International Journal of Electrical and Computer Engineering (IJECE)
Vol. 7, No. 2, April 2017, pp. 888~893
ISSN: 2088-8708, DOI: 10.11591/ijece.v7i2.pp888-893

Wideband Branch Line Coupler with Open Circuit Coupled Lines

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Article Info

Article history:

Received Dec 13, 2016
Revised Mar 15, 2017
Accepted Mar 30, 2017

Keyword:

Branch line coupler
Coupled lines
Fractional bandwidth
Microstrip
Wideband

ABSTRACT

This paper focuses on the design of a Wideband Branch Line Coupler by using open circuits coupled lines technique. The design is implemented by adding four open circuits coupled lines to the structure of the Conventional Branch Line Coupler. The proposed design of Wideband Branch Line Coupler is simulated using CST microwave software. The simulation results show that the coupler is operated at 3.8 GHz with coupling factor of -3dB and 90̊ phase difference between the two output ports. The prototype is fabricated and measured to validate the simulated results. A similar Wide Bandwidth is observed on simulation and measurement. The structure achieved a fractional bandwidth of 42.63%, and return loss of 21 dB compared to the Conventional Branch Line Coupler (BLC).

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1. INTRODUCTION

A Hybrid 3 dB Branch Line Couplers delivering an equal power division and quadrature phase difference are one of the fundamental circuit components for array antenna, power amplifiers, filters, and modulators. However, a narrow bandwidth noticed as a major limitation in the conventional branch line coupler design, where the design method based on transmission line lengths result in a narrow band characteristic of the coupler. A wideband branch line coupler has been recently adopted in microwave devices and applications such as 4G cellular system, Wi-Max systems, and antenna beamforming systems, as an advantages of wider bandwidth provides a more capacity and more date rates, while one of the major limitation beside the Wider bandwidth is the size of the Wideband BLC coupler to be implemented in the RF system devices at low frequency. To overcome this limit a simple technique flowing more sections had been suggested [1]. Additionally, in the last 60 years the researcher were focusing on significant principle based on matching condition between each port [2]. Where various researches [3-9], increased the bandwidth by using this important principle of matching condition. To achieve a good matching condition for wider bandwidth and uniform power distribution characteristics, the equivalent impedance and the flat coupling characteristics of conventional line coupler have been investigated [2], [3]. After these analyses, various single section broadband branch line couplers have been developed by using various matching techniques, such as using a double quarter-wave transformer [4] in 1987, a serial branch and open circuited stub of [5] in 1990, open and short circuited stubs [6] in 2006, tuning stubs [7] in 2008, series open-circuited stubs [8] in 2010, and coupled lines in this work. Another new method such as bond wire was presented [9]. The open circuited coupled lines implemented in this work provide a wideband matching condition [10], inherent DC blocking for various networks of active devices, for various antenna arrays, and for various filters.

2. DESIGN OF WIDEBAND BRANCH LINE COUPLER

A new technique to have a Wider Bandwidth of BLC is proposed by using Coupled Lines Circuits. The lines are designed at quarter wavelength of the center frequency to have equivalent impedances and flat coupling characteristics of a BLC. Wideband properties can be achieved by connection quarter wavelength coupled line to each port of the Branch Line Coupler circuit. The λ/4 open circuits coupled lines in this project provide a wideband matching condition [11] with a DC block capability and band pass filter function. By decreasing the inductance of the coupled lines a wider bandwidth can be achieved and the structure is more compact, thus reducing the mass production cost.

Referring to the equation (1) and (2), the operating frequency, f can be increased by decreasing the inductance, L while the capacitance, C is remains fixed. In other words, tuning the inductance will change the impedance of the line and thus give effects on the matching conditions. In overall least a fractional bandwidth of 30% can be achieved [12].

$$f = \frac{1}{\sqrt{LC}} \tag{1}$$

$$Fractional\ BW = \frac{BW}{f} \times 100\% \tag{2}$$

The structure of the proposed Wideband Branch Line Coupler design is illustrated in Figure 1. To have wideband matching condition characteristics for BLC a λ/4 open circuit coupled line is placed at each port of the Branch Line Coupler circuit.

