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Compact and Performance Evaluation of Branch-Line Hybrid Coupler Microstrip for Long Term Evolution Applications

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Abstract—This paper presents a study and analysis of a high performance microstrip branch-line 3 dB hybrid coupler (BLHC) operating at 2.2 GHz for Long Term Evolution (LTE) application. High and low impedance meander lines are used to miniaturize the conventional Branch Line Hybrid Coupler. A prototype of the proposed coupler is fabricated and tested using a Rohde and Schwarz ZVB 20 vector network analyzer. The measured results agree well with the simulated ones.

1. INTRODUCTION

The Branch-Line Hybrid Couplers (BLHCs) is the most passive component that finds various applications in modern microwave and millimeter communication systems [1, 2]. This component is used in transmitting and receiving RF and microwave systems to divide or combine power simultaneously. The couplers are mostly used in microwaves circuits, such as balanced amplifiers, mixers, phase shifters, frequency discriminators [3] and for high isolation between ports. Due to their simplicity, we can use branch-line couplers such as antenna feeding networks for automatic level controls. Bandwidth and compactness are two important factors to meet the demand of the high performance systems.

Several approaches have been developed to miniaturize BLHCs structure [4–8], such as shunt lumped capacitors with short high impedance transmission lines, two-step stubs, high and low impedance open stubs, stepped impedance stub lines, artificial transmission line, distributed capacitor inside the area of coupler, planner transformer coupling method, and discontinuous microstrip lines for branch-line hybrid coupler [4, 9–15].

In this paper, a new branch-line hybrid coupler using a meander lines for LTE applications is proposed [5, 16]. The proposed coupler is designed to cover wide band frequency. Compared to a conventional hybrid coupler, the proposed coupler reveals a good performances, and it can be used in phase shift applications. The designed coupler structure is fabricated and tested in the lab, and the practical results are found to be well consistent with the simulated ones.

2. PROPOSED METHODOLOGY OF THE NOVEL MICROSTRIP COUPLER

2.1. Branch-Line Hybrid Coupler

Branch line hybrid is 3 dB directional couplers with a 90° phase shift between the outputs of the through and coupled ports, and port 4 is the isolated port. The scattering matrix of branch-line coupler has the following form (see Fig. 1).

$$[S] = -\frac{1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix} \tag{1}$$

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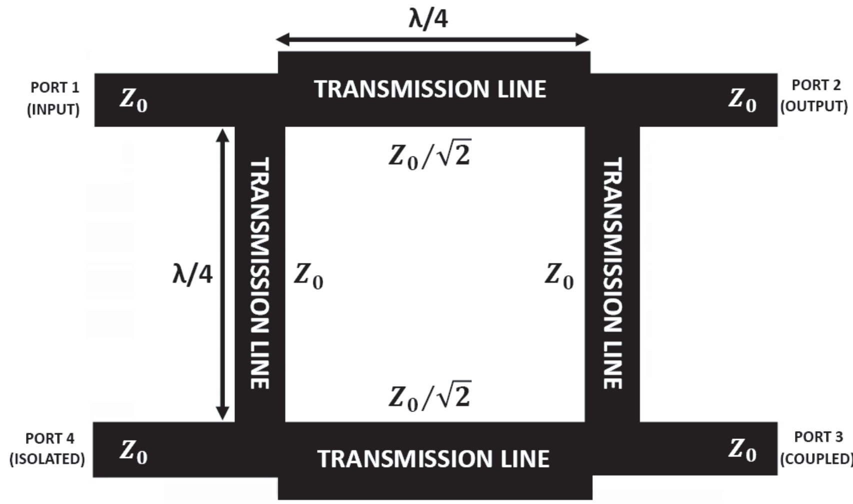


Figure 1. Schematic diagram of a conventional BLHC.

The key of design is substituting the quarter wavelength branch line with an equivalent section that exhibits desirable characteristics at center frequency.

2.2. Meander-Line Section

The layout of a typical meander line is shown in Fig. 2. To extract the equivalent inductance of a meander line, the total inductance is found from the sum of the self inductances of all the segments and the mutual inductances between all combinations of the straight segments.

