A Miniaturized Wideband 3 dB Rat-Race Coupler Utilizing Meander Lines

[1]Jalil ur Rehman Kazim, [1]Hasan Abbas, [1]Masood Ur Rehman, [2]Akram Alomainy, [3]Coskun Kocabas, [4]Elif Ozden Yenigunc, [1]Muhammad Ali Imran, [1]Qammer H. Abbasi
[1]James Watt School of Engineering University of Glasgow, Glasgow, UK
[2]School of Electronic Engineering and Computer Science, Queen Mary University of London, United Kingdom
[3]Department of Materials and National Graphene Institute, University of Manchester, United Kingdom
[4]School of Design, Textiles, Royal College of Art, London, United Kingdom
[1]j.kazim.1@research.gla.ac.uk, {Hasan.Abbas, Masood.UrRehman, Muhammad.Imran, Qammer.Abbasi}asgow.ac.uk, [2]a.alomiany@qmul.ac.uk, [3]coskun.kocabas@manchester.ac.uk, [4]elif.ozden-yenigun@rca.ac.uk

***Abstract*—This paper proposes a wideband miniaturized 3 dB 180˚ rat-race coupler. For ease of fabrication and measurement, the operating frequency of the 180˚ coupler is designed from 700-960 MHz. Hence, an operating bandwidth of around 30% is achieved at the center frequency of 830 MHz. A size reduction of 95% is accomplished along with a fractional bandwidth of 30%. A meander line configuration is adopted and gaps between the lines are optimized to enhance the capacitance of the structure. The proposed design is fabricated on Rogers 4360 substrate and measured results of the prototype show good agreement with simulated results.**

Keywords—180˚ Rat-race Coupler; Miniaturized; Wideband

I. INTRODUCTION

The rate-race coupler also known as hybrid ring coupler is an important microwave passive device used in the wireless communication system. The rat-race coupler can provide both 0˚ and 180˚ output[1] which makes it suitable for differential to single-ended output and vice-versa. Moreover, the rat-race coupler can add and/or subtract the signals. Hence, this property is exploited in applications such as direction of arrival estimation [2, 3] and quadrature differential waveforms generation [4].

Contrary to the 90˚ hybrid coupler the rat-race coupler occupies a larger footprint. The size of the rat-race coupler becomes larger at lower frequencies and hence this increases the overall PCB board size. Additionally, the 180˚ coupler also suffers from reduced bandwidth i.e., around 10% [1]. Hence, it is equally important to realize both miniaturization as well as enhance the bandwidth of the rat-race coupler.

In the existing literature, more emphasis has been given to the hybrid coupler. Different techniques have been presented for size reduction of the hybrid coupler which includes [5] have used folded structure, in [6] fractal construction, stepped impedance resonators [7] and artificial transmission lines [8].

Similarly, for the rat-race coupler [9] employed an artificial transmission line with a size reduction of 78.6% and [10] used T-shape stubs and achieved a size reduction of 70%. In [11] a stepped impedance technique has been adopted to miniaturize the rat-race coupler. The design achieved a fractional bandwidth of 50% with a 86% size reduction but a very complex design. Alongside, the existing techniques either focus on miniaturization or bandwidth improvement and/or both in some cases. In the proposed work we have achieved a higher degree of miniaturization, i.e., 95% and at the same time wider operating bandwidth, i.e., around 30%.

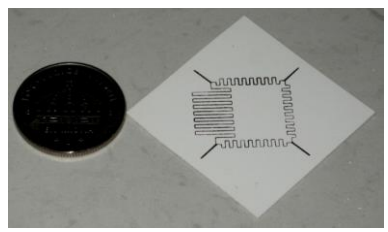


Fig. 1. Fabricated prototype of the proposed rat-race coupler

II. RAT-RACE COUPLER DESIGN

The proposed 180˚ rat-race coupler is designed and simulated using CST MWS 2019. The fabricated prototype can be seen in Figure 1. The rat-race coupler is designed on a 0.305 mm Rogers 4360 dielectric substrate with permittivity $\varepsilon_r = 6.15$ and $\tan\delta = 0.0038$.

The design of the conventional rate-race coupler has three ports separated by 90˚ length and a fourth port separated by 270˚. The lengths of the 90˚ arms at the center frequency of 860 MHz is calculated to be 42.5 mm while the fourth arm has a length of 132 mm. Moreover, the width of the microstrip lines is 70 Ω resulting in the trace width of 0.2 mm. Normal rat-race couplers are designed in a circular shape; hence they can occupy considerable space at lower frequencies. To shrink the coupler size, a meander line technique is adopted. This in turn reduces the size by approximately 95 %.

