Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

DESIGN, SIMULATION AND REALIZATION OF A COMPACT DUAL BAND MEANDERED COUPLER

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Received: 10 November 2018 / Accepted: 26 July 2019 / Published online: 01 September 2019

ABSTRACT

Telecommunication systems increasingly require the use of miniaturized passive microwave components. One of these is the directional coupler, a four-port component intended to distribute power to two output ports, the fourth port being isolated. This paper proposes a dual-band branch-line coupler (BLC) with an extremely compact microstrip structure. The application of meandering lines as the coupler's central connector yields dual-band operation. HFSS is used to optimize the device and to verify its transmission characteristics. This yields a design of a coupler with a footprint is 23×34.6 mm², operating at 1.65 / 3.30 GHz, with ports that can be adapted to a load impedance of 50 Ohm. To validate the model, the coupler is fabricated using microstrip technology on a FR4 substrate. A good agreement between measurement and simulation results is obtained. The coupler achieves an excellent isolation of –42.41 dB and a transmission loss of only –2.29 dB at 3.30 GHz.

Keywords: meandered line; miniature size; dual-band; directional coupler; microstrip.

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doi: http://dx.doi.org/10.4314/jfas.v11i3.16

1. INTRODUCTION

Since the 1980s, miniaturisation has been a driving force in the design of civilian and military microwave devices, particularly in the fields of aeronautics and telecommunications. Device components must therefore have a small footprint and low cost, and at the same time operate at higher frequency bands. Dual- or multiple-band operation is also required as well.

Directional and hybrid couplers are passive components that allow signals to be split or combined. They find application in a wide variety of microwave systems, including radars, satellite links and microwave circuits.

An ideal directional coupler is a passive, lossless, impedance-matched reciprocal component with four ports. The power injected into the input port (In) is distributed between the direct port (Co) and the coupled port (TH); no power is transmitted into the isolated port (Is) (see Fig. 1).

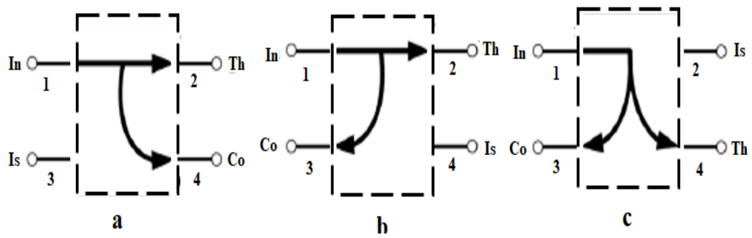


Fig.1. Three types of COD directional couplers with Input, through, isolation and coupled port

A directional coupler that splits the input power equally between the direct and coupled ports, with a phase difference of 90° between the two output signals, is also known as a 3-dB quadrature hybrid coupler. An analytical theory of the operation of directional couplers is presented in [1–3].

The aim of this work is to design, fabricate and validate the performance of dual-band coupler wich operates at 1.7 and 3.26 GHz using the meandering transmission line for microwave applications. In this paper, a planar microstrip branch-line coupler is specifically designed to have dual-band operation by modifying the classical branch-line coupler.

Recently, a few designs of dual-band branch-line couplers have been proposed [4,5] and fabricated on different substrates. The specific dimensions of the equivalent structure are discussed in [4], according to the theory of transmission line. The proposed structure may be applied to coupler design with both large and small frequency-band separation [4].

In [6], dual-band operation is obtained by the introduction of composite right/left-handed (LH) transmission lines, whereas in [7] this is achieved by the addition of a pair of cross coupling branches. Stub loading [8–10] and three-branch-line coupler geometry [11] have also been proposed as a means to obtaining dual-band operation. Other designs of compact dual-band couplers are presented in [12,13].

