Modified Millimeter-Wave Wilkinson Power Divider for Antenna Feeding Networks

Article *in* Progress In Electromagnetics Research Letters · January 2010

DOI: 10.2528/PIERL10061805

Progress In Electromagnetics Research Letters, Vol. 17, 11–18, 2010

MODIFIED MILLIMETER-WAVE WILKINSON POWER DIVIDER FOR ANTENNA FEEDING NETWORKS

F. D. L. Peters, D. Hammou, S. O. Tatu, and T. A. Denidni

University of Quebec
Centre INRS, Énergie, Matériaux et Télécommunications
800, de la Gauchetiére Ouest, suite 6900
Montréal (Québec), H5A 1K6, Canada

Abstract—This paper outlines typical issues in the design and fabrication of microstrip Wilkinson power dividers. As a practical solution, a modified Wilkinson divider configuration is proposed and designed for millimeter-wave antenna feeding networks. In this design, all microstrip branches and the resistive strip exhibit the same characteristic impedance. Probe measurements of S-parameters underline good matching, transmission and isolation characteristics of the proposed divider.

1. INTRODUCTION

Recently, much attention has been drawn on millimeter-wave antennas for future radar and communication applications. Microstrip is widely used as technology for both the feeding network and radiating elements. Supporting advantages for applying this technique are low cost, low profile and ease of production. In addition, when edged on very thin high dielectric substrates, parasitic effects like substrate waves and spurious radiation can be effectively suppressed [1].

While composing an antenna array, series or corporate feeding may be selected. In the latter case, the feeding network requires power dividers in various topologies, such as Lange [2], Wilkinson [3] or a simple T-junction [4].

Recently, solutions using microstrip technique for millimeter-waves have been proposed in [5–8]. Although of good performance, the design and manufacturing procedures of some of these dividers are accompanied by several issues described in the second section.

Received 18 June 2010, Accepted 11 August 2010, Scheduled 17 August 2010
Corresponding author: F. D. L. Peters (peters@emt.inrs.ca).

In order to overcome these typical issues, a new practical approach is described in the next section followed by measurement results.

2. DESIGN

2.1. Modified Wilkinson Divider

The theory of a Wilkinson power divider may be studied in [4]. Note that two transitions from - and back to the characteristic impedance Z_0 are necessary. A transmission line of Z_0 is split into two lines of $\sqrt{2}Z_0$ and vice versa after a section of $\lambda_g/4$ from $\sqrt{2}Z_0$ back to Z_0. The resistance of the value $2Z_0$ should be connected in the course of the second transition.

Design constraints and difficulties accompany the conventional realization of the power divider with microstrip. First, the angle φ, see Figure 1(a), of the outgoing branches is limited since the impedance conversion has to be achieved without severe losses. Second, this latter mentioned transition from one width to another generally exhibits higher losses than a simple mitered curve with only one width. Finally, in theory, the resistance needs to be between both parts of different widths, which yields an ambiguous situation for the design procedure and often leads to more optimization runs from case to case.

Figure 1(b) together with a detailed view in Figure 2, depicts the modified structure and the solution to all three given typical disadvantages of its original equivalent in Figure 1(a). The simple design approach is as follows: By choosing $Z_0/\sqrt{2}$ as intermediate impedance preceding point **B**, the subsequent impedance according to the Wilkinson design rules is

$$Z_{in} = \frac{\sqrt{2}\, Z_0}{\sqrt{2}} = Z_0, \tag{1}$$

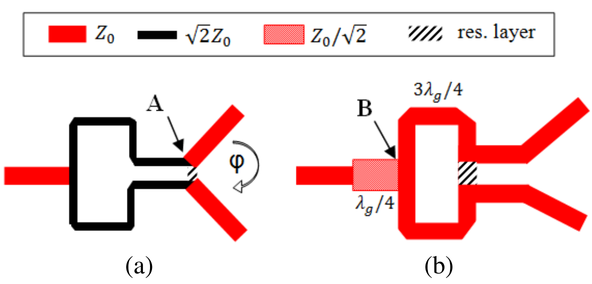

Figure 1. (a) Common architecture and (b) modified Wilkinson divider.

