New types of MMIC circulators

D. Köther*, B. Hopf,* Th. Sporkmann* and I. Wolff,* FELLOW IEEE, and St. Koßlowski**

*IMST, Institut für Mobil- und Satellitenfunktechnik
Moerser Straße 316, D-47475 Kamp-Lintfort, FRG
**Daimler Benz Forschungszentrum Ulm
Wilhelm-Runge-Straße 11, D-89013 Ulm, FRG

Abstract

Circulators can be used to separate transmit/receive (T/R) signals and for two-port tuners. Conventional ferrite devices are not applicable for MMICs. Two new types of electronical circulators are presented in this paper covering the frequency range from 1.8GHz up to 80GHz.

Introduction

In the past, ferrite circulators have been used in many waveguide (WG) circuits but this technique can not be used for MMIC applications. It is not so easy to realize circulators with rotational symmetry in a MMIC design, but for almost every application this feature is not required. Thus, T/R separation as well as two-port tuners can be realized by a quasi-circulator (Fig. 1).

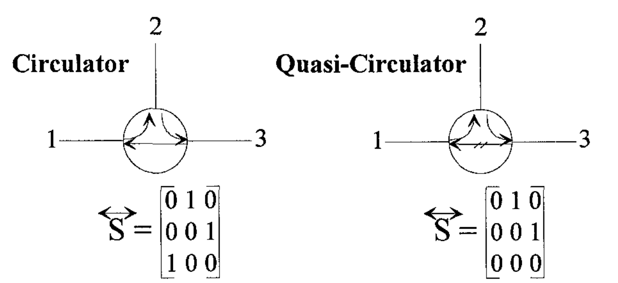

Fig. 1: Comparison between a circulator with rotational symmetry and a quasi-circulator

The only difference between both circuits is the fact, that there is no transmission from port 3 (receiver) to port 1 (transmitter) in the case of the quasi-circulator. In the frame of an ongoing BMFT-Project active circulators have been investigated for 1.8GHz, 40GHz, 55GHz, and 80GHz. Two different principles were investigated and realized for such MMIC devices. All designs were conducted utilizing state-of-the-art simulation software including numerical calculations for the CPW elements [4]. All circuits were fabricated at the Daimler Benz foundry in Ulm based on a 0.25µm HFET technology as well as on a new 0.15µm PMHFET technology.

2-Branches quasi-circulators

The first principle described here is based on a symmetrical setup of four identical transistors. The idea for this type of quasi-circulator was derived from line unified (LU) FET circuits (Fig. 2). The new quasi-circulator is also shown in the bottom half of Fig. 2. In this case, the signal from port 1 goes into the two branches. Within these branches the incident signal will be amplified. Thus, an amplified part of the input signal goes to port 2. Due to a 180° phase shift between the two branches however, the combined signals vanish at port 3 [1]. In addition a part of the antenna signal is transmitted from port 2 to port 3. Since HEMTs are present in each branch of the circuit there are no backward signals from the ports 2 and 3 to port 1. Symmetry is a requirement for this circuit and thus four identical active devices are needed for such a quasi-circulator. This is hard to realize. The devices must be biased independently in order to adjust for small manufacturing tolerances.
Such quasi-circulators were designed for many different frequencies and with independent HEMT bias as well as without this possibility. The results depicted in Fig. 4 represent a first shot design without independent HEMT biasing. The device utilized for this circuit has a l_g=0.25µm with w_g=320µm periphery. Fig. 3 depicts a photograph of such a circuit.