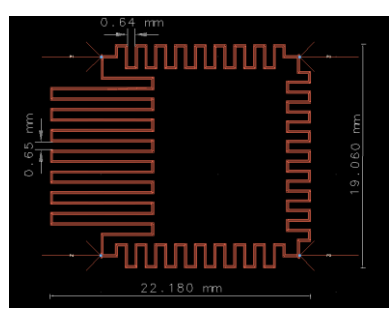


Fig. 2. Layout of the of the proposed meandered rat-race coupler

As seen in Figure 2, the vertical arm is meandered with a spacing of 0.65 mm between the gaps. Similarly, the gap in the horizontal arm is kept at 0.64 mm. It is important to note that the total electrical length is kept the same as that of the conventional coupler. The proposed area reduction is compared in Table 1.

III. RESULT AND DISCUSSION

The mode of operation of the rate-race coupler is kept as a power divider with the output taken at either of the two ports i.e., the Sum port with a phase difference of 0˚ and Delta port with a phase difference of 180˚. The simulated and measured reflection coefficient (S_{22}) and isolation (S_{23}) are plotted in Figure 3. Both (S_{22}) and (S_{33}) are well below -10 dB in the entire operating bandwidth with a maximum of -20 dB at the center frequency of 830 MHz. The isolation between the input ports is also below -20 dB. Due to the symmetry of structure results of other ports are not shown.

Table 1: Comparison of the size of the proposed vs conventional rat-race coupler

	Dimension (mm)	**Area (mm^2)**
Conventional Circular shape	88×88	7744
Proposed	22×19	418

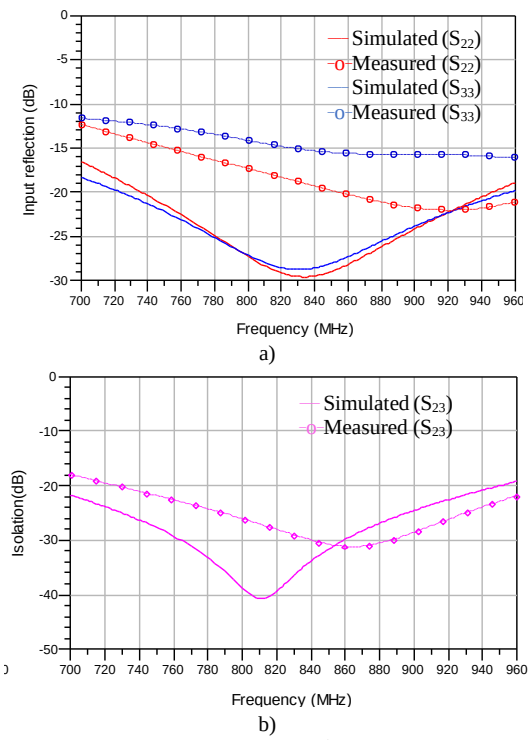


Fig. 3. Simulated and measured (a) Input reflection at port 2 and port 3 and (b) Isolation at between port 2 and port 3

A. Sum Port Excitation

The results in Figure 4 are obtained by keeping the delta port terminated with 50 Ω and excitation is applied to port 2 & port 3. The output is observed on the sum port which is at port 1. The simulated and measured insertion loss is given in Figure 4a for both the output ports.

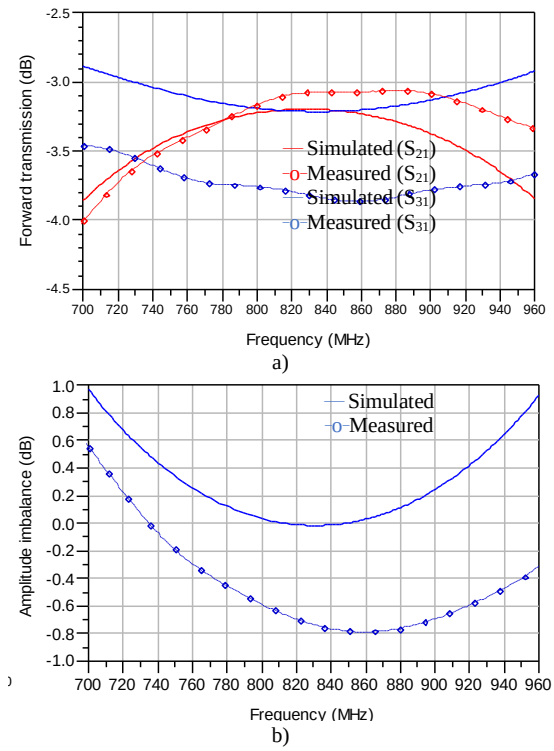


Fig. 4. Simulated and measured : (a) Forward transmission with respect to port 1 (Sum Port): a) Port 2 and port 3 and b) Amplitude imbalance between port 2 and port 3

The measured amplitude imbalance and the phase imbalance obtained from figure 4b and figure 5b at the sum port is less than 1 dB and 10˚.

