Progress In Electromagnetics Research Letters, Vol. 46, 43–48, 2014

Bandpass-Response Power Divider with High Isolation

Long Xiao*, Hao Peng, and Tao Yang

Abstract—A novel wideband multilayer power divider with high isolation and bandpass response is presented in this article. This presented power divider employs microstrip-slotline coupling structure to realize the basic function of dividing input power. One lumped isolation resistor is introduced to improve the isolation between output ports. In order to solder the chip resistor between output branches, bending microstrip structure is utilized. For the sake of rejecting the unwanted signals locating in adjacent channels, interdigital structure and defected ground structure are designed to obtain a bandpass response and a wide upper stopband. The experimental results have indicated that the proposed wideband power divider has good performance on return losses, isolation, amplitude and phase balances, as well as group delay over the band 4.5 GHz–10 GHz.

1. INTRODUCTION

Power divider is one of the greatly important microwave and RF components in a number of wireless systems, such as balance mixes, phase shifters, six-port networks and so on. Wilkinson power divider is the most famous power divider, which can obtain good impedance matching at all ports and high isolation between output ports. The bandwidth, however, is less than 20% for traditional single-section one. With the increasing applications for ultra wideband (UWB) systems, various UWB power dividers based on slotline techniques have been designed [1–11]. In [1], a compact coplanar UWB out-of-phase power divider based on slotline techniques has been proposed, which could obtain low insertion loss and good impedance matching at input port over the range 3.1 GHz–10.6 GHz. In [2], one non-coplanar UWB out-of-phase slotline power divider was designed, which, compared with the one proposed in [1], introduced two circular open-circuited microstrip stubs as compensatory circuits to improve the performances in the passband. Another UWB slotline power divider that derived from the one in [1] with an additional metal pin placed between input stub and ground was proposed in [3], whose operating bandwidth was improved from 85% to about 133% successfully. However, no matter the basic one designed in [1] or the improved ones proposed in [2, 3], they cannot obtain good impedance matching at all ports simultaneously and high isolation between output ports.

In order to overcome the disadvantages, some novel power dividers have been proposed [7–11]. In [7], a multilayer UWB power divider was designed, which installed one isolation resistor at the ends of output stubs. By breaking the lossless balance of three-port network, good return losses at the all ports and high isolation between output ports were obtained for the proposed power divider. In [8, 9], a two-way and a three-way multilayer power dividers were proposed respectively, which was the first time to obtain high isolation for out-of-phase power dividers. However, the isolation resistors of these proposed power dividers were inconvenient and difficult to install, which no double restricts the practical applications.

In this article, a novel wideband power divider with bandpass response is developed, whose isolation resistor is placed in the top layer so that it is greatly convenient to solder. The interdigital structure

Received 31 March 2014, Accepted 2 May 2014, Scheduled 7 May 2014

* Corresponding author: Long Xiao (XL740512@126.com).

The authors are with the School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan 611731, China.

and defected ground structure (DGS) are designed to obtain a good performance for bandpass response. The simulated and measured results, which show a good agreement, have exhibited that the presented two-way power divider has good impedance matching at all ports, high isolation, excellent amplitude and phase balances, as well as flat group delay in the band 4.5 GHz–10 GHz. In addition, the width of upper stopband (responding to attenuation more than 20 dB) surpasses 4 GHz (14 GHz–18 GHz).

2. CIRCUIT DESIGN AND ANALYSIS

The configuration of the presented novel power divider with interdigital structure is shown in Figure 1. The input port (port 1) is located in bottle layer, while the output ports (port 2 and port 3), which are symmetrical to input branch, are fabricated in top layer. The slotline as well as DGS are etched in mid layer, namely the ground plane. This power divider consists of the basic circuit unit microstrip-to-slotline transition, which abandons the traditional microstrip-to-slotline configuration with quarter-wavelength slotline like the ones in [1–7], so that the isolation resistor can be installed easily. In order to obtain perfect impedance matching between microstrip and slotline, the characteristic impedances of them must meet following expression [12]:

$$Z_m = Z_s \times n^2 \tag{1}$$

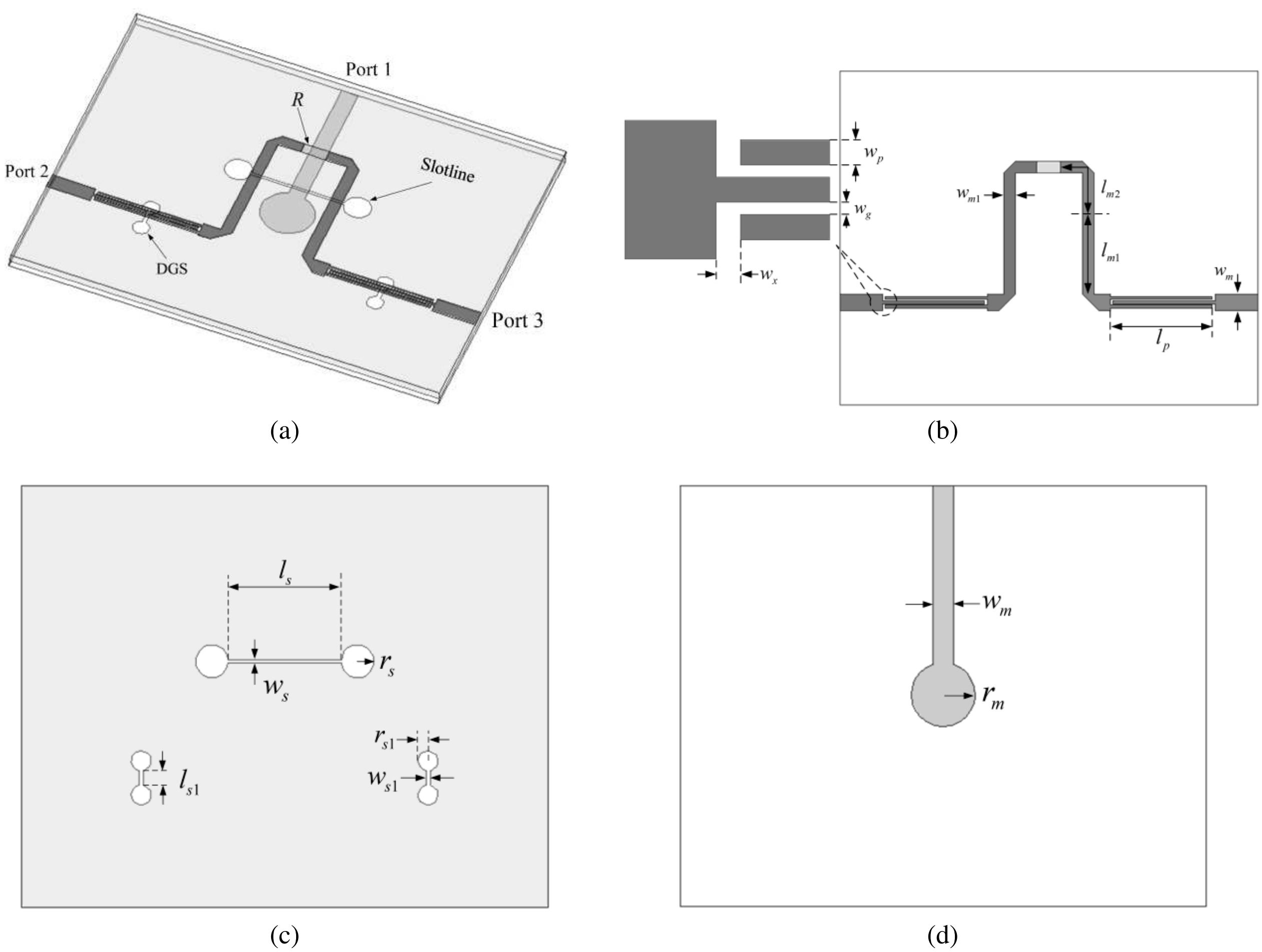

Figure 1. Configuration of the presented power divider. (a) 3D view. (b) Top layer. (c) Mid layer. (d) Bottom layer.

