Progress In Electromagnetics Research Letters, Vol. 64, 73–79, 2016

Planar Wideband Balun with Novel Slotline T-Junction Transition

Ya-Li Yao*, Fu-Shun Zhang, Min Liang, and Mao-Ze Wang

Abstract—A planar wideband balun is proposed. The proposed balun consists of a novel slotline T-junction and three microstrip-slotline transitions. Similar to the principle of the E-plane waveguide T-junction, the slotline T-junction acts as a phase inverter. With the microstrip-slotline transition, the device employs microstrip as feedlines. The radiation loss of the slotline is reduced to improve the insertion loss by loading the slotline with a superstrate and adding via holes along the slotline. An experimental balun with a bandwidth of 128% from 2.2 GHz to 10 GHz is designed, fabricated, and measured for validation. The measured results have reasonable agreement with the simulated ones.

1. INTRODUCTION

Baluns are used to convert an unbalanced signal into a balanced differential signal. Baluns are important components in many wireless communication systems for realizing components such as balanced mixers, push-pull amplifiers, and antenna feed networks [1]. Many studies have been done on baluns. A complex impedance-transforming coupled-line balun [2] and a compact balun based on microstrip EBG cell [3] have bandwidths of 19% and 20%, respectively. A miniature CPW balun is designed in [4], which can achieve good electrical performance but only has a relative bandwidth of 38%. Because rapid development of microwave circuits has imposed a strong demand for wideband components, various balun configurations with enhanced bandwidth have been reported for applications in microwave circuits. The balun designed in [5] is based on the artificial-transmission-line and has a bandwidth of 50%. The balun based on higher order mode SIW [6] and the planar balun composed of a divider and a phase shifter [7] have bandwidths of 60% and 64%, respectively. The use of metamaterial transmission lines in baluns [8, 9] further improves the bandwidth. The Marchand balun [1, 10, 11] is also a popular microwave balun structure, the bandwidth of which can be as wide as 100%. Particularly worth mentioning are the ultra-wideband balun employing coupled microstrip lines [12] with a bandwidth of 105%.

In this work, a planar wideband balun is introduced with a novel slotline T-junction. Both the simulated and measured results show that the designed balun has a bandwidth of 128% from 2.2 GHz to 10 GHz, characterized by return loss better than 10 dB and amplitude and phase imbalance within 0.7 dB and ±2.5°. The radiation loss of the slotline is reduced to improve the insertion loss by loading the slotline with a superstrate [13] and adding via holes along the slotline.

2. DESIGN

Unlike the microstrip T-junction, the slotline T-junction acts as a phase inverter [14], which is similar to the E-plane waveguide T-junction. However, the working frequency band of the traditional slotline T-junction needs to be broadened. Therefore, a novel slotline T-junction is proposed to improve the traditional slotline T-junction's bandwidth and to be used in a wide band balun. To clearly understand

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Received 28 September 2016, Accepted 22 November 2016, Scheduled 5 December 2016

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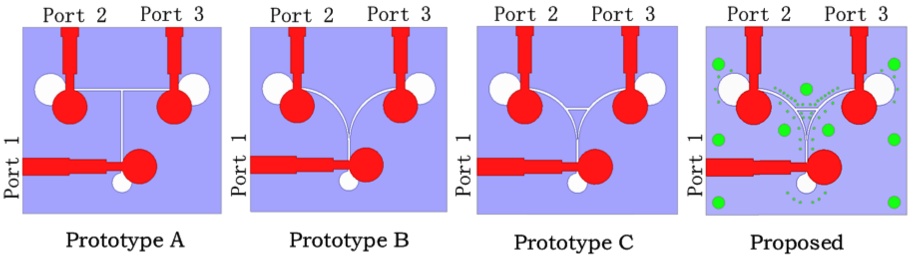


Figure 1. Design evolution of the balun.

the structure and the operation principle of the proposed balun, the design evolution of the balun is shown in Fig. 1 and the corresponding simulated results are presented in Fig. 2. All the simulations are conducted with the commercial software Ansys High Frequency Structure Simulator (HFSS).

