Novel Balun Structure for Dipole Antenna

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Abstract: A novel balun structure for dipole antenna, which is based on the current distribution on parallel microstrip lines and the emission cancellation characteristic of close equal and opposite currents, is proposed. The principle of the balun structure is first elaborated and verified. Then, a dipole antenna with resonance at 2.45 GHz is constructed using the balun and its radiation pattern is measured. The simulated and measured reflection coefficients (S_{11}) of the antenna are in good agreement 2—3 GHz. The relative bandwidth with an S_{11} of below −10 dB is more than 25%. The antenna also shows a good radiation pattern at 2.45 GHz. The proposed structure can provide a new balun design method for dipole antennas.

Key words: coplanar balun; dipole antenna; wideband; compact balum

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0 Introduction

Since the 1970s, microstrip antennas with good performance in terms of light weight, small size, low cost, low profile, and easy conformability, have attracted considerable attention and research interest. Among these antennas, dipole antennas and their derivative quasi-Yagi antennas are widely applied in fields such as telecommunication, detection, broadcasting, and military affairs because of their simple structures and stable performance[1-8].

Dipole antennas and quasi-Yagi antennas are differential balanced antennas. When an unbalanced coaxial feeder is used to feed the antennas, for the purpose of rejecting cross-polarization, increasing the radiation efficiency and improving impedance characteristics, we need to use a balun to provide transformation between balanced and unbalanced signals. At present, dipole antennas and their matching baluns are becoming increasingly diverse and functional[9-16]. They have advantages for specific applications, however, they also have corresponding limitations. In Ref. [9], a compact broadband balun utilizing a weak coupling line between parallel lines was proposed. The structure achieves a stable gain over its designed band, however its cost may be high because of its complex structure. In Ref. [10], a coplannar balun was realized by suppressing the even mode signals and matching the odd mode signals of microstrip lines. It has advantages of good balanced property and simple structure, but it has a narrow bandwidth. In Ref. [11], an ultra-wideband dipole antenna with an integrated-balun, which utlized capactive coupling, was proposed. It has a simple structure, but the overall size is large and the radiation performance is unsatisfactory. In Refs. [12—14], balun structures based on four-port networks were realized. They have low insertion loss and good phase characteristics. However, in Refs. [12, 13], no analysis was carried out on the load characteristics of the baluns and in Ref. [14], the balanced property of

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the dipole antenna with the corresponding balun is unsatisfactory.

This paper proposes a novel balun structure in which parasitic microstrip lines are designed in parallel to transmission lines to eliminate the cross-polarization caused by unbalanced feed, according to the current distribution on the parallel microstrip lines. First, the principle of the balun structure is elaborated. Then, the performance of the balun is verified using a dipole antenna with resonance at 2.45 GHz and constructed using the balun. Both the simulated and experimental results indicate good unbalanced-to-balanced performance of the balun structure.

1 Design of the Balun and Principle

The proposed balun structure is shown in Fig. 1. The input port is the unbalanced port and the output port is the balanced port. The main body of the balun has a coplanar structure, and the middle line is connected with the other lines by the metal via.

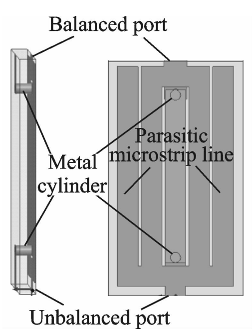

Fig. 1 The proposed balun

When a coaxial feed feeds the arms of a dipole antenna differentially, there will be unbalanced currents in the inner and outer conductors and the two arms due to unbalanced impedance matching between them. In theory, the strong coupling between the inner and outer conductors makes the outer surface of the inner conductor and the inner surface of the outer conductor distribute equal and opposite currents (I_1 and I_2), as shown in Fig. 2. The equal and opposite currents will not radiates outward. The current (I_3) distributed on the outer surface of the outer conductor are perpendicular to the current direction of the arms, which will result in cross-polarized radiation. The current (I_3) also cause unequal currents in the two arms ($I_1 \neq I_2 + I_3$), which will lead to a further distortion of the antenna radiation pattern. Therefore, in order to improve the radiation performance of the antenna, a balun that is capable of suppressing the current (I_3) is required to realize impedance matching between the coax cable and the dipole antenna.

