A Compact UWB Three-Way Power Divider

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***Abstract*—A three-way power divider with ultra wideband behavior is presented. It has a compact size with an overall dimension of 20 mm $\times$ 30 mm. The proposed divider utilizes broadside coupling via multilayer microstrip/slot transitions of elliptical shape. The simulated and measured results show that the proposed device has 4.77 $\pm$ 1 dB insertion loss, better than 17 dB return loss, and better than 15 dB isolation across the frequency band 3.1 to 10.6 GHz.**

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

I. Introduction

POWER dividers (PDs) are fundamental components of many microwave circuits and subsystems. They are widely used in antenna arrays, power amplifiers, mixers, phase shifters and vector modulators [1].

The simplest three-way PD is the Wilkinson divider [2]. Although it provides a match at all ports and high isolation between output ports, a three-way Wilkinson divider presents serious packaging problems. It requires a 3-D floating common node to connect all isolation resistors together. This requirement makes fabrication difficult and complex, especially in high frequency bands using monolithic microwave integrated circuits [1]. To overcome these problems, a modified circuit, which uses additional isolation resistors and wire bonding, was proposed in [3]. However, the isolation performance of the proposed circuit is very sensitive to the length of the bond wire, and its operation is limited to the lower frequency band.

A new configuration of the three-way divider was introduced in a recent paper [4]. It consists of two resistors and three four microstrip coupled lines. The proposed configuration can modify a three-way Wilkinson PD from a 3-D configuration into a two-dimensional one. However, the measured performance of the divider shows that it has a narrow bandwidth. Furthermore, it requires a narrow spacing between the microstrip lines. This makes the fabrication process difficult, knowing that its performance is sensitive to the coupled lines spacing.

Another type of broadband planar three-way PD is the tapered-line PD [5]. It provides a broadband high-pass characteristic because of the tapered-line impedance transformers. The tapered-line PDs utilize resistive films or strip resistors which cover all or part of the area between the tapered-line conductors to obtain good output isolation. However, those resistors cause a significant insertion loss in the high frequency range. Thus, they degrade the performance of the divider and limit its useful bandwidth [6].

In this letter, the configuration of a compact multilayer three-way PD with ultra wideband (UWB) performance is presented. Simple rules are proposed to design the device. The simulated and measured results show that the insertion loss is equal to 4.77 $\pm$ 1 dB for each of the three output ports across the band 3.1–10.6 GHz. The proposed divider exhibits better than 17 dB return loss at its ports with more than 15 dB isolation across the ultra wide frequency band.

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II. Design

The configuration of the proposed multilayer three-way PD is shown in Fig. 1. It consists of five conductor layers interleaved by three dielectrics. The input and one of the output ports, which are stripline ports, are located at the mid layer of the structure, while the other two output ports, which are microstrip ports, are at the top and bottom layers. The ground plane, which also includes the coupling slot, is at the second and fourth layers of the circuit. The microstrip coupled patches and the slots are of elliptical shapes, similar to those used to fabricate the UWB directional couplers in [7]. The two isolated ports, which are Ports 5 and 6 in Fig. 1(f), have no power output. They are terminated in matched loads to absorb any reflected signal from the output ports which may degrade the isolation performance of the device.

The mid layer of the proposed divider is considered to be connected to the input port (Port 1) at one side, and one of the output ports (Port 2) at the other side. As the power is required to divide equally between the three output ports, then the coupling between the mid layer and any of the two output ports (Port 3 and Port 4 in Fig. 1) is equal to; $\boldsymbol{C} = \sqrt{1/3} = 0.5773$ (or -4.77 dB). The output power from Port 2 is; $\sqrt{1-2\boldsymbol{C}^2} = \sqrt{1/3} = 0.5773$, i.e. insertion loss = 4.77 dB.

The even ($\boldsymbol{Z_{oe}}$) and odd ($\boldsymbol{Z_{oo}}$) mode characteristic impedances for each of the coupled patches are calculated using the following equations:

$$\boldsymbol{Z_{oe}} = \boldsymbol{Z_o}\sqrt{\frac{1+\boldsymbol{C}}{1-\boldsymbol{C}}}; \quad \boldsymbol{Z_{oo}} = \boldsymbol{Z_o}\sqrt{\frac{1-\boldsymbol{C}}{1+\boldsymbol{C}}} \tag{1}$$

where $\boldsymbol{Z_o}$ is the characteristic impedance of the input/output ports of the coupler. Assuming that $\boldsymbol{Z_o} = 50\ \Omega$ and $\boldsymbol{C} = \sqrt{1/3}$ then; $\boldsymbol{Z_{oe}} = 96.5\ \Omega$ and $\boldsymbol{Z_{oo}} = 25.9\ \Omega$..