Firstly, the traditional slotline T-junction and three external microstrip feedlines constitute Prototype A. A microstrip line terminated with a capacitive circular disk and a slotline terminated with an inductive circular slot constitute wideband microstrip-slotline transition. With the wideband microstrip-slotline transition, the signals are coupled from the microstrip line at the input port (Port 1) to the slotline and then coupled from the slotline to the microstrip lines at the output ports (Port 2 and Port 3). Due to the inherent property of the slotline T-junction, the output signals are equal in magnitude but have 180° phase difference. The microstrip-to-slotline transition is a typical conventional broadband balun, which can be equivalent to a coupler with the coupling coefficient n. According to the equivalent circuit and equations for the microstrip-slotline transition in [15] and [16], the impedance transition can be calculated as follows:

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

Where Z_m and Z_S are the characteristic impedance of the microstrip and the slotline, respectively.

The coupling coefficient of the coupler is:

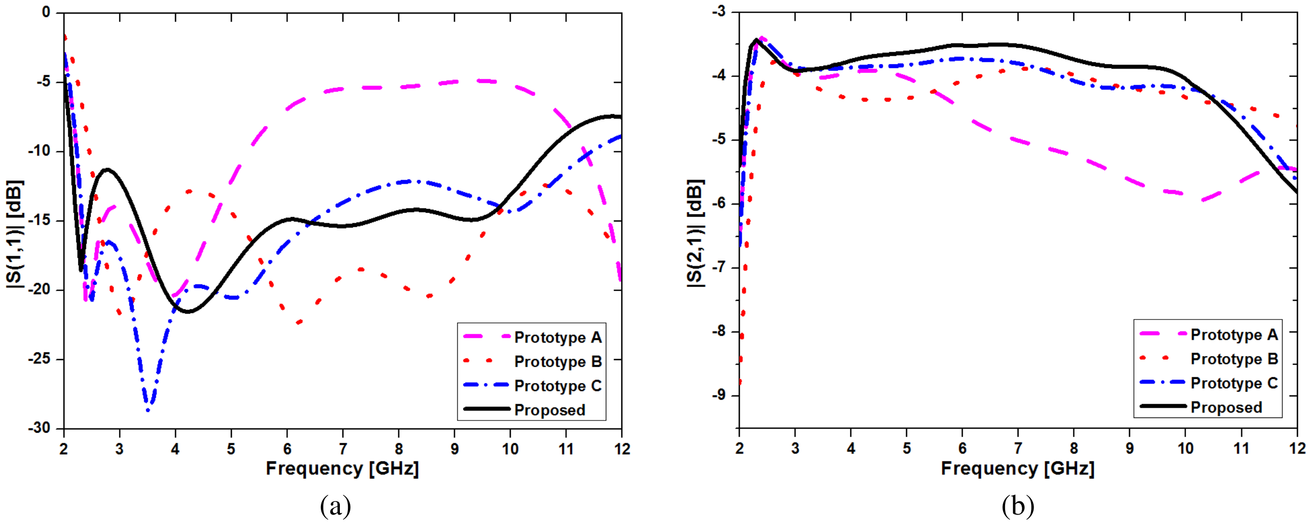
$$n = \cos 2\pi \frac{h}{\lambda} u - \cot q_0 \sin 2\pi \frac{h}{\lambda} u \tag{2}$$

where

$$\begin{aligned} q_0 &= 2\pi \frac{h}{\lambda} u + \tan^{-1}\left(\frac{u}{v}\right) \\ u &= \left[\varepsilon_r - \left(\frac{\lambda}{\lambda_s}\right)^2\right]^{\frac{1}{2}} \\ v &= \left[\left(\frac{\lambda}{\lambda_s}\right)^2 - 1\right]^{\frac{1}{2}} \end{aligned}$$