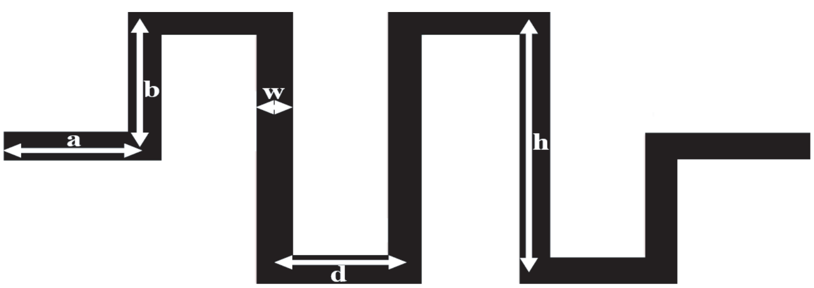


Figure 2. Characteristic geometrical dimensions of the meander inductor.

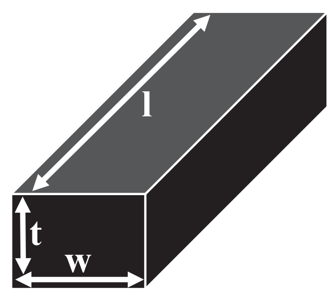


Figure 3. A conducting segment of a meander line.

Expression for self-inductance of the conductive segment, as in Fig. 3, is given by the following equation [17, 18]:

$$L = 0.002 \times l \times \{\ln(2l/GMD) - 1.25 + (AMD/l) + (\mu/4) \times T\} \tag{2}$$

where L is the inductance in (µH); l is the length of conductive segment; GMD and AMD represent the geometrical and arithmetical mean distances of the conductor's cross-section; μ is the permeability conductor; T is the frequency dependent correction factor; width is w; thickness is t of the conducting segment; GMD is $0.2232 \times (w + t)$; approximation of AMD is $(w + t)/3$. Then the expression for self-inductance is:

$$L = 0.002 \times l \times \{\ln[2l/(0.2232(w + t))] - 1.25 + [(w + t)/3l] + (\mu/4) \times T\} \tag{3}$$

Expression (3) will be used as an analytical expression for calculation of self-inductance of individual straight segments, and by that also for calculation of total inductance of the meander inductor. As an example, let us consider the meander inductor geometry shown in Fig. 2. The total self-inductance $L_{Selftotal}$ is calculated as a sum of self-inductances of all individual line segments, which form the meander inductor,

$$L_{Selftotal} = 2 \times L_a + 2 \times L_b + N \times L_h + (N+1) \times L_d \tag{4}$$

This is a generalized equation where $L_{a,b,h,d}$ are self-inductances of segments where the lengths are $l = a, b, h, d$, respectively and are calculated by means of the expression for self-inductance in Eq. (3). In Equation (4), N is the number of turns, a the length of a lead (mm), h the height of the meander (mm), d the width of the meander (mm), b the half of the height h (mm), and w the width of the printed strip (mm).

The design procedures of the proposed branch-line hybrid coupler can be summarized as follows.

The various values of the length and width of transmission line are obtained from Fig. 4. The coupler parameters are summarized in Table 1.

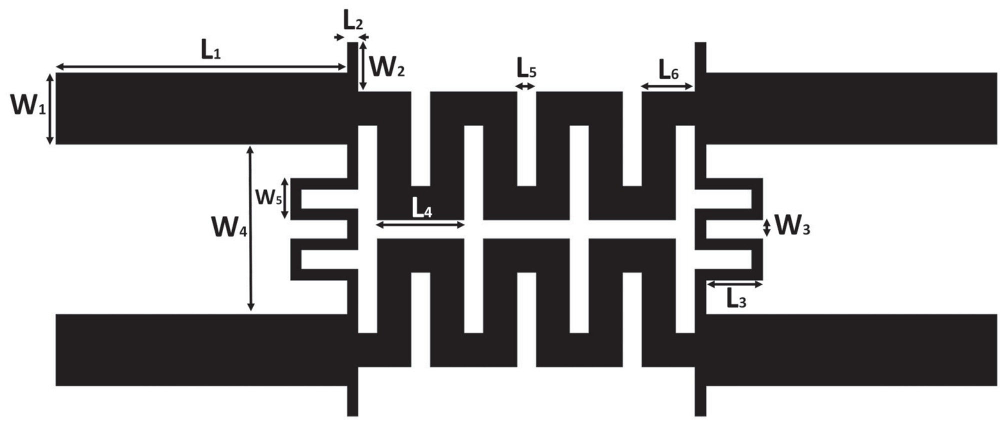


Figure 4. Dimensions of proposed BLHC.

Table 1. Length and width of the transmission line.

