Design of Wideband Microstrip-Slot Six-Port Complex Ratio Measuring Unit

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***Abstract*—A wideband six-port Complex Ratio Measuring Unit (CRMU) design is presented in this paper. CST Microwave Studio is used to design the CRMU by integrating one in-phase Wilkinson power divider with stubs and three 90° microstrip-slot two-section branch-line couplers (BLCs). Wilkinson power divider is improved by implementing additional stubs at transmission line of Port 1, Port 2 and Port 3. Meanwhile, slot is placed underneath each parallel branch arm of BLC to broaden its bandwidth performance. The presented simulated result of the proposed CRMU offers good wideband performance of amplitudes and phase characteristics between 2.5 and 5.2 GHz.**

Keywords—branch-line coupler; Complex Ratio Measuring Unit (CRMU); wideband; Wilkinson power divider.

I. INTRODUCTION

In microwave network analysis, six-port was developed in 1970's for measurement purpose, while in 1990's, its use was expended to communication applications [1-3]. Low cost, less complexity, accurate measurement such as a reflection coefficient and voltage ratio and able to be used in high-speed communication application are several advantages of six-port technology [1, 2, 4]. Nowadays, wireless communication needs to perform in high speed, which the demand for data usage is increasing due to social networking and multimedia streaming [4-6]. Thus, fifth generation (5G) is being researched to fulfill the higher-speed communication demand. Therefore, alternatively in modulation/demodulation process, active mixers commonly used for transceiver application can be replaced by six-port Complex Ratio Measuring Unit (CRMU) that having low power consumption and less complexity [5].

CRMU is one of six-port circuit technologies that integrated by only passive devices such as power dividers, quadrature couplers and/or H-hybrids. CRMUs proposed in [3, 4, 7, 8] are designed by using a multilayer technique. Multilayer technique helps to achieve very wideband performance but facing fabrication challenge due to the need of extra attention to minimizing the misalignment and air gap between the layers that can degrade the performance. Instead of multilayer technique, six-port CRMU can be designed by using single substrate [9]. The design in [9] proposed a configuration that integrated by six double-stage Wilkinson power dividers and four quadrature Wilkinson dividers. The requirements of 10 passive components lead to relatively larger size six-port. Furthermore, the additional phase shifter in the design of quadrature Wilkinson divider contributes to the quite large phase imbalance of ± 25° from its ideal phase characteristics of -90° and 90°. Thus, this high phase imbalance between outputs of Port 3 to Port 6 might be less compatible for quadrature phase shift keying (QPSK) or QAM modulation/demodulation application purposes, which very sensitive to phase performance.

Therefore, a six-port network CRMU is proposed by using one Wilkinson power divider with stubs and three microstrip-slot two-section branch-line couplers to overcome the limitation in previous designs. The Wilkinson power divider is improved by additional stubs at transmission line of Port 1, Port 2 and Port 3, while the two-section branch-line coupler is added with slots underneath the branch arms to broaden the bandwidth performance.

II. SIX-PORT COMPLEX RATIO MEASURING UNIT (CRMU) DESIGN

Fig. 1 shows the six-port CRMU configuration, which consist of one in-phase Wilkinson power divider (D) and three two-section branch-line couplers (Q). The CRMU consists of two inputs, which are 'a' and 'b' into Port 1 and Port 2, respectively. Meanwhile, Port 4 to Port 7 are the output ports that connected to the scalar power detector. This six-port CRMU can be used to determine the ratio of two complex input signals from the measured power at its four output ports of Port 4 to 7.

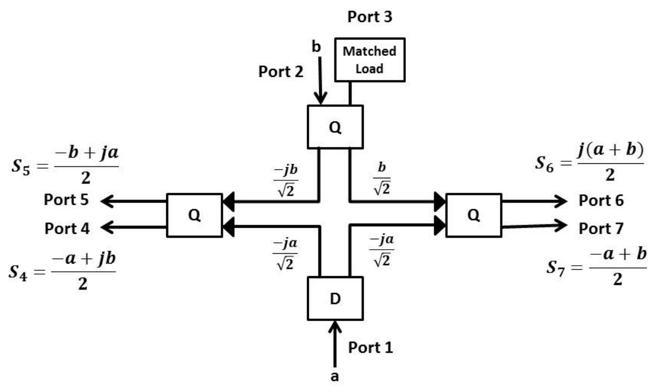

Fig 1. The configuration of six-port complex ratio measuring unit (CRMU).

