Design of a Compact UWB Out-of-Phase Power Divider

M. E. Bialkowski and A. M. Abbosh

***Abstract*—The design of a compact out-of-phase uniplanar power divider operating over an ultra wide frequency band is presented. To achieve an out-of-phase signal division over a large frequency range, a T-junction formed by a slotline and a microstrip line accompanied by wideband microstrip to slotline transitions is employed. The simulated and experimental results of the developed divider show a low insertion loss and good return loss performance of the three ports across the band 3.1–10.6 GHz.**

***Index Terms*—Power divider, ultra wideband (UWB), Wilkinson divider.**

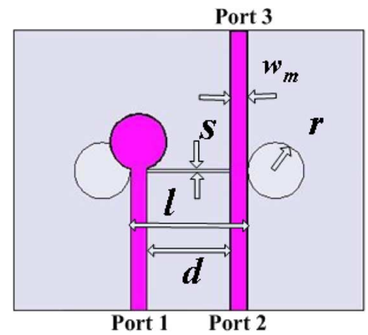

Fig. 1. Configuration of the proposed power divider.

I. Introduction

POWER dividers are fundamental components extensively used in a variety of microwave circuits such as balanced mixers, modulators, phase shifters, and antenna array feed networks [1]. The simplest type of power divider is a T-junction. It is a three-port network with one input port and two output ports. According to the phase between output ports, this type of power divider can be an in-phase or out-of-phase. In the latter case, a 180° phase difference between the output ports is offered. This phase difference is required in some applications such as a push–pull type amplifier, where the two transistors are fed 180° out-of-phase.

In [2], the authors have shown that the out-of-phase type Wilkinson divider can be designed using parallel strip transmission lines (PSTLs). The symmetrical characteristic of PSTL implies that the “ground” and “signal” lines can be freely interchanged. This leads to the possibility of having in-phase or out-of-phase signal division. One extra step required to use this arrangement is a PSTL to microstrip transition, which the authors of [2] also included in their design. By using this approach, a three-stage Wilkinson divider operating from 1 to 8 GHz was demonstrated. The shortcoming of the presented configuration is that it is not suitable for implementations in which the microwave device requires a uniplanar microstrip arrangement. This arrangement is required for creating an efficient heat sink.

In this letter, the configuration of a compact uniplanar out-of-phase divider with a low insertion loss is presented accompanied by simple design rules. Opposite to the Wilkinson divider, this device does not use any resistive elements. Because of the inherent properties of a lossless three-port [1], which are governed by unitary properties of its scattering matrix, it cannot offer a perfect match at its three ports, as its counterpart with resistors. In addition, isolation between its two output ports is compromised by the quality of match of its input and output ports. The better the match at the input and output ports, the worse is the isolation between the output ports.

In the presented design, the three-port exhibits return losses at its ports in the order of 10 dB across an ultra wide frequency band from 3.1 to 10.6 GHz, as demonstrated via simulations and measurements. The isolation between the output ports is about 8 dB across the same band. This return loss and isolation performance may be found sufficient in many applications even those involving a push–pull type of amplifier.

II. Design

The configuration of the proposed power divider is shown in Fig. 1. The three ports of the divider are at the top layer of the printed circuit board (PCB) while the ground plane is at the bottom layer of the circuit. There is a slot in the shape of a narrow rectangle ended with two circles in the middle of the ground plane. This slot is responsible for guiding the wave from the input port to the output ports.

Prior to its design, it is important to understand the operation of this device. The divider utilizes the series type T-junction formed by a slotline and two arms of a microstrip line. The inherent property of this junction is that the signals coupled from the slotline to the two arms of the microstrip line are of equal magnitude but their phases differ by 180°. In order to efficiently (without reflections) couple a signal from the slotline to the microstrip, the end of the slotline needs to be compensated with an inductive element. Here, it is chosen in the form of a circular slot. In order to convert the input port from the slot type to the microstrip type, a wideband slot to microstrip transition needs

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to be employed [3]. As seen in Fig. 1, the chosen transition is formed by two complementary structures. One includes a microstrip line terminated with a capacitive circular disk and the other one is a slotline terminated with an inductive circular slot. The two are electromagnetically coupled.

