Jurnal
Teknologi

Full Paper

DESIGN OF A COMPLEX RATIO MEASURING UNIT USING ENHANCED BRANCH-LINE COUPLER FOR WIRELESS COMMUNICATION APPLICATIONS

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Article history
Received
31 March 2015
Received in revised form
10 July 2015
Accepted
10 July 2015

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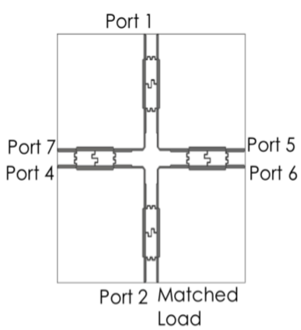
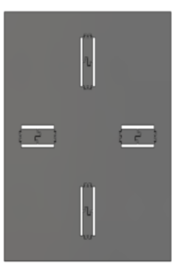
Graphical abstract





Abstract

This article presents the complex ratio measurement unit (CRMU) design formed by enhanced 3-dB branch-line couplers (BLCs), which are placed symmetrically. The first CRMU is formed by four wideband 3-dB BLCs implementing Defect Ground Structure (DGS) and stub impedance techniques that operate over the frequency of 2.5 to 4 GHz. Meanwhile, the other CRMU is formed by four reduced size of enhanced two-section microstrip-slot BLCs with tight coupling of 3-dB over frequency of 2 to 5 GHz. The performances of the CRMU designs are observed and analyzed. The BLCs and CRMUs are designed using CST Microwave Studio. While, the S-parameter performances of the CRMUs are analyzed using Keysight's Advanced System (ADS) software.

Keywords: Passive component, CRMU, two-section, branch-line coupler, microstrip-slot

Abstrak

Artikel ini membentangkan reka bentuk unit ukuran nisbah kompleks (CRMU) yang dibentuk oleh pengganding garis bercabang (BLC) 3-dB tertingkat yang diletakkan secara simetri. CRMU pertama dibentuk oleh empat BLC jalur lebar 3-dB yang menggunakan Struktur Kerosakan Bumi (DGS) dan teknik puntung impedans di frekuensi 2.5 hingga 4 GHz. Sementara itu, CRMU lain terbentuk dengan empat mikrojalur–slot dua-seksyen tertingkat BLC yang mempunyai saiz terkurang dengan gandingan ketat 3-dB pada frekuensi 2 hingga 5 GHz. Prestasi reka bentuk CRMU diperhatikan dan dianalisis. Pengganding dan CRMU direka menggunakan CST Microwave Studio. Manakala, prestasi S-parameter CRMU dianalisis menggunakan perisian Advanced System (ADS) Keysight.

Kata kunci: Komponen pasif, CRMU, dua-seksyen, pengganding garis bercabang, mikrojalur-slot

1.0 INTRODUCTION

Nowadays, mobile and wireless network has been focusing on developing the next generation of fifth generation (5G) technology, which is demanding on higher data rates and mobility of wireless applications. The 5G technology is having unlimited and expectation of perfect wireless communication, which is likely to be rolled up by 2020 [1]. Traditionally, due to development of a high-speed connectivity system, the excessive challenges need to be faced by researchers, which involved radio-frequency (RF) and microwave components, antenna and networking system.

The important characteristic of the RF front-end configuration in communication applications is the mixer-based approach. Commonly, the mixer that consists of active devices needs a certain biasing voltage to be in the active state. Thus, it will increase the design and fabrication complexity. Alternative to that, the mixer-based approach can be replaced by six-port component, which for this specific case named as a complex ratio measuring unit (CRMU) without having the additional voltage source to individual component [2]. The configuration of CRMU can be formed by using passive devices such as coupler and power divider [3]. CRMU also can be used for modulation and demodulation where, this device can control the complex ratio between two signals [4-6].

To be used in CRMU configuration, the design of individual component must be able to tolerate with the certain losses that can occur at the integration stage. Therefore, CRMU is proposed to form by the wideband branch-line couplers (BLCs) with a tight coupling of 3-dB. BLCs are chosen to form the proposed CRMU to overcome the problems occurred due to the use of the multilayer directional couplers in [3]. Multilayer technique offers wideband performance but facing problems of misalignment and air gap between the substrates during the fabrication and integration, which directly affect the CRMU performance [7]. While, another design proposed in [8] using BLC and Wilkinson power divider has a relatively narrower bandwidth than [3]. In addition, an improved bandwidth performance demonstrated in [5] that contributed by the implementation BLC with impedance stubs, but still limited compared to [3].