As illustrated in Fig. 1, the six-port CRMU device emerges four complex signals from Port 4 to Port 7, which are indicated as S_4, S_5, S_6 and S_7, respectively while Port 3 is terminated with 50Ω matched load. Two input signals 'a' and 'b' are injected through Port 1 and Port 2, while 'j' symbol in

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the block diagram denotes the $\sqrt{-1}$ of complex microwave signal. The emerging signals from Port 4 to Port 7, of proposed six-port CRMU can be defined as follows:

$$S_4 = \frac{-a + jb}{2} \quad (1)$$

$$S_5 = \frac{-b + ja}{2} \quad (2)$$

$$S_6 = \frac{j(a+b)}{2} \quad (3)$$

$$S_7 = \frac{-a+b}{2} \quad (4)$$

Substrate Rogers RO4003C with 0.508 mm thickness, 0.017 mm thickness of conducting coating, loss tangent of 0.0027 and dielectric constant of 3.38 is chosen to be applied in the design of the proposed six-port CRMU. The design of the in-phase Wilkinson power divider with stubs (D), two-section microstrip-slot branch-line couplers (Q) and the proposed six-port CRMU are presented in the following sub-sections.

A. Wilkinson power divider with stubs (D)

Fig. 2 shows the prototype of the Wilkinson power divider used in the design of six-port CRMU [10]. A stub is added to each transmission line of Port 1, Port 2 and Port 3 to enhance the bandwidth [11] and remove undesired reflection [12]. Parametric study is done to determine the best position to place the stubs. From the study, the size of the stubs is 0.4 mm x 1 mm at transmission line of Port 2 and Port 3, while the stub at transmission line of Port 1 is 1 mm x 1 mm as reported in [10]. This power divider is fabricated with overall size 30 mm x 20 mm. Then, its performance is verified using a vector network analyzer (VNA).

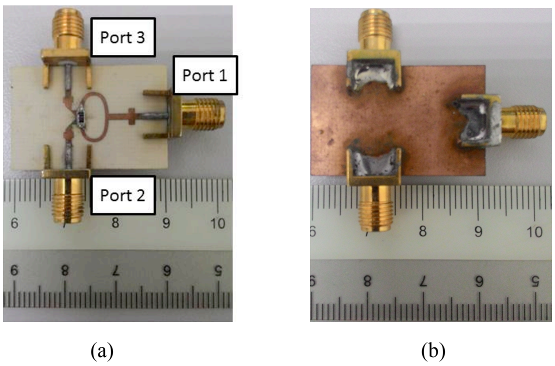


Fig 2. The configuration of Wilkinson power divider with stubs; (a) top and (b) bottom view.

The performance of the Wilkinson power divider with stubs is plotted as in Fig. 3 (a) and (b) for S-parameter and phase difference between output ports of Port 2 and Port 3, accordingly. This power divider has a very well wideband performance across 2 to 6 GHz. Simulated S11 performs less than -15 dB compared to measured S11 of less than -11 dB across this band. While, the transmission coefficients of simulated and measured S21 and S31 performances are -3 ± 1 dB, which indicate very low amplitude imbalance of output signals at Port 2 and 3. Whilst, the simulated and measured isolations between output ports demonstrate comparable performance of more than 10 dB and 11 dB, respectively. Furthermore, it has good in-phase performance with the simulated and measured phase difference between Port 2 and Port 3 of 0° ± 1°.