Dimensions of the elliptical microstrips and slots offering the required even and odd mode characteristic impedances can be determined by extending the quasi-static approach presented in [7], [8] to the case of multilayer coupler. That approach was found to give accurate results when the distance between the coupled lines is less than $\lambda/20$ [9], where λ is the wavelength inside the used substrate. In this letter, I used a substrate that meets this requirement across the UWB.

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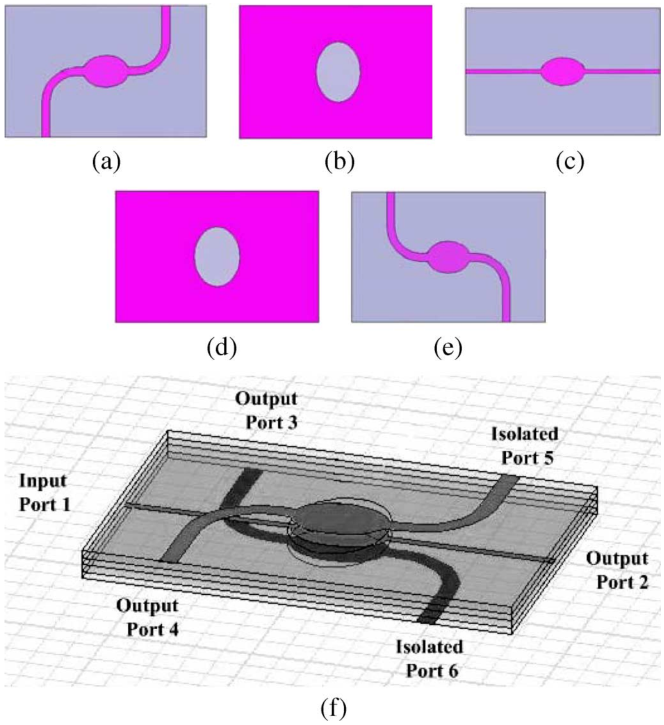

Fig. 1. Configuration of the proposed PD: (a) top layer, (b) second layer (ground with coupling slot), (c) mid layer, (d) fourth layer (ground with coupling slot), (e) bottom layer, and (f) the whole configuration.

Using the quasi-static method, $\boldsymbol{Z_{oe}}$ and $\boldsymbol{Z_{oo}}$ can be proven to be

$$\boldsymbol{Z_{oe}} = \frac{60\pi}{\sqrt{\varepsilon_{\boldsymbol{r}}}} \frac{\boldsymbol{K}(\boldsymbol{k}_1)}{\boldsymbol{K}'(\boldsymbol{k}_1)}; \quad \boldsymbol{Z_{oo}} = \frac{60\pi}{\sqrt{\varepsilon_{\boldsymbol{r}}}} \frac{\boldsymbol{K}'(\boldsymbol{k}_2)}{\boldsymbol{K}(\boldsymbol{k}_2)} \tag{2}$$

where $\varepsilon_{\boldsymbol{r}}$ is the dielectric constant of the substrate, $\boldsymbol{K}(\boldsymbol{k})$ is the first kind elliptical integral and $\boldsymbol{K}'(\boldsymbol{k}) = \boldsymbol{K}(\sqrt{1-\boldsymbol{k}^2})$.

