Miniaturized Quadrature Hybrid Couplers based on Novel U-shaped Transmission Lines

Olukoya, O., Ilic, A.Z., Basu, A. and Budimir, D.

This is the peer reviewed version of the following article: Olukoya, O., Ilic, A.Z., Basu, A. and Budimir, D. (2019) Miniaturized Quadrature Hybrid Couplers based on Novel U-shaped Transmission Lines. Microwave and Optical Technology Letters. 61 (2), pp. 509-512, which has been published in final form at:

https://dx.doi.org/10.1002/mop.31555

Miniaturized Quadrature Hybrid Couplers based on Novel U-shaped Transmission Lines

Oludotun Olukoya[1], Andjelija Ilic[2], Ananjan Basu[3] and Djuradj Budimir[1, 4],

[1]Wireless Communications Research Group, Faculty of Science and Technology, University of Westminster, 115 New Cavendish Street, London, W1W 6UW, UK.
[2]Institute of Physics Belgrade, University of Belgrade, Zemun-Belgrade, Serbia.
[3]C.A.R.E. IIT Delhi, New Delhi, India
[4]School of Electrical Engineering, University of Belgrade, Belgrade, Serbia.

Abstract: In this paper, a miniaturized microstrip quadrature hybrid coupler (QHC) using U-shaped transmission lines (USTL) is presented. The proposed approach replaces all arms of the conventional QHC with its equivalent U-shaped transmission line to achieve compactness. The proposed coupler structure is designed to operate in the 1.5 GHz (1427 – 1518 (MHz)) band which is one of the 5G bands of interest. At such low RF/microwave bands below 3 - 4 GHz, the size of the conventional coupler is considerably very large which raises a concern for the next generation networks. The proposed coupler is designed, simulated and fabricated using Rogers 5880 with thickness of 0.79 mm, dielectric constant (εr) of 2.2 and loss tangent of 0.0021. The proposed QHC size is 70% smaller in circuit area (30% relative area) than the conventional equivalent. Simulation and measured results are presented and good matching between the results is observed, confirming the outstanding coupler performance properties. The proposed miniaturized QHC structure will play a vital role for next generation 4G and 5G wireless communication systems operating below 6 GHz.

Index Term— U-Shaped Transmission line (USTL); Quadrature Hybrid Couplers (QHC)

I. INTRODUCTION

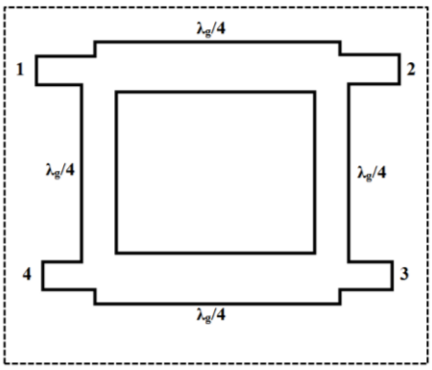
Quadrature hybrid couplers belong to most vital passive microwave circuits in mobile and wireless communication systems. However, the conventional QHCs typically occupy a very large circuit area, which is especially manifested at low RF/microwave frequencies below 4 GHz. As a result, the conventional QHCs are very bulky for practical use [1].

In recent years, different microstrip transmission line concepts [2] – [7] have been proposed for the design of hybrid couplers with compact size. However, some of these structures are very complex to realize; thus, even though the overall area is reduced, there seems to be an increase in the overall width of the structure. To overcome the problem of complexity and increase in width size, a U-shaped transmission line is proposed to achieve compact size as well as good performance.

In this paper, a 3dB quadrature hybrid coupler based on a novel U-shaped transmission line (USTL) technique is proposed to maintain excellent performance while reducing the coupler size, circuit area and complexity of realization. An example of such structure is presented, exhibiting a total reduction of about 70% in the occupied circuit area when compared to the equivalent conventional coupler structure. When compared to other presented microstrip QHC designs in [3] – [7], the USTL design achieves a good size reduction with even better performance. Moreover, it could be easily incorporated in modern wireless communication systems, due to its compactness and simple practical realization. The measured return and insertion loss results for the fabricated structure present good matching with the simulation results.