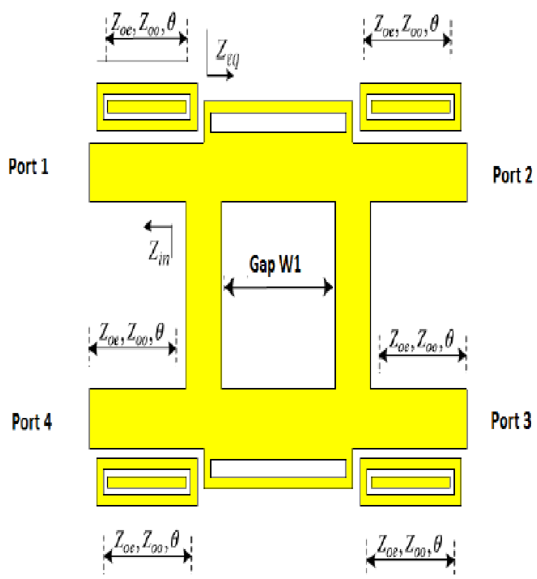

Figure 1. Configuration for the proposed Wideband BLC

And for each coupled line the cutting in the structure made to be 0.5 mm to have a proper matching condition for the wideband BLC. The Following characteristics impedances are normalized corresponding to generator impedance which is 50Ω, the admittance and the electrical length are $y01 = \sqrt{2}$, $y02=1$, $\theta0=\pi/2$ respectively. The input impedance at each port were assumed to be matched then the equivalent impedance Zeq at the input port can be obtained by using the following equation [11], where the θ is the electrical length of the circuit.

$$Zeq = \frac{1}{1/\sin\theta - j(1+\sqrt{2})\cot\theta} \tag{3}$$

To evaluate the matching property of the coupled line, an open circuited coupled line in Figure 2 is only analyzed. Based on the coupled line structure with the open circuited matching condition, a matrix impedance for the coupled line is used.

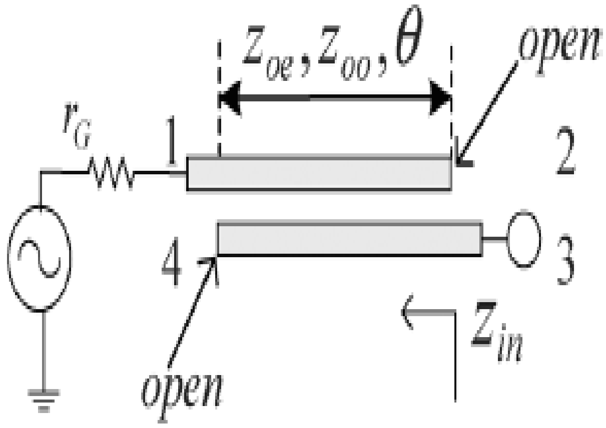

Figure 2. Coupled line structure of the input impedance [10]

$$\begin{bmatrix} V1 \\ V3 \end{bmatrix} = \begin{bmatrix} \frac{j}{2}(zoe + zoo)\cot\theta & \frac{j}{2}(zoe - zoo)\csc\theta \\ \frac{j}{2}(zoe - zoo)\csc\theta & \frac{j}{2}(zoe + zoo)\cot\theta \end{bmatrix} \begin{bmatrix} I1 \\ I3 \end{bmatrix} \tag{4}$$

The coupled line input impedance can be found using symmetry [11]:

$$Zin = \frac{Z33 + Z33Z11 - Z13Z31}{1 + Z11} \tag{5}$$

And the important following condition must be achieved:

$$\overset{*}{Z}in = Zeq \tag{6}$$

When using electrical length θ = π/2 , Zin = Zeq = 1. And equation 4 used the equation 5 becomes:

$$(Zoe - Zoo) = 2 \tag{7}$$

Based on (3), (5), (6), (7) and by simplifying, the real and imaginary parts of (8) and (9) the equation can be written as [11]:

$$\frac{4}{Z^2 + cos^2\theta + 4sin^2\theta} = \frac{sin\,\theta}{(2\sqrt{2}+3)cos^2\theta + 1} \tag{8}$$

$$\frac{z + (z^2 - 4)cos^3\theta}{2(z^2 + cos^2\theta + 4sin^2\theta)\sin\theta} = \frac{\sin\theta\cos\theta(\sqrt{2}+1)}{(2\sqrt{2}+3)cos^2\theta + 1)} \tag{9}$$

where [12]:

$$Z = Zoe + Zoo \quad \text{and } \theta\pm = \frac{\pi}{2}\frac{f\pm}{fc} \tag{10}$$

Where *f-* is the lower frequency which provide matching condition and *f+* is the upper frequency that also provide matching condition for wider band. Another matching condition parameter is at the centre frequency *f0* is found from the hybrid branch line coupler section. By resolving (8) and (9) for Z and θ and maintain the conditions (8) and (5) in solving, the normalized values of the even and odd mode impedances $zoe = 3.783$ and $zoo = 1.783$, can be found for the coupled lines. And the two frequencies *f+* = 0.770*f* and *f-* = 1.222*f*. Wideband matching and coupling can be achieved Thus, the wideband matching can be achieved when S21=S31. The dimensions of the coupler are calculated by using equations in [12]. The values are summarized in Table 1. The input impedance is set to be 50 Ω with the centre frequency of 3.8 GHz, *f-*=3.5 GHz, while *f+*= 5.2 GHz. Figure 3 and Figure 4 show the dimensions of the structure and fabricated model respectively. The structure is fabricated by means of photolithography process on a standard FR4 board with relative permittivity of 4.6.