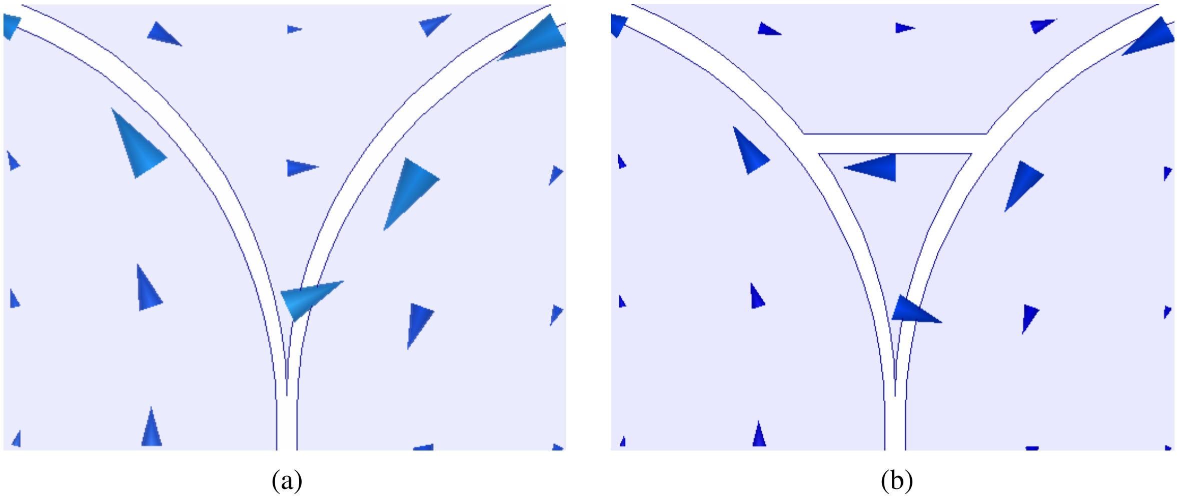
h is the thickness of the dielectric substrate, ε_r the permittivity of the dielectric substrate, and λ and λ_s represent the wavelength of the center frequency in air and the effective wavelength of the center frequency in slotline, respectively. The slot width is chosen to give impedance 110 ohm, and the coupling coefficient is 0.8. So the impedance as seen from the microstrip line next to the slotline is $(110 \times 0.8^2 =)$70.4 ohm. Then the impedance is transformed from 70.4 ohm to about 50 ohm via the stepped microstrip lines.

Secondly, the traditional slotline T-junction in Prototype A is evolved into a novel one in Prototype B with all other dimensions unchanged. The novel T-junction is inspired by the research results of the modified E-plane waveguide T-junction in [17]. It consists of two quasi-arc-shaped slots, the edges of which are two quarter-circles with the same radius (R) tangent to the red dotted lines and the blue dotted lines respectively as shown in Fig. 5(a). The distance along the X axis between the centers of the two quarter-circles is equal to the slot width (Wslot) and along the Y axis is half of the slot width (Wslot/2). It can be seen from Fig. 2(a) that the working frequency band of Prototype A for the return loss at the input port better than 10 dB is from 2.3 GHz to 5.2 GHz, whereas that of Prototype B is



(a) (b)

Figure 2. Simulated results of the baluns in the design evolution process from Fig. 1. (a) Reflection coefficient of the input port (Port 1). (b) Transmission coefficient from the input port (Port 1) to the output port (Port 2).



(a) (b)

Figure 3. Current distributions around the slots at 5 GHz. (a) Prototype B. (b) Prototype C.

from 2.5 GHz to 12.8 GHz. And the only difference between Prototype A and Prototype B is the shape of the slotline T-junction. As a result, significant improvement is obtained in the bandwidth of the slotline T-junction. However, the insertion loss for Prototype B is poor around 5 GHz.