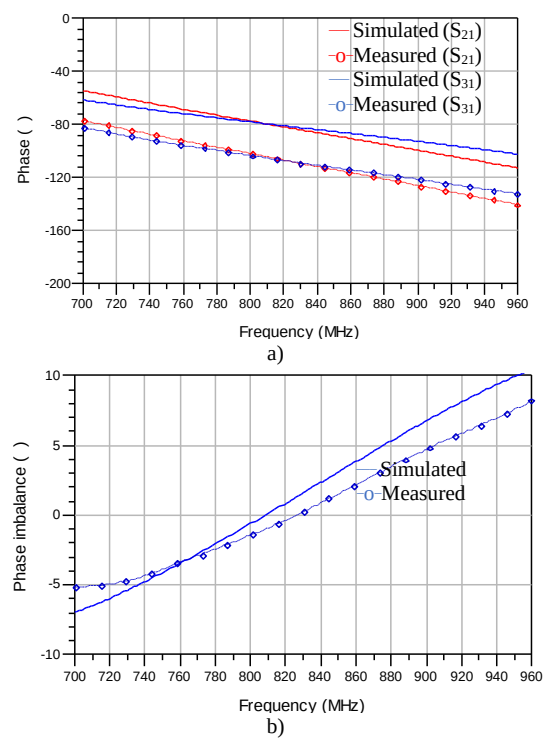
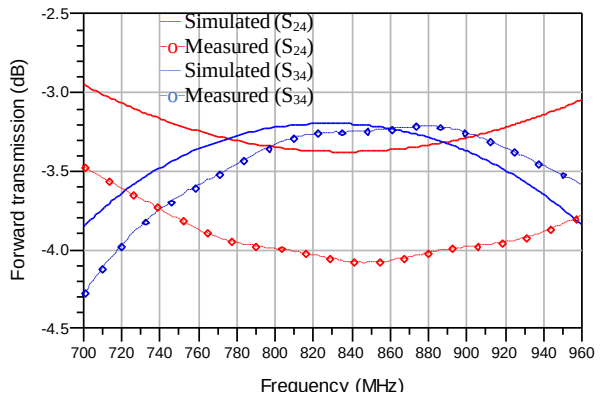


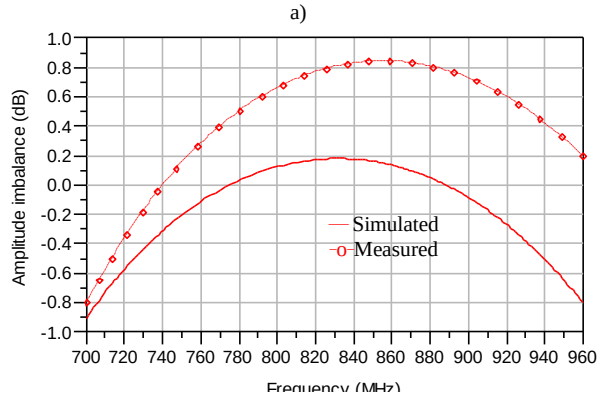
Fig. 5. Simulated and measured phase response with respect to port 1 (Sum port): Phase response at port 2 and port 3 and (b) Phase difference between port 2 and port 3.

B. *Delta Port Excited*

Similarly, the sum port is terminated with 50 Ω and port 2 & port 3 are simultaneously excited. The result of the delta port which is port 4 can be seen in Figure 6. It can be seen in Figure 7 that the phase difference among the ports is around 180˚ with a phase imbalance of 10˚.

