A low loss rat race balun in gap waveguide technology

Proceedings of the 5th European Conference on Antennas and Propagation, EUCAP 2011. Rome, 11-15 April 2011

Citation for the published paper:
Raza, H. ; Yang, J. (2011) "A low loss rat race balun in gap waveguide technology". Proceedings of the 5th European Conference on Antennas and Propagation, EUCAP 2011. Rome, 11-15 April 2011 pp. 1230-1232.

(article starts on next page)

A Low Loss Rat Race Balun in Gap Waveguide Technology

Hasan Raza, Jian Yang

Department of Signal and Systems, Chalmers University of Technology
Gothenburg, Sweden
hasan.raza, jian.yang@chalmers.se

Abstract— **Hybrid ring (or rat-race coupler) has found many applications in millimeter and sub-millimeter wave technology. This paper describes a new type of hybrid ring realized in the ridge gap waveguide technology. The advantages of the new gap waveguide hybrid ring are low manufacture cost since the good electric contact between metal plates is not required, and lower transmission loss compared to microstrip line since there is no dielectric material needed. In addition, the gap waveguide technology opens up the possibility of waveguide integration circuit from millimetre wave up to terahertz. The focus of this work is on the realization of the new hybrid ring at 16 GHz, for the sake of concept verification. The simulated and measured results show that this structure works well and has a frequency band of 2.5 GHz around 16 GHz, with the reflection coefficient below -10dB and the phase difference between two output ports of 180^o ± 5^o.**

I. Introduction

Hybrid 3dB coupler (0^o /180^o) is often needed in feeding networks for antennas [1]. Among different geometries of hybrids, the hybrid ring (rat-race coupler) provides out-of-phase equal power division at the output ports with good isolation between them [2] – [3]. However, for high frequency applications, such as in millimetre wave, sub-millimetre wave and up to terahertz, it is very challenging to realize a low-loss and low-cost hybrid. By using rectangular waveguide, the tolerance requirement and a good electric contact for the metal waveguide walls impose difficulties for manufacture. On the other hand, by using planar microstrip circuits, the loss in the device is often unacceptable.

This paper proposes a new solution to 3 dB hybrid coupler, potentially for high frequency applications - the gap-waveguide ring hybrid. Gap waveguide is a new planar microwave circuit technology introduced recently [4]-[6]. By using the gap waveguide technology to realize the hybrid, there is no need to have good electric conduct between the top metal plate and the low pin metal texture plate, and no dielectric substrate. Therefore, the new hybrid has potential to have low manufacture cost and low transmission loss in high frequency applications.

The focus of this work is on the concept realization of the new type hybrid. Therefore, a prototype at 16 GHz is designed and manufactured. Simulations and measurements for this prototype are presented in the paper for the verification of the design. The reason for selecting this center frequency is that the current model of coaxial SMA to rig gap waveguide transition is applicable up to 18 GHz and to make and test gap waveguide component at a higher frequency, 16 GHz is the most suitable center frequency.

II. Geometry and Design

The geometry of the new hybrid is a gap-waveguide ring surrounded by metal pins which provide the parallel-plate stop band; see Fig. 1. Since the wave propagation is suppressed in any direction other than that along the conducting ridge [7], mechanical joints for the two surfaces (the top flat metal plate and the metal pin plate) can be applied at the locations away from the propagation path, and it is not required to have a good conducting contact at the joints. In this work, the operating frequency band of 15-18 GHz has been chosen.

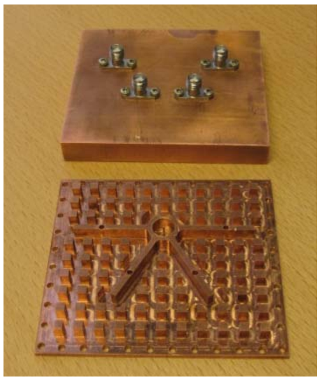

Fig. 1. Photo of the 15 – 17.5 GHz 3dB hybrid in ridge gape waveguide. The texture plate showing the ring hybrid surrounded by metal pins.

The hybrid is excited by coaxial probes inserted from the top plate. The height and width of the ridge are chosen as 5 mm and 2 mm, respectively, in order to have 50 Ω characteristic impedance. The distance between the upper plate and the ridge is 0.3 mm. A circular hole with a diameter of 1.8 mm is made in the ridge and the inner conductor of the coaxial probe is extended 3.75 mm down into the hole; see Fig. 2. All these parameters are decided through a parameter study in order to have an optimal transition from the coaxial connectors to the ridge gap waveguide.

