An UWB Planar Out-of-Phase Power Divider Employing Microstrip-Slot and Parallel Stripline-Microstrip Transitions

A. M. Abbosh* and M.E. Bialkowski

School of ITEE, University of Queensland, Qld. 4072, Australia

E-mail: abbosh@itee.uq.edu.au

*Abstract-***The design of a planar out-of-phase power divider in microstrip/parallel stripline technology for ultra wideband (UWB) applications is presented. The device employs two substrates with a common ground plane. A coupling between two microstrip lines on the top and bottom substrate layers through a slot in the ground plane, and a suitable transition from two microstrip lines to a parallel stripline are used to achieve an UWB operation. The simulated and measured results of the proposed divider show low insertion losses, good return loss at the three ports, fine isolation and the required 180º phase difference for signals emerging from the two output ports across the band 3.1 to 10.6GHz.**

*Index Terms***- Microstrip line, stripline, ultra wideband, power divider.**

I. INTRODUCTION

A power divider formed by a three-port network with an input port and two output ports is a fundamental component extensively used in a variety of microwave circuits [1]. According to the phase difference between the output ports, this device can be classified as a quadrature (90º), in-phase (0º) or out-of-phase (180º).

While most of the early dividers used the waveguide structure, the increasing use of planar technology has led to the development of a wide range of planar dividers such as the Wilkinson divider, the branch line hybrid and the coupled line divider. Wilkinson divider is the most commonly used device to achieve in-phase or out-of-phase signal division [2] - [5]. Because of the use of resistive elements, this type of divider offers good impedance match at its three ports and high isolation between the two output ports. However, the resistive elements also contribute to some insertion loss, which in some applications is unwelcome. In order to achieve a wideband performance a few sections, each of about one quarter wavelength (at the centre frequency) has to be used. This makes the Wilkinson divider of a relatively large size in comparison with the operational wavelength.

In this paper an alternative configuration of a planar out-of-phase divider, accompanied by simple design rules, is presented. The device does not use any resistive elements and achieves an ultra wideband performance using a very compact size. From the inherent properties of a lossless three-port [1] it does not offer the same quality of return loss at its three ports and isolation between output ports, as the Wilkinson divider. However, as shown via computer simulations and measurements its return loss and isolation performance is very reasonable. The return loss at the input port is in the order of 15dB across an ultra wide frequency band from 3.1 to 10.6GHz. The return loss at its output ports is in the order of 10dB while the output ports isolation is about 12dB on the average across the same band. This may be found sufficient in many useful applications.

II. DESIGN

The configuration of the proposed power divider is illustrated in Fig.1. The device uses two substrates supported by a common ground plane. The first section of the power divider includes an input port (*E* port), which is formed by a parallel strip line. Next, a transition from a parallel strip line to two microstrip lines is formed to divide the signal equally in magnitude but out-of-phase. Note that the common ground plane exists in the two microstrip lines region but is removed in the parallel strip line section. Details can be viewed in Fig.1 b. Next, the two microstrip lines are bent so they can be connected to two elliptically shaped conducting discs, which together with a slot in the common ground plane form a coupling structure.
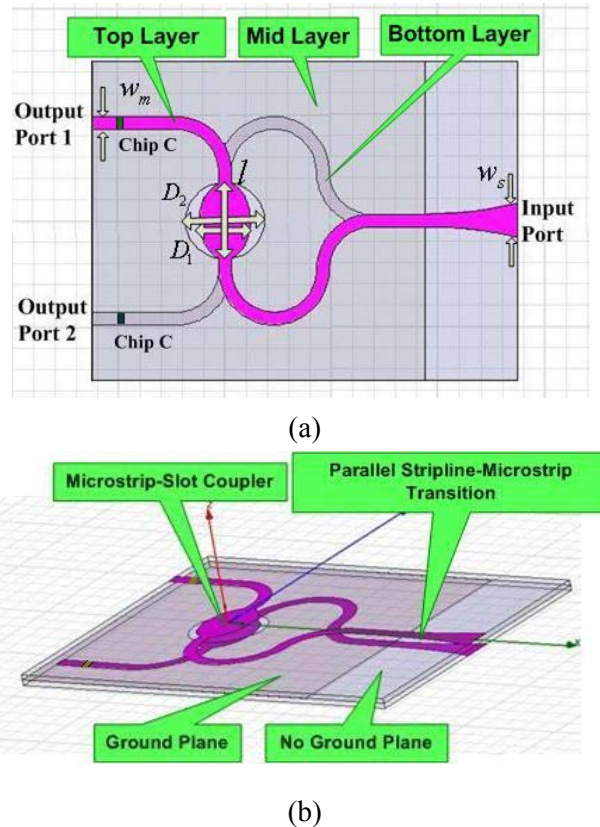

(a)

(b)

Fig. 1   Configuration of the proposed out-of-phase power divider, (a) parameters of design and (b) side view revealing individual layers.