2. THEORY

In a classical quadrature coupler, the input power injected into Port 1 is coupled to Port 4 (the coupled port) whereas while the remainder of this power is delivered to Port 3, so, there is no power that can be delivered to Port 2 (isolation). The BLC coupling factor from port 1 to port 4 is given as *C* dB (where *C* is a positive quantity) as [14], is given by the formula (1). The directivity of a coupler is the measure of the coupler's ability to isolate forward and backward waves, as is the isolation [3]. The coupling, directivity, isolation, the quadrature phase and the operating frequency band are generally used to characterize a ideal coupler.

$$k = 10^{-C/20} \tag{1}$$

k is given by :

$$k = \frac{Z_{O_e} - Z_{O_o}}{Z_{O_e} + Z_{O_o}} \tag{2}$$

Where Z_{0e} and Z_{Oo} denote the characteristic impedance of the even-mode and odd mode of symmetrical coupled lines respectively, which verify this condition [14] :

$$Z_{O_o} Z_{O_e} = Z_O{}^2 \tag{3}$$

We can write Z_{0e} /Z_{0o} in terms of a voltage coupling coefficient *k* as [14]:

$$\frac{Z_{O_e}}{Z_{O_o}} = \frac{1+k}{1-k} \tag{4}$$

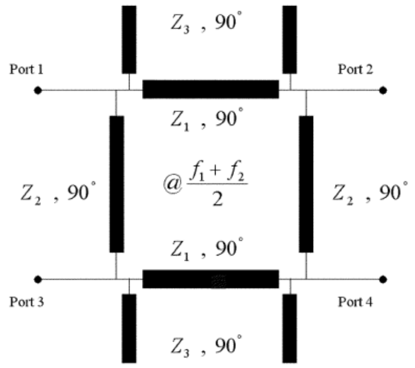


Fig.2. A novel dual-band proposed quadrature coupler with open-circuit stubs [4].

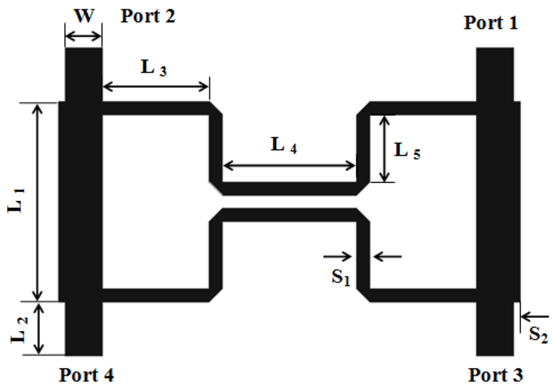


Fig.3. Geometry and dimension of the proposed coupler.

According to transmission line theory, the equivalent structure of quarter-wavelength branch line show in Fig. 3, is discussed in [4].

The conventional dual-band branch-line hybrid coupler is a component accomplishing the same function at two different arbitrary frequencies f1 and f2, consisting of two through and two shunt arms, this basic structure was proposed by Cheng and Wong [4] is shown in Fig. 2.

To design a dual-band components is to replace the shunt branch-lines with a section that exhibits the desirable characteristic an at two arbitrary operation frequency bands.

The branch-line coupler is operates at 1.65 GHz and 3.30 GHz was designed according to the formulas [4].

$$f_0 = \frac{f_1 + f_2}{2} \quad (5)$$

$$\delta = \frac{f_2 - f_1}{f_2 + f_1} \quad (6)$$

$$Z_1 = \frac{Z_O}{\sqrt{2}} \times \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} \quad (7)$$

$$Z_2 = Z_O \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} \quad (8)$$

$$Z_3 = \frac{Z_O}{1+\sqrt{2}} \times \frac{1}{\sin\left(\frac{\delta\pi}{2}\right)\cos\left(\frac{\delta\pi}{2}\right)} \quad (9)$$

The substrate used in this study is the FR4 with relative dielectric constant of 4.7 and height of 1.6 mm is used. In that case, the physical parameters of the branch-line coupler which can be calculated by using the formulas (5) to (10) given in [15] are listed in Table 1.

$$\lambda_g = \frac{3.10^8}{f\left(GHz\right)\sqrt{\varepsilon_r}}\left(m\right) \quad (10)$$

The physical length of the BLC is optimized as L=27 mm, using formula (10), the **width** of the **access** lines is **W** = 2.8 mm.