The initial value of the width of the ridge ring is set as 1.35 mm according to width require to set $\sqrt{2}\,Z_o$[8], where Z_0 is the characteristic impedance for the ridge ring and calculated by the formula for gap waveguide given in [7]. Then, a parameter study through CST MS was carried out and an optimal value of 1.95 mm for the maximum bandwidth was obtained. The circumference of the ridge ring is $3\lambda/2$, where λ is the wavelength of the frequency 16 GHz. The distances between ports 1 and 2, ports 2 and 3, and ports 3 and 4 are the same as $\lambda/4$, whereas the distance between ports 1 and 4 is $3\lambda/4$. With these distances and matched ports, the incident field at port 1 splits equally between the two output ports 2 and 4 with 180^{o} phase difference, and port 3 is kept as an isolated port. If the incident field is at port 3, it splits equally between ports 2 and 4 with the same phase, and port 1 is then the isolated port.

The height, width and the periodicity of the pins around the ring have also been designed for the frequency of 15 GHz. The detail drawing is shown in Fig. 2. It can be seen from Fig. 2 that some of the pins are not rectangular in shape. In order to keep the same distance from the ridge circle as that from the normal straight ridge some of the area has been removed from the closest rectangular pins. Same procedure has been adopted for the pins around port 2 and 3 as the ridges are not in align with the pattern of pins.

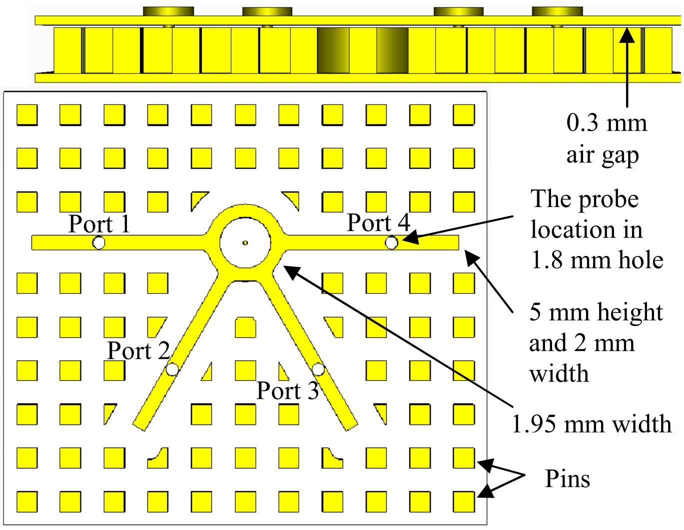

Fig. 2. Geometry of the Ridge gap waveguide hybrid.

III. Simulated and Measured Results

In order to verify the design, a prototype was constructed, where the ring and pins were made by milling a copper plate, as shown in Fig. 1.

Measurements were performed using a Vector Network analyser (E8363B PNA Network Analyser) over the frequency range from 10 to 20 GHz. All simulations are obtained by using CST MS. Figures 3 - 5 show the simulated and measured reflection and transmission coefficients, respectively, when port 1 is the input port. It can be observed that the gap-waveguide ring hybrid has a very promising performance over the band of 15.25 – 17.75 GHz: the reflection coefficient is below -10 dB; the ohmic loss is very low, the transmission loss is mainly due to the mismatch loss; and the phase difference between the two output ports 2 and 4 is about $180^{o} \pm 5^{o}$ as shown in Fig. 6.