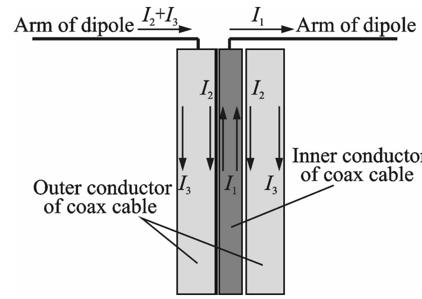

Fig. 2 Cross-sectional view

The current distribution of the balun structure is shown in Fig. 3. The metal line A is connected to one arm by the upper metal cylinder. The line A is also connected to the feed point and inner conductor of the coax cable by the lower metal cylinder. The upper end of the lines B are connected to the other arm. The lower end is connected to the coplanar feed point and outer conductor of the coax cable. The upper ends of the parasitic strips C are open and the lower ends are connected to the lines B.

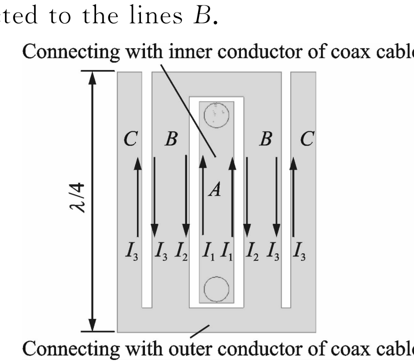

Fig. 3 Current distribution of the balun structure

There exists strong coupling among the lines A, B, and C due to their small intervals. Therefore, when the balun operates, the current (I_1) in the line A will be symmetrically distributed on the sides near the intervals, and the equal and opposite currents ($I_2 = -I_1$) in the line B will be distributed on the sides near the line A. The additional current (I_3) caused by the unbalanced feed structure will be distributed in opposite directions on the adjacent sides of lines B and C. When the lengths of the lines B and C are equal to quarter of the operating wavelength, the radiation effect of the additional current (I_3) will be offset, and thus the currents on the two arms will be balanced along the same direction.

2 Verification of Balun Performance

The balun proposed in Section 1 is used to construct the dipole antenna, as shown in Fig. 4. The dielectric substrate is modeled as FR-4, whose relative permittivity ε_r is 4.4 and tangent loss is 0.02. Through theoretical estimation and optimization using a commercial software HFSS, detailed dimensions of the antenna for operation at around 2.45 GHz were obtained, and they are listed in Table 1. Fig. 5 shows the fabricated sample of the balun-integrated dipole antenna.

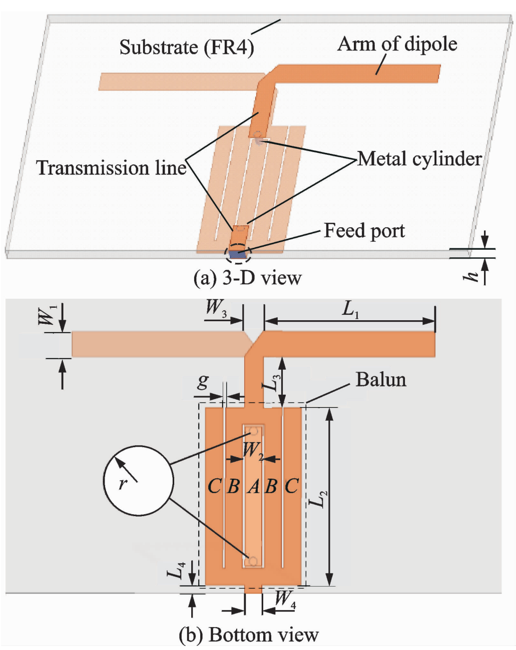

Fig. 4 Simulation model of the balun-integrated dipole antenna

Tab. 1 Dimensions of balun-integrated dipole antenna mm

L_1	W_1	L_2	W_2	L_3	W_3	L_4	W_4	r	g	h
21.5	2	21	3	6	2.2	1	2	1	0.3	1.6

The current distribution is shown in Fig. 6 from which the operation principle of the balun can be verified, as mentioned in Section 1. The following observations can be made from Fig. 5: (1) The currents on the two arms are approximately equal and in the same direction. (2) The currents on the outer sides of line A are approximately equal and opposite to the currents on inner sides of line B. (3) The currents on the inner sides line C are approximately equal and opposite to the currents on the outer sides line B. These observations confirm the feasibility of our balun design describe in Section 1.