Thirdly, to improve the insertion loss of Prototype B, Prototype C is obtained with a short horizontal slot across the two quasi-arc-shaped slots on the basis of Prototype B. Fig. 3 and Fig. 4 present the current distributions and radiation patterns at 5 GHz for Prototype B and Prototype C, respectively. It is shown that the short slot brings an opposite current and weakens the currents between the two quasi-arc-shaped slots, which decrease the radiation loss, as shown in Fig. 3. It can be seen form Figs. 2(a) and (b) that the insertion loss of Prototype C is improved with its return loss at the input port remaining better than 10 dB from 2.3 GHz to 11.4 GHz compared with Prototype B.

Finally, the proposed balun is obtained by loading the slotline with a superstrate and adding via holes along the slotline to further improve its insertion loss, which can decrease the radiation loss of the slotline and restrain the surface wave around the slotline. The via holes are located along the slotline and close to the edge of the slotline. The locations and radii of the via holes are given referred to the theory

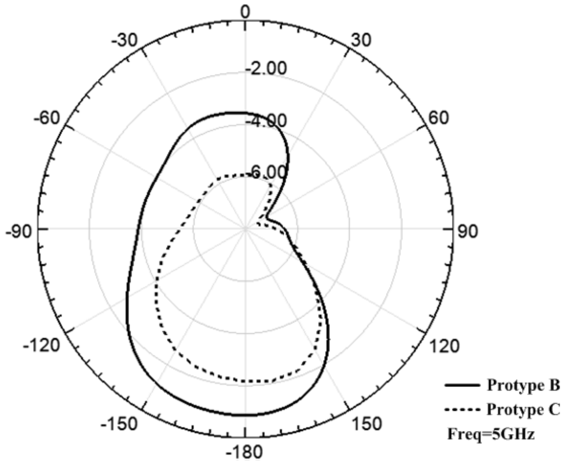


Figure 4. Radiation patterns of Prototype B and Prototype C at 5 GHz.

