

Broadband Wilkinson Divider

Andreas Wentzel and Dariusz Pienkowski

Technische Universität Berlin, Microwave Engineering Group, Einsteinufer 25, 10587 Berlin, Germany,
tel. 00493031426984, pienkows@mwt.ee.tu-berlin.de

Short Abstract — This paper introduces a hybrid wideband architecture of the Wilkinson divider with tapered line and compares it with two-stage architecture. Such a combiner is broadband and works from 0.5 up to 3.5 GHz. The limiting factor of this solution is the insertion loss.

Keyword: wilkinson power divider, combiner, tapering, power amplifier

I. INTRODUCTION

The Wilkinson power divider is often made in microstrip or stripline form and is in common use in RF design, since it was introduced quite a lot years ago [1]. The divider/combiner is used to combine the power of multiple transistors in an amplifier or antennas in a system, or divide the power among channels in a receiver [2]. The main disadvantage of the circuit is relatively narrow band of operation, which gains more on importance when ultra wide band solutions are required. Even with the use of new wide band gap SiC or GaN transistors achieving high output power in power amplifiers require the use of power combining and dividing. Dividing is required at the input of the power amplifier and combining is needed at its output. In ideal case, when two amplifiers are considered the output power can be doubled. However, the combiner and splitter, which are in most cases the same structure introduces losses. Therefore a low loss combiner is required what for one frequency or even narrow band operation could be realized. The problem enlarges when broadband power amplifier like this shown in [6] are combined. This two-stage 5-W wide-band RF power amplifier has been designed using a SiC MESFET power stage covering the frequency range from 10 MHz up to 2.4 GHz. Another important combiner parameter is isolation. The output power of one amplifier should not appear at the output of another amplifier's output. With high output power this issue gains on importance. Thus, power combiner has to feature with low loss and good isolation over a wide band at the same time.

One of the established methods that enable the broadband operation of the Wilkinson divider (combiner) is the use of multiple stages, as it was introduced in [3]. Generally, each stage makes the bandwidth wider, but simultaneously introduces transmission losses, which are critical for high power applications, as it is already written. This leads to the trade-off between the losses and the bandwidth. More sections require also more area. In case of system on board solutions it is not the problem, but in some cases where area constraints are important it could play an important role. Another possibility for broadband operation is the use of tapered lines as it is

described in [4]. The tapered solution requires a similar area, but shows the wider bandwidth.

An optimum solution seems to be a hybrid one that combines two-stage and tapered combiners. Therefore, in this paper we introduce two-stage Wilkinson power combiner with the second section tapered. We investigate and compare a two-stage combiner with a combiner with the second stage tapered. This paper is organized as follows: section II describes the design of the compared circuits, section III compares measured and simulated data regarding insertion loss, return loss at the input and output and isolation. Section IV completes this paper.

II. CIRCUIT REALIZATION

The simplified schematic of the two-stage Wilkinson combiner is shown in Figure 1.

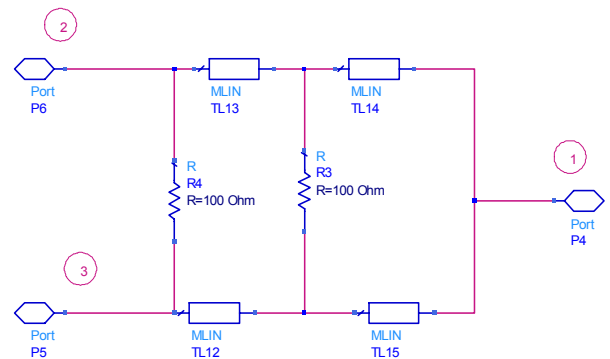


Figure 1. Two-stage Wilkinson combiner.

