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Compact Wideband Quadrature hybrid for 3G/LTE Technology

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Abstract. This paper proposes a new design for wideband quadrature hybrid with four stubs printed on the inner area of coupler for size reduction. To make easy of reduction a four stub consisting of high- and low impedance section, we present parameters to minimize its physical size (line width and line length). Its structure is relatively simple as it can be fabricated on a single layer printed-circuit board. Also, size reduction of the hybrid is one of the aims for the proposed design. As a result, its size can be reduced up to 55.5% comparative to the conventional one. The prototype of proposed hybrid is constructed in order to demonstrate its true performance. The prototype is designed for 3G and LTE applications covering frequencies from 1.92 to 2.17 GHz. From the obtained results, we have a good agreement between simulation and measurement.

Keywords : Branch-line hybrid; quadrature hybrid; compact planar circuit; 3G/LTE; miniaturized hybrid

1. Introduction

At present, evolution on mobile wireless communication systems has been developed rapidly. The developments have been made to adapt the systems from analog to digital transmissions, and/or operating from narrow to wideband frequency range. Standard technology of each generation and related applications have been adopted and thus further developed. For example, the 3rd Generation (3G) for mobile communications has been developed from 2.5G in order to support higher data transfer rate. However, technologies supporting 3G may not be adequate to accommodate highly advanced applications. The 4th Generation (4G) of mobile communications mentioned along with Long Term Evolution (LTE) was developed by 3GPP being one candidate for 4G standard [1]. So far, beamforming technique has gained lots of attention from researchers around the world as it is able to improve the performance of wireless communication systems. The key of success for beam formation is the beamforming network. The key element of famous beamforming network e.g. Butler matrix is a quadrature hybrid [2]-[4]. According to this, miniaturization of quadrature hybrid is an attractive topic nowadays as this results in compact beamforming network. From literatures [5], a slot-coupled muti-section quadrature hybrid for UWB applications has been proposed. However, this has to be fabricated on multilayer printed-circuit board. In addition, the work presented in [6] has proposed a method to reduce the size of branch-line coupler using eight two-step stubs. As a result, the overall size can be reduced up to 25%. Also, the authors of the work presented in [7] have proposed a compact branch-line and rat-race coupler which can be fabricated on a standard printed-circuit board. The size reduction can be achieved using artificial transmission line where its physical length is shorter than a transmission line with the same electrical length. As a result, area reduction can be obtained up to 36.8% for the branch-line coupler. Another approach using monolithic-microwave integrated-circuit (MMIC) techniques has been proposed to reduce the size of branch-line coupler up to 55.2% [8]. Furthermore, the works presented in [9] and [10] have presented the reduction of quadrature hybrid with distributed capacitors printed on the inner area of coupler. This can reduce overall size of hybrid up to 62%

and 70%, respectively. However as seen in its structure, the gap between the line in the coupler is too close. This causes an extreme difficulty in fabrication.

Therefore, this paper proposes a compact wideband quadrature hybrid. The proposed structure is simple as it can be fabricated on a single layer printed-circuit board. This hybrid is designed to cover the frequency band for 3G and LTE applications. Also, the proposed design provides size reduction up to 55.5% compared with the conventional one.

The remainder of paper is organized as follows. Section II describes the design of proposed quadrature hybrid. Its size and dimension are designed for 3G and LTE technologies covering frequencies from 1.92 to 2.69 GHz. After presenting its structure, the simulation results are shown to indicate its performance in section III. Section IV presents the full prototype of proposed quadrature hybrid followed by the measurement results to confirm the true performance of the proposed prototype. Finally, Section V concludes the paper.

2. Design of proposed Wideband Quadrature Hybrid

Fig.1 shows geometry of a quadrature (90°) hybrid coupler is a 4-port device, otherwise known as the quadrature coupler or branch-line hybrid is 3-dB directional coupler with a 90° phase difference in the outputs of the through and coupled arms. It has dimensions of a quarter-wave length by quarter-wavelength at the center frequency. This is usually fabricated on simple printed-circuit board. So

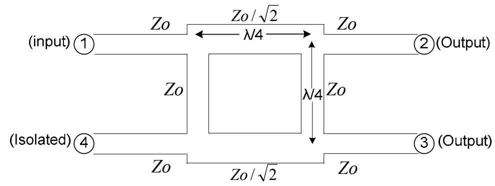


Figure1. Geometry of a quadrature (90□) hybrid coupler.