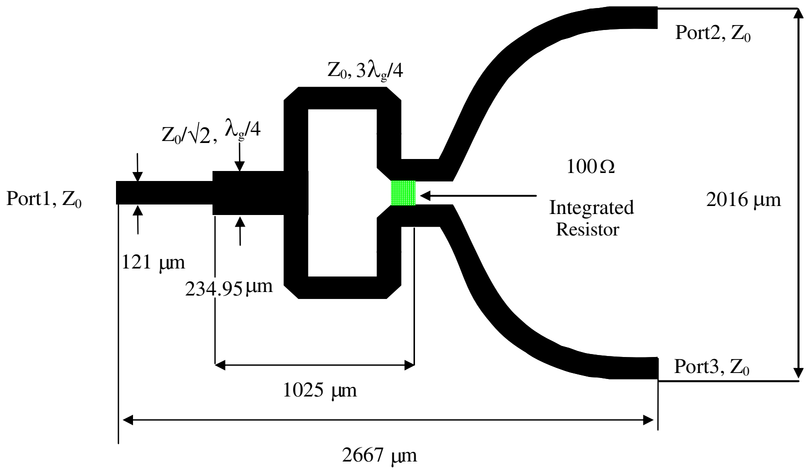

Figure 2. Layout dimensions of the modified Wilkinson power divider.

since the resistance is kept to be $2Z_0$. This allows forming a homogenous structure of the characteristic impedance Z_0 in the following entire course of the divider. The transition from Z_0 to $Z_0/\sqrt{2}$ however has to provide acceptable results, which is the case as we will see.

Applying this approach also yields the advantage of having the same width in both the conductive and resistive part. Furthermore, the space and the isolation increase between the branches in the zone of the resistance. This is due to the fact that a resistance of $2\ Z_0$ is obtained by designing a square of resistive layer (in our case $100\,\Omega$/square), which should have the width of the microstrip in optimal case.

As a result, in contrast to the transition in Figure 1(a), at point **A**, a hassle-free design is guaranteed in the modified design at the same location.

2.2. Patch Antenna Design

In order to prove the feasibility regarding substrate thickness, dielectric constant and matching of *all* components of an arbitrary antenna array, a patch antenna is designed and fabricated.

The radiating element length and width are calculated and optimized to carry a TM_{01}-mode. Inset fed technique [9] is applied for impedance matching. The latter technique is still applicable for designing the feeding line, as seen in previous work [10]; however, some degradation compared to the perfect current distribution and radiation is expected.

3. RESULTS

The above proposed power divider and the patch antenna have been fabricated on a 0.127 mm substrate with $\epsilon_r = 9.9$ and a loss tangent of 0.001. Gold has been selected as conductive layer. This section depicts the results in terms of S-parameters of both the divider as well as the patch.

3.1. Measurement Setup and Conditions

In order to perform on-wafer measurements of the S-parameters, several circuits adapted for two-port measurements were fabricated. The branches of each circuit are designed and optimized to ensure a good phase balance. In addition, to provide connection with ground-zero-ground (GSG) 150 µm-probes, CPWG to microstrip transitions were also designed and included. In order to eliminate the impact of the transitions on the network parameters, a through-reflect-line (TRL) calibration is done equally with the same transitions. The resulting reference planes are marked in Figure 4 as dotted vertical lines.

Figure 4(a) and (b) show the micro-photograph of the modified Wilkinson power divider prepared for the two-port measurements. The unused ports (marked by dashed rectangles) are terminated by 50 Ω loads. These loads are implemented using an integrated resistor of 50 Ω, fabricated on 100 Ω per square titanium 20 nm thin resistive layer. The entire architecture is given in the following Figure 3.

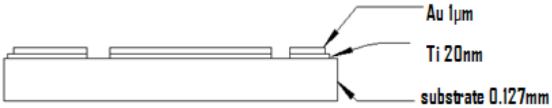

Figure 3. Physical layers of the fabricated Wilkinson power divider.

In order to improve the measurement accuracy, the standard of the TRL calibration technique is edged on the same alumina substrate as the circuits to be measured. Due to the fragility of the very thin gold layer metallization (1 µm), multiple TRL identical standards and circuits were fabricated on the same wafer to ensure repeatable and successful calibration and measurements.