Thus in this article, two CRMU designs formed by two enhanced BLCs are presented. The first CRMU is formed by 3-dB BLCs implementing Defect Ground Structure (DGS) and impedance stub at each arm of the BLC. Whilst, another CRMU design is formed by two-section microstrip-slot BLCs with the overlapped λ/4 open circuited lines at ports. The CRMU designs and analysis are performed using CST Microwave Studio and Keysight's Advanced System (ADS) software across the designated frequency band. The performances of the proposed designs are compared to [3, 5, 8] as shown in Table 1.

Table 1 Comparison of between previous works in [3, 5, 8] and proposed designs

Parameters	Design				
	[3]	[5]	[8]	These works: Design 1	These works: Design 2
Frequency (GHz)	2 - 6	3.1 - 4.8	2 - 3	2.5 – 4	2 -5
% BW	100%	43%	40%	46%	86%
Return loss (dB)	> 10	Not specified	Not specified	> 10	> 10
Transmission Coefficients (dB)	6 ± 2	≈ 6 ± 2	Not specified	≈ 9	8 ± 3
Phase Imbalance	± 20°	≈ ± 15°	Not specified	± 20°	± 20°

* BW = Bandwidth

The second design has comparable performance to [3] with slightly smaller bandwidth, which expected due to the use of BLC that known for its narrowband characteristic. However, this design is better than [5, 8], which also formed by BLCs. Whilst as observed in Table 1, the transmission coefficients are varied depending on the chosen configuration and components constructing the CRMU. The proposed designs, results and analysis are presented in the following sections.

2.0 DESIGN OF CRMU FORMED BY ENHANCED 3-dB BRANCH-LINE COUPLERS

In this section, it concerns onto the designs of 3-dB branch-line couplers (BLCs) and CRMUs using Rogers RO4003C substrate that has a dielectric constant of 3.38, loss tangent of 0.0027, substrate thickness, h of 0.508 mm and thickness of conductor coating, t of 17 µm. The proposed CRMU design, which formed by four BLCs that denoted as blocks of 'Q' is having the symmetry configuration as in Figure 1. The BLC designs are described in subsection 2.1 and 2.2. While, the proposed designs of CRMUs are shown in subsection 2.3.

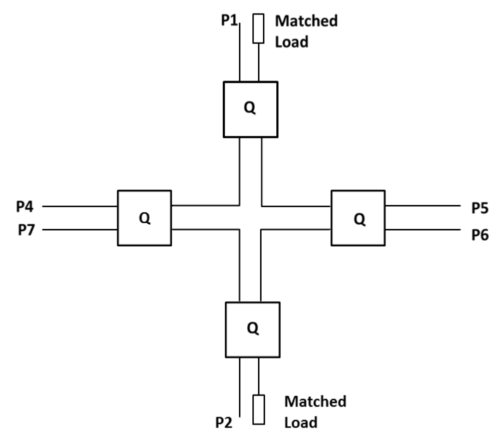
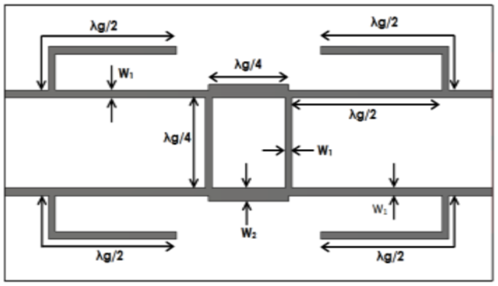