This combiner is called “normal” further in the scope of this text. This circuit represents a lossy three-port network which can be made having all ports matched with isolation between the output ports (port 3 and port 2) [5]. It has the useful property of being lossless when the output ports are matched; that is, only reflected power is dissipated. This normal Wilkinson combiner contains two pairs of quarter-wavelength transmission lines having a characteristic impedance of $\sqrt{2} \cdot Z_0$ (70.7Ω if we define Z_0 to be 50Ω) and two bridging resistors with a value of $2 \cdot Z_0$ (100Ω) to match the ports. The electrical length of the transmission lines is different in each stages; it is optimized for the broad band operation. The second combiner introduced in this paper is shown in Figure 2. This circuit is called “tapered” further in the text. The first stage is almost

identical with the “normal” combiner, and the second stage is tapered. In reality more complicated structures are used, because of area and feasibility constraints. Therefore, transmission lines fabricated on the laminate are not straight; they are curved this way, that small surface mounted resistor can be placed at the end of the branches. Moreover in physically realized structure which has been simulated additional microstrip components (Tee, Bends, Steps) are used. Therefore it was possibly to use the automatic layout

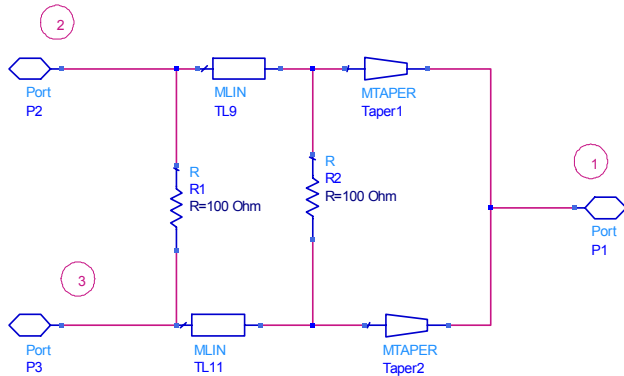


Figure 2. Two-stage Wilkinson divider with the second stage tapered.

generation tool, the feature from ADS. The photograph of these two dividers is shown in Figure 3. It is clear to see from the photograph that second tapered stage consumes less area.



Figure 3. Photograph of the realised combiners; tapered on the left, normal on the right side.

Among a possible few solutions for tapered microstrip line the triangular taper has been chosen, because of the fact that such transmission lines are available in layout design software ADS form Agilent. The impedance of the triangular tapered transmission line along its length $Z(z)$ and the reflection coefficient magnitude response $|\Gamma|$ varies like it is shown in Figure 4 and 5. The Z_0 means the impedance seen at the beginning of the line, Z_L is the load impedance connected to the line. This two figures show the possibility of broadband operation of such a transmission line. The impedance along the line length and the reflection coefficient do not change as

rapidly as in the case of normal transmission line. Thus with proper combining of transmission and tapered lines desired passband operation of the divider can be achieved.

