MMIC Wikinson Couplers for Frequencies up to 110 GHz

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Abstract

Reciprocal power splitters and combiners can be realized by using Wilkinson couplers. However, for frequencies lower than a few GHz such couplers are normally too large for application in MMICs. At the same time, for designing Wilkinson couplers at high frequencies discontinuities must be considered. For the first time, this paper reports on miniaturized Wilkinson couplers for 1.8GHz with space requirements of 1.2x0.8 mm^2 as well as on designing couplers for frequencies up to 80GHz.

Introduction

Standard Wilkinson couplers are required for many applications such as power amplifiers, mixers or active circulators. In [1] such n-port power dividers were first presented. For MMICs, most designers avoid using these couplers on-chip since normally the space requirement is quite large due to the $\lambda/4$ length of the coupling section. In designing MMICs, the Wilkinson coupler is typically utilized at medium and high frequencies (>10GHz). Most papers on novel coupler types are still considering conventional dimensions for the coupling section. The recent paper by Merneyei et al. [3] for instance explains the design of a broadside coupled line structure where the two coupled lines are on two different metallisation layers. Similar couplers have been described before. The drawback in all these cases is, that such couplers become quite large at low frequencies. First attempts in miniaturizing couplers were shown in [4] and [5]. Also, the idea of applying lumped elements for couplers is not new [2]. In addition, there are clearly a lot of applications at lower and higher frequencies where compact couplers are desperately needed. Unfortunately, such coupler designs are not yet available in practice. At low frequencies for instance, the phase shift of 90° can hardly be realized on-chip by using transmission lines. At high frequencies in contrast, the applied discontinuities (e.g. T-junctions) lead to an undesired response which in return must be considered by a modified structure. Therefore, new types of Wilkinson couplers are required. For the first time, this paper gives practical design guides for two types of Wilkinson couplers. The simulations shown in the following are based on a 3D-FD algorithm which was verified in large extend up to about 67GHz for most calculated structures [6]. The hardware for all described structures was fabricated by the Daimler Benz Foundry on a PMHFET wafer.

Conventional Wilkinson couplers

A standard Wilkinson coupler consists out of two transmission lines with a characteristic impedance of $\sqrt{2}\,Z_L$ (Z_L = port reference impedance) and an extension of a quarter wave length. Both branches are combined by a resistor with $R = 2 \times Z_L$ (Fig. 1).

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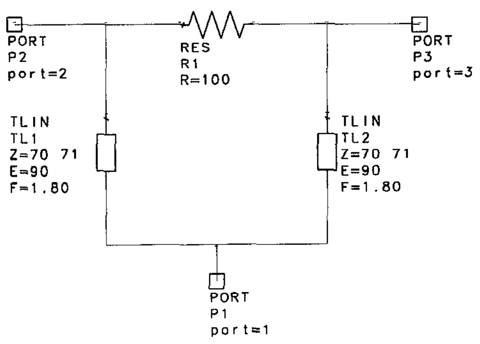

Fig. 1: Schematic of a standard Wilkinson coupler for 1.8GHz

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This fact makes it impossible to realize such a coupler e.g. at a frequency of 1.8GHz or lower in a MMIC design. On GaAs for instance the length of such a coupler will be around 12mm. The scattering parameters of this ideal structure are shown in Fig. 2.

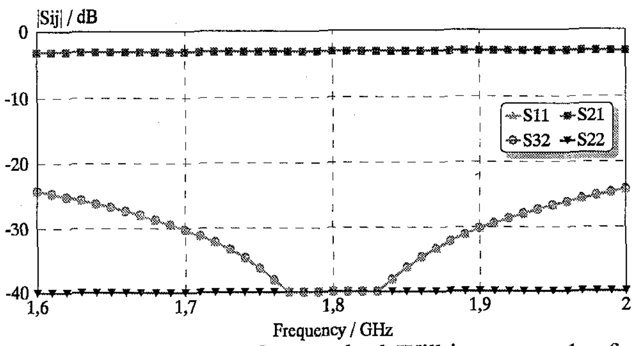

Fig. 2: S-parameters of a standard Wilkinson coupler for 1.8GHz

It can clearly be seen that the isolation bandwidth is limited by the quarter wave length requirement.

Wilkinson couplers with discrete elements (not for MMICs)

At low frequencies, a Wilkinson coupler can also be designed based on concentrated elements. The basic idea in this case is, that the 90° phase shift may be realized by using serial inductors and serial capacitors (Fig. 3).