CH3577-4/95/0000-0877$01.00 © 1995 IEEE

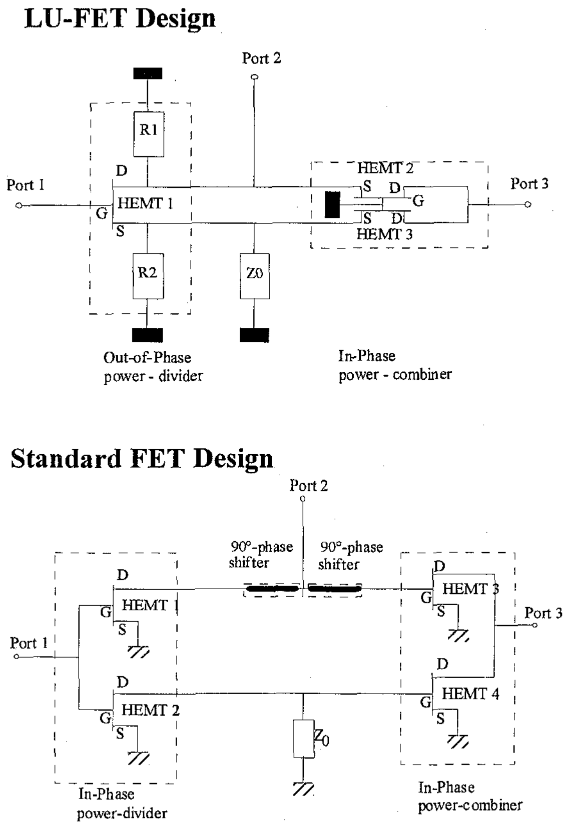

Fig. 2: 2-branches quasi-circulator principles

The simulated and measured forward gain S_{21} and the matching S_{11} are results for a 40GHz quasi-circulator are shown in Fig. 4. Simulation and measurements agree well over the whole frequency band.

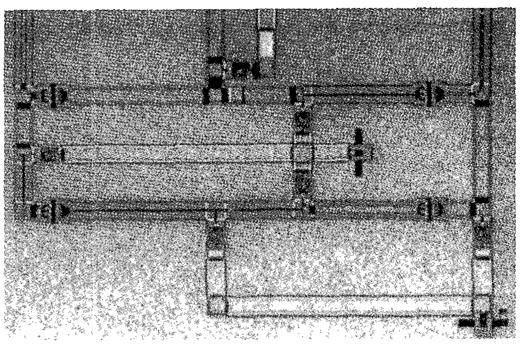

Fig. 3: Fotograph of a 40GHz 2-branches quasi-circulator with individual HEMT biasing

The matching at the three ports is better than 10dB and the insertion loss between port 1 and 2 for instance is about 2dB at 40GHz. The isolation between ports 3 and 2 is better than 25dB over the whole frequency band for this circuit.

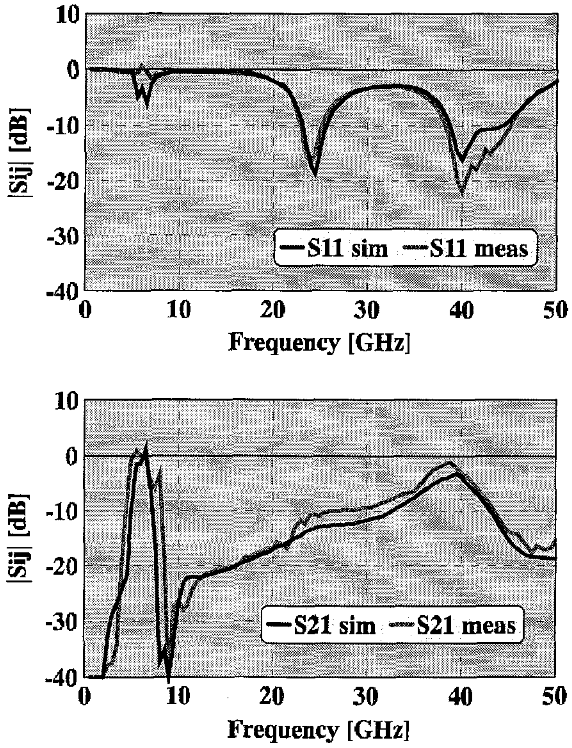

Fig. 4: Comparison of measured and simulated results for a 2-branches quasi-circulator for 40GHz

In order to show the capabilities of the devices and the technology we have simulated and designed quasi-circulators for 80GHz. Results of this investigation are shown in Fig. 5. In this case, the device has a gate length of l_g=0.15μm and a gate width of w_g=60μm. The simulated input return loss is better than 15dB at all ports and the transmission path 1-2 for instance shows an insertion loss of 2dB at 80GHz. The isolation between port 2 and 1 is about 20dB in this case. This circuit was designed and fabricated. Measurements will be conducted soon. Even though these results could not yet be verified, they are quite remarkable for such a high frequency. For frequencies below 10GHz the out-of-phase power-divider (Fig. 2) can be realized by using a floating-source transistor as three-port device. Our investigations have shown however, that such a FET has limited power handling capability. In total it must be pointed out, that the design of such a circuit is a very hard task for most design tools. Problems occur due to the closed loop structure for instance (Fig. 2 and 3).

