Ultra-Wideband Power Divider With Good In-Band Splitting and Isolation Performances

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***Abstract*—An ultra-wideband (UWB) power divider on microstrip line is proposed, analyzed and designed. This divider is formed by installing a pair of stepped-impedance open-circuited stubs and parallel-coupled lines to two symmetrical output ports. In addition, a single resistor is properly placed between two output ports. After simple transmission line theory analysis, it is demonstrated that 3 dB power splitting from one input to two output ports, good impedance matching at all the three ports and excellent isolation between two output ports are achieved over the specified 3.1–10.6 GHz UWB range. Finally, a prototype divider is fabricated and measured to provide an experimental verification on the predicted attractive features.**

***Index Terms*—In-band splitting and isolation, power divider, roll-off skirt, ultra-wideband (UWB).**

I. Introduction

POWER dividers are one of the key passive components in many microwave circuits and subsystems. The most useful power divider is the Wilkinson divider that has excellent isolation between two output ports [1]. However it has less than 20% fractional bandwidth. Due to the rapid growth of unlicensed use of ultra-wideband (UWB) for short-distance wireless communications, there has been tremendous interest in exploration of various UWB components that operate in the UWB range, i.e., 3.1–10.6 GHz. For this purpose, a few wideband power dividers [2]–[7] have been developed so far. Normally, wideband divider can be constituted by cascading multi-section matching networks at two output ports of a single Wilkinson divider. But this approach requires more resistors for isolation. According to the analysis in [2], at least three sections and three isolation resistors are required as implemented in [3]. In [4], a three-section wideband Wilkinson power divider was developed with an arbitrary ratio of power division. Recently, two wideband power dividers based on microstrip-to-slotline transition [5] and broadside coupling structure [6] were developed and they exhibited good power splitting performance over the UWB range.

In this work, an UWB power divider on single- layer microstrip-line is proposed, analyzed and designed. As shown in Fig. 1(a), this divider is constructed by introducing a pair of stepped-impedance open-circuited stubs and parallel coupled lines in two output ports, so that the sharp roll-off skirt can be achieved to better regulate the UWB performance. Herein, only a single resistor needs to be placed between two coupled lines for isolation. Good power splitting, impedance matching and isolation can be achieved over the UWB as shown in simulation and confirmed in experiment. In the following, the proposed UWB divider will be designed on the RT/Duroid 6010 substrate with a dielectric constant of 10.8 and thickness of 0.635 mm.

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II. Analysis and UWB Characteristics

The schematic of the proposed UWB power divider is shown in Fig. 1(a). As a signal is incident at port 1, its power can be equally divided to port 2 and port 3 over a wide frequency band. Thus, a pair of parallel coupled-lines and stepped-impedance open-circuited stubs is introduced at two output ports of a traditional Wilkinson power divider. Following the basic idea in the UWB bandpass filters in [7], [8], multiple transmission poles can be produced over the UWB. Further, to prevent signal transmission between port 2 and port 3, a single resistor of R is installed. Based on the even- and odd-mode analysis [9], its UWB characteristics can be analyzed in terms of S-parameters.

Fig. 1(b) shows the two-port circuit model for a bisection of the UWB divider in Fig. 1(a) under odd-mode excitation. In this case, port 1 can be simply considered as a short circuit since the strip conductor of this port is grounded via virtual electric wall. Thus, this model becomes a one port network and the input impedance at port 2 is derived as

$$Z_{\mathrm{in2}}^{o}=\frac{2Z_{+}\cot(\theta)+jY_t^oZ_{-}^2\csc^2(\theta)-jY_t^oZ_{+}^2\cot^2(\theta)}{4j+2Y_t^oZ_{+}\cot(\theta)} \tag{1}$$

where $Y_t^o = 2/R - jY_1\cot(\theta) + 1/Z_{\mathrm{in}A}, Z_- = Z_{oe} - Z_{oo}, Z_+ = Z_{oe} + Z_{oo}$, and $Z_{\mathrm{in}A} = jZ_2(Z_2\tan(\theta) - Z_3\cot(\theta))/(Z_2+Z_3)$. Z_{oe} and Z_{oo} are the even- and odd-mode impedances of the coupled-line, respectively.