II. PROPOSED COUPLER STRUCTURE AND DESIGN

Figure 1(a) shows the structure of conventional quadrature hybrid coupler QHC with four quarter wavelength ($\lambda_g/4$) transmission line segments which can be very large at low RF frequencies of interest. Figure 1(b) presents the modified conventional quadrature hybrid coupler (QHC) structure.



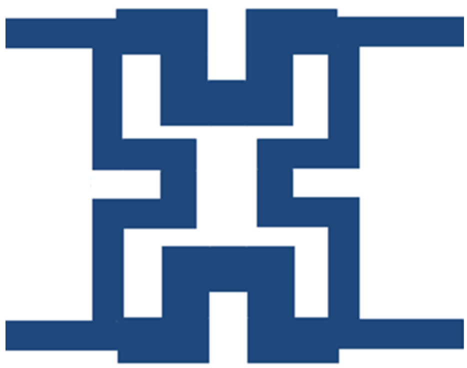


Figure 1 (a) Conventional QHC structure. (b) Modified QHC structure

For the characteristic impedances Z_{0LH} of 50Ω and 35.35Ω, the abcd matrix parameter equivalent of the conventional coupler is obtained and the dimensions are shown in Table I. The USTL parameter values in Table 1 are used to form the USTL quadrature hybrid coupler as shown in Figure 2.

TABLE I. USTL DESIGN PARAMETERS

Characteristic impedance (Ω)	**W_1 (mm)**	**W_2 (mm)**	**W_3 (mm)**	**L_1 (mm)**	**L_2 (mm)**	**L_3 (mm)**
50 (Z_0)	2.44	8	4	12	2.44	12
35.35($Z_0/\sqrt{2}$)	3.96	8.2	3.96	10	3.96	10

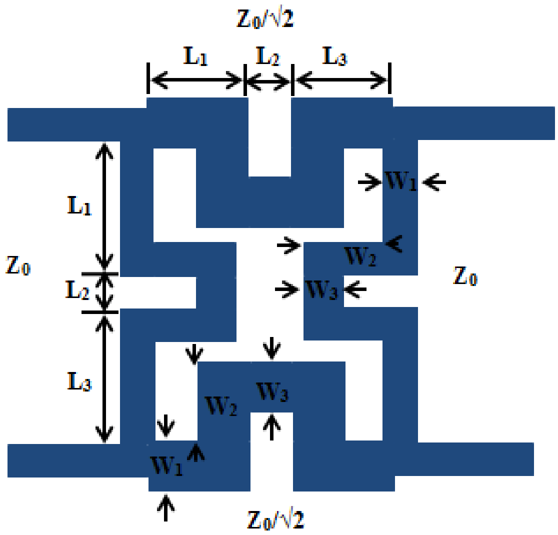


Figure 2 The layout of the proposed USTL hybrid coupler structure.

Figure 3 compares the proposed structure with its conventional equivalent and shows a considerable size reduction with a circuit area of 41.96 x 31.84 mm^2 as compared to the conventional design which has an area of 108.86 x 40.8 mm^2 at the same center frequency of 1.5 GHz.