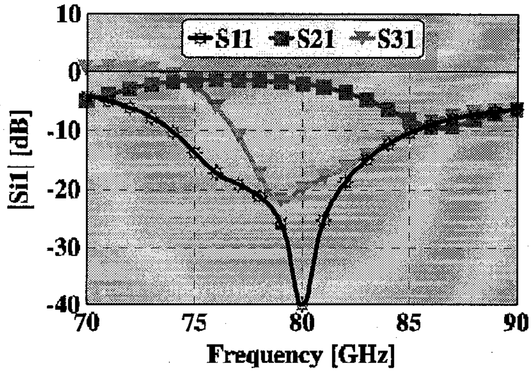

Fig. 5: Simulated results for a 2-branches quasi-circulator for 80GHz

Layout generation and circuit optimization must go hand in hand which means that a parametric optimization must be used. Also stability can not easily be maintained and simulated for the whole circuit. Our experience has shown that, once the topology of the structure is well defined to meet the needs of the simulator and the layout generator, the desired frequency can simply be defined and a layouted circuit can easily be found by an optimization.

Wilkinson quasi-circulator

The design of the second kind of quasi-circulator is much easier and offers also a better adaptation to different applications. Such a circuit consists of only two amplifiers and a Wilkinson coupler. Fig. 6 depicts the principle circuitry. In comparison to the previous quasi-circulator it should be mentioned that only about half the size is required while the performance can be maintained. In addition, a low noise receiver part can be combined with a high power transmitting path. Because of this it is clear that the Wilkinson coupler based quasi-circulator is more suitable for real applications.

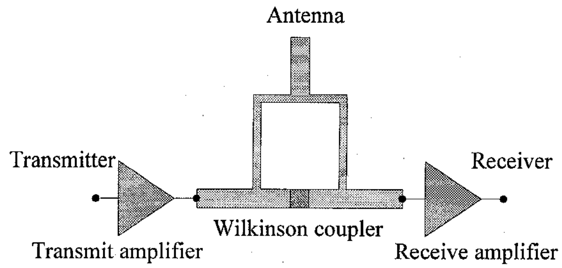

Fig.6 : Principles of Wilkinson quasi-circulator

In this circuit the transmitter signal is magnified by the first amplifier. The Wilkinson coupler provides the transmitted signal only to the antenna port [3]. The received signal (antenna) is splitted by the coupler. While the transmit amplifier isolates the path from antenna to transmitter, the other part is magnified by the receiving amplifier. A big advantage of this design is the fact that the transmit amplifier may be designed for power applications, while the receiver amplifier can be a low noise one. As for the other type of quasi-circulators, designs for various frequencies were conducted. In this paper a 1.8GHz, 40GHz, and 80GHz example are shown. It should be mentioned that the same technology (l_g = 0.15µm) was utilized for all frequencies. It is clear however that at 1.8GHz for instance a much cheaper MESFET technology will as well be applicable. It should be pointed out, that at 1.8GHz many lumped elements, e.g. spiral inductors were used, while at 40GHz and 80GHz simple transmission lines were sufficient for matching purposes. A first example of this type of quasi-circulator for 1.8GHz is shown in Fig. 7. The size of the Wilkinson coupler is reduced significantly by using lumped CPW elements. The size of the complete circuit shown in Fig. 7 is 5300x1450µm^2 including all bias networks. Some of the S-para-

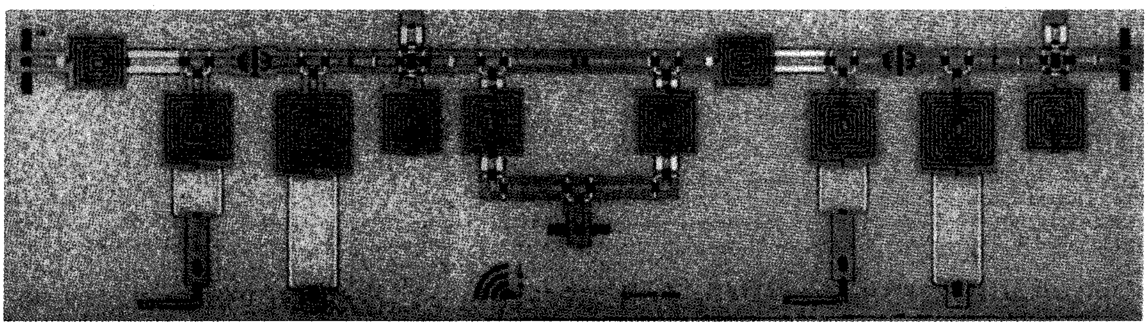
Fig. 7: Layout of a Wilkinson quasi-circulator for 1.8GHz

meters for this circuit are shown in Fig. 8. The matching at all ports is better than 15dB and the insertion loss was designed to be around 0dB in this case. The isolation between port 2 and 1 or port 3 and 1 is around 15dB. It should be noticed that a bandwidth of 400MHz can easily be achieved at 1.8GHz.