Having established the principles of operation of the power divider, a simple procedure can be applied to its design. The width w_m of the input and output microstrip ports is determined assuming 50 Ω characteristic impedance. The distance d between the input and output microstrip line does not have to be fine tuned. Here, it is chosen to be a quarter of the effective wavelength at the center frequency of operation (f_c). As a result, the length of the slot l is $l = d + 2w_m$.

In order to achieve a high return loss at the microstrip ports, the slot width (s) should be chosen to give impedance close to 50 Ω as seen from the microstrip side. At the same time, the slot width should not be too narrow to avoid problems with the manufacturing errors. To meet this requirement, a slot with acceptable width and suitable impedance transformation ratio (N) [3] can be used. The equations in [3] and [4] can be employed to accomplish this task. In the present design, the slot width is chosen to give impedance 90 Ω and the impedance transformation ratio is 0.8. As the result, the impedance of the slot as seen from the microstrip line is ($90 \times 0.8^2 =$) 55 Ω.

Radius r of the microstrip and slot circles terminating the microstrip and slot lines are chosen to be around twice of the microstrip width w_m. This choice conforms to the guidelines for designing wideband microstrip/slotline transitions [3].

III. Results and Discussion

The above outlined design method was applied to design an out of phase (180°) power divider that would cover the ultra wideband (UWB) range from 3.1 to 10.6 GHz. Rogers RO4003C with thickness 0.508 mm, dielectric constant 3.38 and tangent loss 0.0023 was used as a substrate. Values of the design parameters (w_m, d, r, and s) obtained using the outlined design procedure (without any involvement of sophisticated full EM analysis and design packages) were 1.2 mm, 7.3 mm, 2 mm, and 0.2 mm, respectively. According to these dimensions the proposed divider is compact and its length is around quarter of the effective wavelength in microstrip. This compares favourable against the Wilkinson divider presented in [1] where the length was larger than three quarters of the wavelength.

Having determined all of the parameters of the divider, the next step concerned the testing of its performance. The simulated results of the proposed power divider obtained using Ansoft HFSSv9.2 are shown in Fig. 2. These results reveal that the power is equally divided between the two output ports with an insertion loss less than 0.5 dB across the band 3.1 to 10.6 GHz. Also the return loss for the input port and two output ports (note that because of symmetry, $S33 = S22$ and thus S33 is not shown explicitly) is in the range of 10 dB for the whole band. Because of good quality return loss at the three ports, isolation between the output ports is sacrificed and is in the range of 8 dB. This is the result of the earlier discussed unitary properties of the scattering matrix of a lossless three port [1]. The difference in phase between the two output ports (not plotted here) is $180° \pm 0.25°$ over the same band.

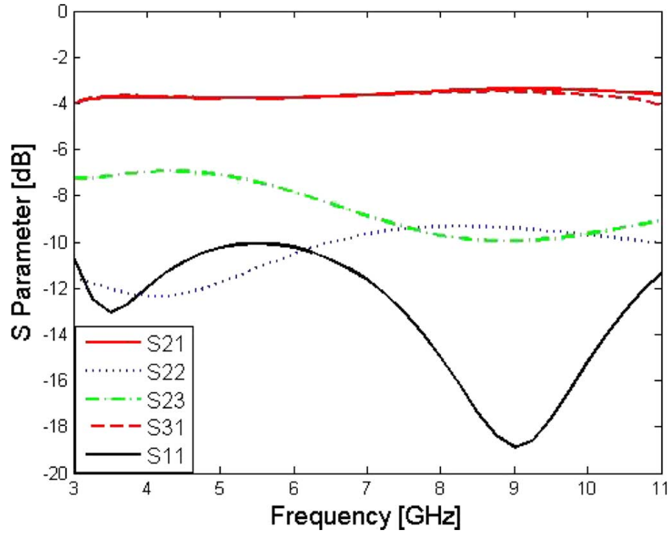

Fig. 2. Simulated performance of the designed power divider.