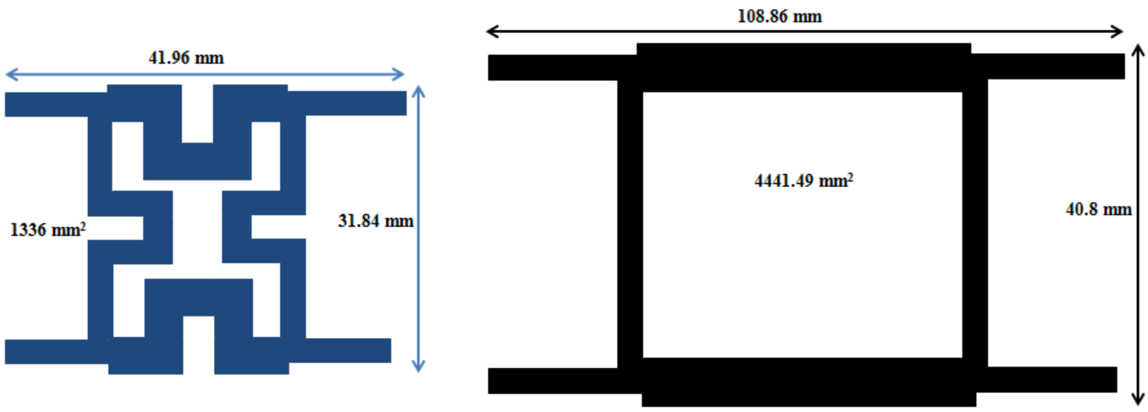


Figure 3 Comparison of circuit area of proposed USTL coupler with the conventional QHC.

The relative circuit area of the proposed coupler and other designs, improved in comparison with the conventional one, are compared in Table II. The proposed coupler structure achieved about 70% circuit area reduction which is more miniaturized than other-coupler designs found in literature. This circuit has been fabricated and measured results will be presented in the next section. The coupler aims to achieve reduced size while still being able to maintain an excellent performance, which is typical for the large conventional quadrature hybrid couplers. The proposed coupler design can be easily implemented in different power amplifier configurations like Doherty power amplifier and balanced power amplifiers without making the circuit become too large for practical use [8].

TABLE II. CIRCUIT AREA COMPARISONS WITH PROPOSED COUPLER

Reference	**Technique**	**Relative Area**
Conventional	Conventional Design	100%
[3]	Bended Transmission Line (simulated)	56%
[4]	T-shaped transmission line (measured)	46%
[5]	Coupled transmission line (measured)	42%
[6]	Pi-Shaped transmission line (measured)	40%
[7]	Fractal Shaped transmission line (measured)	33%
This Work	U-Shaped Transmission Line (measured)	30%

III. EXPERIMENTAL RESULTS

Electromagnetic Simulation results were obtained using the Sonnet software which was used for the coupler design. The coupler was fabricated in microstrip technology using RT/Duroid 5880, with dielectric constant (ε_r) of 2.2 and substrate thickness of 0.79 mm. Figure 4 compares the measured results of the coupler with its simulated model. The results obtained by measurements and those obtained by simulations show a relatively good match; we attribute the minor disagreements to be mainly due to the fabrication tolerances and lesser frequency points in measurement. Namely, a slight centre frequency shift, from 1.5 GHz to 1.47 GHz, has been noticed for the measured coupler, with a slight deviation in *S*-parameter values over its simulation equivalent.

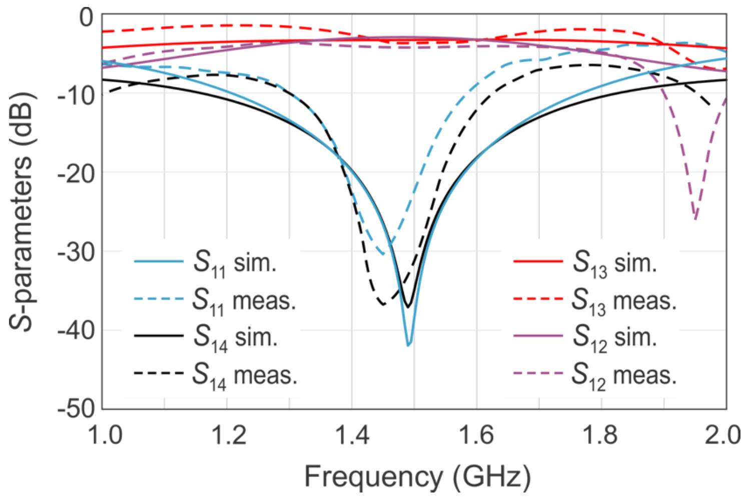


Figure 4 Measured and simulated results of the fabricated quadrature hybrid coupler.

From Figure 4, the return loss, S_{11}, at the centre frequencies for simulations and for the measured data are both below 30 dB, which is excellent. Isolation (S_{14}), obtained by measurements, is slightly better, with two groups of results being very close and both below 35 dB. The coupling and transmission coefficients (S_{12} and S_{13}) are both near 3 dB at the centre frequency range.