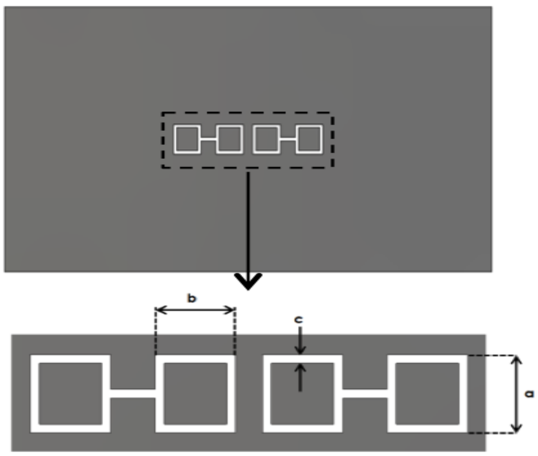
Figure 1 The configuration of the proposed complex ratio measuring unit (CRMU)

2.1 3-dB Branch-Line Coupler Implementing DGS And Impedance Stub

Initially, the configuration of this BLC is based on conventional BLC in [9]. The BLC is enhanced by implementation of DGS at the ground plane and stub impedance at each port. Figure 2 presents the CST generated layout of the 3-dB BLC implementing DGS and impedance stubs as reported in [10]. The implementation of DGS controls the characteristic impedance and coupling by changing the physical dimension of DGS [11]. The BLC coupling can be depending on the ratio of series and shunt branch. Furthermore, a good matching can be obtained by implementing a half wavelength impedance stub that positioned approximately a half wavelength from the BLC at each port's transmission line.



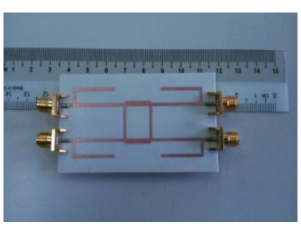
(a)

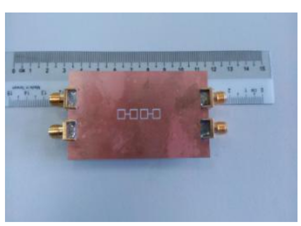


(b)

Figure 2 The CST generated layout of enhanced BLC design with the implementation of DGS and impedance stub; (a) top and (b) bottom view [10]

Referring to the detailed layout in Figure 2, the optimized dimensions of the BLC are W_1 = 1.1 mm, W_2 = 1.9 mm, a = 4.5 mm, b = 4.5 mm, c = 0.55 mm and $\lambda g/4$ = 13.14 mm, which resulting overall size of 80 x 40 mm. Its fabricated prototype is shown in Figure 3.





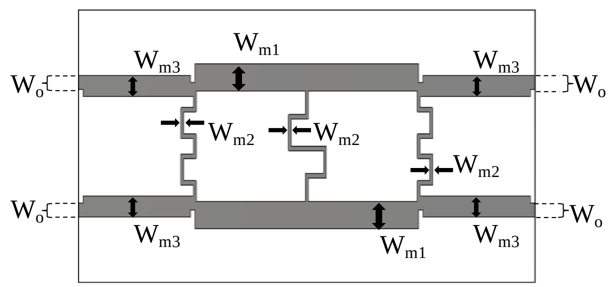
(a) (b)

Figure 3 The photography of the fabricated 3-dB BLC with the implementation of DGS and impedance stubs; (a) top and (b) bottom view [10]

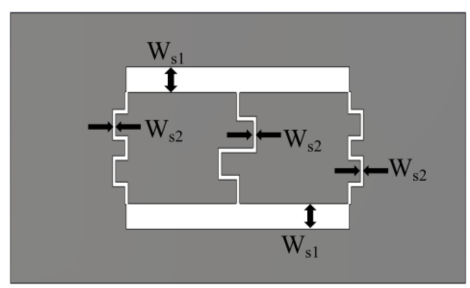
Concerning the frequency range from 2.5 to 4 GHz, the simulated and measured return losses are better than 10 dB, accordingly. Meanwhile, the respective simulated and measured isolations are greater than 10 dB and 13 dB within similar frequency range of 2.5 to 4 GHz. The simulated and measured transmission coefficients of S_{21} depict the performance of -3 dB ± 1 dB. Meanwhile, the simulated and measured coupling coefficients are 3 dB ± 1 dB. This BLC is then used to form the first CRMU as presented in Section 2.3.