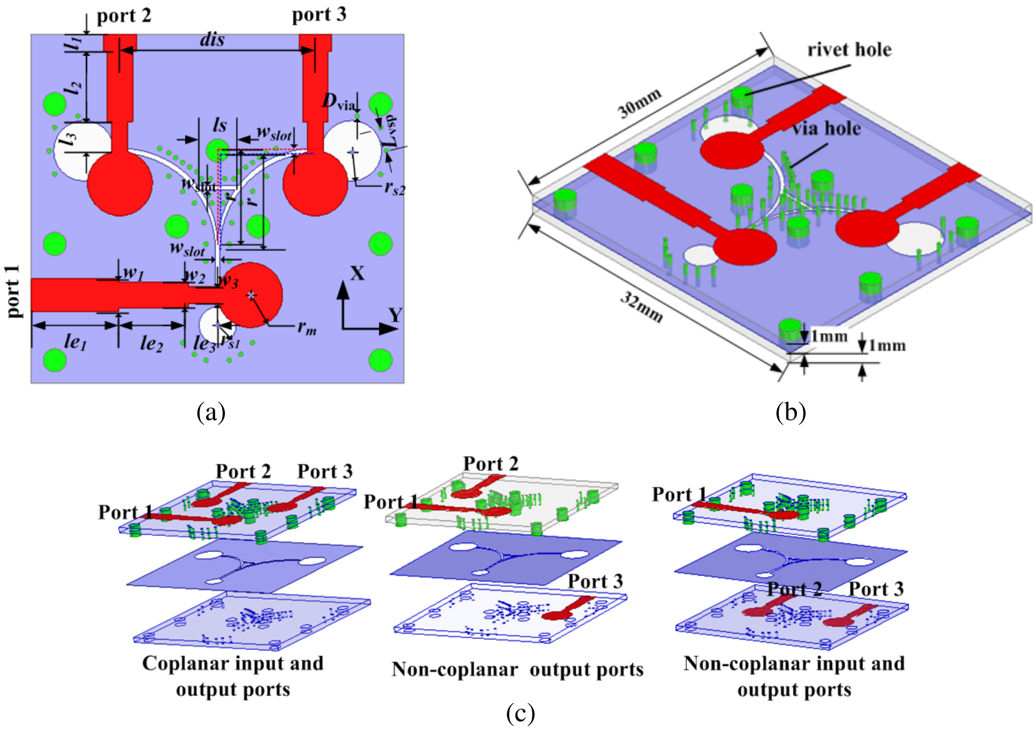


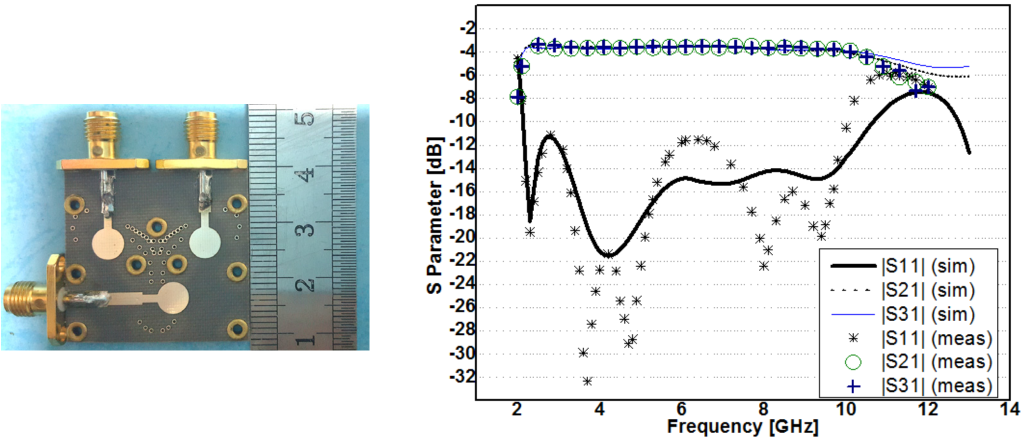
Figure 5. Configuration of the proposed balun. (a) Front view. (b) 3-D view. (c) Exploded view.

of substrate-integrated waveguide. According to [18], the via diameter are chosen to be Dvia = 0.4 mm and the separation Lvsp between adjacent vias is less than 2.5 mm (Lvsp $< \lambda_0/20$) respectively and to achieve low radiation loss. The configuration of the proposed balun is shown in Fig. 5. The novel slotline T-junction terminated with three circles is etched on the middle layer between two riveted identical substrates. The stepped microstrip lines at the three ports can be placed on either the top layer or the bottom layer according to the engineering requirement as shown in Fig. 5(c). This can bring great convenience to microwave integrated circuits. It is shown in Fig. 2(b) that the insertion loss of the proposed balun is within 1 dB, which is obviously lower than that of three others from 2.2 GHz to 10.0 GHz. This is due to the radiation loss reduction of the slotline by loading the slotline with a superstrate and adding via holes along the slotline. And the return loss of the proposed balun at the input port remains better than 10 dB from 2.2 GHz to 10.0 GHz.

3. RESULTS

Based on the evolution procedure mentioned above, the proposed balun is simulated, fabricated, and measured. Two identical pieces of Arlon AD260A substrates with a thickness of 1 mm and a dielectric permittivity of 2.6 are used as the substrates of the designed balun. Table 1 lists the optimized values of design parameters of the balun in Fig. 5. The prototype of the balun was fabricated as shown in Fig. 6(a).

The simulated and measured performances of the proposed balun are shown in Fig. 6(b). According to the measured results, the balun has a return loss better than 10 dB over an 128% bandwidth from 2.2 GHz to 10 GHz. The magnitude for ports 2 and 3 is less than 4 dB with an amplitude imbalance less than 0.7 dB. The insertion loss is due to the radiation loss, substrate and metal loss as well as the loss from the connection between microstrip line and SMA test connector. And the measured differential phase between two output terminals is 180° ±2.5° over the whole frequency band as shown in Fig. 7. The



(a) (b)

Figure 6. (a) Photograph of the developed balun. (b) Simulated and measured performance of the developed balun.

