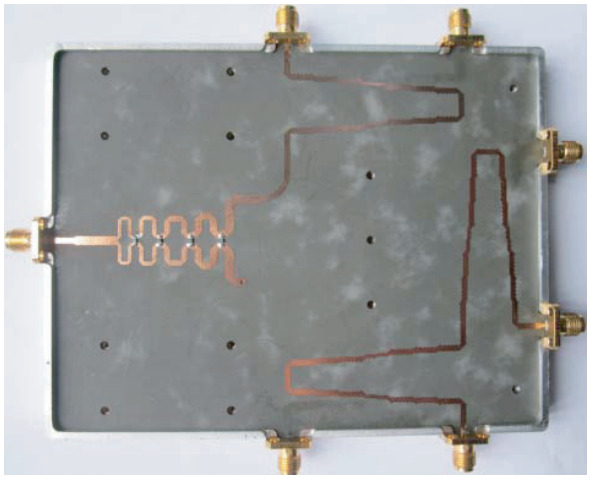

Figure 6. Photograph of the fully integrated six-port device.

is greater than 23 dB over the frequency band from 2 to 8 GHz. It is an excellent performance in the wideband six-port network, as shown in Fig. 5. When the input port are port 1 and port 2, respectively, the insertion losses Si1 and Si2 are 6.75 dB ± 1 dB. It is determined that the six-ports device has a good performance of amplitude consistency. The phase characteristics of the six-port network are observed by the transmission coefficient phase of S31–S41 and S51–S61. The referenced phase values stay approximately constant in 2–8 GHz. They deviate to small extent from the required values of −90, 0, and 90 degrees.

A photograph of the fabricated six-port device prototype is shown in Fig. 6. The structure is very compact, with dimension of 128 × 98 mm.

Another six-port device was designed which was published at 2014 IEEE Asia-Pacific Conference on Applied Electromagnetic [13]. The detail between two devices is exhibited in Table 1. It is obvious that the device designed by this method has a wider waveband and more excellent microwave performance with nearly the same dimension. Compared with [3] and [13], the six-port module with the structure can achieve wider bandwidth, more excellent S parameters and more compact structure.

Table 1. Details of two devices.

details	Device in this paper	Device in 2014 APACE
Band frequency	2–8 GHz	3–8 GHz
Divider structure	Wilkinson	Wilkinson
Coupler structure	Quadrature	Elliptical
Substrate	Rogers RT 5880	Rogers 4003C
Dimension	128 × 98	122 × 111
Transmission coefficient	6.75 ± 1 dB	7 ± 2 dB
Return loss	Better than 15 dB	Worse than 10 dB

4. CONCLUSION

The design of a fully integrated six-port device that features wide operational bandwidth (2 to 8 GHz) on a Rogers RT5880 substrate material is presented. The six-port network is composed of three quadrature directional couplers and an in-phase Wilkinson power divider by stripline/suspended stripline technology. The six-port device is designed, manufactured and measured. Wide operation band and satisfactory performance are obtained in experiment research, which proves that the device can be applied in measurement system.

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