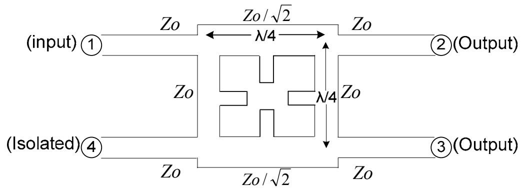


Figure2. Geometry of propose quadrature hybrid.

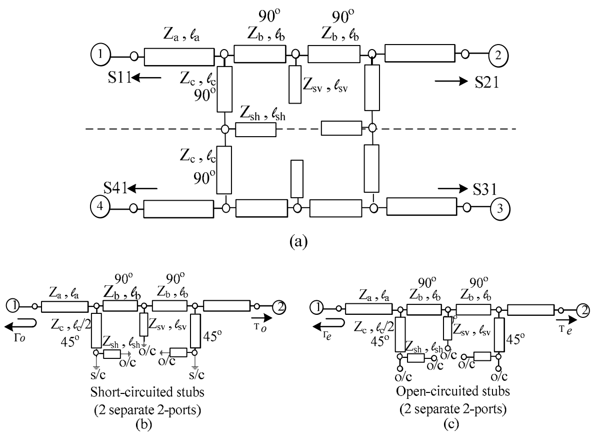


Figure3. Schematic diagrams of proposed quadrature hybrid in (a) normal mode theory (b) Odd mode (c) Even mode.

$$[S]=\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \tag{10}$$

Where

$$S_{11}=S_{22}=S_{33}=S_{44}=\frac{1}{2}\Gamma_e+\frac{1}{2}\Gamma_o$$
$$=\frac{1}{4}\left[\frac{1}{A_e}\left(\frac{B_e/Zo-C_eZo}{B_e/Zo+C_eZo}\right)\right]+\frac{1}{4}\left[\frac{1}{A_o}\left(\frac{B_o/Zo-C_oZo}{B_o/Zo+C_oZo}\right)\right] \tag{2-a}$$

$$S_{21}=S_{12}=S_{43}=S_{34}=\frac{1}{2}T_e+\frac{1}{2}T_o$$
$$=\frac{1}{2}\left[\frac{1}{A_e}\left(\frac{1}{B_e/Zo+C_eZo}\right)\right]+\frac{1}{4}\left[\frac{1}{A_o}\left(\frac{1}{B_o/Zo+C_oZo}\right)\right] \tag{2-b}$$

$$S_{31}=S_{13}=S_{42}=S_{24}=\frac{1}{2}T_e-\frac{1}{2}T_o$$
$$=\frac{1}{2}\left[\frac{1}{A_e}\left(\frac{1}{B_e/Zo+C_eZo}\right)\right]-\frac{1}{4}\left[\frac{1}{A_o}\left(\frac{1}{B_o/Zo+C_oZo}\right)\right] \tag{2-c}$$

$$S_{41}=S_{14}=S_{32}=S_{23}=\frac{1}{2}\Gamma_e-\frac{1}{2}\Gamma_o$$
$$=\frac{1}{4}\left[\frac{1}{A_e}\left(\frac{B_e/Zo-C_eZo}{B_e/Zo+C_eZo}\right)\right]-\frac{1}{4}\left[\frac{1}{A_o}\left(\frac{B_o/Zo-C_oZo}{B_o/Zo+C_oZo}\right)\right] \tag{2-d}$$

far, a conventional quadrature hybrid works very well for single frequency or within a limited frequency band. For this paper, an extension is made in order to be able to operate in wide frequency band.

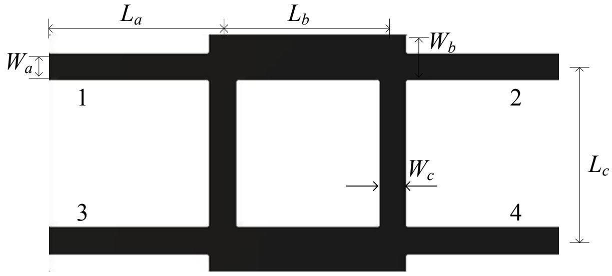
As seen in Fig. 2, the modification is made by adding four stubs into the inner of hybrid. To find an analytic solution, the structure is decomposed into the superposition of odd/even mode excitation [11] and [12], as shown Fig. 3. As the circuit is linear, the actual response can be obtained from the sum of the responses to the even and odd mode excitations.