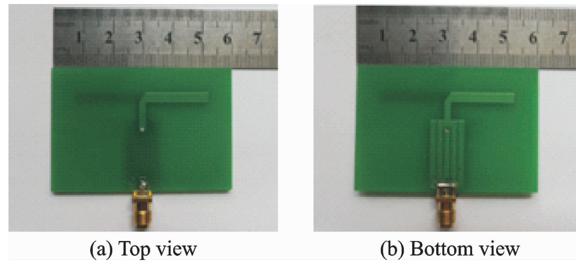

Fig. 5 Photograph of fabricated sample of the balun-integrated dipole antenna

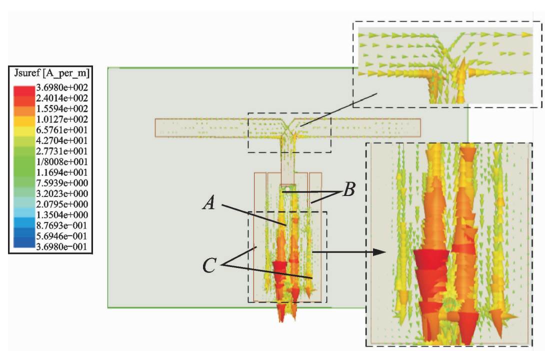

Fig. 6 Current distribution of the balun-integrated dipole antenna

To further validate the significance of the balun in improving the radiation performance of the dipole antenna, we use an unbalanced structure in analogy to a coaxial feed to feed a dipole antenna at 2.45 GHz, as shown in Fig. 7. The comparison between the E-plane radiation patterns of the dipole antenna without the balun and that with the balun are shown in Fig. 8. From the radiation patterns shown in Fig. 8, we can find that there is an approximate 30° deviation from the main direction (along the x-axis) without the balun, while the antenna with the balun radiates along the x-axis. The deviation is caused by the unequal currents distributed on the two arms of the dipole antenna due to the unbalanced struc-

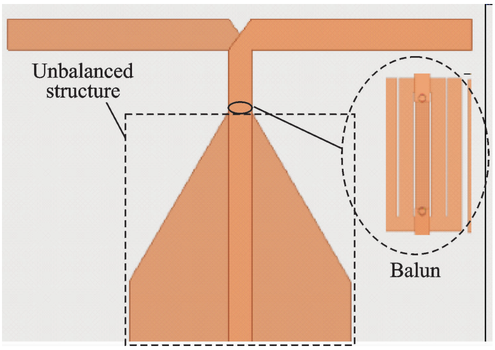

Fig. 7 A dipole antenna with an unbalanced feed structure

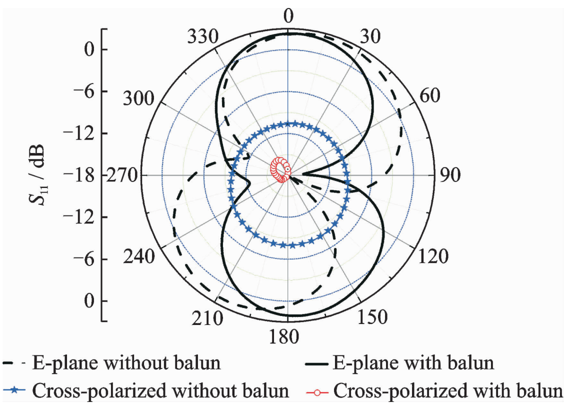

Fig. 8 Simulated E-plane and cross-polarized radiation patterns of the dipole antenna at 2.45 GHz (without the balun and with the balun)

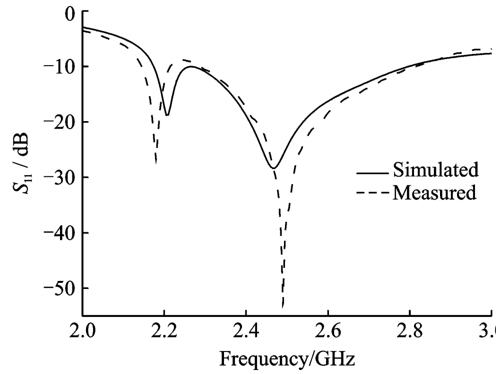

Fig. 9 Reaction coefficient (S_{11}) of the balun-integrated dipole antenna

ture. The balun causes the currents to be distributed almost equally on the two arms. Thus, the distortion of the radiation pattern can be rectified. As shown in Fig. 8, the cross-polarization is also significantly reduced when the proposed balun is used.