Rearranging the equations in [7] and [8], it is possible to find the design parameters as (3) and (4), shown at the bottom of the page, where $\boldsymbol{D_s}$ and $\boldsymbol{D_m}$ are the major diameters of the elliptical slot and coupled microstrip, respectively, $\boldsymbol{D}_{\mathrm{sec}}$ is the secondary diameter of the slot and coupled microstrip, $\boldsymbol{h}$ is thickness of the substrate, and $\boldsymbol{l}$ is equal to quarter of the effective wavelength calculated at the centre frequency, which is 6.85 GHz. The relation between $\boldsymbol{D}_{\mathrm{sec}}$ and $\boldsymbol{l}$ is given by [7]

$$\boldsymbol{D}_{\mathrm{sec}} = \left(\sqrt{\boldsymbol{l}^2 + [0.7855\boldsymbol{D_m}\boldsymbol{D}_{\mathrm{sec}}/\boldsymbol{l}]^2} + \boldsymbol{l}\right)/2. \tag{5}$$

The last step of the design is to calculate the width of the input and output stripline/microstrip ports. They are determined

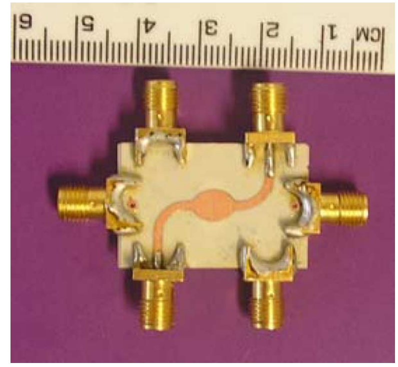

Fig. 2. Photo for the fabricated three-way PD.

to give 50 Ω characteristic impedance using the well known stripline/microstrip equations [1].

III. Results and Discussion

The validity of the presented design method was tested by building a three-way PD aimed at the operation in the UWB range 3.1 to 10.6 GHz. Rogers RO4003C (with $\varepsilon_{\boldsymbol{r}} = 3.38$, $\boldsymbol{h} = 0.508$ mm, and loss tangent $= 0.0027$) was selected for the divider's development. Using the proposed design method and with the help of the optimization capability of the software Ansoft HFSSv10, parameters of the coupler were found to be; $\boldsymbol{D_m}$ for the top and bottom layers $= 4.8$ mm, $\boldsymbol{D_m}$ for the mid layer $= 4.4$ mm, $\boldsymbol{D_s} = 9$ mm, $\boldsymbol{D}_{\mathrm{sec}} = 6.8$ mm, width of the stripline input/output port $= 0.64$ mm, and width of the microstrip output ports $= 1.2$ mm. It was found that the optimized values of the design parameters are less than 10% different from those obtained by the described design method. This indicates the high accuracy of the method. A photograph of the developed device is shown in Fig. 2. It has a compact size with an overall dimension of 20 mm $\times$ 30 mm.

The designed PD was tested via simulation and measurements. The simulation was performed using the commercial software Ansoft HFSSv10, whereas the measurements were done using a vector network analyzer.

The insertion loss of the three output ports, as shown in Fig. 3, is equal to 4.77 ± 1 dB (ideal value $= 4.77$ dB) across the band 3.1 to 10.6 GHz revealing an UWB performance. The return loss for the input/output ports of the device is shown in Fig. 4 (note that because of symmetry, $S22 = S11$ and $S44 = S33$). It is better than 17 dB for all the ports of the device. The isolation between the three output ports is presented in Fig. 5 (due to symmetry $S32 = S42$). The simulated and measured isolation between ports 3 and 2 (or between the ports 4 and 2) is better than 19 dB, whereas it is better than 17 dB between the

$$\boldsymbol{k}_1 = \sqrt{\frac{\sinh^2(0.617\boldsymbol{D_s}\boldsymbol{D}_{\mathrm{sec}}/(\boldsymbol{hl}))}{\sinh^2(0.617\boldsymbol{D_s}\boldsymbol{D}_{\mathrm{sec}}/(\boldsymbol{hl})) + \cosh^2(0.617\boldsymbol{D_m}\boldsymbol{D}_{\mathrm{sec}}/(\boldsymbol{hl}))}} \tag{3}$$

$$\boldsymbol{k}_2 = \tanh(0.617\boldsymbol{D_m}\boldsymbol{D}_{\mathrm{sec}}/(\boldsymbol{hl})) \tag{4}$$