2.2 Reduced-Size and Enhanced Two-Section Branch -Line Microstrip-Slot Coupler with Overlapped $\lambda/4$ Open Circuited Lines at Ports

The second proposed BLC is presented in Figure 4 that having microstrip-slot branches and overlapped λ/4 open circuited lines at ports. Basically, the narrowband performance of single-section BLC can be overcome by using two-section or more. Where, the number of section in the design is limited to two. The microstrip-slot is implemented to the series and parallel branches following the reported work in [12]. Where, the microstrip-slot consists of a microstrip line on the top layer, and a slot placed symmetrically underneath at the ground plane. Meanwhile, the overlapped λ/4 open-circuited line has impedance of 50Ω. However, this two-section BLC occupies a larger area due to its configuration formed by seven quarter-wavelength transmission lines. In order to reduce the size of two-section BLC, the shunt arms of the BLC is bended. The total length of bending structure is remained to be $\lambda/4$. The bending must be done properly to minimize the coupling and discontinuity effect [13].



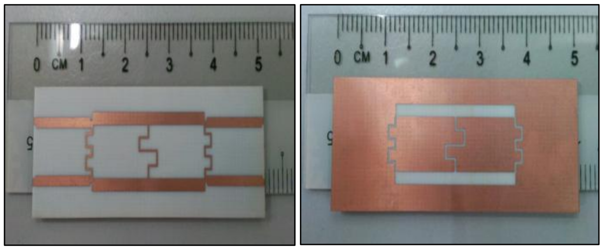
(a)



(b)

Figure 4 The CST generated layout of BLC with the bended shunt branches; (a) top and (b) bottom view

Referring to the detailed layout in Figure 4, the optimized dimensions of the BLC with bended shunt branches are W_o = 1.0 mm, W_{m1} = 2.0 mm, W_{m2} = 0.33 mm, W_{m3} = 1.6 mm, W_{s1} = 1.3 mm and W_{s2} = 0.35 mm. This BLC has total size of 53.56 mm x 20 mm, which its fabricated BLC is shown in Figure 5.



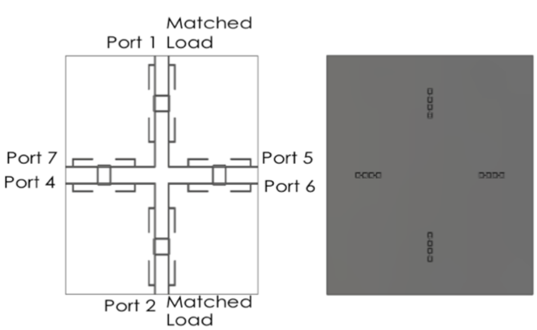
(a) (b)

Figure 5 The photography of the fabricated BLC with the bended shunt branches; (a) top view (b) bottom view

Concerning the frequency range from 2 to 5 GHz, the simulated and measured return losses are better than 10 dB and 11 dB, accordingly. Meanwhile, the simulated and measured isolations are better than 10 dB and 11 dB, respectively. The simulated and measured transmission coefficients of S_{21} depict the performance of -3 dB ± 2 dB and -3 dB ± 1.8 dB within similar frequency range, accordingly. Meanwhile, the respective simulated and measured coupling coefficients are 3 dB ± 1.6 dB and 3 dB ± 1.5 dB. Afterward, by having well simulated and measured performance, this BLC is applied to construct the second CRMU.

2.3 CRMU Design Formed By Enhanced 3-dB Branch-Line Couplers

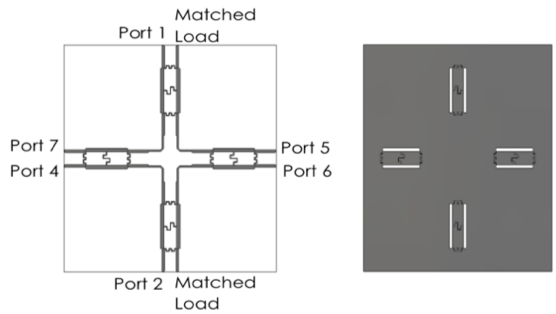
The overall CST generated layouts of CRMUs with the port labels that having configuration shown in Figure 1 and formed by the enhanced BLCs are presented in Figure 6 and 7. The input BLC that denoted as Port 1 is acting as the input port of the CRMU. While, Port 4, 5, 6 and 7 are denoted as the output ports.