Z_m and Z_s represent the characteristic impedances of microstrip line and slotline, respectively. n is the coupling coefficient deduced by (2).

$$\begin{cases} n = \cos(2\pi h\mu/\lambda) - \sin(2\pi h\mu/\lambda) \cdot \cot q \\ q = 2\pi h\mu/\lambda + \tan^{-1}(\mu/v) \\ \mu = \sqrt{\varepsilon_r - (\lambda_0/\lambda_s)^2} \\ v = \sqrt{(\lambda_0/\lambda_s)^2 - 1} \end{cases} \tag{2}$$

h is the thickness of substrate, and ε_r is the dielectric constant, λ_0 and λ_s are the wavelengths at center frequency in air and in slotline at center frequency.

The microstrip interdigital resonators are designed at output ports to obtain bandpass response, which are six-port networks essentially. The equivalent circuit of this network can be seen as a two-port admittance inverter circuit exhibited in Figure 2 [13]. For the sake of obtaining good performances for low insertion losses, high isolation, and wide stopband, DGS, which is similar to the slotline, are etched under the interdigital resonator.

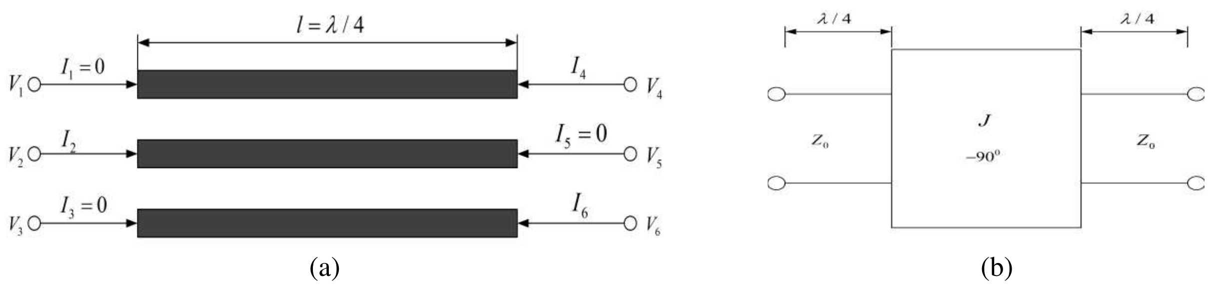

Figure 2. Equivalent circuit model of the interdigital resonator. (a) Six-port network. (b) Two-port network.

Having established the designing principles of the power divider with high isolation and bandpass response, a simple procedure can be utilized to design it. To cascade with other devices or systems conveniently, the width of input and output microstrip lines w_m is chosen to give impedance $50\,\Omega$. In order to obtain good impedance matching between slotline and microstrip line, the characteristic impedance of slotline should be selected to be approximately $50\,\Omega$. However, the width of slotline responding to characteristic impedance of $50\,\Omega$ is too narrow to manufacture for current processing technic. In view of the mentions above, the width of slotline w_s is selected to apply impedance about $90\,\Omega$. Thus the coupling coefficient n is about 0.75. Radius r_m of the microstrip stub and r_s of the slotline stub are selected to be about $\lambda_m/12$ and $\lambda_s/24$ (λ_m and λ_s are the guided wavelength of microstrip line and slotline at center frequency). The length of output microstrip branch l_{m1} and the length of microstrip stub l_{m2} all are chosen to be approximately $\lambda_m/4$. And the length of interdigital structure l_p is also chosen as about $\lambda_m/4$. The value of isolation resistor usually selected as twice of the port impedance. As to the width of microstrip branch w_{m1}, it commonly is associated with the characteristic impedance and the length of slotline. In addition, the length of slotline, which does not employ conventional quarter-wavelength structure, is determined by the package of isolation resistor. In this design, the package of resistor is selected to be 1206.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The novel wideband power divider based on slotline techniques is designed and fabricated on Rogers 4350B substrate with relative dielectric constant of 3.48, tangent loss of 0.0037, and thickness of 0.508 mm. Figure 3 exhibits the photograph of the presented power divider, whose dimension is $24\,\text{mm} \times 30\,\text{mm}$. By making full use of the theories about microstrip-to-slotline transitions and utilizing the simulator HFSS V13.0, the final dimensions about the power dividers can be obtained easily, which