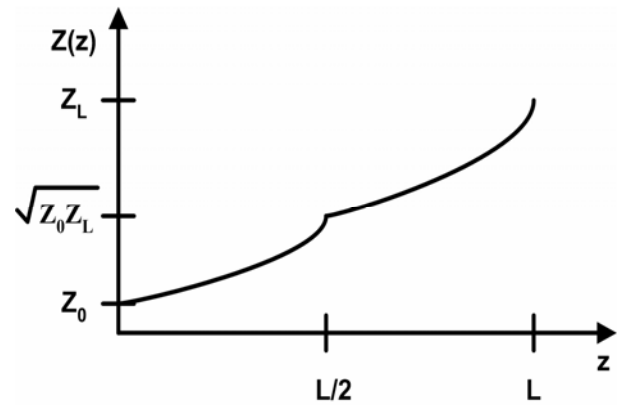


Figure 4. Variation of impedance of a tapered line

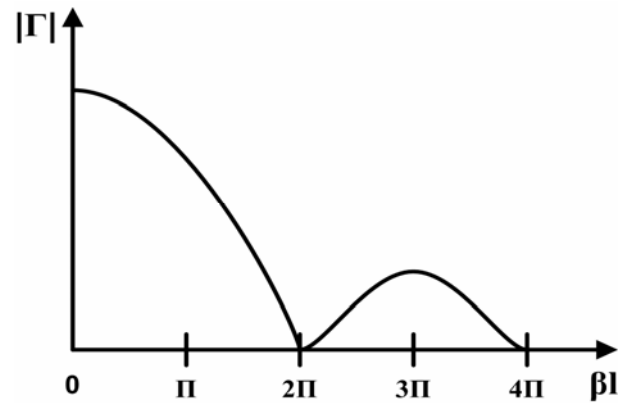


Figure 5. Reflection coefficient magnitude response of a triangular taper

III. MEASUREMENT RESULTS

In this section measurement data of the combiners are shown. Both combiners have been fabricated using the RO 4003 PCB laminate form ROGERS and measured in the frequency range from 500 up to 5000 MHz. The resistors used the circuit posses of 1 % tolerance. On the each following Figure we compare both types of combiners.

In Figure 6 the input reflection coefficient at Port 1 (common port) of both combiners is shown. If we assume that -10 dB is the highest possible value; we see that the input matching at Port 1 for “normal” combiner is not satisfactory for the frequencies higher than 2.5 GHz. In turn, the tapered combiner shows good input matching at this port in the whole, measured frequency range.

In Figure 7 the input reflection coefficient at Port 2 and Port 3 is shown. Since the circuits are symmetrical both values are the same, and for that reason only input matching at Port 3 is depicted. Taking the same criterion as an in the previous case we see that both solutions work in wide frequency range.

The transmission loss of the combiners is shown in Figure 8. This is important parameter and should be as low as possible. The “normal” combiner has lower insertion losses than “tapered” up to 2.5 GHz, but for the higher frequencies the losses are unacceptable. In turn, “tapered” combiner works in wider frequency range. With maximum 1 dB loss it works up to 3.5 GHz, when the “normal” combiner only up to 2 GHz. The insertion loss of the second branch (S_{13}) is identical and not shown here..

The last measured parameter is isolation between the ports shown in Figure 9. Once again taking as a criterion the value of 10 dB is easy to see that “tapered combiner” works at least up to 5 GHz. In turn, “normal” combiner works up to 2.5 GHz. However the lowest value of less then -35 dB shows the “normal” combiner.

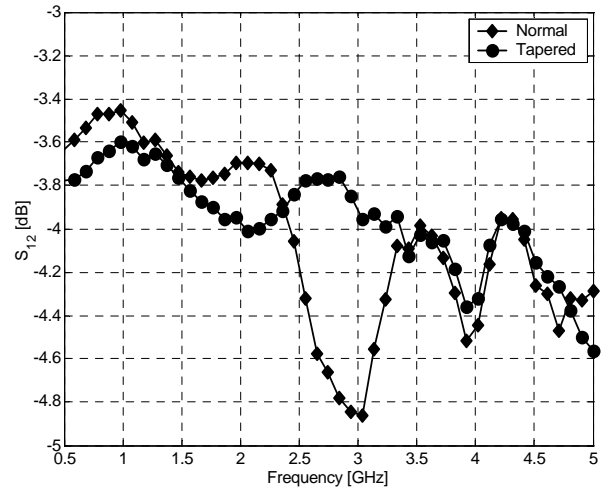


Figure 8. Measured S_{12} of the combiner.

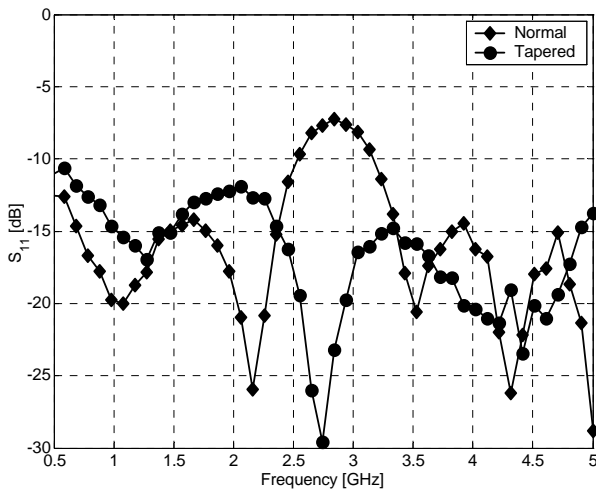


Figure 6. Measured S_{11} of the combiner.