Note that the device can also function without the disc-coupling structure. However, its use

improves isolation between the two output ports and their return loss.

In order to eliminate a path for a DC signal, two capacitors are used in the output ports. For microwave frequencies, 1nF chip capacitors offer this function with a minimum insertion loss. In the configuration shown in Fig.1, 1nF chip capacitors are placed in the two microstrip lines just before the connection of the two output ports. The use of these DC blocks is necessary as one of the strips in the parallel stripline section has to function as ground.

The two microstrip lines (as well as the remaining microstrip lines in the divider structure of Fig.1) are assumed to have 50Ω characteristic impedance. Therefore, for a given substrate their width w_m is determined using the standard formula [1], which is rewritten here in (1), (2).

$$Z_o = \frac{60}{\sqrt{\varepsilon_{me}}} \ln\left(\frac{8h}{w_m} + \frac{w_m}{4h}\right) \qquad (1)$$

for $w_m / h \le 1$ and;

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{me}}[w_m / h + 1.39 + 0.67\ln(w_m / h + 1.44)]} \qquad (2)$$

for $w_m / h \ge 1$.

where h is thickness of the substrate and ε_{me} is the effective dielectric constant for the transmission line and it is given by;

$$\varepsilon_{me} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2 * \sqrt{1 + 12h / w_m}} \qquad (3)$$

where ε_r is the dielectric constant of the substrate.

Width w_s of the parallel strip line is chosen to give 50Ω impedance using another formula from [1], which is rewritten as (4).

$$w_s = \frac{2.4\pi h}{\sqrt{\varepsilon_r}} \qquad (4)$$

When calculating width of the strip line using (4) the thickness h is equal to twice of the substrate thickness. This is because the two parallel strip lines are on top and bottom of the structure formed by two identical substrates.

As the width required for the parallel strip line (w_s) is usually wider than that for the microstrip line (w_m) then an elliptical arc is used to make the smooth transition. It can be found from computer simulations that the length of the transition of the order of a quarter wavelength (at the centre frequency) can provide good return loss of the input (E) port.

The second part of the divider is formed by a microstrip-slot coupler. In this coupler, the microstrip lines are connected to two elliptically shaped conducting discs/patches. The coupling between those two patches is controlled using an elliptical slot in the common ground plane. Dimensions of the three ellipses shown in Fig.1 are chosen to obtain a 3dB coupling between the top and bottom layers. To this purpose, the method described in [4] can be applied. This method initially determines the dimensions of the rectangular shaped slot and the discs. In the next step, the equivalence, in terms of the occupied area, is used to determine the size of ellipses. The initial values for the design parameters (l, D_1 and D_2) shown in Fig.1a are calculated using (5) to (9).

$$\frac{K(k_1)}{K^{'}(k_1)} = \frac{2.01 \times \sqrt{\varepsilon_r}}{\pi} \tag{5}$$

$$\frac{K^{'}(k_2)}{K(k_2)} = \frac{0.345 \times \sqrt{\varepsilon_r}}{\pi} \tag{6}$$

where $K(k)$ is the first kind elliptical integral and $K^{'}(k) = K(\sqrt{1-k^2})$. Values of the parameters k_1 and k_2 are calculated using (7) and (8):

$$k_1 = \sqrt{\frac{\sinh^2(\pi D_2/4h)}{\sinh^2(\pi D_2/4h) + \cosh^2(\pi D_1/4h)}} \tag{7}$$

$$k_2 = \tanh(\pi D_2/4h) \tag{8}$$

$$l = \frac{c}{4f\sqrt{\varepsilon_{me}}} \tag{9}$$

The final dimensions of the two elliptical patches and the slot can be determined using an iterative process involving the finite element analysis. The aim of this process is to obtain a 3dB coupler and a transition from a parallel strip line to two microstrip lines with high quality performance over an UWB frequency range. Using this approach, usually only a few iterations are required to obtain a satisfactory performance of the divider.