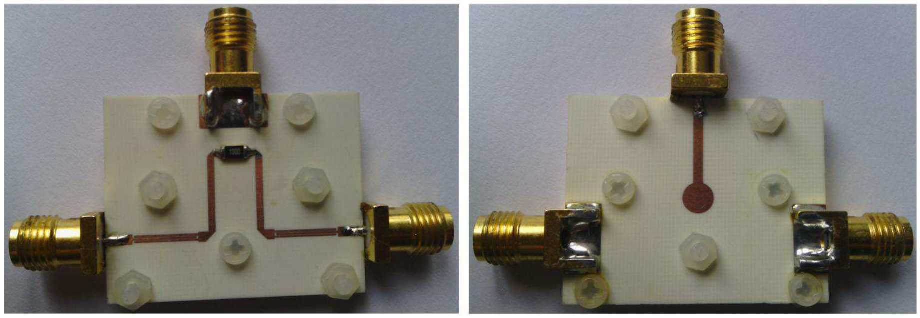

Figure 3. Photograph of the proposed power divider.

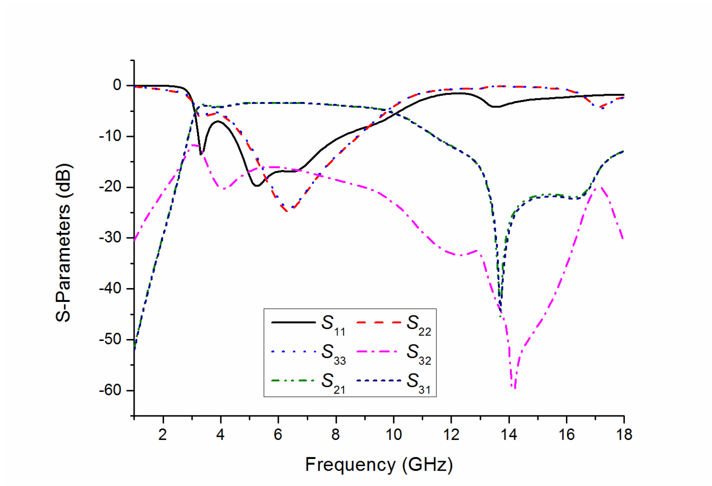

Figure 4. Simulated results of the proposed power divider without DGS.

are listed as (unit: mm): $w_p = 0.21$, $w_x = 0.2$, $w_g = 0.1$, $w_{m1} = 0.8$, $w_m = 1.15$, $l_{m1} = 6.05$, $l_{m2} = 5.92$, $l_p = 7.32$, $w_s = 0.19$, $w_{s1} = 0.27$, $l_s = 6.44$, $l_{s1} = 0.83$, $r_s = 0.93$, $r_{s1} = 0.56$, $r_m = 1.83$. In addition, the lumped isolation resistor is selected as $R = 100\,\Omega$.

For the sake of comprehending the performances of DGS, the simulated results of the power divider without DGS is exhibited in Figure 4. Comparing with the data with DGS shown in Figure 5, we can find that the insertion losses and return losses have been worsened in the passband, especially in the high frequency band. What's more, the DGS also can influence the width of upper stopband, which can be observed via comparing Figure 4 with Figure 5 easily.