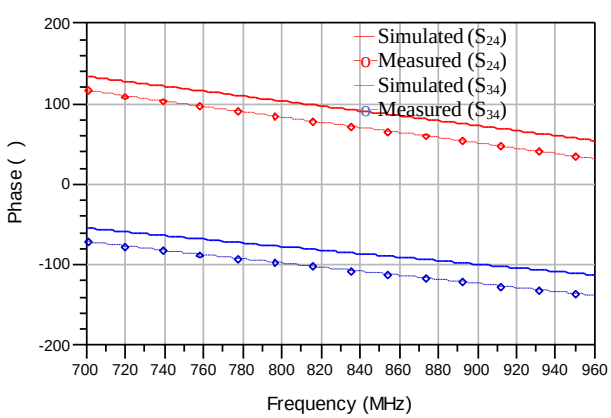


a)

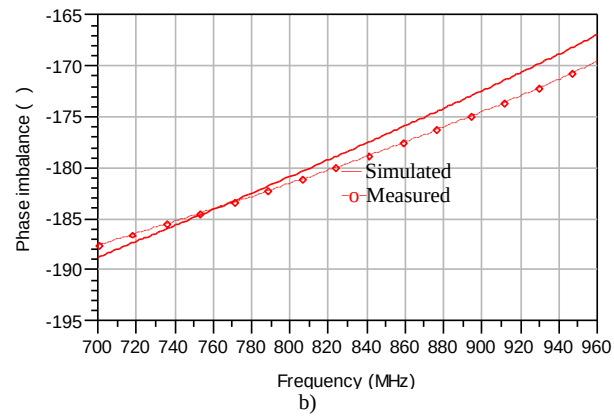


b)

Fig. 6. Simulated and measured forward transmission with respect to port 4 (Delta port): (a) Forward transmission at port 2 and port 3 and (b) Amplitude imbalance



a)



b)

Fig. 7. Simulated and measured phase response with respect to port 4 (Delta port): (a) Port 2 and port 3 and (b) Phase imbalance

IV. CONCLUSION

A wideband and miniaturized 3 dB 180˚ rat-race coupler is designed, simulated and fabricated. The proposed rat-race coupler has a measured operating bandwidth of 260 MHz at the center frequency of 860 MHz. A total miniaturization of 95% is achieved by carefully optimized meander lines. The input reflection and isolation between ports is below -10 dB. The average amplitude imbalance among the output ports, i.e., the sum port and the delta port is around 1 dB while the phase imbalance is also around 10˚. Due to symmetry, simplicity and attained percentage bandwidth, the proposed design is scalable to higher frequencies. The design can be modified to work in the millimeter-wave band for future wireless applications.

REFERENCES

[1] D. M. Pozar, *Microwave engineering*. John wiley & sons, 2011.

[2] S. A. Shaikh and I. Tekin, "Two axis direction finding antenna system using sum–difference patterns in X band," *Microwave and Optical Technology Letters*, https://doi.org/10.1002/mop.29269 vol. 57, no. 9, pp. 2085-2092, 2015/09/01 2015.

[3] M. I. Mohammed and T. R. Adhena, "Angle of arrival estimation using hybrid rat race coupler for X-band applications," *The European Physical Journal Plus*, vol. 135, no. 8, p. 632, 2020/08/06 2020.

[4] M. Harada and H. Hayashi, "Quadrature differential output six-port rat-race coupler," *Electronics Letters*, vol. 57, no. 10, pp. 407-409, 2021.

[5] J.-H. Chen, S.-Y. Yuan, and S.-R. Liou, "Extremely compact microstrip branch-line coupler with a novel fold structure," *Microwave and Optical Technology Letters*, vol. 59, no. 12, pp. 3166-3171, 2017.

[6] A. Ladu *et al.*, "High-performance cryogenic fractal 180° hybrid power divider with integrated directional coupler," *Radio Science*, vol. 52, no. 6, pp. 757-766, 2017.

[7] M. Naderi and H. Abbasi, "Design of compact microstrip branch line coupler using semi-circular and rectangular resonators with wide range suppressed harmonics," *AEU - International Journal of Electronics and Communications*, vol. 84, pp. 171-176, 2018/02/01/ 2018.

[8] D. Letavin, "Miniature microstrip branch line coupler with folded artificial transmission lines," *AEU-International Journal of Electronics and Communications*, vol. 99, pp. 8-13, 2019.

[9] D. A. Letavin, "Common-Mode-Anti-Phase Coupler with a Wide Band and Reduced Dimensions," in *2020 International Conference on Actual Problems of Electron Devices Engineering (APEDE)*, 2020, pp. 123-125.

[10] M. Moubadir, H. Aziz, I. Badaoui, N. A. Touhami, and A. Mohamed, "Miniaturized design of rat-race coupler by utilizing T-shape stubs," *Procedia Manufacturing*, vol. 22, pp. 79-84, 2018/01/01/ 2018.

[11] K. V. Phani Kumar and S. S. Karthikeyan, "Highly compact wideband double-section rat-race hybrid with harmonic suppression using series and shunt stepped impedance transmission lines," *International Journal of Microwave and Wireless Technologies*, vol. 9, no. 4, pp. 797-803, 2016.