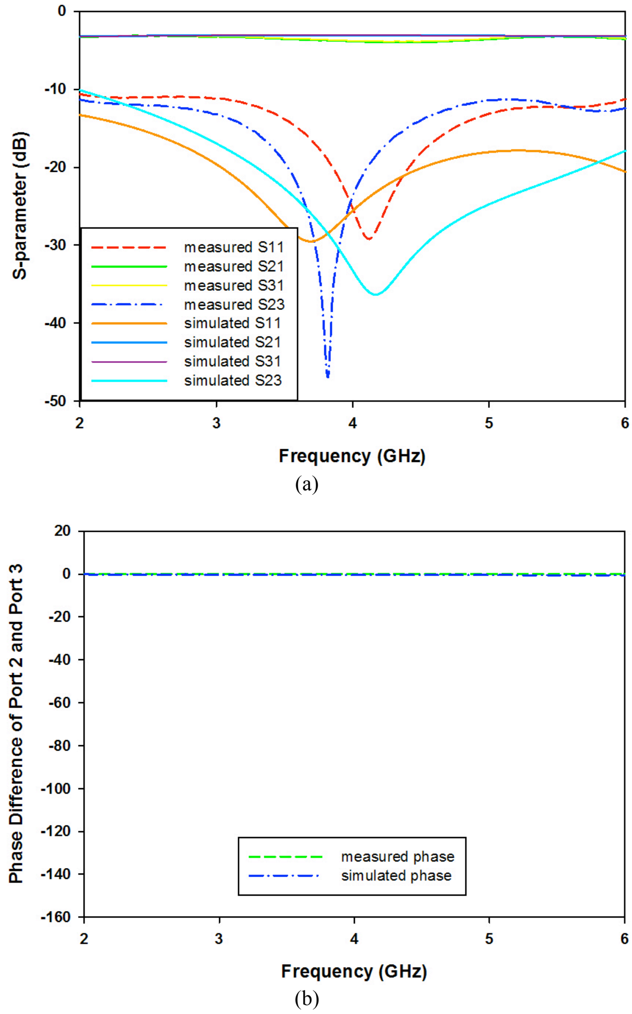


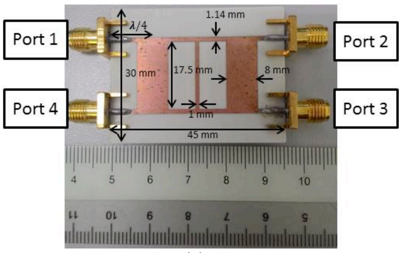
Fig. 3. Simulated and measured performance of Wilkinson power divider with stubs: (a) S-parameters and (b) phase difference between output ports

B. Two-section microstrip-slot branch-line coupler (Q)

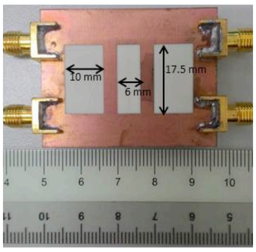
The design of microstrip-slot branch-line coupler is depicted in Fig. 4. The branch-line coupler is designed with two-section to broaden the bandwidth. The number of section is limited to two as the size will increase directly to the number of section [13-15]. Meanwhile, slot is added underneath the parallel branches to enhance further the bandwidth performance. The initial width of microstrip and the slot underneath are calculated by referring to [16]. Each branch has initial length that calculated approximately a quarterwave length. The design is then fabricated with the overall size of 45 mm x 30 mm. Afterward, its performance is measured via the use of VNA and compared to the simulation.

This branch-line coupler has a comparable well wideband performance of simulation and measurement from 2.3 to 5.3

GHz. As illustrated in Fig. 5 (a), the simulated and measured S11 are less than -10 dB and -11 dB, accordingly. Meanwhile, it has isolation that greater than 10 dB across the concerned band. As for the coupling coefficient, the measured and simulated results show the performance of 3 with the deviation of ± 2 dB. In Fig. 5 (b), the measured phase difference is better than simulated phase difference, which simulated at 90° ± 5°, while measured at 90° ± 1°.

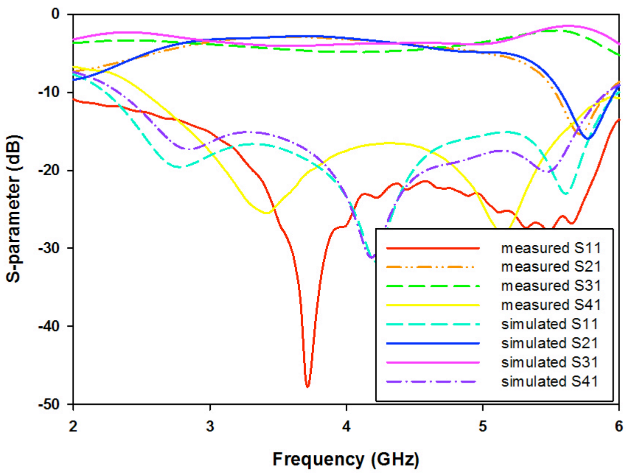


(a)