In Fig. 1, Z_{p1} and Z_{p2} represent characteristic impedance at port 1 and 2, respectively. Under the constraint at port 2 of $Z_{\mathrm{in2}}^o = Z_{p2} = 50\ \Omega$ at $\theta=\pi/2$, (1) can be simplified as

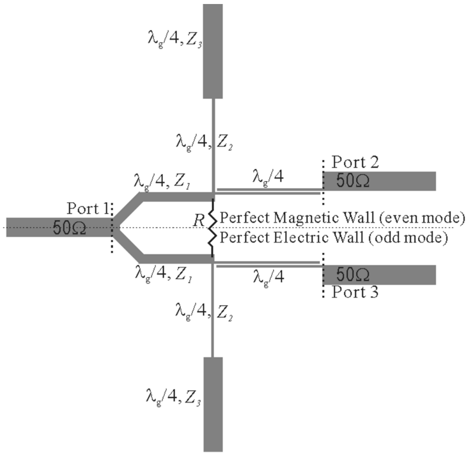
$$R=\frac{Z_-^2}{2Z_{p2}} \tag{2}$$

and this provides a simple guideline in selection of R. For instance, if $R = 100\ \Omega$ is selected, $Z_- = 100\ \Omega$ is obtained.

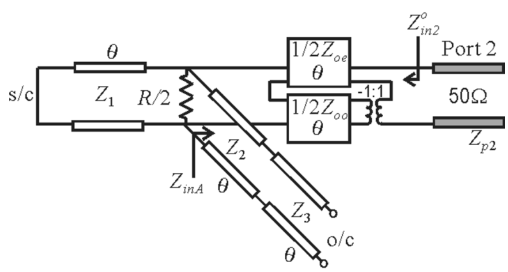
Under the even-mode excitation, a bisection of the divider in Fig. 1(a) is expressed as a two-port network shown in Fig. 1(c). The symmetrical plane becomes a perfect magnetic wall and the characteristic impedance at port 1 is double Z_{p1}, or $100\ \Omega$. Thus, the input impedances at port 1 and port 2 can be derived as

$$Z_{\mathrm{in1}}^{e}=Z_1\frac{1+jY_{t1}^eZ_1\tan(\theta)}{Y_{t1}^eZ_1+j\tan(\theta)} \tag{3}$$

$$Z_{\mathrm{in2}}^{e}=\frac{2Z_{+}\cot(\theta)+jY_{t2}^eZ_{-}^2\csc^2(\theta)-jY_{t2}^eZ_{+}^2\cot^2(\theta)}{4j+2Y_{t2}^eZ_{+}\cot(\theta)} \tag{4}$$



(a)



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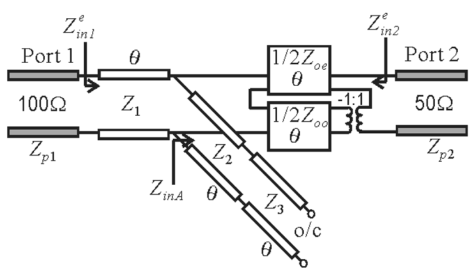
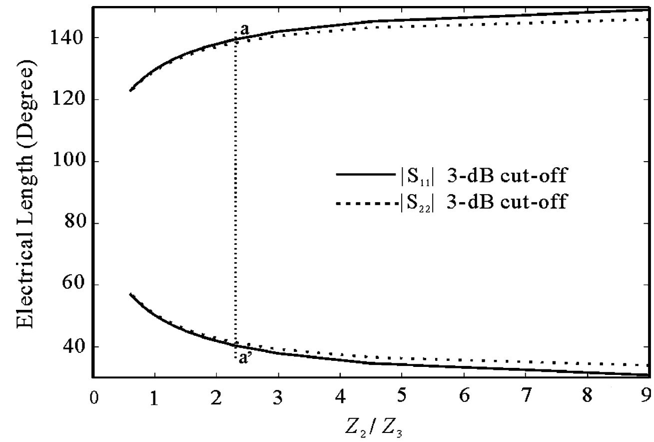
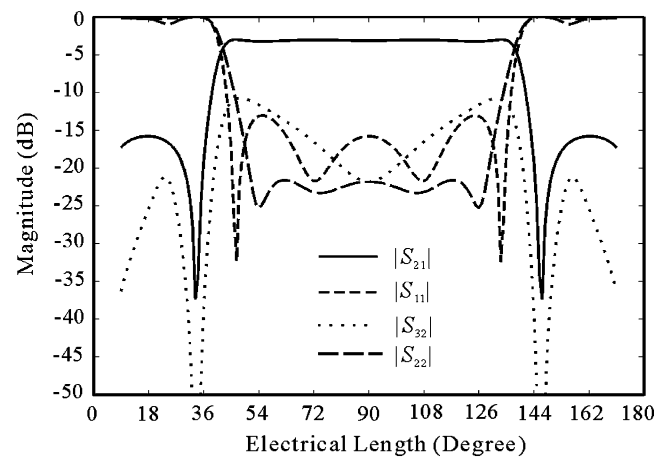