Table 1. Calculated impedance values of the branch-line coupler using the formula (7), (8) and (9)

Impedance Z (Ω)	$Z_0 = 50.60$	$Z_1 = 41.81$	$Z_2 = 69.45$	$Z_3 = 31.40$

At 2.3 GHz, the lengths of two transmission lines, through and shunt lines are connected alternately by λ/4, as shown in Fig. 3.

3. PROPOSED MEANDERED BRANCH LINE COUPLER

To reduce the size of the BLC and optimize its performance in dual-band, we proposed a structure whose shunt arm was transferred to the array of coupled parallel equivalent to conductors called a meander line.

The objective of this study is to design a compact coupler with reduced dimensions. To achieve this objective, we are introduced Meandered lines to replace the shunt arm for generating multiband response. The symbolic design of a proposed branch-line coupler is illustrated in Fig. 3.

The proposed coupler is simulated by Ansoft HFFS. The substrate has been chosen to be FR4 with the relative permittivity of 4.7, loss tangent of 0.0197, and the thickness is set as 1.6 mm. The central dual-band frequencies are designed to be 1.65 GHz and 3.30 GHz.

The dimension of proposed branch-line coupler are listed below in Table 2.The total of lengths of the horizontal and vertical branches are 23 mm and 34.6 mm, respectively, there are about 0.4 λ_g and 0.3 λ_g, respectively at 1.60 GHz in the lower frequency band.

Table 2. Dimensions of the Meander Branch Line Coupler

L_1 (mm)	**L_2 (mm)**	**L_3 (mm)**	**L_4 (mm)**	**L_5 (mm)**	**S_1 (mm)**	**S_2 (mm)**	**W (mm)**	**Z (Ω)**
15	4	8	10	5	1	0.5	2.8	50.60

4. RESULTS AND DISCUSSION

The results of the simulation parameters of the proposed branch-line coupler are illustrated in Fig. 5. The resulting characteristic impedance is equal to 50.60 **Ω** for its ports (see the Table 1).

The lenght of the middle segment in the meander line were chosen to be L1= 15 mm, L_2= 4 mm, and L3 = 8 mm, As shown in the Table 1 . If the lenght of L1 increased, the transmission and the coupling phenomenons will disappear. If L1 decreased, both low-band and high-band resonant frequencies will be shifted to the lower value towards f1. In addition, the variation of L2 provokes the displacement of the central frequency of thupper band towards the lower band. If the lenght of L3 increased, the reflection will be optimized and the isolation will be degraded. While the decrease of the parameter L3 leads to a degradation of S41. The variation of the distance between two meanders lines degrades the S parameters, while the variation of the gape S_1 or S_2 has a slight effect on the parameters.

Therefore, the length of L1, L2, L3, S_1 and S_2 was tuned for the optimum component performance. The variation of the width of the access line has an impact on the impedance line's widths and component performance.

All the valves of the different parameters are well chosen in this design to achieve good performance for each of S11, S21, S31, and S41 parameters, at dual-band frequencies (f1 = 1.65 GHz and f2 = 3.30 GHz). The optimization of the dimmensions led to a considerable reduction in size of component.

5. EXPERIMENTAL RESULTS

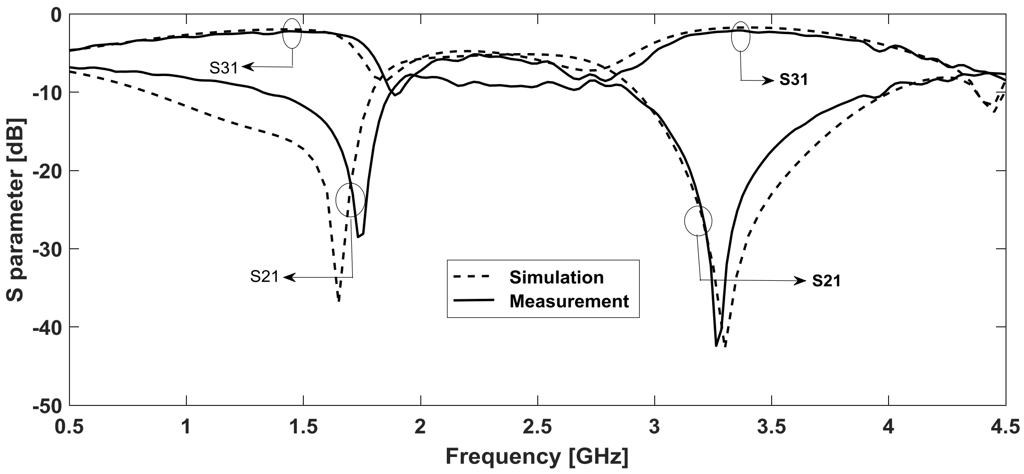
To validate the design approach, The couplers was fabricated on a FR4 (ε_r=4.7, h = 1.6mm) substrate and it was measured, respectively. The size of fabricated coupler is 23×34.6 mm^2.