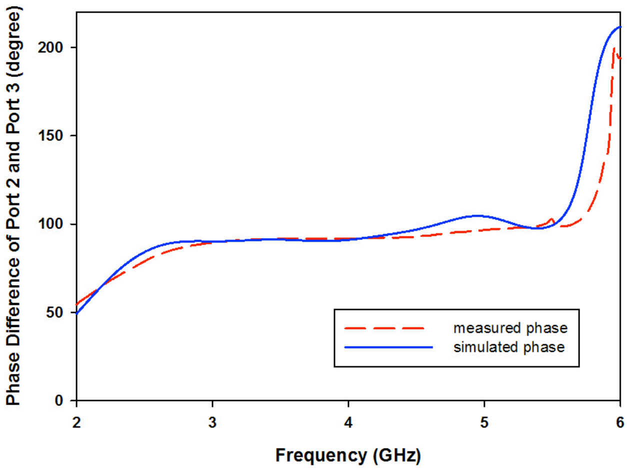


(b)

Fig 4. The (a) top and (b) bottom view configuration of two-section microstrip-slot branch-line coupler.



(a)

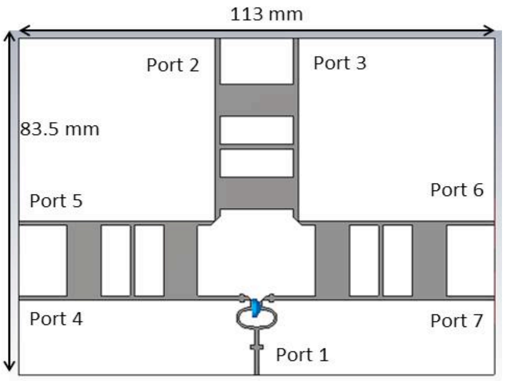


(b)

Fig 5. Simulated and measured results of two-section microstrip-slot branch-line coupler: (a) S-parameter performance and (b) phase difference between output ports.

C. Six-port CRMU

The CST generated layout of the proposed six-port CRMU is presented in Fig. 6. The proposed design is integrated by using three two-section microstrip-slot branch-line couplers and one in-phase Wilkinson power divider with stubs. This design aims to have wide bandwidth performance and low phase difference imbalance between output ports of Port 4 and Port 5; and Port 6 and Port 7. The overall size of the integrated six-port CRMU is 113 mm x 83.5 mm.



(a)

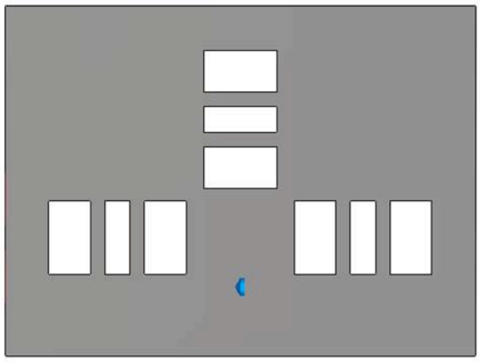

(b)

Fig 6. The CST layout of proposed six-port CRMU; (a) top and (b) bottom view.

As observed in Fig. 7 (a), the reflection coefficients at Port 1 and 2 of S11 and S22 demonstrate the simulated performance less than -13 dB and -19 dB across 2.5 to 5.2 GHz band, respectively. The ideal transmission coefficients of Sij (where, i = 4, 5, 6, 7, and j = 1, 2) from Port 1 or Port 2 to Port 4 to Port 7 are -6 dB. However, the simulated transmission coefficients in Fig. 7 (b) are depicting -6 dB ± 4 dB between a frequency band of 2.5 GHz and 5.5 GHz referring to Port 1 and -6 dB ± 6 dB across 2.5 to 5.2 GHz referring to Port 2. These deviations are contributed by the amplitude imbalance of the used Wilkinson power divider with stubs and two-section microstrip-slot branch-line couplers. In Fig. 8, phase differences between Port 4 and Port 5, and Port 6 and Port 7 are 90° ± 10° across 2.55 GHz to 5.2 GHz. Since the phase difference of output ports is about ± 90° with quite minimal phase imbalance, the proposed CRMU can be used for QPSK/QAM modulation/demodulation application.