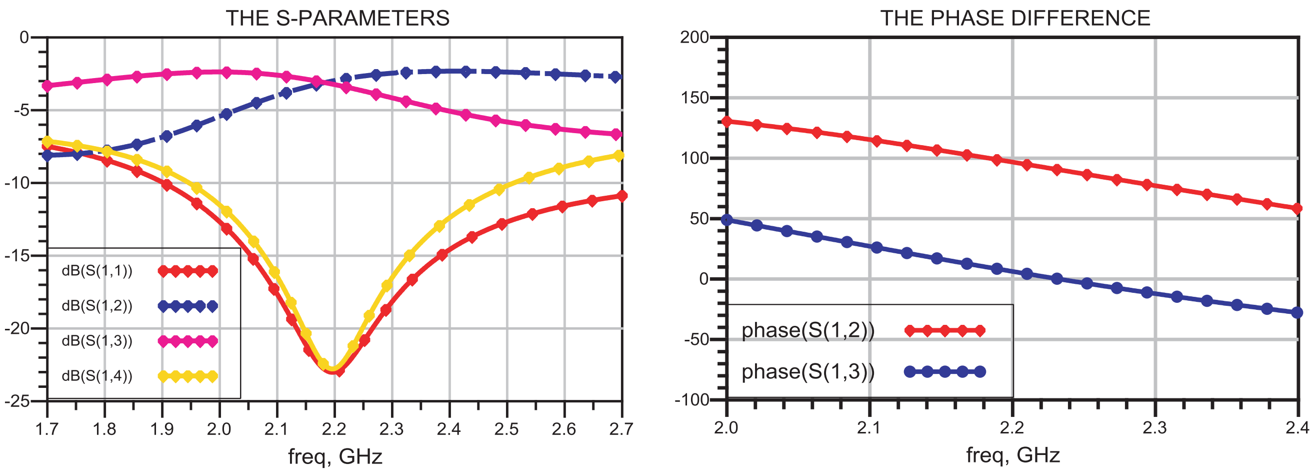
Parameter	Value (mm)	Parameter	Value (mm)
$L1$	17.58	$W1$	2.99
$L2$	0.27	$W2$	1.81
$L3$	2.39	$W3$	1
$L4$	4	$W4$	8.30
$L5$	1	$W5$	2.08
$L6$	2.5		2.08

3. SIMULATION RESULTS OF THE PROPOSED COUPLER

3.1. Scattering Parameters

In order to evaluate the performance of the proposed branched-line hybrid coupler, a simulation study is carried out using ADS software (see Fig. 5).

As shown in Fig. 5(a), -3 dB insertion loss is achieved for output ports (2 and 3) at resonance frequency. The isolation (S_{41}) and return loss (S_{11}) coefficients are better than -10 dB over 60% of bandwidth. In terms of phase, the phase shift between the output signals of the through (S_{21}) and coupled (S_{31}) ports of the coupler is around 90° as can be seen in Fig. 5(b).



(a) (b)

Figure 5. (a) The S-parameters. (b) The phase difference between output ports (2 and 3) of proposed branch-line hybrid coupler.

3.2. Current Distribution

Figure 6 shows the surface current distribution of the proposed branch-line hybrid coupler at frequency 2.2 GHz. It can be seen that a large surface current is observed at ports 2 and 3, and port 4 is isolated.