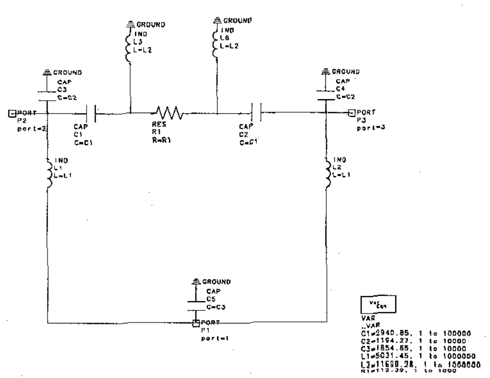

Fig. 3: Schematic of a Wilkinson coupler with discrete elements for 1GHz

For better matching and for increased bandwidth some additional elements are also included. In Fig. 4 the properties of the structure are depicted. This design shows a wider bandwidth than the ideal Wilkinson coupler (see Fig. 2) because only discrete elements are utilized in this principle. The application frequencies for such a coupler can be much lower than 1.8GHz for instance.

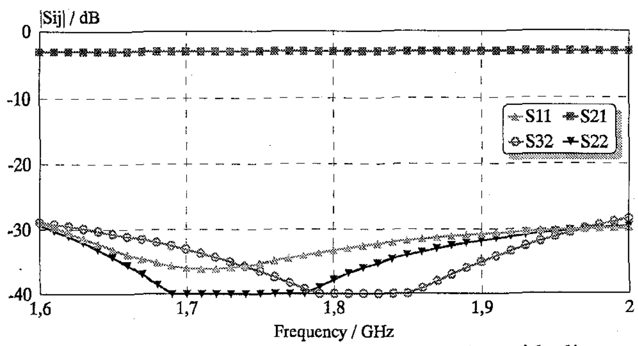

Fig. 4: S-parameters for a Wilkinson coupler with discrete elements (f_{center} = 1.8GHz)

MMIC applicable Wilkinson couplers with lumped CPW elements

For MMICs, a modified version of the above described discrete element coupler is applicable. Such a coupler may utilize only Line Unified (LU-) lumped CPW elements as it is shown in Fig. 5.

In this case, all connecting transmission lines have a length of only 10μm. These lines are required only for separating the important elements (resistor, inductor, tee). A complete layout of this circuit is shown in Fig. 5.

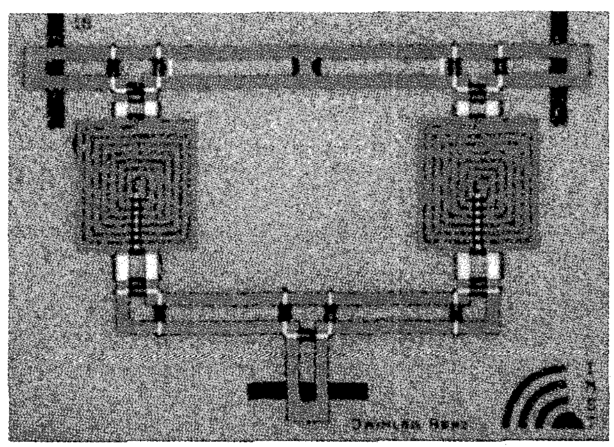

Fig. 5: Layout of a Wilkinson coupler with CPW lumped elements for 1.8GHz (1400x900μm^2)

The coupler consists out of two inductors, a resistor, three tee junctions and some CPW line elements. The size of this circuit is only $1400x900\mu m^2$ and could even be reduced further. Due to the small size the S-parameters (Fig. 6) are comparable to those of the ideal Wilkinson coupler. Mesa based resistors were utilized in all Wilkinson couplers shown in this paper. These resistors have a tolerance of about 10% in the impedance value. Thus it may be more practical to utilize active resistors (tunable) for this type of coupler.

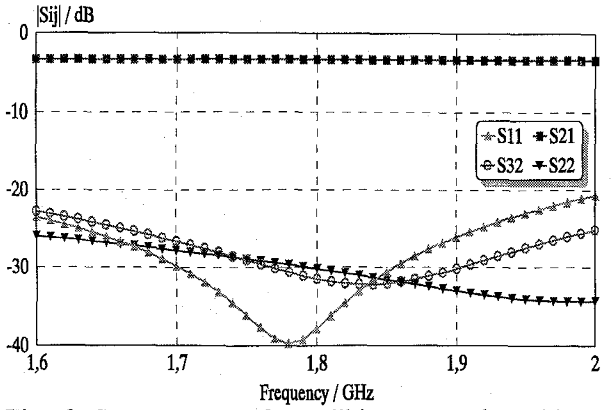

Fig. 6: S-parameters of a Wilkinson coupler with CPW lumped elements for 1.8GHz

The insertion loss between input and output is about 3.1dB while the return loss at the ports is better than 20dB for a bandwidth of 20%. The isolation of the coupler is around 25dB. In some publications couplers with about 3.5dB insertion loss have been reported. In no case however, values of about 3.1dB could be achieved. It should also be pointed out at this time, that the losses of the components are realistically taken into account for the simulation. Such a coupler is ideally suited for low frequencies where $\lambda/4$ dimensions are large and where low insertion loss is required.