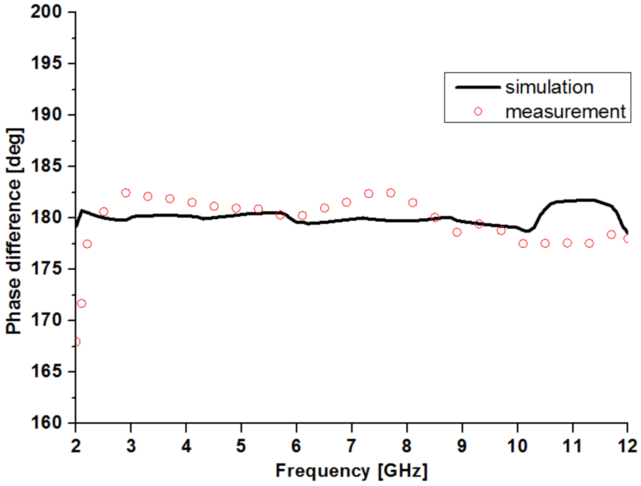


Figure 7. Measured phase difference of the developed balun.

Table 1. Optimized values of design parameters of balun.

Name	w_1	w_2	w_3	l_1	l_2	l_3	r	w_{slot}
Value (mm)	2.8	2.2	1.4	1.5	6	2.6	8.3	0.4
Name	dis	le_1	le_2	le_3	ls	r_{s1}	r_{s2}	r_m
Value (mm)	16.8	7.5	6	2.6	3.05	1.6	2.6	2.8

Table 2. Performance comparison between published baluns and this work.

Reference	Frequency range (GHz)	Bandwidth (%)	Amp./pha. Imbalance (dB/°)	Max.$\|S_{21}\|/\|S_{31}\|$ (dB)
[2]	1.85 ∼ 2.23	19	±1/ ± 5	3.15/ ± 3.29
[3]	2.7 ∼ 3.3	20	1.4/3	4.5/4.5
[5]	1.87 ∼ 3.07	50	0.5/3	3.41/3.40
[6]	7 ∼ 13	60	0.27/2.4	4.0/4.0
[7]	1.7–3.3	64	0.3/ ± 5	/
[8]	1.6 ∼ 3.6	77	0.7/6(±3)	4.0/4.0
[9]	1 ∼ 2.25	83	1/ ± 3.4	3.6/3.8
[11]	1.11 ∼ 2.93	90	0.69/1.4	3.8/4.12
[10]	1 ∼ 3	100	/10	6.0/6.0
[1]	1.2 ∼ 3.3	100	1/ ± 4	/
[12]	3.4 ∼ 11	105	±0.5/ ± 10	3.4/3.4
This work	2.2 ∼ 10	128	0.7/ ± 2.5	4.0/4.0

slight shift in frequency between simulations and measurements is attributed to fabrication uncertainties. From these results, it can be seen that good performance within a wide band for the introduced balun is observed.

The performance comparisons of published baluns and this work are given in Table 2. To our best knowledge, the proposed balun obtains good performance within a comparable wide frequency band (128%) among the available data.

4. CONCLUSIONS

A broadband balun using a modified slotline T-junction has been developed and confirmed by experiments. The proposed balun consists of a modified slotline T-junction and three wideband microstrip-slotline transitions. The simulated and measured results of the balun show that the return loss at its input port is better than 10 dB and that its amplitude and phase imbalance are within 0.7 dB and ±2.5° over a bandwidth of 128% from 2.2 GHz to 10 GHz. In conclusion, the introduced balun can be a good candidate in broadband microwave integrated circuits.

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