The scattering matrix of the quadrature hybrid is shown in (1) and (2). Where $\Gamma_{e,o}$ and $T_{e,o}$ are reflection and transmission coefficients in even and odd modes for the two-port network analysis shown in Fig. 3.

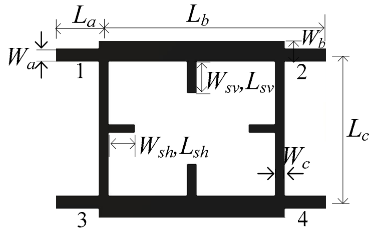
Using solution from even-odd mode analysis, we can minimize hybrid length (l) and width (w) within a designated frequency band. The optimum solution for length and width of the hybrid can be found by own developed programming in MATLAB. As being the aim of this paper, the hybrid is designed to cover frequency band from 1.92 to 2.69 GHz. The layout of quadrature hybrid for the proposed and conventional ones is shown in Fig. 4. The obtained size and dimension of the proposed hybrid is presented in Table I. To confirm the success of miniaturization, the comparison to the conventional one center frequency operating at 2.3 GHz is shown. Please note that parameters shown in Table I are referred from the ones presented in Fig. 4. After calculating their overall size, we can reduce size of convention quadrature hybrid up to 55.5%. Moreover, the proposed one can operate in wide frequency range. Next, the simulation and measurement results are shown to confirm the performance of proposed quadrature hybrid.

3. Simulation Results

To see the performance of the proposed design, the return and insertion losses are evaluated using CST microwave studio. In the simulation, a dielectric substrate having dielectric constant of 4.5 and thickness of 1.6 mm is



(a)



(b)

Figure4. Layout of the quadrature hybrid (a) conventional one (b) proposed one.

TABLE I. DIMENSIONS OF THE PROPOSED QUADRATURE HYBRID

Parameters	**Dimension (mm)**
W_a	1.555
W_b	2.675
W_c	1.055
W_{sh}	1
W_{sv}	1
l_a	5.5275
l_b	20.155
l_c	18.415
l_{sh}	3
l_{sv}	4

utilized. Also, the comparison with conventional one at 2.3 GHz is presented.

Fig. 5 shows the simulated S-parameters of the proposed quadrature hybrid comparing with the conventional one. As we can see, the results obtained from the proposed and conventional ones have a good agreement. For insertion loss (S_{21} and S_{41}) we obtain approximately 3.33-3.24 dB throughout the designated band from 1.92 to 2.69 GHz. Also, it provides the return loss and isolation (S_{11} and S_{31}) better than -10 dB throughout the designated band. One important parameter to maintain the characteristic of

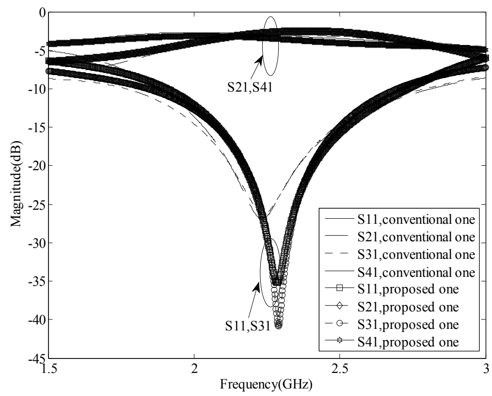


Figure5. Simulated S-parameters in amplitude of conventional and proposed quadrature hybrid.

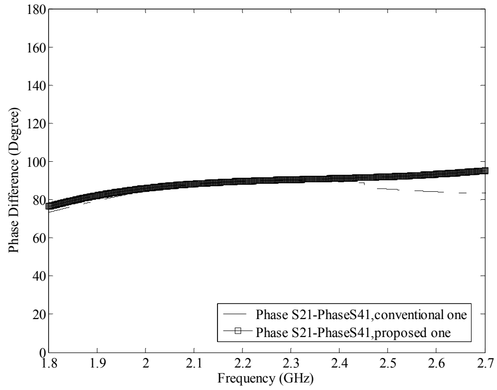


Figure6. Simulated phase difference between through and coupled ports of conventional and proposed quadrature hybrid.