(a)

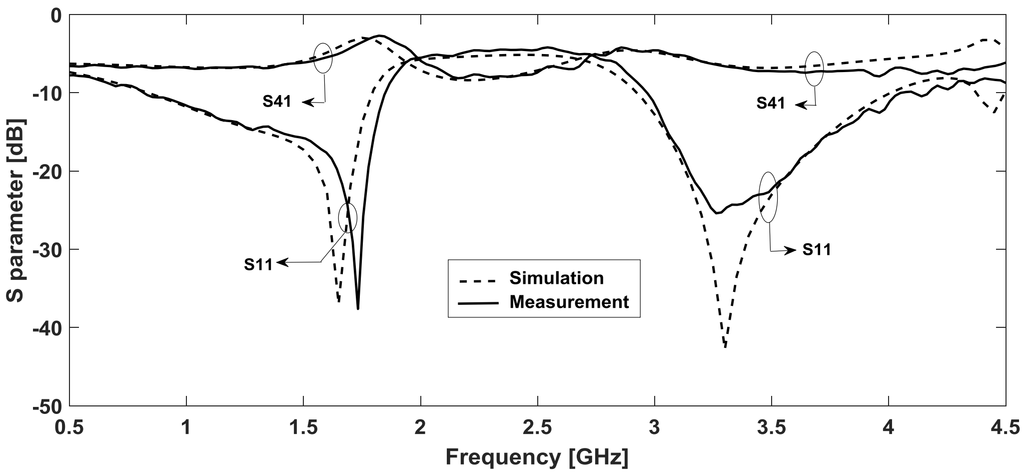
(b)

Fig.4. (a) Photograph of the fabricated proposed coupler, (b) left : Measurement setup: a network analyzer E5071C being used for *S*-parameter measurement, right : component under test

The simulation and measured response of the microstrip branch- line couplers are demonstrated in Fig. 5.



(a)



(b)

Fig.5. Simulated and measured results: (a) Insertion loss S31 and isolation loss S21, (b) return loss S11 and Insertion loss S41

The measurement results shows that the branch line coupler can operate at two frequencies, f_1 = 1.7 GHz and f_2 = 3.26 GHz which are selected as the operating frequencies, in incorporating dual-band operation.

The comparison of The performances of the proposed dual band coupler in both pass-bands are summarized in Tables 3 and 4.

Table 3. Performance of Branch line dual band Coupler at first operating frequency

	Frequency GHz	S21 dB	S31 dB	S41 dB	S11 dB	Phase Difference	$\|S_{41}\| - \|S_{31}\| \leq \pm 1dB$
Simulation	1.65	24.45	2.36	3.90	36.98	87.51°	1.54
Measurement	1.7	28.51	3.75	3.75	37.61	89.15°	0.00

Table 4. Performance of Branch line dual band Coupler at second operating frequency

	Frequency GHz	S21 dB	S31 dB	S41 dB	S11 dB	Phase Difference	$\|S_{41}\| - \|S_{31}\| \leq \pm 1dB$
Simulation	3.30	33.04	1.74	6.45	42.74	-91.30°	4.71
Measurement	3.26	42.41	2.29	6.40	25.39	-91.86°	4.11