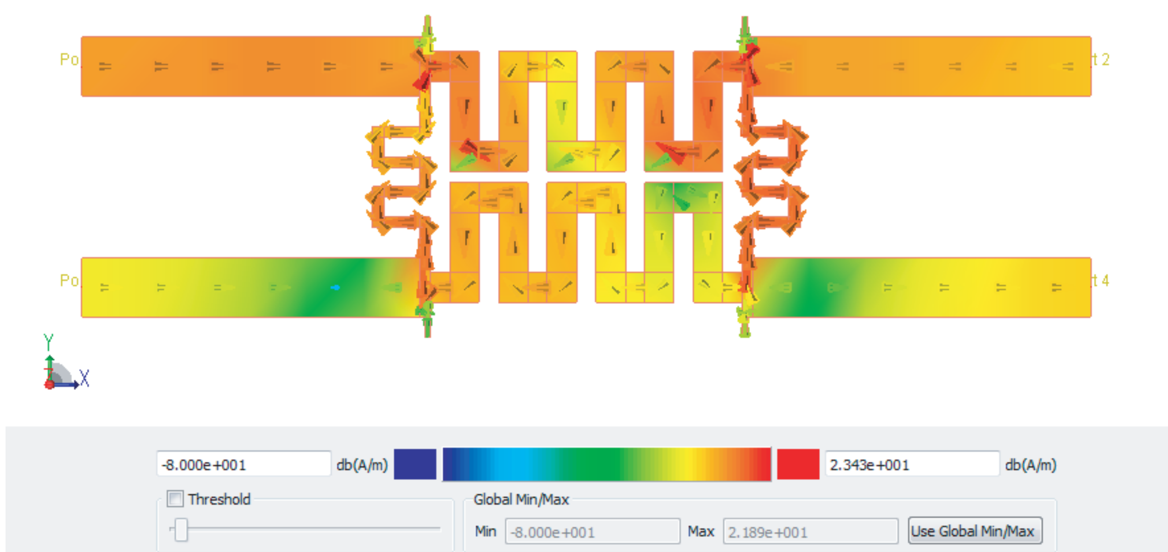


Figure 6. The current distribution of proposed BLHC at 2.2 GHz.

4. ACHIEVEMENT AND MEASUREMENT OF COUPLER

The designed coupler structure is fabricated and tested in the lab, and the practical results are found to be well consistent with the simulated ones. Fig. 7 shows a photograph of the fabricated coupler. The prototype is fabricated on an FR4 substrate with a relative dielectric constant of 4.3 and thickness h of 1.58 mm. Its S-parameters are measured by using Rohde and Schwarz ZVB 20 vector network analyzer (see Fig. 8). Figs. 9 and 10 show the comparison between measurement and simulation results of the

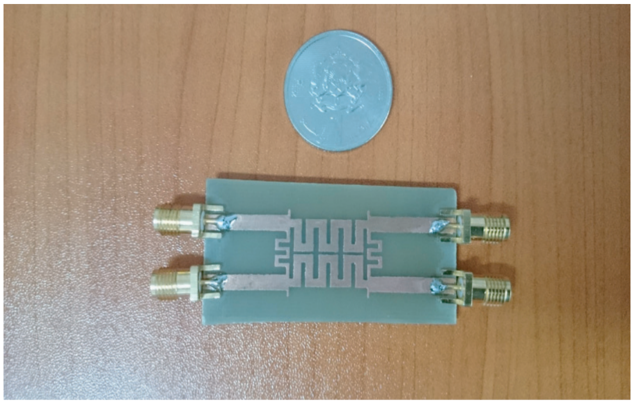


Figure 7. The fabricated proposed of branch-line hybrid coupler.

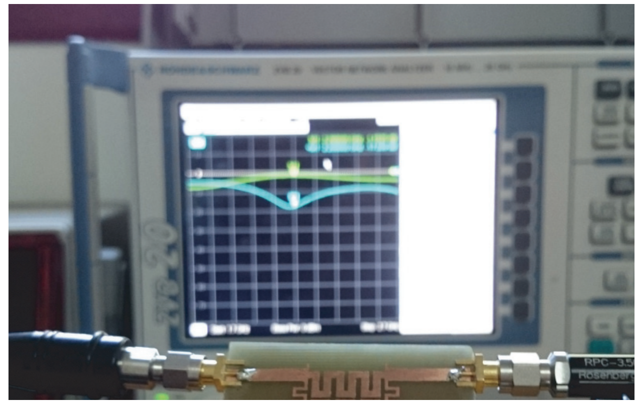
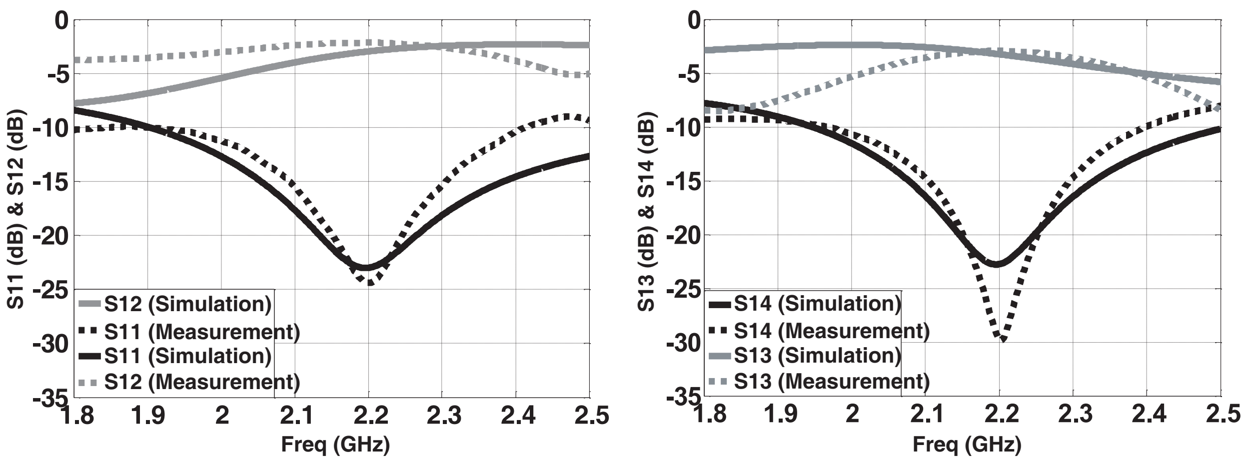