As are exhibited in Figure 5 and Figure 6, the simulated and measured results show a good agreement. The insertion losses, return losses at all ports, isolation about the power divider are exhibited in Figure 5. Figure 5(a) shows the simulated data, while Figure 5(b) shows the measured ones. The measured return loss at input is better than 14 dB over the band 4.5 GHz–10 GHz. While measured return losses at output ports are superior to 11 dB for the same frequency range, which are better than the ones in [1–6] about 5 dB. The insertion losses are within 1.5 dB for the range from 3.4 GHz to 10 GHz from the measured data. Besides, the isolation between output ports is more than 15 dB over the band 4 GHz–10 GHz, which is better than the ones in [1–6] about 9 dB and better than the ones in [8, 9]. Compared with the ones in [1–11], the width of upper stopband, which reaches up to 4 GHz (14 GHz–18 GHz), is more wide because of the introduction of interdigital structure and DGS. In addition, the simulated and measured phase differences and group delays are exhibited in Figure 6, which indicates that the measured phase difference is approximately $\pm 4^\circ$ over the range 3 GHz–11 GHz, and indicates that the measured group delay is greatly flat with maximum dynamic range of 0.1 ns for the band 4 GHz–10 GHz.

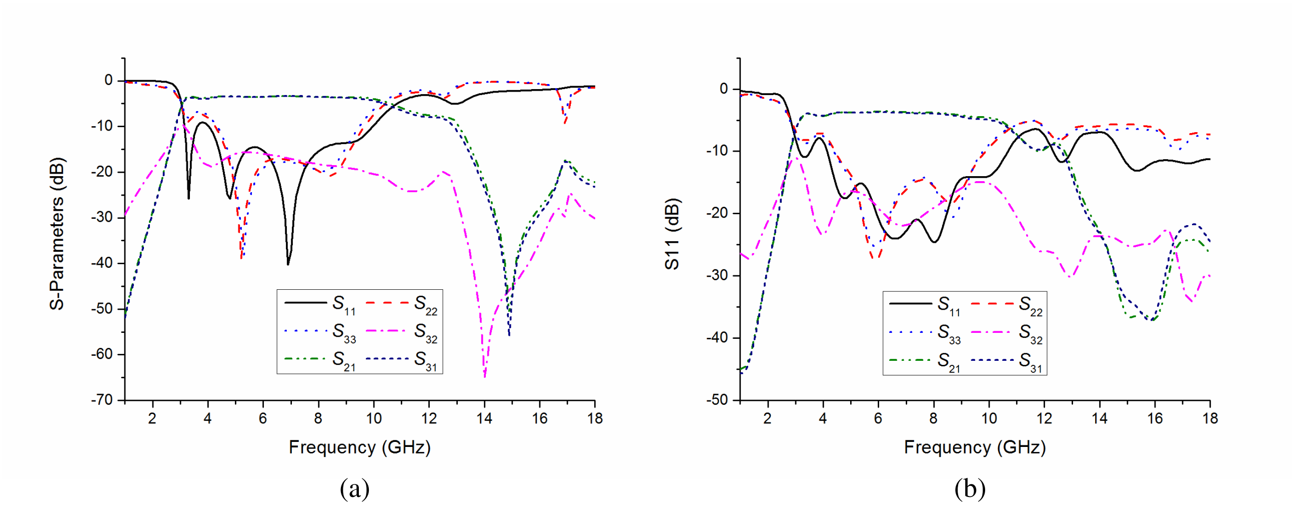

Figure 5. Experimental results of return losses, isolation, and insertion losses. (a) Simulated results. (b) Measured results.

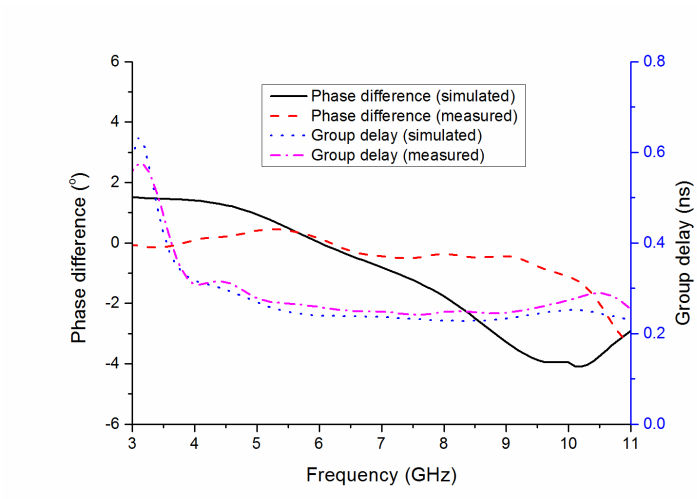

Figure 6. Simulated and measured phase difference and group delay.