For the full characterization of this divider, three measurement configurations are used due to their dimensional symmetry. Measurements are performed for input reflection, forward transmission and isolation between both branches. It is noted that the used vector network

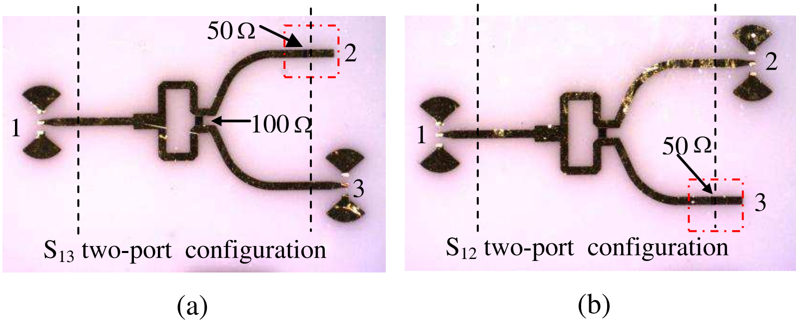

Figure 4. Modified Wilkinson divider and GCPW to microstrip transitions prepared for S-parameter measuring, (a) for S_{11}, S_{22} and S_{21}, (b) for S_{33}, S_{31}.

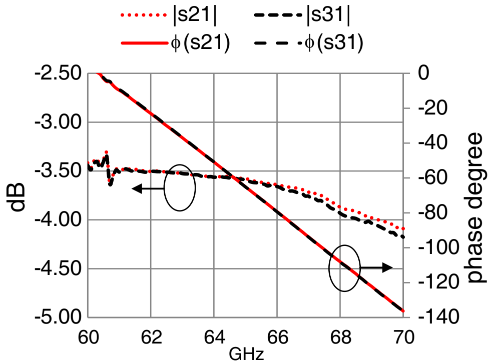

Figure 5. Forward transmission (S_{21} and S_{31}), magnitude and phase.

analyzer provides measurements from 60 to 90 GHz. Nevertheless, only few degradation of the performance is observed in the upper side of the frequency band of interest from 60 to 64 GHz, which allows anticipating similar measurement results to the whole frequency band, from 57 to 64 GHz.

3.2. Scattering Parameters of the Divider

On-wafer GSG probe measurements were performed, the results are given in the following figures. The forward transmission ratio of port 2 and 3 is very close to half. Figure 5 reveals also an insertion loss of 0.5 dB in the considered band, and less than 1 dB over 10 GHz.

Excellent input matching performance is achieved, as shown in

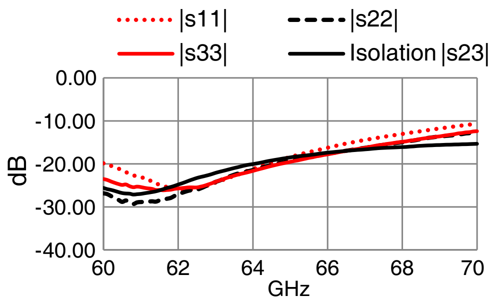

Figure 6. Input reflection (S_{11}, S_{22}, S_{33}) and isolation (S_{23}).

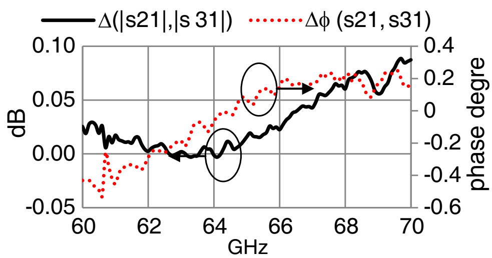

Figure 7. Magnitude and phase deviation of port 2 and 3 of the divider.

Figure 6, over the entire band. Good isolation of at least 15 dB is also noted in the entire decade from 60 to 70 GHz, as presented in Figure 6.

Comparing the forward transmission of both branches, as done in Figure 7, reveals only very minor deviation of both magnitude and phase. In fact, the error is virtually zero in the considered band, excellent condition for a corporate antenna feeding of uniform aperture distribution.

3.3. Scattering Parameters of Patch and Array

For future steps, the rectangular microstrip patch antenna is measured the same way as the Wilkinson divider applying on-waver GSG probes. A picture of the fabricated patch antenna is shown in Figure 8, whereas the results are depicted in Figure 9. They reveal a strong resonance perfectly placed within the considered band of 1.6%.