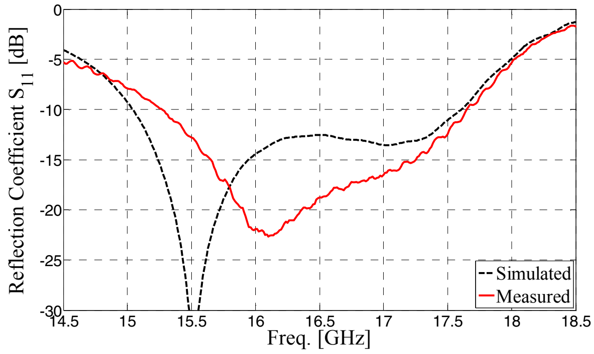

Fig. 3 Simulated and measured reflection coefficient S_{11}

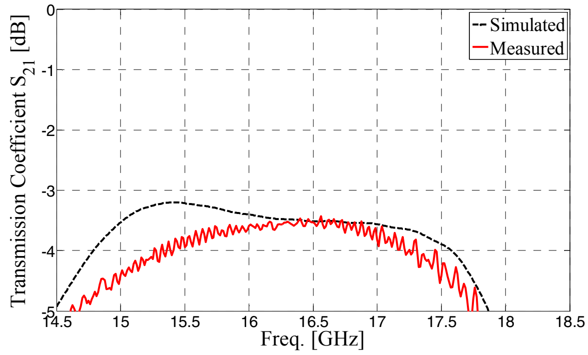

Fig. 4. Simulated & Measured transmission coefficient of port 1 to port 2

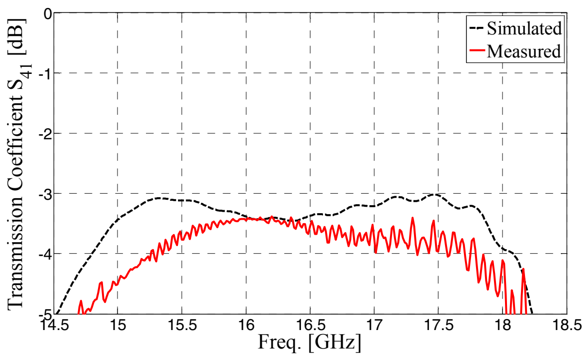

Fig. 5. Simulated & Measured transmission coefficient of port 1 to port 4

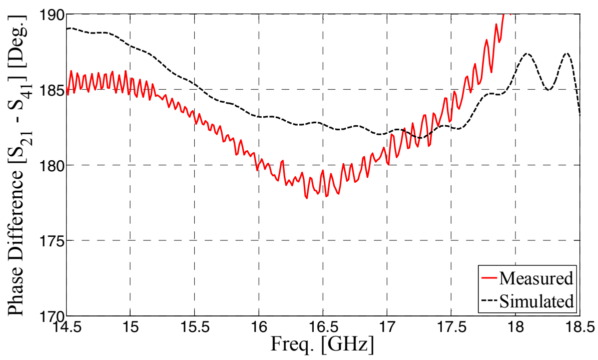

Fig. 6. Simulated & Measured phase difference of port 2 and port 4

Similarly, figures 7 - 9 show the simulated and measured reflection and transmission coefficients, respectively, by considering port 3 as the input port, obtained by using CST MS. Again, it can be observed that the gap-waveguide ring hybrid has a very promising performance over the band of 15.25 – 17.75 GHz. The measurement results follow the simulation results quite well in all figures. The reflection coefficient is below -10 dB; the ohmic loss seems very low; and the phase difference between the two output ports 2 and 4 is about ± 5°. Nevertheless, without adding the complexity in the conventional design parameters, the proposed structure is the practical realization of the ridge gap waveguide component.