3 Experiment using the Balun-Integrated Antenna

The dipole antenna with the integrated balun is measured using an Agilent N5245A network analyzer in a 3 m×5 m×3 m anechoic chamber. The simulated and measured reflection coefficients(S_{11}) are shown in Fig. 9. The simulated and measured S_{11} are in good agreement 2—3 GHz. The simulated S_{11} is below −10 dB for frequencies from 2.17 GHz to 2.80 GHz and the measured S_{11} is below −10 dB for frequencies from 2.14 GHz to 2.81 GHz. The simulated and measured relative bandwidths are both more than 25%, and therefore, the proposed can be regarded as a wideband balun structure. It can be observed from the measured result that there are two resonance points at 2.18 GHz and 2.49 GHz, with S_{11} of −26.82 dB and −52.87 dB, respectively. The resonance point at 2.18 GHz is caused by the designed transmission line between the antenna arms and the balun, and it extends the current path through the arms resulting in the neighboring low-frequency resonance point. The slight errors between the simulated and measured results may be caused by the following factors: (1) The relative permittivity of the fabricated sample's dielectric substrate is slightly less than the simulated permittivity of 4.4. (2) The thickness of the sample's dielectric substrate is slightly less than the simulated thickness of 1.6 mm. (3) There is machining error in the process of fabrication.

The simulated and measured radiation patterns at 2.45 GHz of the balun-integrated dipole antenna are shown in Fig. 10. In Fig. 10(a), the simulated radiation pattern has an "O-shape" in the H-plane. The measured curves agree well with the simulated curves except for the slight backward errors. In Fig. 10(b), the simulated radiation pattern has an "8-shape" in the E-plane. The measured forward curves agree well with the simulated forward curves, whereas the measured backward curves are about 1.6 dB less than the simulated backward curves. Besides, the measured backward curves deviate 20° from the simulated backward curves. These errors are mainly

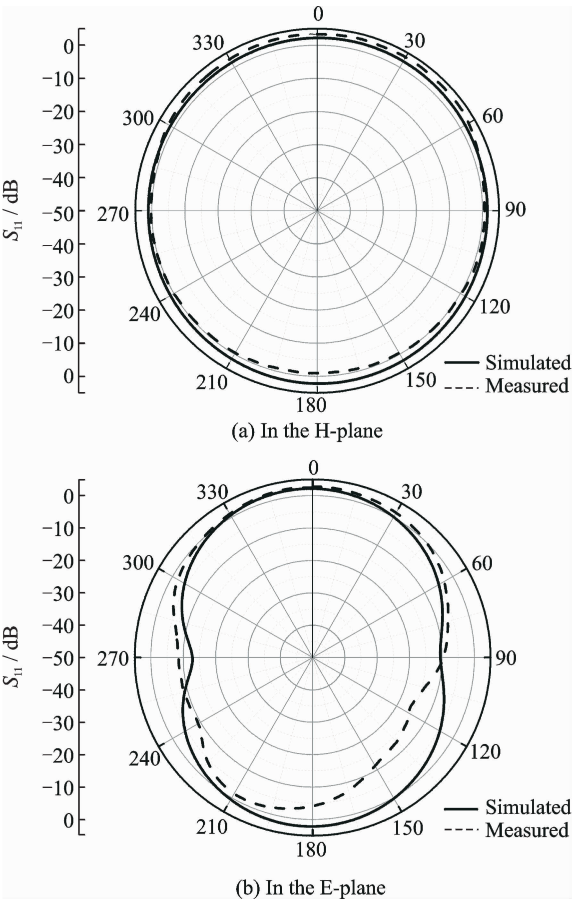

Fig. 10 Simulated and measured radiation patterns with the balun-integrated dipole antenna at 2.45 GHz

caused by the limitations of the chamber's size and spurious radiation of the fixed bracket and SMA (sub-miniature-A) connectors. The measured radiation patterns further indicate the correctness of the design of the balun structure.