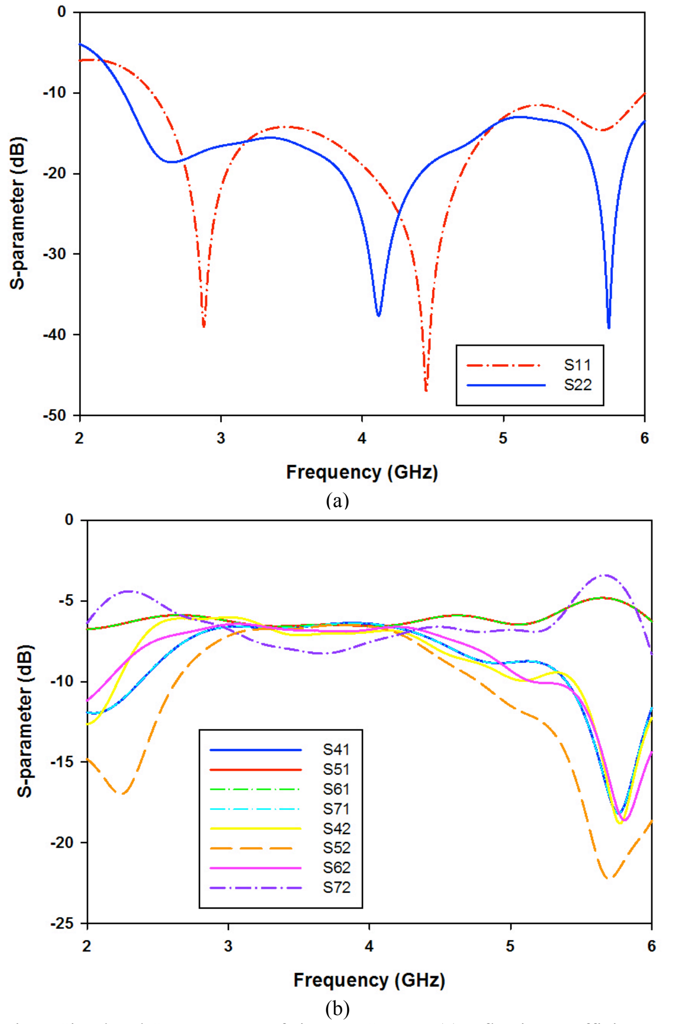


Fig 7. Simulated S-parameters of six-port CRMU: (a) reflection coefficients at Port 1 and 2, and (b) transmission coefficients.

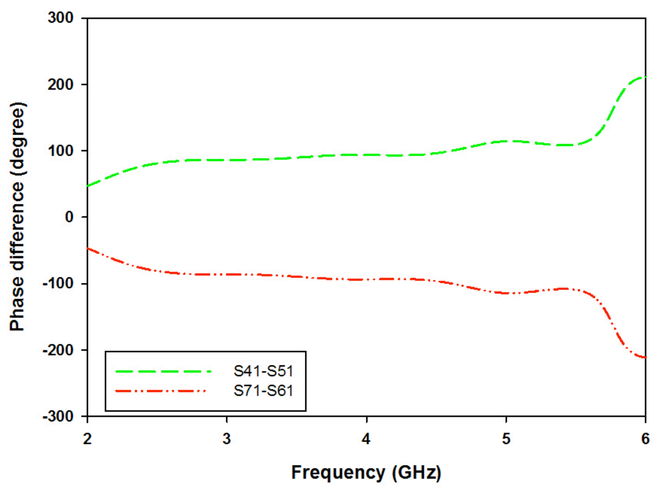


Fig 8. The phase difference between output ports of six-port CRMU.

III. Conclusion

The proposed design of six-port Complex Ratio Measuring Unit (CRMU) has been presented in this paper. The CRMU is implemented by integrating one in-phase Wilkinson power divider with stubs and three 90° two-section branch-line coupler using CST Microwave Studio for simulation process. Good wideband performance has been shown by the proposed six-port CRMU between 2.5 to 5.2 GHz with the respective transmission coefficients' amplitude imbalance of ± 4 dB and ± 6 dB referenced to Port 1 and Port 2, and ± 90° phase differences.

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