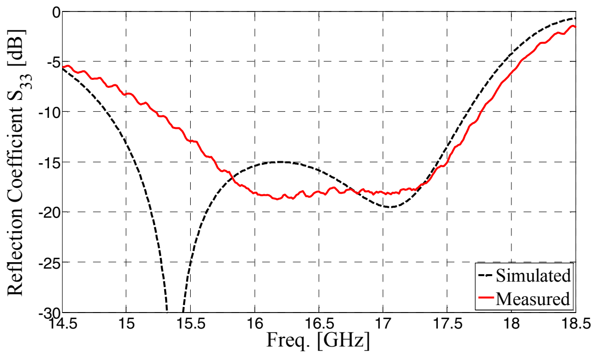

Fig. 7 Simulated and Measured reflection coefficient of port 3

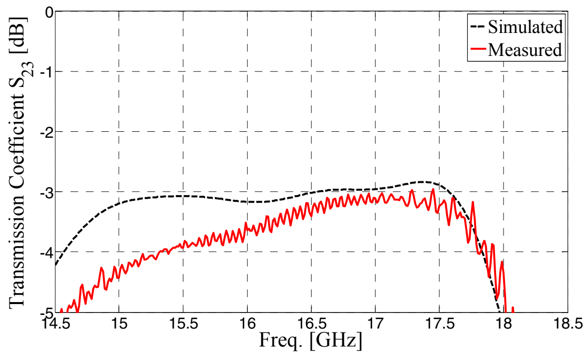

Fig. 8. Simulated & Measured transmission coefficient of port 3 to port 2

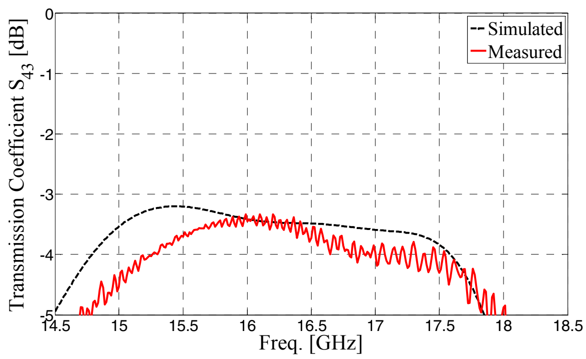

Fig. 9. Simulated & Measured transmission coefficient of port 3 to port 4

IV. CONCLUSION

This paper proposes a new design of 3dB ring hybrid realized in ridge gap waveguide structure. The approach adopted was used to design low loss wideband rat-race balun for the 15.25 GHz to 17.75 GHz frequency bands. Comparable measurement results have been obtained for a manufactured hybrid prototype.

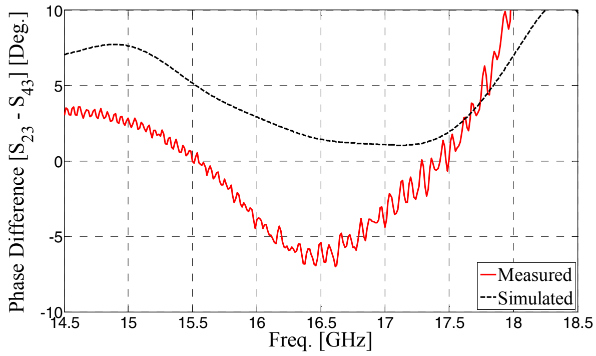

Fig. 10. Simulated & Measured phase difference of port 2 and port 4

V. ACKNOWLEDGEMENT

This work has been supported by The Swedish Foundation for Strategic Research (SSF) within the Strategic Research Center CHARMANT, Pakistan's NESCOM scholarship program and partly by Swedish Research Council VR.

VI. REFERENCES

[1] C. Volmer, M. Şengul, J. Webew, R. Stephan, M. A. Hein, "Broadband Decoupling and Matching of a Superdirective Two-Port Antenna Array", *IEEE Antennas and Wireless Propagation Letters, Vol. 7, 2008.*

[2] K.-K. M. Cheng, and F.-L. Wong, "A Novel Rat Race Coupler Design for Dual-Band Applications", *IEEE Microwave and Wireless Components Letters*, vol. 15, no. 8, August 2005.

[3] Aflaki, P., Negra, R., Ghannouchi, F., "Dual-band rat-race balun structure using transmission-lines and lumped component resonators", Microwave Symposium Digest (MTT), 2010 IEEE MTT-S International Issue Date: 23-28 May 2010, page(s), 1572 - 1575.

[4] P.-S. Kildal, E. Alfonso, A. Valero-Nogueira, E. Rajo-Iglesias, "Local metamaterial-based waveguides in gaps between parallel metal plates", *IEEE Antennas and Wireless Propagation letters (AWPL)*, vol. 8, pp. 84-87, 2009.

[5] P.-S. Kildal, "Three metamaterial-based gap waveguides between parallel metal plates for mm/submm waves", *3rd European Conference on Antennas and Propagation (EuCAP 2009)*, Berlin, Germany, 23-27 March 2009.

[6] P.-S. Kildal, "Waveguides and transmission lines in gaps between parallel conducting surfaces", *European patent application EP08159791.6*, July 7, 2008.

[7] P.-S. Kildal, A. Uz Zaman, E. Rajo-Iglesias, E. Alfonso, A. Valero-Nogueira, "Design and experimental verification of ridge gap waveguides in bed of nails for parallel plate mode suppression", accepted for publication in IET Microwaves, Antennas & Propagation, September 2010.

[8] David Pozar, *Microwave engineering 3rd edition*, p. 353, Wiley, 2005.