4 Conclusions

In this paper, a novel balun for dipole antenna was designed and fabricated. The theoretical and simulation analysis on the current distribution and the unbalanced-to-balanced performance of the balun all indicate the correctness and scientificity of the design. The dipole antenna constructed with the balun has a relative bandwidth of more than 25%. Therefore, it can be regarded as a wideband structure. Overall, the balun has advantages of simple structure, low fabrication cost, and wide bandwidth, which make it promising in engineering applications such as 4 G communications.

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References:

[1] NAZLI H, BICAK E, TURETKEN B, et al. An improved design of planar elliptical dipole antenna for UWB applications[J]. IEEE Antennas & Wireless Propagation Letters, 2010,9(1):264-267.

[2] QUDRAT-E-MAULA M, SHAFAI L. Low-cost, microstrip-fed printed dipole for prime focus reflector feed[J]. IEEE Transactions on Antennas & Propagation, 2012, 60(11): 5428-5433.

[3] ZHANG J P, XU Y S, WANG W D. Ultra-wide band microstrip-fed planar elliptical Dipole antenna [J]. Electronics Letters, 2006, 42(3): 144-145.

[4] XUE N L, ZHI N C, SEE T S P. A UWB dipole antenna with enhanced impedance and gain performance [J]. IEEE Transactions on Antennas & Propagation, 2009, 57(10): 2959-2966.

[5] LIM S, LING H. Design of a closely spaced, folded Yagi antenna[J]. IEEE Antennas & Wireless Propagation Letters, 2006, 5(1): 302-305.

[6] KAN H K, WATERHOUSE R B, ABBOSH A M, et al. Simple broadband planar CPW-fed quasi-Yagi antenna[J]. IEEE Antennas & Wireless Propagation Letters, 2007, 6(11): 18-20.

[7] WU J, ZHAO Z, NIE Z, et al. A broadband unidirectional antenna based on closely spaced loading method[J]. IEEE Transactions on Antennas & Propagation, 2013, 61(1): 109-116.

[8] FEI P, JIAO Y C, HU W, et al. A miniaturized antipodal Vivaldi antenna with improved radiation characteristics[J]. IEEE Antennas & Wireless Propagation Letters, 2011, 10(1): 127-130.

[9] TSAI C H, CHEN H C, WU T L. A novel compact balun using a weakly coupled line with grounded resonator[J]. IEEE Microwave & Wireless Components Letters, 2014, 24(11): 763-765.

[10] SÁNCHEZ A M, RIBÓ M, PRADELL L, et al. CPW balun for printed balanced antennas[J]. Electronics Letters, 2014, 50(11): 785-786.

[11] KOZIEL S, OGURTSOV S, ZIENIUTYCZ W, et al. Design of a planar UWB dipole antenna with an

integrated balun using surrogate-based optimization [J]. IEEE Antennas & Wireless Propagation Letters, 2015, 14(99): 366-369.

[12] SHEN A L, ZHOU M, ARIGONG B, et al. Dual-band balun with flexible frequency ratios[J]. Electronics Letters, 2014, 50(17): 1213-1214.

[13] ZHOU M, SHAO J, ARIGONG B, et al. Design of microwave baluns with flexible structures[J]. IEEE Microwave & Wireless Components Letters, 2014, 24(10): 695-697.

[14] ZHANG H, XIN H. A dual-band dipole antenna with integrated-balun[J]. IEEE Transactions on Antennas & Propagation, 2009, 57(3): 786-789.

[15] PIEKARZ I, SOROCKI J, GRUSZCZYNSKI S, et al. Input match and output balance improvement of marchand balun with connecting line[J]. IEEE Microwave & Wireless Components Letters, 2014, 24 (10): 683-685.

[16] MA T G, WANG C C, LAI C H. Miniaturized distributed march and balun using coupled synthesized CPWs[J]. IEEE Microwave & Wireless Components Letters, 2011, 21(4): 188-190.

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(Executive Editor: Xu Chengting)