III. RESULTS

The above outlined design method was applied to a 180º power divider, which would cover the UWB frequency range from 3.1 to 10.6GHz. Rogers RT6010 with thickness 0.64mm, dielectric constant 10.2 and tangent loss 0.0023 was assumed as substrate. Values of the design parameters shown in Fig.1a (w_m, w_s, l, D_1 and D_2) were 0.6mm, 2mm, 3.7mm, 2.4mm and 4.2mm respectively. The overall size of the structure is 2.5cm×3cm. A photograph of the developed device is shown in Fig.2.
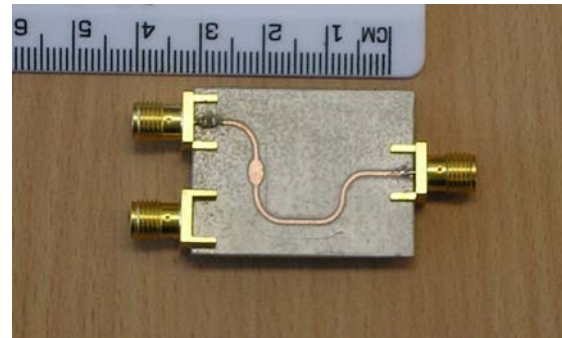

Fig.2 Photo for the developed device.

The design was assisted with a finite element analysis method while the measurements were performed using a vector network analyser. Results of the simulations and measurements are shown in Fig.3. These results reveal that the

power is equally divided between the two output ports with an insertion loss less than 0.5dB across the band 3.1 to more than 10.6GHz. Also the return loss for the input port is better than 15dB for the whole band. At the same time, return loss of the output ports is in the range of 10dB for the same band. Because the device is virtually lossless, isolation between the output ports is sacrificed and is in the range of 12dB. The difference in phase between the two output ports (not plotted here) is $180° \pm 0.5°$ over the same band.

IV. CONCLUSION

The design of an UWB out-of-phase power divider in the planar format involving two substrates supported by a common ground plane has been presented. In order to achieve an UWB performance, the device employs a microstrip-slot coupling arrangement and a transition from a parallel strip line to two microstrip lines. The simulated and measured results of this device show a low insertion loss and good return losses and isolation over the band 3.1 to 10.6GHz.

In the presented design, the input port (*E*) is of the parallel strip line type. However, it can easily be modified to the microstrip type. This can be accomplished by gradually increasing the width of one of the strips to form a fin shaped ground plane and by adjusting the width of the second strip to obtain the required characteristic impedance of 50Ω.

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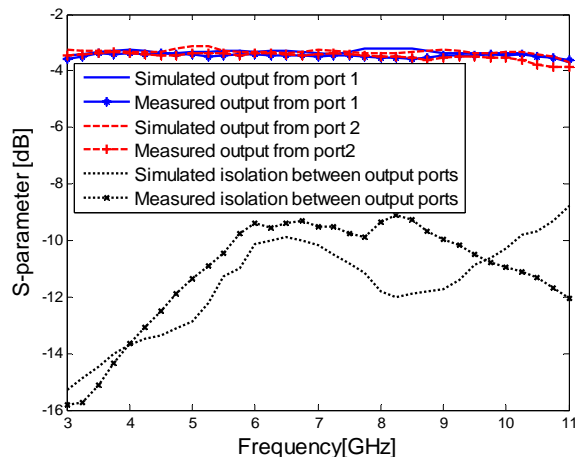
(a)
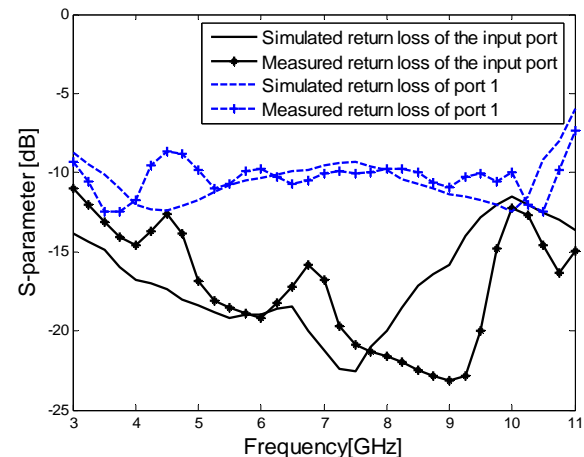
(b)

Fig.3   Simulated and measured performance of the proposed out-of-phase power divider: (a) coupling and isolation (b) return loss of the ports.