The photograph of the fabricated coupler under measurement is shown in Figure 5. The proposed QHC is very compact, achieving a size reduction of 70%. The design does not only achieve a significantly reduced size, but also maintains the performance of the large conventional QHC. The compactness and excellent performance of the proposed coupler design makes it a very good candidate for various power amplifier configurations for 5G communication systems.

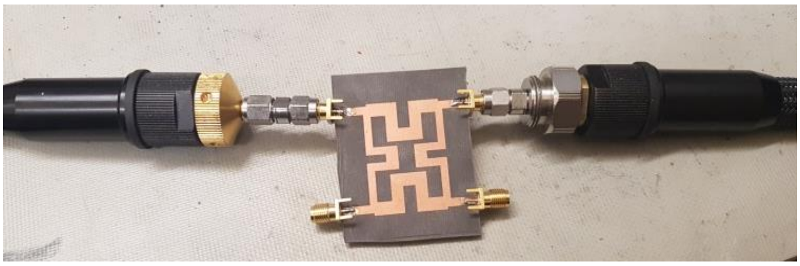


Figure 5 Photograph of the fabricated quadrature hybrid coupler under test.

IV. CONCLUSION

A miniaturised U-shaped microstrip quadrature hybrid coupler has been proposed in this paper. The coupler structure was designed, simulated and fabricated. The simulated and measured results show a very good match. The fabricated U-shaped quadrature hybrid coupler gives good performance at 1.5 GHz. The design achieves 3 dB coupling and transmission with a very high return loss > -30 dB and isolation > -35 dB. The proposed structure is very compact achieving a size reduction of 70% when compared to the conventional QHC at the same frequencies and more miniaturized when compared with the couplers described in the publications of other authors. The structure is very useful for balanced amplifier configurations, mixers, phase shifters, beam-forming networks and antenna arrays.

ACKNOWLEDGMENT

This work was supported by UK India Education Research Initiative University Grants Commission under grant IND/CONT/G/16-17/63.

REFERENCES

[1] K. V. Phani Kumar and S. S. Karthikeyan, " Miniaturized quadrature hybrid coupler using modified T-shaped transmission line for wide-range harmonic suppression," *IET Microwaves, Antennas & Propagation*, vol. 10, no. 14, pp. 1522–1527, Aug. 2016.

[2] C.-F. Chen, S.-F. Chang, and B.-H. Tseng, "Compact Microstrip dual-band Quadrature coupler based on Coupled-Resonator technique," *IEEE Microwave and Wireless Components Letters*, vol. 26, no. 7, pp. 487–489, Jul. 2016.

[3] A. C. Das, L. Murmu ansd S. Dwari, "A compact branch-line coupler using folded microstrip lines," *2013 International Conference on Microwave and Photonics (ICMAP)*, 13-15 December 2013, Dhanbad, India.

[4] A. R. Hazeri and T. Faraji, "Miniaturization and harmonic suppression of the branch-line hybrid coupler," *International Journal of Electronics*, vol. 98, no. 12, pp. 1699–1710, Dec. 2011.

[5] J. Shi et al., "A balanced filtering branch-line coupler," *IEEE Microwave Wireless Components Letters*., vol. 26, no. 2, pp. 119–121, Feb. 2016

[6] M. A. Maktoomi, M. S. Hashmi, and F. M. Ghannouchi, "Systematic design technique for dual-band branch-line coupler using T- and pi-networks and their application in novel

Wideband-Ratio crossover," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 6, no. 5, pp. 784–795, May 2016.
[7] C. S. Reshma and M. K. Mandal, "Miniaturization of a 90° hybrid coupler with improved bandwidth performance," *IEEE Microwave and Wireless Components Letters*, vol. 26, no. 11, pp. 891–893, Nov. 2016.
[8] R. Kalyan, K. Rawat, and S. K. Koul, "Reconfigurable and concurrent dual-band Doherty power amplifier for Multiband and Multistandard applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 65, no. 1, pp. 198–208, Jan. 2017.