(a) (b)

Figure 6 The CST generated layout of CRMU formed by 3-dB BLC implementing with DGS and stub impedance; (a) top and (b) bottom view

Referring to Figure 6, the CRMU is formed by enhanced 3-dB BLC with DGS and stub impedance. The overall size of the CRMU is 200 mm x 200 mm. Meanwhile, the CRMU formed by the reduced size 3-dB BLCs is presented in Figure 7 and has the overall size of 133.56 mm x 133.56 mm.



(a) (b)

Figure 7 The CST generated layout of CRMU formed by 3-dB BLC with bended shunt branches; (a) top and (b) bottom view

3.0 RESULTS AND ANALYSIS OF CRMU FORMED BY ENHANCED 3-dB BRANCH-LINE COUPLERS

The results are divided into two subsections; where, the results of CRMU formed by 3-dB BLC with DGS and impedance stub and CRMU formed by reduced size BLC are presented and discussed in each different subsection. The designs of CRMUs are simulated using CST Microwave Studio software. While, Keysight's Advanced System (ADS) software is applied to analyze the CRMUs' S-parameter performances.

3.1 Result of CRMU design formed by 3-dB Branch-Line Couplers implementing DGS and stub impedance

Figure 8 illustrates the simulated results of the reflection coefficients at Port 1 and 2 that demonstrate good performance within frequency range of 2.5 to 4 GHz. As in Figure 8, it can be noted that the reflection coefficient performances depict the respective S_{11} and S_{22} lower than -10 dB within the stated frequency range.

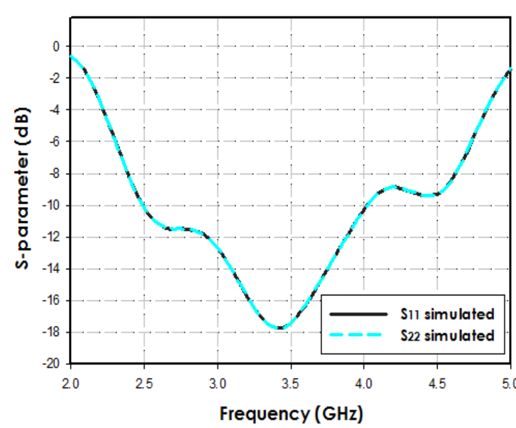


Figure 8 The reflection coefficients at Port 1 and 2 of CRMU formed by 3-dB BLC with DGS and stub impedance

Then, referring to Figure 9, it shows the performance of transmission coefficients, *Sij*, where *i* = 4, 5, 6 and 7 and *j* = 1. The transmission coefficients of S_{41}, S_{51} and S_{61} show the responses of approximately -9 dB between 2.5 and 4 GHz. These transmission coefficients are then started to deviate when the frequency is higher than 4 GHz. Better performances can be observed from S_{71}, where -9 dB response can be noted across a wider range from 2.5 to 4.6 GHz.

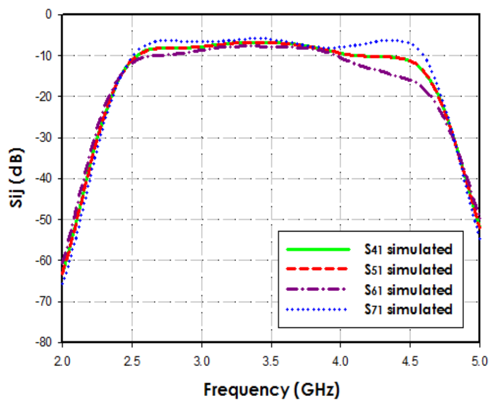


Figure 9 The simulated transmission coefficients of CRMU formed by 3-dB BLC with implementation of DGS and stub impedance referenced to Port 1

Next, Figure 10 illustrates the performance of simulated transmission coefficients, *Sij* where *i* = 4, 5, 6 and 7 and *j* = 2 across the designated frequency range. Based on the obtained result in Figure 10, it shows that the performance of S_{42} is approximately at -9 dB within frequency range of 2.5 to 4 GHz. Meanwhile, the performances of S_{52}, S_{62} and S_{72} are -9 dB ± 1 dB within the similar frequency range, accordingly.