(c)

Fig. 1. (a) Schematic of the proposed UWB power divider on microstrip line. (b) Odd-mode circuit model. (c) Even-mode circuit model.



(a)



(b)

Fig. 2. (a) Electrical length (θ) of open-circuited stubs at the lower/upper 3 dB cutoff frequencies against impedance ratio (Z_2/Z_3). (b) S-parameters of the proposed UWB power divider with stepped-impedance stubs.

where

$$Y_{t1}^e = \frac{4jZ_{p2} + 2Z_+ \cot(\theta)}{2Z_{p2}Z_+ \cot(\theta) + jZ_-^2 \csc^2(\theta) - jZ_+^2 \cot^2(\theta)} + \frac{1}{Z_{\mathrm{in}A}}$$

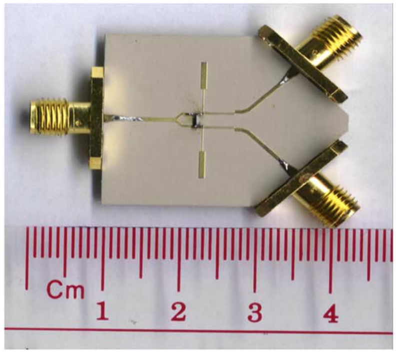
$$Y_{t2}^e = [Z_1 + jZ_{p1}\tan(\theta)]/[Z_1(Z_{p1} + jZ_1\tan(\theta))] + 1/Z_{\mathrm{in}A}.$$

Under the constraint of good impedance matching at port 1 and port 2, i.e., $Z_{\mathrm{in}1}^e = Z_{p1}$ and $Z_{\mathrm{in}2}^e = Z_{p2}$, one can simplify (3) and (4) as a unified expression at the frequency of $\theta = \pi/2$

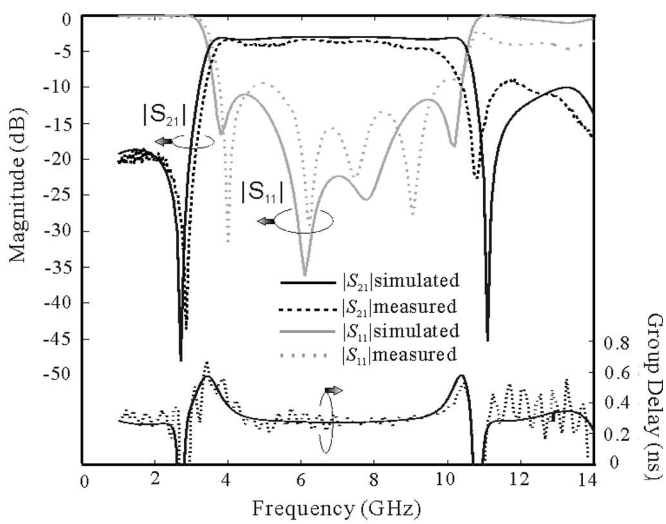
$$Z_1^2 = \frac{Z_{p1}Z_-^2}{4Z_{p2}}. \tag{5}$$

Due to $Z_{p1} = Z_- = 100\ \Omega$ and $Z_{p2} = 50\ \Omega$, one can determine $Z_1 = 70.7\ \Omega$ from (5). Noted that (2) and (5) are only accurate at $\theta = \pi/2$ and they are gradually degraded as θ deviates away from $\pi/2$. However, as stepped-impedance stubs and coupled-lines are installed as illustrated in Fig. 1(a), four additional transmission poles can be generated, two on each sides of $\theta = \pi/2$. Thus, good impedance matching still can be achieved in the overall UWB range if these poles are properly allocated.