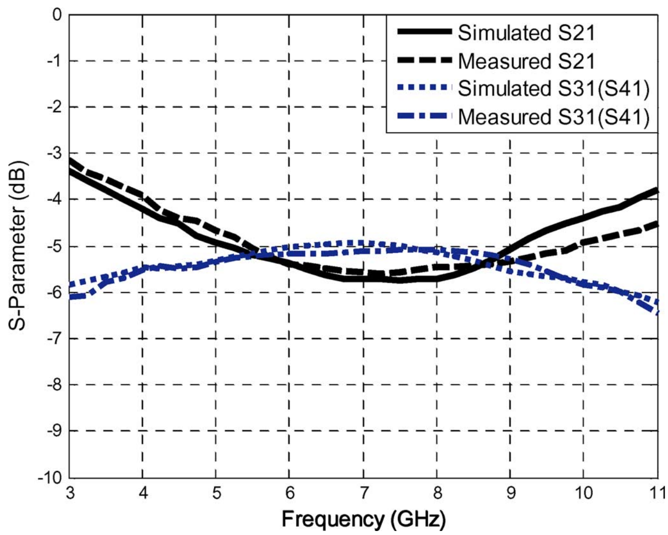

Fig. 3. Measured and simulated insertion loss of the device.

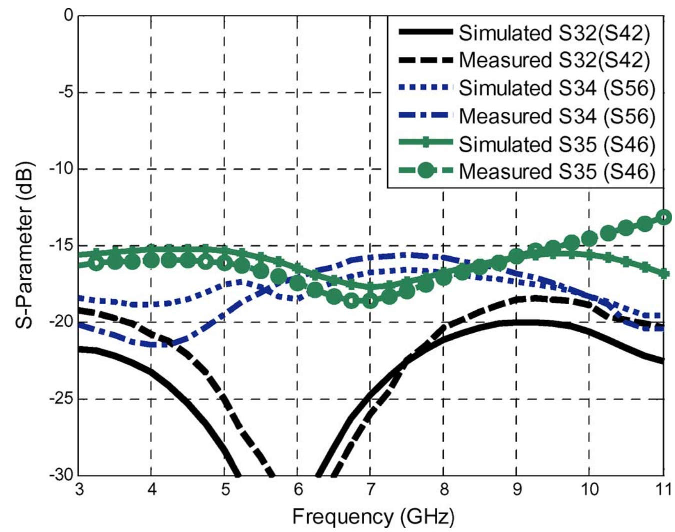

Fig. 5. Measured and simulated isolation of the device.

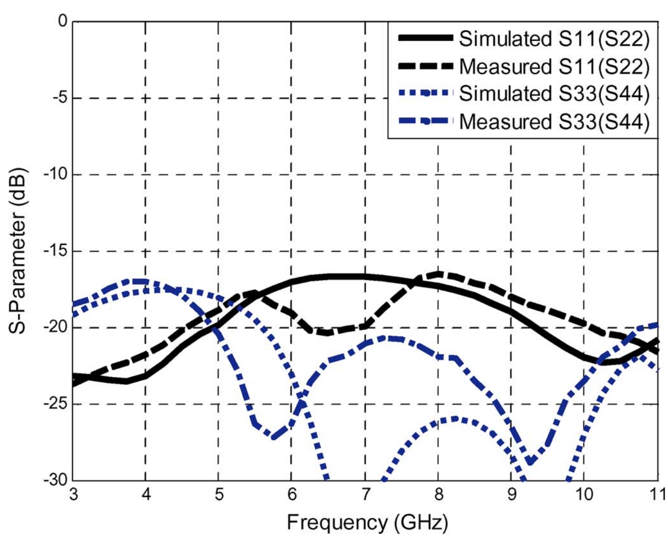

Fig. 4. Measured and simulated return loss of the device.

ports 3 and 4 (or between the ports 5 and 6) across the band 3.1–10.6 GHz.

The simulated and measured results in Fig. 5 also show that there is negligible coupling between the top and bottom layer. The two ports of the top layer (ports 4 and 5) are well isolated from the two ports of the bottom layer (ports 3 and 6) by more than 15 dB across the whole band.

Concerning the phase performance of the splitter, the measured and simulated results (not shown here) indicated that the output signals from ports 3 and 4 are in phase and they are different by $90^\circ \pm 0.5^\circ$ from that of port 2.

IV. Conclusion

A three-way PD with UWB behavior has been presented. It has a compact size with an overall dimension of 20 mm $\times$ 30 mm. The proposed divider utilizes broadside coupling via multilayer microstrip/slot transitions of elliptical shape. The simulated and measured results of the developed device have shown equal three-way power division, good return loss, and isolation over the band 3.1–0.6 GHz.

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