4. CONCLUSION

A novel wideband power divider with high isolation and bandpass response based on microstrip-slotline techniques is designed in this article. Due to the introduction of isolation resistor and the utilization of interdigital structure and DGS, the return loss at output port and isolation have been improved compared to the ones in [1–6]. Both the simulated and measured results show that the presented wideband power divider has good performance on impedance matching at all ports, isolation between output ports, amplitude and phase balances, as well as group delay over the frequency range from 4.5 GHz to 10 GHz. Moreover, the width of upper stopband reaches up to about 4 GHz, which has been expanded widely in comparison with the ones in [1–11].

ACKNOWLEDGMENT

This work was sponsored by the National Natural Science Foundation of China (Grant No. 61006026) and the Fundamental Research Funds for the Central Universities (Grant No. ZYGX2012J030).

REFERENCES

1. Bialkowski, M. E. and A. M. Abbosh, "Design of a compact UWB out-of-phase power divider," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, No. 4, 289–291, Apr. 2007.
2. Bialkowski, M. E., A. M. Abbosh, and N. Seman, "Compact microwave six-port vector voltmeters for ultra-wideband applications," *IEEE Trans. Microw. Theory Tech.*, Vol. 55, No. 10, 2216–2223, Oct. 2007.
3. Li, Q., X. W. Shi, F. Wei, and J. G. Gong, "A novel planar 180° out-of-phase power divider for UWB application," *Journal of Electromagnetic Waves and Applications*, Vol. 25, No. 1, 161–167, 2011.
4. Song, K.-J. and Q. Xue, "Ultra-wideband out-of-phase power divider using multilayer microstrip-slotline coupling structure," *Microw. Opt. Tech. Lett.*, Vol. 52, No. 7, 1591–1594, 2010.
5. Peng, H., Z.-Q. Yang, Y. Liu, T. Yang, and K. Tan, "An improved UWB non-coplanar power divider," *Progress In Electromagnetics Research*, Vol. 138, 31–39, 2013.
6. Seman, N., M. E. Bialkowski, and W. C. Khor, "Ultra-wideband vias and power dividers in microstrip-slot technology," *Asia-Pacific Microwave Conference 2007, APMC 2007*, 11–14, 2007.
7. Song, K. J. and Q. Xue, "Novel ultra-wideband (UWB) multilayer slotline power divider with bandpass response," *IEEE Microw. Wireless Compon. Lett.*, Vol. 20, No. 1, 13–15, Jan. 2010.
8. Chen, J.-X., C. H. K. Chin, K. W. Lau, and Q. Xue, "180° out-of-phase power divider based on double-sided parallel striplines," *Electron. Lett.*, Vol. 42, No. 21, 1229–1230, Oct. 2006.
9. Yang, T., J.-X. Chen, and Q. Xue, "Three-way out-of-phase power divider," *Electron. Lett.*, Vol. 44, No. 7, 482–483, 2008.
10. Wei, F., W.-T. Li, X.-W. Shi, and Y.-Y. Wang, "Design of compact inphase power divider with narrow notch band for UWB application," *Electron. Lett.*, Vol. 48, No. 3, 166–168, 2012.
11. Abbosh, A. M., "Broadband multilayer inphase power divider for C-band applications," *Electron. Lett.*, Vol. 44, No. 2, 120–121, 2008.
12. Knorr, J. B., "Slot-line transitions," *IEEE Trans. Microw. Theory Techn.*, Vol. 22, No. 5, 548–554, 1974.
13. Kuo, J.-T. and E. Shih, "Wideband bandpass filter design with three-line microstrip structures," *Microwaves, Antennas and Propagation, IEE Proceedings*, Vol. 149, No. 5, 243–247, 2002.