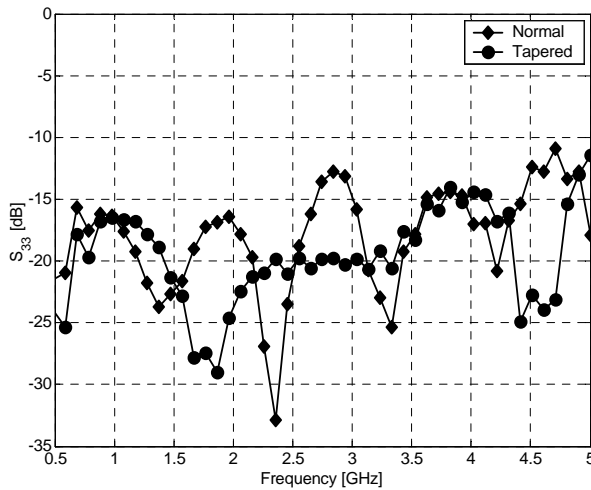


Figure 7. Measured S_{33} of the combiner.

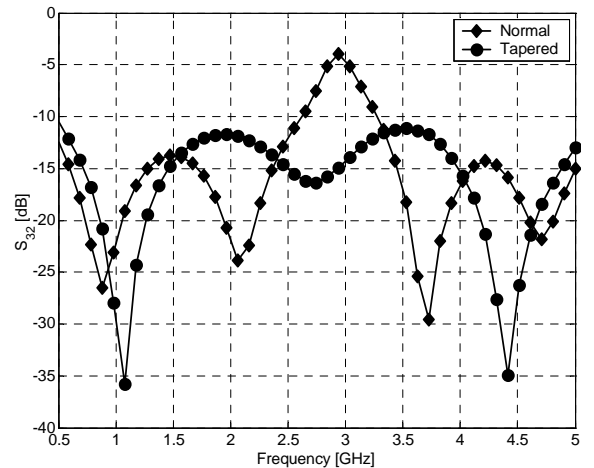


Figure 9. Measured S_{32} of the combiners.

IV. CONCLUSION

Two wideband architecture of the Wilkinson divider are shown in this paper. Two-stage transmission line architecture is compared with the architecture with the second stage tapered. The second architecture is broadband and works up to 3.5 GHz, since the architecture without tapered stage only up to 2.5 GHz. The limiting factor of the tapered solution is insertion loss, because other parameters are broadband. Two stages untapered solution is limited by insertion losses, isolation and input matching at the common port.

There are several possibilities to improve the performance of the combiner presented in this paper. The third stage would also increase the the transmission loss, but additive inductive and capacitive elements connected in the branches of existing two stages will help to decrease loss.

REFERENCES

- [1] E. Wilkinson, "An *N*-Way Hybrid Power Divider", IRE Transactions on Microwave theory and Techniques, January 1960, p. 116-119
- [2] I.D. Robertson, S. Lucyszyn, "RFIC and MMIC design and technology", IEE Circuits, Devices and Systems Series 13
- [3] S. B. Cohn, "A Class of Broadband Three-port TEM Hybrids", IEEE Transaction on Microwave Theory and Techniques, vol MTT-16, No 2, February 1968, pp 110 - 116
- [4] D.I. Stones, P. D. Chowm, "Q and V band Combiners" MTT-S Digest, 1991, pp 1049 – 1052.
- [5] D. Pozar, "Microwave Engineering", 3rd Edition, John Wiley & Sons, Inc., 2005
- [6] Sayed, A.; Boeck, G. "Two-stage ultrawide-band 5-W power amplifier using SiC MESFET", Transactions on Microwave Theory and Techniques, Volume 53, Issue 7, July 2005 Pages:2441-2449