The three individual input impedances are derived in (1), (3) and (4). Thus, S_{11} and S_{22} can be simply calculated. In order to demonstrate the performance of UWB divider, the lower/upper cutoff frequencies of the passband can be derived under the definitions of 3-dB S_{11} and S_{22} magnitudes. Fig. 2(a) plots the calculated electrical length (θ) at the two cutoff frequencies versus impedance ratio (Z_2/Z_3) of the stepped- impedance stubs. These two cutoff frequencies are found to go up and down, respectively, as the ratio (Z_2/Z_3) increases from 0.6 to 9.0. Fig. 2(a) is plotted to determine the operation bandwidth of the divider and the vertical plane $Z_2/Z_3 = 2.25$ (a-a') in Fig. 2(a) achieves the 110% fractional bandwidth that corresponds to the 3.1–10.6 GHz UWB. Then, $Z_3 = 40\ \Omega$ if $Z_2 = 90\ \Omega$ is chosen. The four independent S-parameters, i.e., $|S_{11}|, |S_{21}|, |S_{22}|$ and $|S_{32}|$, can be calculated and they are plotted over a wide range of the phase (θ) in Fig. 2(b). In addition to good in-band splitting, impedance matching and isolation performances, Fig. 2(b) demonstrates that this UWB divider can achieve much sharper roll-off skirts near the lower/upper cutoff frequencies. It is mainly benefited from the transmission zeros of the stepped-impedance stubs and coupled lines. $|S_{11}|$ and $|S_{22}|$ are lower than -13 dB and -20 dB, respectively, while $|S_{32}|$ between two output ports is lower than -10 dB over the UWB passband.



(a)



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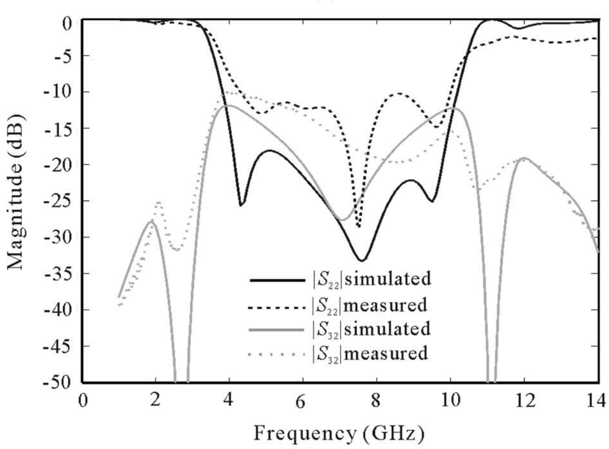

(c)

Fig. 3. Predicted and measured frequency responses of the proposed power divider. (a) Photograph of the fabricated circuit. (b) S_{21} and S_{11} magnitudes as well as group delay. (c) S_{22} and S_{32} magnitudes.

III. Experimental Verification

To confirm the above-exhibited attractive features of this proposed UWB power divider, one prototype divider is fabricated and measured. Fig. 3(a) shows its photograph. Fig. 3(b) plots the predicted and measured $|S_{11}|$ and $|S_{21}|$ in a frequency range of 1.0 to 14.0 GHz as well as the group delay. They matched with each other. The measured $|S_{11}|$ is lower than -10.0 dB and $|S_{21}|$ is close to -3.0 dB over the frequency range from 3.5 to 10.1 GHz with 0.4 dB insertion loss at center frequency. In particular, the roll-off skirts near the two cutoff frequencies are significantly sharpened as demonstrated in simulation. The simulated and measured group delay show good linearity within the UWB passband as derived in UWB filters [7], [8]. There are some visible discrepancies between them in $|S_{21}|$ at high frequencies. This is primarily due to fabrication tolerance in etching the tight coupled-line with a small gap of 0.06 mm and unexpected effects in soldering the resistor. Fig. 3(c) shows the predicted and measured $|S_{22}|$ and $|S_{32}|$. The measured $|S_{22}|$ at port 2 and port 3 as well as $|S_{32}|$ between port 2 and port 3 are all lower than -10 dB over the UWB band.

IV. Conclusion

This letter has proposed a novel UWB power divider with good in-band power splitting, impedance matching and isolation. This divider is analyzed and designed based on a symmetrical three-port circuit model under even- and odd-mode excitations. As the two output ports are properly linked with two identical step-impedance stubs and coupled lines, the expected UWB performances of this proposed divider are theoretically demonstrated. A prototype divider is fabricated to confirm the predicted results in experiment.

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