CPW Wilkinson coupler for 80GHz

For high frequencies „conventional“ Wilkinson couplers may be designed. These couplers utilize transmission lines, tee's, bends and a resistor. A schematic of such a classical Wilkinson coupler is depicted in Fig. 7. Matching elements are applied to each port in order to provide good matching (better 20dB) at a broad frequency band (> 20GHz). In Fig. 8 a photograph of a circuit for 80GHz is shown. The airbridges required for suppressing the odd mode can also be seen in this picture.

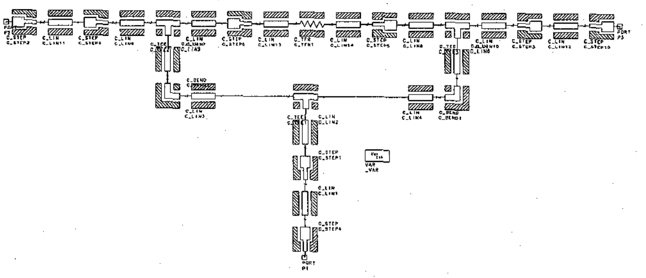

Fig. 7: Schematic of a Wilkinson coupler in CPW line technique for 80GHz

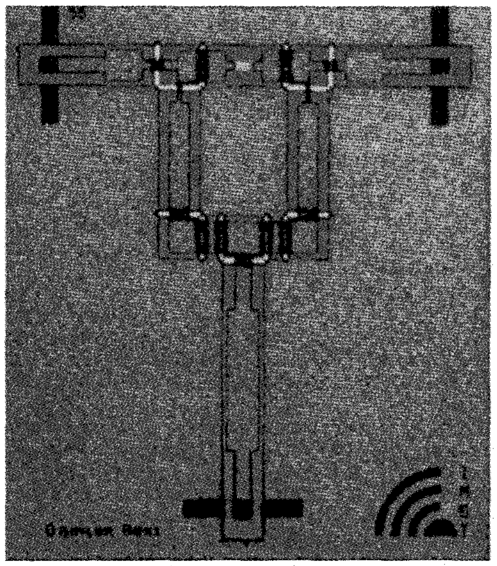

Fig. 8: Layout of a Wilkinson coupler in CPW line technique for 80GHz

However, all effects due to discontinuities have to be taken into account. It is no longer possible to apply inductors for realizing the 90° phase shift. Such a phase shift can now be realized with transmission lines as in the standard Wilkinson coupler. The size of the nominal $2xZ_L$ resistor must be appropriate to the frequencies (line effects) and technological limitations (too short). In order to compensate for the non-ideal T-junction some additional matching elements have been introduced.

The design of this coupler was conducted by utilizing the accurate CPW element models as described in [5].

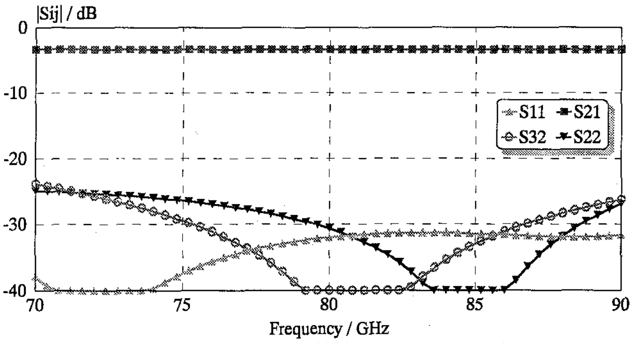

Fig. 9: S-parameters of a Wilkinson coupler in CPW line technique for 80 GHz (1200x800μm^2)

The simulated S-parameters vs. frequency are depicted in Fig. 9 for such a 80GHz coupler. The predicted properties are comparable to the result of the other types of Wilkinson couplers. It is also interesting to see, that even at these high frequencies it is no problem to realize a bandwidth of about 20%.

Conclusion

For the first time, Wilkinson couplers for MMIC application at 1.8GHz and 80GHz have been shown. This paper demonstrates that such couplers no longer need to be avoided in designing MMICs. All interesting frequencies can be covered by the described coupler designs. LU-lumped CPW couplers are suitable at the low frequency end. It is clear that such couplers not only can be realized in CPW technique but also in conventional microstrip line technique. All designs feature a very low insertion loss around 3.1dB (3dB for the ideal coupler) and isolation as well as input reflection below -25dB with a bandwidth of over 20%.

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