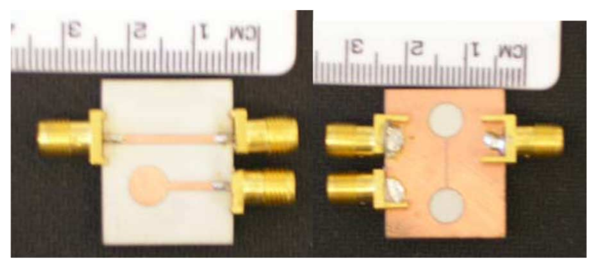

Fig. 3. Photograph of the top layer (left) and bottom layer (right) of the developed power divider.

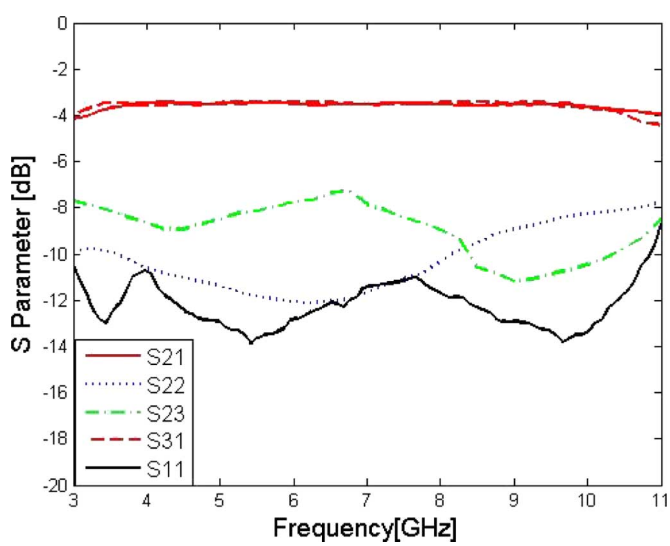

Fig. 4. Measured performance of the developed power divider.

The power divider was developed and tested experimentally. Photograph of the developed power divider is presented in Fig. 3.

Measurement results are shown in Fig. 4. The presented results confirm the UWB behaviour of the designed divider. Also they show good agreement with the simulated results. Small discrepancies can be explained by the use of coaxial ports in the experiment. As observed in Fig. 4, the power is equally divided be-

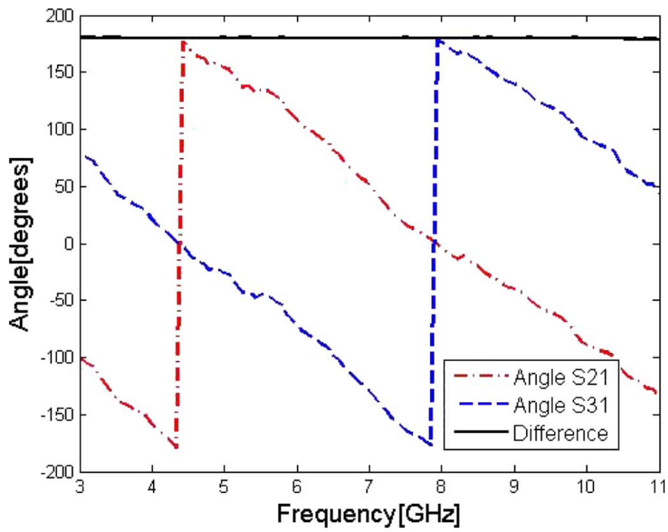

Fig. 5. Measured phase of transmission coefficients of the developed divider.

tween the two output ports with average insertion loss less than 0.5 dB. This insertion loss is lower than that of the Wilkinson divider presented in [1] where 0.8-dB insertion loss was noted. The return loss for the input port and output ports is in the order of 10 dB and isolation between the two output ports is between 7.5 and 11.5 dB across the band. Note that the presented measured results include losses of coaxial connectors that were used in the experimental testing.

The measured difference in phase between the two output ports is $180^\circ \pm 0.5^\circ$ over the band 3–11 GHz, as shown in Fig. 5. This proves that the proposed divider is an out-of-phase type.

IV. Conclusion

A simple method has been presented to design a compact UWB out-of-phase power divider. The proposed divider is of the uniplanar type and uses complementary structures in the form of microstrips and slots to achieve its UWB performance. The measured results of the developed power divider have shown a low insertion loss, less than 0.5 dB, a good return loss and isolation with high phase stability over the band 3.1–10.6 GHz.

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