Figure 8. Measurement was performed with a vector network analyzer (ZVB20).



(a) (b)

Figure 9. Comparison of S-parameters between simulations results and measurements. (a) Return & Insertion loss. (b) Isolation S_{14} and Insertion loss of coupled port.

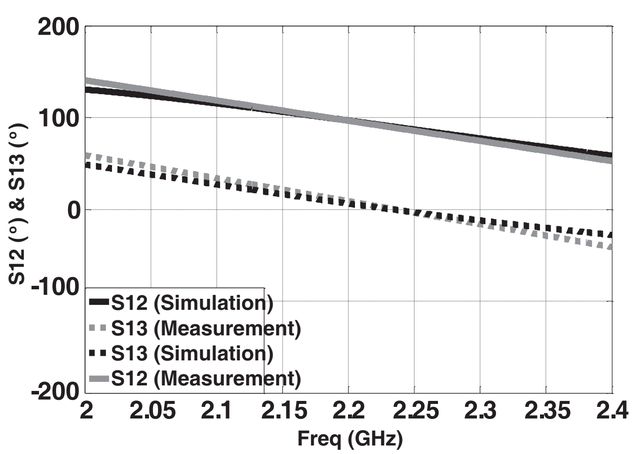


Figure 10. Comparison of phase difference between simulations and measurements.

proposed coupler. As can be seen, the measured results agree well with the simulated ones, but some discrepancies have occurred, due to the fabrication inaccuracy and conditions of measurement.

The S-parameters of the proposed design obtained from simulation and measurement are shown in Fig. 9.

We have summarized full specification of our proposed branch-line hybrid coupler and compared with the conventional one in detail as shown in Table 2. We can conclude that the proposed coupler has a good performance.

Table 2. Performance comparison between conventional and proposed branch-line coupler.

Parameters	The conventional BLHC	The proposed BLHC	
Frequency (GHz)	2.2	2.2	
	Simulation	Simulation	Measured
S_{11} (dB)	−34.096	−22.998	−24.8
S_{21} (dB)	−3.208	−2.963	−2.81
S_{41} (dB)	−35.445	−22.753	−30
S_{31} (dB)	−2.931	−3.242	−3.14
Phase difference (°)	89.878	90.47	89.8
Isolation bandwidth (10 dB) (GHz)	0.6	0.66	0.48
Fractional bandwidth of Return Loss (> 15 dB) (%)	34	30.9	22
Fractional bandwidth of Insertion Loss (3 dB) (%)	52.5	54	39.5
Size (mm^2)	60×23.18	51.70×14.29	

The performance analysis of recently published and proposed compact Branch-Line Hybrid Couplers is shown in Table 3. The corresponding performance analysis in terms of the bandwidth and miniaturization requirement is achieved.

Table 3. Comparison of published compact branch-line couplers and this works.

References	Miniaturization Topology	Substrate	Freq (GHz)	Reduction Ratio (%)	BW (%)	Phase Error (°)
[19]	Benchmark circuit	RO-4003	0.9	0.12	33.3	~ 5
[20]	Interdigitated capacitors shunt	FR4	0.825	0.26	18.1	~ 2
[18]	Combination of T and Π-model	FR4	2.3	0.54	26.1	~ 4
[4]	Lumped-distributed elements	R0-4003	5	0.5	40	> 5
[21]	Quasi-lumped elements	FR4	2.4	0.29	33.3	~ 5
This work	Meander-line	FR4	2.2	0.48	32.2	~ 0.2

5. CONCLUSION

In this paper, a new miniaturized microstrip branch-line coupler with large bandwidth has been presented. The proposed coupler is based on combinational models meander line model in order to improve the performances. The prototype of the proposed coupler is designed, fabricated and tested. A good agreement is obtained between simulated and measurement results. So this new design can be used in Butler matrix networks.

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