Table 1. Specifications Design of the wideband Branch Line Coupler

Coupler	Impedance(Ω)	Width(mm)	Length(mm)
Z1	35.49	2.65	7.45
Z2	50.28	2.65	8.45
Zoo	89.19	2.65	7.62
Zeo	198.49	2.65	7.62
	FR4 Board (t=0.035mm)		
εr	4.6	High	1.6 mm

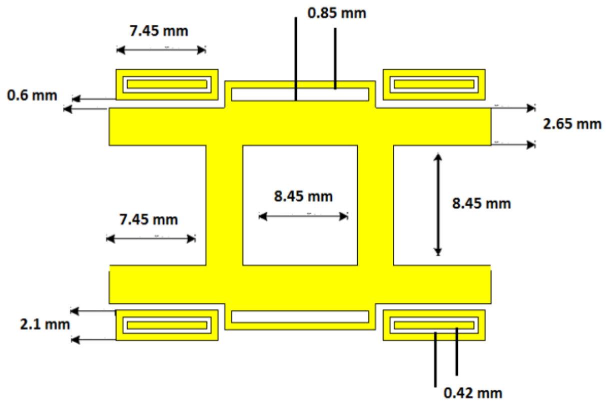

Figure 3. The dimensions of the wideband BLC

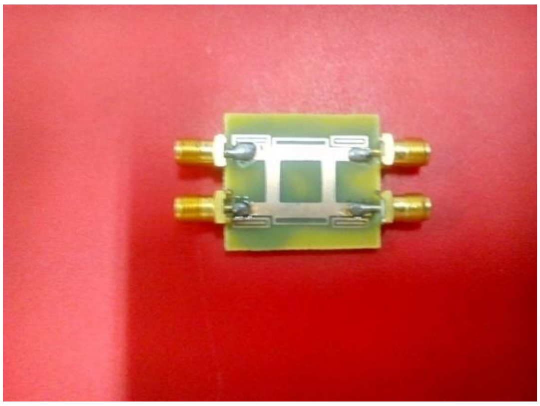

Figure 4. Wideband BLC four ports Prototype

3. RESULTS AND ANALYSIS

Computer Simulation Technology (CST) is used to simulate the structure. The software used finite-difference time domain (FDTD) for 3D EM field analysis. Simulation results show that the coupler is operating at the desired frequency with -3 dB coupling and 89 degrees phase difference. The fabricated coupler is measured using network analyzer. The responses of Conventional BLC are shown in Figure 5 in comparison to the proposed Wideband BLC responses in Figure 6 for the simulated and measured results, the phase difference between port 2 and 3 is 89 degrees as shown in Figure 7. Three matching points at low, high, and center frequency and are shown for wideband characteristics in Figure 8. The measurement results show that insertion loss is 3.62 dB. Return loss and isolation characteristics were achieved both better than 20 dB above 43% fractional bandwidth of 1.66 GHz. The comparison between Proposed Wideband BLC and Conventional BLC is summarized in Table 2. Further the comparisons between this work and previous couplers published are summarized in Table 3.