Applying the above designed Wilkinson power divider and patch antenna, simulations of an appropriate four-element array were performed. The input reflection and the radiation pattern are given in Figure 9 and Figure 11 respectively. Side lobe level of 11.4 dB is

Figure 8. Microphotograph of the patch antenna.

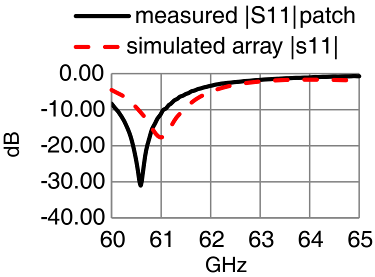

Figure 9. Input reflection measurement results of the patch and simulated array.

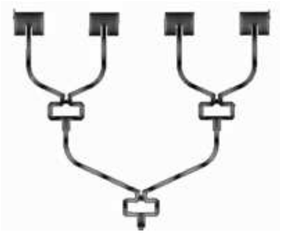

Figure 10. Simulated structure.

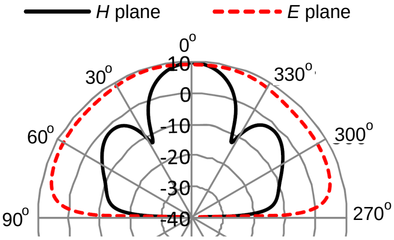

Figure 11. Simulated radiation pattern of an array of four radiating elements.

obtained, together with a max. gain of approx. 9.4 dBi.

Unfortunately far field measurement resources have not been allocated by the time of writing this paper.

4. CONCLUSIONS

In this paper, a microstrip solution for a Wilkinson divider with modified structure has been proposed. The modification leads to a more simple design procedure and less degradation of the forward transmission and matching performance. In the considered band, the measured reflection loss stayed below -20 dB, the insertion loss below 0.5 dB and high isolation of at least 20 dB have been observed between branches. A good performance has been obtained also above the band over at least 10 GHz. A patch antenna has been designed and used with the proposed power divider to form an antenna array. Simulations of a four-element array underlined the concept of the divider.

Furthermore, this equal in-phase divider may be useful for all V-band antenna feeding networks with high requirements on phase and magnitude accuracy.

REFERENCES

1. Deslandes, D. and K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *IEEE Microwave and Wireless Components Letters*, Vol. 11, No. 2, 68–70, 2001.
2. Lange, J., "Interdigitated stripline quadrature hybrid (correspondence)," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 17, No. 12, 1150–1151, 1969.
3. Wilkinson, E. J., "An N-way hybrid power divider," *IRE Transactions on Microwave Theory and Techniques*, Vol. 8, No. 1, 116–118, 1960.
4. Pozar, D. M., *Microwave Engineering*, 3rd edition, Wiley, Hoboken, NJ, 2005.
5. Boukari, B., D. Hammou, E. Moldovan, R. G. Bosisio, K. Wu, and S. O. Tatu, "MHMICs on ceramic substrate for advanced millimeter wave systems," *IEEE MTT-S International Microwave Symposium Digest, 2009, MTT '09*, 1025–1028, 2009.
6. Chang, C.-P., C.-C. Su, S.-H. Hung, Y.-H. Wang, and J.-H. Chen, "A 6 : 1 Unequal Wilkinson Power Divider with EBG CPW," *Progress In Electromagnetics Research Letters*, No. 8, 151–159, 2009.
7. Hammou, D., E. Moldovan, and S. O. Tatu, "Modeling and analysis of a novel V-band MHMIC six-port circuit," *Progress In Electromagnetic Research*, Vol. 24 No. 10, 1419–1427, 2010.
8. Shamsinejad, S., M. Soleimani, and N. Komjani, "Novel miniaturized Wilkinson power divider for 3G mobile receivers," *Progress In Electromagnetic Research Letters*, Vol. 3, 9–16, 2008.
9. Ramesh, M., Y. I. P. KB, and P. Motorola, "Design formula for inset fed microstrip patch antenna," *Journal of Microwaves and Optoelectronics*, Vol. 3, No. 3, 5–10, 2003.
10. Peters, F. D. L., S. O. Tatu, and T. A. Denidni, "77 GHz microstrip antenna with gap coupled elements for impedance matching," *Progress In Electromagnetics Research C*, Vol. 9, 35–45, 2009.