TABLE II. SUMMARY OF PERFORMANCE FOR THE PROPOSED QUADRATURE HYBRID AT CENTER FREQUENCY

Design Methods	**Specifications**				
	Area (mm^2)	***Reduction size***	***Return loss (dB)***	***90° Phase error***	
				Sim.	***Meas.***
Conventional	1556.2	-	-	0.09	-
Proposed	693.2	55.5%	-20.45	0.09	0.1

quadrature hybrid is phase difference between through and coupled ports (S_{21} and S_{41}), which is given at 90°. From the simulation presented in Fig. 6, we obtain the approximate error in phase difference within ±2.38° from frequencies 1.92 to 2.69 GHz

Next, the prototype of wideband quadrature hybrid proposed in this paper is constructed and tested to validate the design.

4. Prototype

Fig. 7 shows the photograph of the prototype of proposed wideband quadrature hybrid. As we can see, its structure is relatively simple as it can be fabricated on a single layer printed-circuit board. This prototype is fabricated on printed-circuit board having dielectric constant of 4.5 and dielectric thickness of 1.6 mm. Please note that, size and dimensions of the prototype can be found in Table I.

The comparison of S-parameters of the proposed design obtained from simulation and measurement is shown in Fig.8. The measurement was performed using Network Analyzer over the frequencies from 1.9 to 2.7 GHz. As we can see, the measured results have a good agreement with the simulated one. We obtain the return loss and isolation better than -10 dB throughout the designated band from 1.9 to 2.7 GHz. Also, this figure shows that the prototype provides its insertion loss in through port and coupled port of approximately 3.94 to 3.92 dB, respectively.

Fig. 9 presents phase difference between through and coupled ports of the prototype obtained from measurement and simulation. From the figure, we obtain a good agreement between measurement and simulation in term of phase difference. It also reveals that we obtain the approximate error in phase difference less than ±2.85° from frequencies 1.9 to 2.7 GHz.

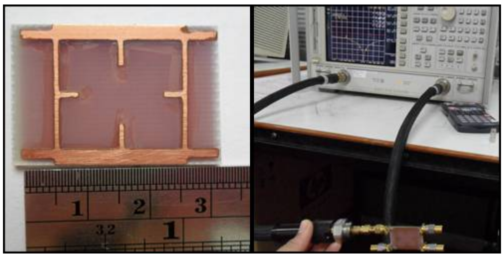


Figure7. Photograph of the proposed wideband quadrature hybrid

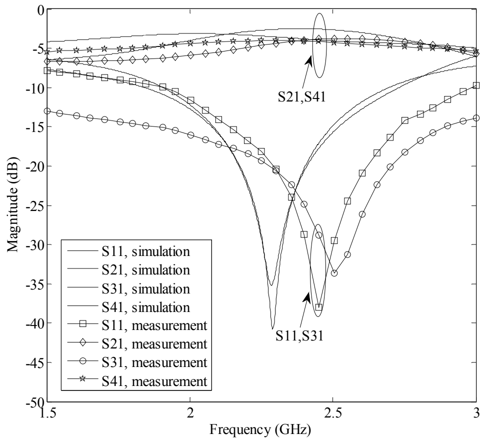


Figure8. Simulated and measured S-Parameter in amplitude of the proposed quadrature hybrid.

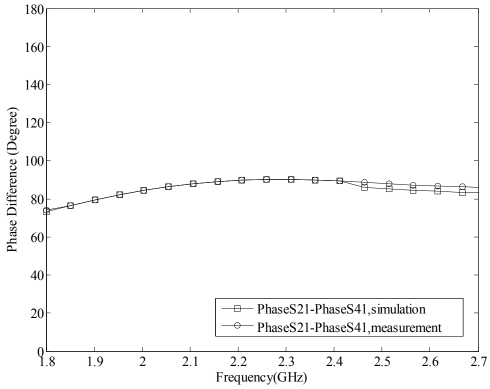


Figure9. Simulated and measured phase difference between through and coupled ports of the proposed quadrature hybrid.

5. Conclusion

This paper has proposed a compact quadrature hybrid which can operate in wide frequency band. The designated band covers frequencies from 1.92 to 2.69 GHz covering 3G and LTE applications. The proposed design was initiated in computer simulation. Then, the prototype of proposed quadrature hybrid is constructed and tested to confirm its true performance. The structure of proposed quadrature hybrid is relatively simple as it can be fabricated on single layer PCB. Both simulation and measurement results confirm that the proposed design works very well over designated frequency band. Also, the final design corresponds to 55.5% size reduction compared to the conventional one with similar performance. This reduction is considerably beneficial as the quadrature hybrid is one important component of various wireless communication systems. Table II summarizes the performance and occupied area for both the proposed circuit and the conventional one at a center frequency of 2.3 GHz.

6. Acknowledgment

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