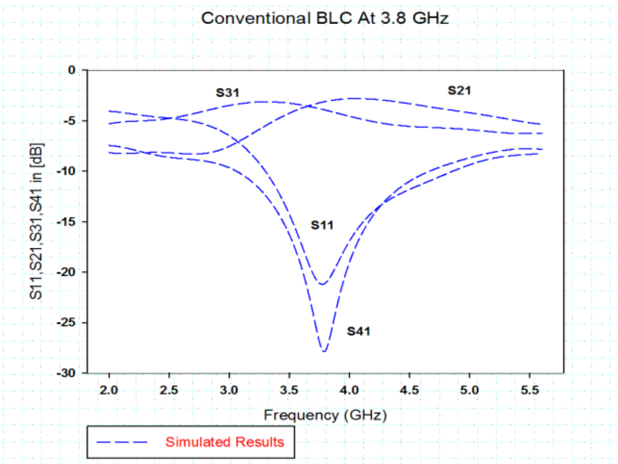

Figure 5. Simulation results of Conventional BLC

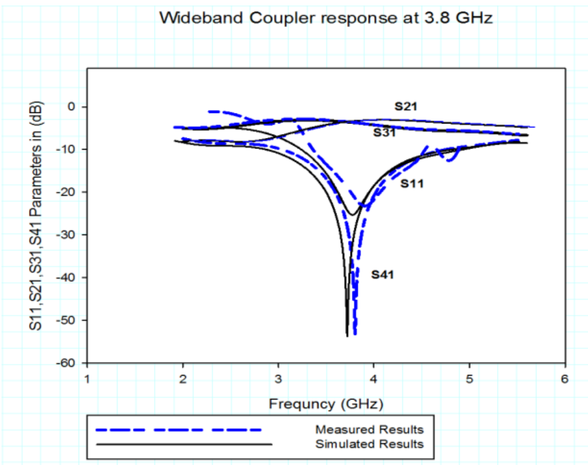

Figure 6. Simulation and Measurement results of Wideband BLC

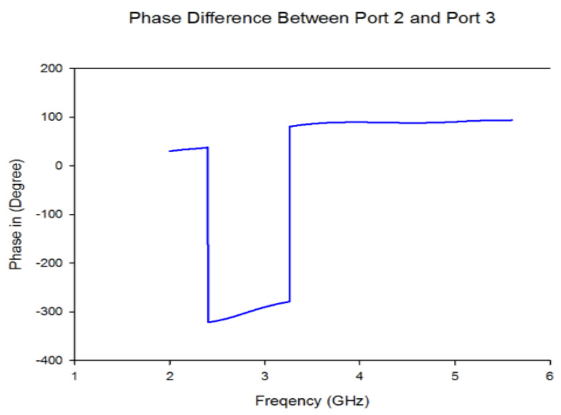

Figure 7. Phase Difference between port 2,3 of Wideband BLC

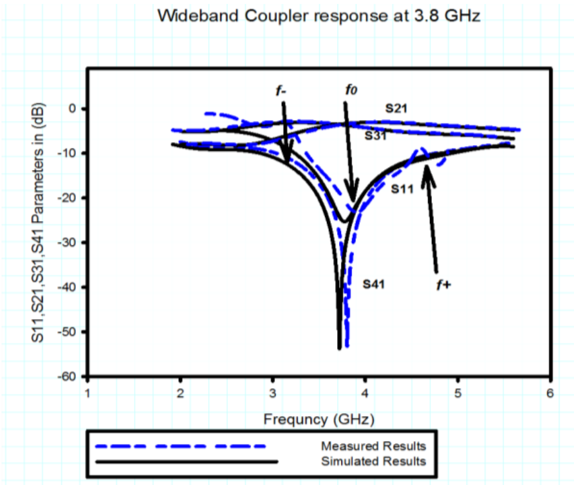

Figure 8. Three matching points at low, high, and center frequency of Wideband characteristics

Table 2. The comparison between proposed Wideband BLC and Conventional BLC

Design	Freq.(GHz)	S11(dB)	S21 dB)	S31 dB)	S41 dB)	BW	FBW%
Conventional BLC	3.8	25	3.3	3.8	51	800 MHz	21.1
Wideband BLC	3.8	21	3.1	3.7	31	1.62 GHz	43.0

Table 3. Comparison of this work with the previous Couplers published

Parameters	Ref [9]	Ref [11]	Ref [12]	Ref [13]	This Work
Year	2011	2011	2011	2012	2014
S11	20	19	20	16.3	21
S21	-3	-3.6	-3	-3	-3
Phase Difference	89	88	89	89	89.8
Fractional Bandwidth %	43	49	49	50	43
Freq. Range	2.3-3.5	4.54-7.21	2.5-8.5	2-4	3.5-5.2

4. CONCLUSION

A 4-ports Wideband Branch Line Coupler is discussed in this paper. The fabricated Wideband Branch Line Coupler is experimentally tested and the results show a very good agreement with simulated responses. The Wideband BLC has high bandwidth up to 43.02%. The Wideband BLC explained in this paper, has good profile with overall size reduction of 28.2% compared to Conventional BLC. The proposed Wideband Branch Line Coupler is potentially suitable to use in LTE application or WIMAX applications. Future works related to this work will be developed a Multi Wideband Hybrid Line Coupler which can easily be adopted to other LTE bands and other wireless standards. The structure can be integrated to form a Wideband Butler Matrix for Antenna Beamforming.

ACKNOWLEDGEMENTS

The Authors thank the Research Management Centre (RMC), School of Postgraduate (SPS), Communication Engineering Department (COMM) Universiti Teknologi Malaysia (UTM) and all members of Advanced Microwave Lab P18 FKE-UTM for giving motivation, knowledge sharing and support of the research under grant no 10H04.

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Muataz Watheq Sabri was born in Baghdad, Iraq in 1987. He obtained his B.Eng communication and computer from Alzaytoonah University of Jordan, Jordan in 2013 and M.Eng Electronics and Telecommunications from University Technology Malaysia (UTM), Malaysia in 2015. Currently he is a PhD candidate in the field of mm-wave beamforming at department of communication engineering in Faculty of Electrical Engineering (FKE), University Technology Malaysia (UTM), Malaysia. His research interests include wideband couplers design, mm-wave Antenna beamforming, RF propagations at mm-waves, and link budget design for 5G cellular networks.

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