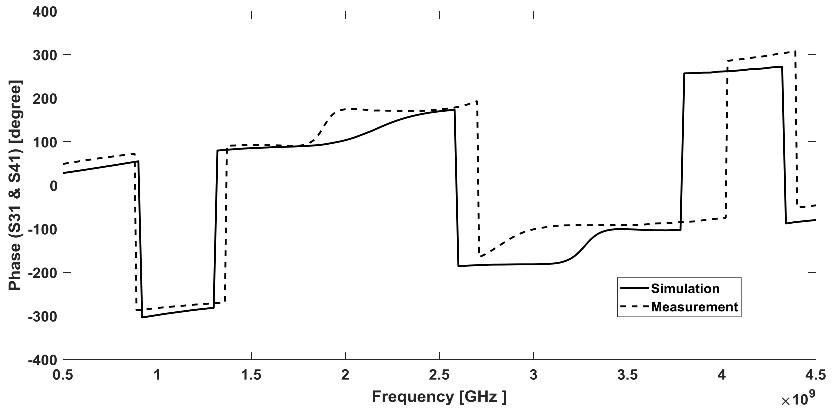


Fig.6. Phase difference phase S31–phase S41 of the dual proposed coupler

The phase difference response result of proposed branch line coupler is shown in Fig. 6.

As observed from the measured results, the directivity transmission characteristics represented by S_{31}= -2.29 dB, is observed at 3.26 GHz. The signal propagates from port 1 to port 4 with insertion losses is -6.40 dB, in the lower band, that proves that the insertion loss has been improved. Measured phase difference between Port 3 and Port 4 is 89.15° at and -91.86° at 3.26 GHz operating bandwidth. The frequency shifting may be caused by weld of SMA connectors.

Above all, the proposed Branch-line dual band Coupler has a considerable size reduction and easily fabricated configuration. The Comparison between simulation and measurement results shows a good agreement, and that verifies the proposed device.

This work shows that we can improve the transmission characteristic that can reach -1.74 dB, and that prouve that the dual band proposed presents advantageous characteristics compared to ordinary couplers that operate in a single frequency band. For miniaturization, the design and manufacture of the device operating in at 1.65 GHz and 3.30 GHz has been completed for WLAN applications.

To the best of our knowledge, very little research has studied the dual band couplers, we cite some papers done in 2013 and 2015, referenced in [16, 17, 18] and [19].However, there is a A recent study [20] is done in 2017, which allowed us to compare our work with this presented in [20]. The following table provides the results of the comparison:

Table 5. Comparaison between our results and those published in [20]

Reference	**[20]** **TRD**	**This work** **COD**
Operating frequencies (GHz)	1.2/ 2.52	1.65/3.30
Isolation (dB)	> 20 dB	-28.51/-42.41
insertion loss (dB)	-4.2/ -4.5	-3.75/-2.29
Coupling loss (dB)	-2.7/ -2.8	-3.75/-6.40
Phase diference	91.7°/ -92.8°	89.15°/-91.86°
Perfect tramsission carachteristic	medium	better
Perfect impedance matching	No	Yes

Reading these results, it appears that the performance of our circulator was highly elevated.

6. CONCLUSION

We have proposed a BLC coupler using dual transmission lines. Its distinguishing feature is the replacement of the shunt arms known from the classical coupler by a meandering dual transmission-line section. The component has been designed for operation at 1.6 ^{GHz} and 3.30 GHz; its frequency response was optimized by numerical simulation. A size reduction of 53.91% and an appropriate coupling has been achieved. To validate the design, the device has been fabricated on an FR4 substrate. The measurement results are in good agreement with simulation. Notably, the measured characteristic dual-band transmission is even higher than that predicted numerically, especially in the higher frequency band. The good experimental performance of the proposed device, its low cost and simplicity of fabrication demonstrate its suitability as an efficient coupler for dual-band systems.

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How to cite this article:
El Bouslemti R, Salah-Belkhodja F. Design, simulation and realization of a compact dual band meandered coupler. J. Fundam. Appl. Sci., 2019, *11(3), 1279-1291*.