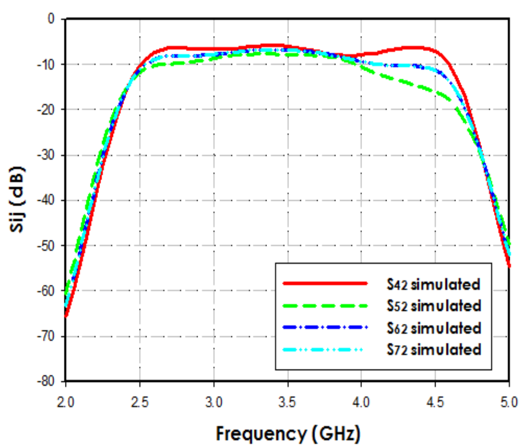


Figure 10 The simulated transmission coefficients of CRMU formed by 3-dB BLC with the implementation of DGS and stub impedance referenced to Port 2

By referring to Figure 11, it shows the phases of transmission coefficients that plotted against the S_{41} phase. Figure 11 depicts that the phases of transmission coefficients of $S_{\Delta 71}$ and $S_{\Delta 42}$ are at 90° ± 10° within the frequency range of 2.5 to 4 GHz. Meanwhile, the phases of transmission coefficients of $S_{\Delta 51}$, $S_{\Delta 62}$ and $S_{\Delta 72}$ are approximately at 0° within similar frequency range. Whilst, the phases of transmission coefficient of $S_{\Delta 61}$ and $S_{\Delta 52}$ are at -90° ± 10° across the frequency of 2.5 to 4 GHz.

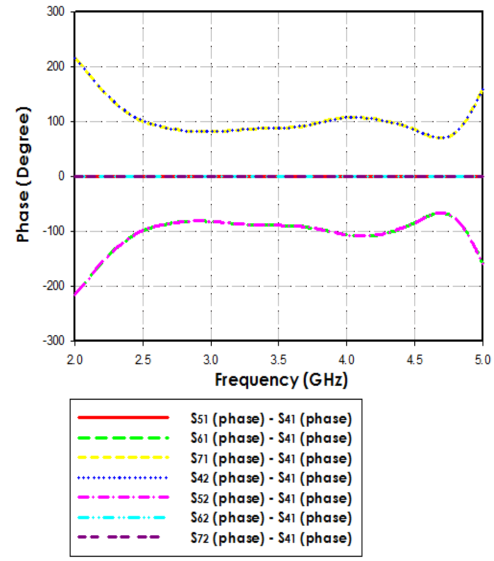


Figure 11 CRMU phase characteristics of transmission coefficients, S_{ij} referenced to phase characteristic of transmission coefficient, S_{41}, where *i* = 4, 5, 6 and 7 and *j* = 1 and 2

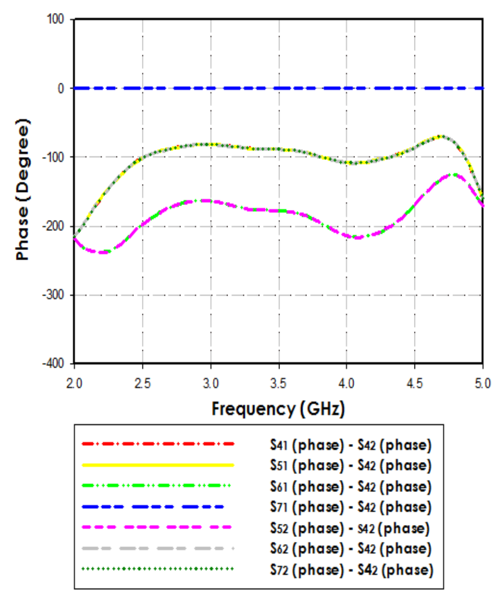


Figure 12 CRMU phase characteristics of transmission coefficient S_{ij} referenced to phase characteristic of transmission coefficient, S_{42}, where *i* = 4, 5, 6 and 7 and *j* = 1 and 2.