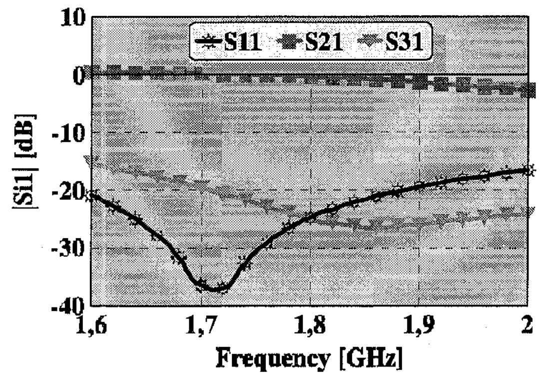

Fig. 8: Simulated results for a Wilkinson quasi-circulator for 1.8 GHz

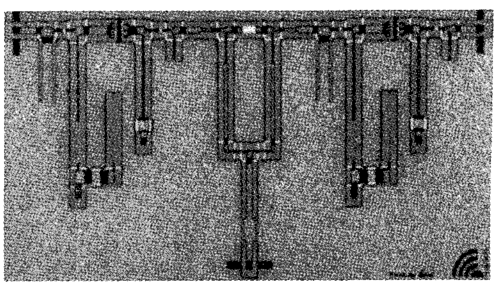

Fig. 9: Layout of a Wilkinson quasi-circulator for 40GHz

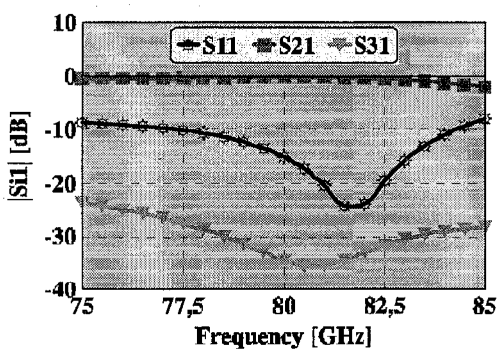

Fig. 10: Simulated results for a Wilkinson quasi-circulator for 80GHz

In Fig. 9 the layout for a 40GHz Wilkinson quasi-circulator is depicted. The 80GHz circuits have identical topology only the matching elements are shorter. At these high frequencies transmission lines and other distributed elements are used instead of lumped elements. Likewise this circuit has an isolation of the DC ports better than 20dB for frequencies up to the highest frequency of interest. The size of this circuit is 2900x900μm^2. The S-parameters in Fig. 10 demonstrate the applicability of this principle even for highest frequencies.

Conclusion

In this paper two principles of new quasi-circulators have been presented. Thus, a very wide frequency range from around 1GHz up to 80GHz can be covered. Even for the lower frequencies the small space requirements open new fields for the applications of circulators in MMIC design.

Acknowledgements

The work described in this paper was supported by the BMTF under the project number TK 0355/6. The authors would like to thank the people at Daimler Benz for fabricating the circuits. We would also like to thank the members of the IMST who supported this paper in many details.

References

[1] M. Muraguchi, T. Hirota, A. Minakawa, K. Ohwada and T. Sugeta: „Uniplanar MMICs and their applications“, IEEE Transactions on Microwave Theory and Techniques, Vol. 36, No. 12, 1988, pp. 1896-1901.

[2] D. Köther, B. Hopf, Th. Sporkmann, I. Wolff and St. Koßlowski: „Active CPW MMIC circulator for the 40GHz Band“, Proceedings of the 24th European Microwave Conference, Cannes (France), 5.-8. September 1994, Vol. 1, pp. 542-547.

[3] E. J. Wilkinson: „An n-way hybrid power divider“, IRE Transactions on Microwave Theory and Techniques, MTT-8, 1960, pp. 116-118

[4] P. Pogatzki, R. Kulke, Th. Sporkmann, D. Köther, R. Tempel, and I.Wolff: „A Comprehensive Evaluation of Quasi-Static 3D-FD Calculations for more than 14 CPW Structures - Lines, Discontinuities and Lumped Elements“, MTT-S, San Diego, 23-27 May 1994, Vol. 2, pp. 1289-1292