Similarly in Figure 12, the phases of transmission coefficients are plotted against the S_{42} phase. As seen in the plotted graph, the phases of transmission coefficients of $S_{\Delta 41}$, $S_{\Delta 51}$, $S_{\Delta 62}$ and $S_{\Delta 72}$ are at -90° ± -15° across the frequency range of 2.5 to 4 GHz. Whilst, the phases of transmission coefficient $S_{\Delta 61}$ and $S_{\Delta 52}$

are at -180° ± 20° within the similar frequency range. Meanwhile, the phase of transmission coefficient of $S_{\Delta 71}$ is approximately at 0°.

3.2 Result of CRMU design formed by Reduced-Size and Enhanced Two-Section Branch-Line Microstrip-Slot Couplers with Overlapped λ/4 Open Circuited Lines at Ports

Figure 13 illustrates the simulated performance of reflection coefficients at Port 1 and 2 that demonstrate good performance within frequency range of 2 to 5 GHz. As in Figure 13, it can be depicted that S_{11} and S_{22} are less than -10 dB across the designated range. Furthermore, the performance of transmission coefficients, *Sij* where *i* = 4, 5, 6 and 7 and *j* = 1 is presented in Figure 14. The transmission coefficients of S_{41} and S_{51} show the deviation of ± 1.8 dB from 8 dB. Meanwhile, the plotted responses displays that the respective performances of S_{61} and S_{71} are -8 dB ± 3 dB and -8 dB ± 4 dB within the similar frequency range.

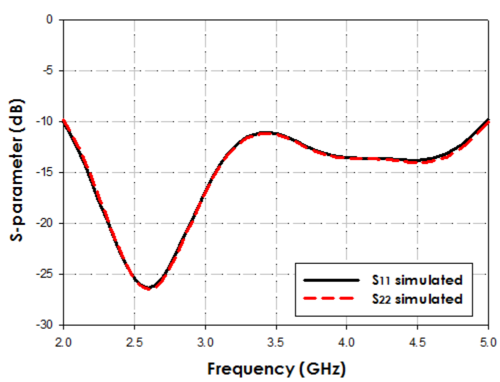


Figure 13 The reflection coefficients at Port 1 and 2 of CRMU formed by reduced size 3-dB BLC

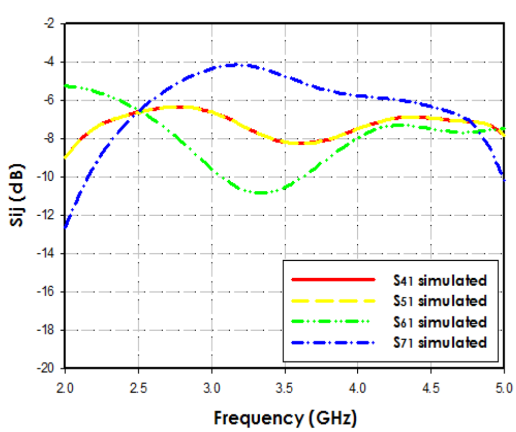


Figure 14 The simulated transmission coefficients of CRMU formed by reduced size 3-dB BLC referenced to Port 1

Next, Figure 15 shows the plotted performance of simulated transmission coefficients, *Sij* where *i* = 4, 5, 6 and 7 and *j* = 2. Based on the obtained results in Figure 15, it shows that the performances of S_{42} and S_{52} are at -8 dB ± 1.8 dB within frequency range of 2 to 5 GHz. Meanwhile, the performances of S_{62} and S_{72} are -8 dB ± 3 dB and -8 dB ± 4 dB, accordingly.

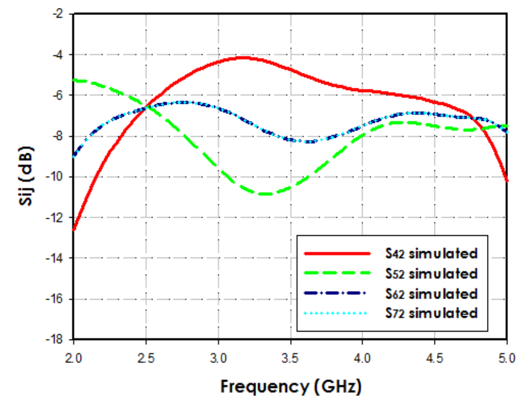


Figure 15 The simulated transmission coefficients of CRMU formed by reduced size 3-dB BLC referenced to Port 2

By referring to Figure 16, the phases of transmission coefficients referenced to the S_{41} phase are shown. The phases of transmission coefficients of $S_{\Delta 71}$ and $S_{\Delta 42}$ are at 90° ± 2° within the frequency range of 2 to 5 GHz. While, the phases of transmission coefficient $S_{\Delta 51}$, $S_{\Delta 62}$ and $S_{\Delta 72}$ are approximately at 0° within similar frequency range. Whilst, the phases of transmission coefficient of $S_{\Delta 61}$ and $S_{\Delta 52}$ are -90° ± 10°.

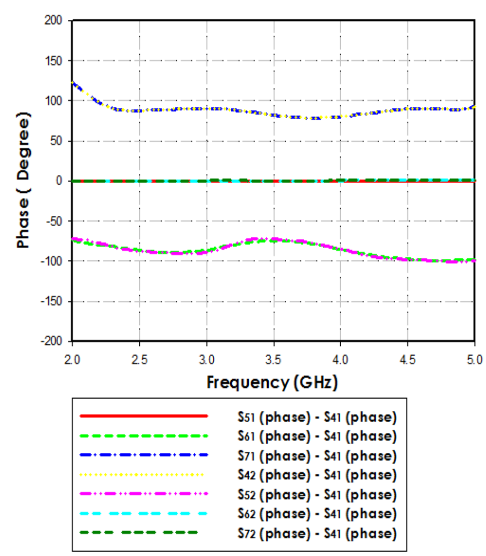


Figure 16 CRMU phase characteristics of transmission coefficients, S_{ij} referenced to phase characteristic of transmission coefficient, S_{42}, where *i* = 4, 5, 6 and 7 and *j* = 1 and 2

Afterward, Figure 17 depicts the phases of transmission coefficients that are plotted against the S_{42} phase. As seen in the plotted graph, the phases of transmission coefficients of $S_{\Delta 41}$, $S_{\Delta 51}$, $S_{\Delta 62}$ and $S_{\Delta 72}$ are at -90° ± -15° across the frequency range of 2 to 5 GHz. Whilst, the phases of transmission coefficient of $S_{\Delta 61}$ and $S_{\Delta 52}$ are at -180° ± 20° within the similar frequency range. Meanwhile, the phase of transmission coefficient of $S_{\Delta 71}$ is approximately at 0°.

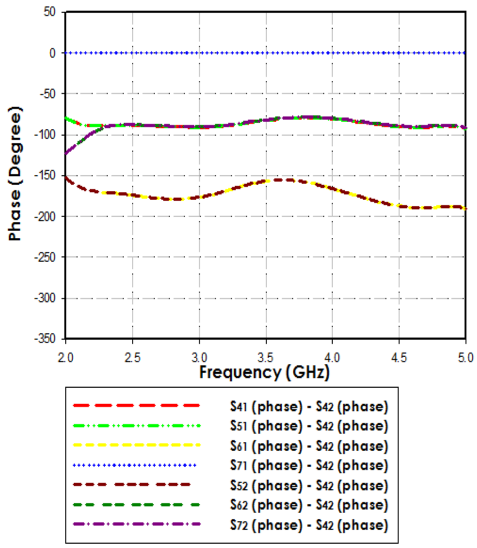


Figure 17 CRMU phase characteristics of transmission coefficients S_{ij} reference to phase characteristic of transmission coefficient, S_{42}, where i = 4, 5, 6 and 7 and j = 1 and 2

4.0 CONCLUSION

Two designs of complex ratio measuring units (CRMUs) formed by the combination of four enhanced 3-dB branch-line couplers with different techniques have been presented using CST Microwave Studio software. The S-parameter performances are analysed by Keysight's Advanced System (ADS) software. The wideband performances of 46.15% and 86% bandwidth have been demonstrated by the first and second proposed CRMU. In addition to the better bandwidth performance, the second CRMU has a smaller size of 133.56 mm x 133.56 mm, which having a size reduction of 55.4% compared to the first CRMU.

Acknowledgement

The authors are grateful to Ministry of Education Malaysia (MOE) and Universiti Teknologi Malaysia (UTM) for the financial aid via Research University Grant with Vote Number of 05H43.

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