A Novel Balun Structure for Dipole Antenna

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**Abstract:** Based on the current distribution on the parallel microstrip lines and emission cancellation characteristic of close equal and opposite currents, a novel balun structure for dipole antenna is proposed. In this paper, the principle of the balun structure is elaborated and verified. Then a dipole antenna with resonance at 2.45 GHz constructed with the balun is fabricated and measured. The simulated and measured reaction coefficient (S11) of the antenna are in good agreement over 2~3 GHz. The relative bandwidth with S11 of below -10 dB is more than 25%. The antenna also shows a good radiation pattern at 2.45 GHz. The structure can provide a new balun design method for dipole antennas.

**Key words:** Coplanar balun, dipole antenna, wideband, miniaturized

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# **0 Introduction**

After 1970s, microstrip antennas with good performance of light weight, small size, low cost, low profile and easy conformal, have aroused wide attention and research. Of those, dipole antennas and their derivative quasi-Yagi antennas are even more widely applied in fields like telecommunication, detecting, broadcasting and military affairs because of their simple structures and stable performance [1-8].

Dipole antennas and quasi-Yagi antennas are differential balanced antennas. Then, 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 use a balun to provide transformation between a balanced signal and an unbalanced one. Recently, dipole antennas and their matching baluns are increasingly diverse and functional[9-16]. They have specific application values respectively, but also have corresponding limitations. In [9], a compact broadband balun utilizing weak coupling line between parallel lines was proposed. The structure has a stable gain over its designed band, but the cost may be high because of its complex structure. In [10], by suppressing even mode signal and matching odd mode signal of microstrip lines, a coplanar balun was realized. It has advantages of good balanced property and simple structure, but the bandwidth is narrow. In [11], utilizing capacitive coupling, an ultra-wideband dipole antenna with an integrated-balun was proposed. It has a simple structure, but the total size is large and the radiation performance is unsatisfactory. In [12-14], the balun structures were realized based on four-port networks. They have low insertion loss and good phase characteristics. But in [12, 13], no analysis of load characteristics on the baluns was carried on. In [14], the balanced property of the dipole antenna with the corresponding balun is unsatisfactory.

According to the current distribution on the parallel microstrip lines, parasitic microstrip lines parallel to transmission lines are designed to reject cross-polarization caused by unbalanced fed, thus a novel balun structure is realized in this paper. The principle of the balun structure is elaborated. Then, a dipole antenna with resonance at 2.45 GHz constructed with the balun will be given to verify the working principle. The simulated and experimental results both indicate the 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 unbalanced port and the output port is balanced port. The main body of the balun is a coplanar structure, the middle line is connected with other lines by the metal via.

When a coaxial feed feeds differentially on the arms of a dipole antenna, there are unbalanced currents in the inner and outer conductors and 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 inner surface of the outer conductor distribute equal and opposite currents (and ), as shown in Fig.2. The equal and opposite currents will not radiates outward. The currents () 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 currents () also cause unequal currents of the two arms (), which will lead to a further distortion of the antenna radiation pattern. Therefore in order to improve radiation performance of the antenna, a balun that is able to suppress the currents () is required to realize impedance matching between the coax cable and the dipole antenna.

Fig. 1 The proposed balun Fig. 2 Cross-sectional view

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

Fig.3 Current distribution of the balun structure.

 There exists strong coupling between lines A, B and C due to their small intervals. Therefore, when the balun operates, the currents () on the line A will be symmetrically distributed on sides nearby the intervals, and the equal and opposite currents () on the line B will be distributed on sides nearby the line A. The additional currents () caused by unbalanced feed structure will be distributed reversely on the adjacent sides of lines B and C. When the length of the lines B and C is equal to quarter operating wavelength, the radiation effect of additional currents () will be offset, and thus the currents on two arms are balanced and along the same direction.

# **2 Verification of the 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  is 4.4 and tangent loss is 0.02. Through the theoretical estimation and the optimization of commercial software HFSS, detailed dimensions of the antenna are shown in Table 1 for operation at around 2.45 GHz. Fig.5 shows the fabricated sample of the balun-integrated dipole antenna.

Table 1 Dimensions of the balun-integrated dipole antenna (mm)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| L1 | W1 | L2 | W2 | L3 | W3 | L4 | W4 | r | g | h |
| 21.5 | 2 | 21 | 3 | 6 | 2.2 | 1 | 2 | 1 | 0.3 | 1.6 |



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



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

The current distribution is shown in Fig.6 to verify the operation principle of the balun, which we have mentioned in section 1. What can be observed from the Fig. 5 are as follows: （1）the currents on the two arms are approximately equal and in the same direction; （2） the currents on the line A outside side are approximately equal and opposite to the currents on line B inside side; （3）the currents on the line C inside side are approximately equal and opposite to the currents on the line B outside side. All those observed confirm the feasibility of our balun design in section 1.



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

To further validate the significance of the balun on improving 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. Then, comparisons of E-plane radiation patterns between the dipole antenna without the balun and that with the balun are drawn, as shown in Fig.8. Combined with radiation patterns shown in Fig. 8, we can find that there is an approximate 30° deviation from the main direction (along x-axis) without the balun, while the antenna with the balun radiates along x-axis. The deviation is caused by the unequal currents distributed on two arms of the dipole antenna due to the unbalanced structure. The balun can make the currents distribute approximately equally on the two arms. Thus, distortion of the radiation pattern can be rectified. In Figure.8, the cross-polarization is also significantly reduced when using the balun designed in this paper.

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 2.45GHz (without the balun and with the balun).

# **3 Experiment of Balun-Integrated Antenna**

The dipole antenna with integrated-balun was measured by an Agilent N5245A network analyzer in an 3m×5m×3m anechoic chamber. The simulated and measured reaction coefficient(S11) are shown in Fig.9. The simulated and measured S11 are in good agreement over 2~3 GHz. The simulated S11 of below -10dB is from 2.17 GHz to 2.80 GHz and the measured S11 is from 2.14 GHz to 2.81 GHz. The simulated and measured relative bandwidth are both more than 25%, which 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 S11 of -26.82 dB and -52.87 dB respectively. The resonance point at 2.18 GHz emerge due to the designed transmission line between the antenna arms and the balun, which extends the current path flowing on the arms, thus bringing the neighboring low-frequency resonance point. The slight errors between simulated and measured results may be caused by following factors: (1) the relative permittivity of the fabricated sample’s dielectric substrate is slightly less than the simulated permittivity 4.4; (2) the thickness of the sample’s dielectric substrate is slightly less than the simulated thickness 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 is “O-shape” in the H-plane. The measured curves agree well with the simulated curves except for slight backward errors. In Fig.10(b), the simulated radiation pattern is “8-shape” in the E-plane. The measured curves forward agree well with the simulated curves forward, but measured curves backward are about 1.6dB less than the simulated curves backward. Besides, the measured curves backward deviates 20° from the simulated curves backward. These errors are mainly caused by limitation of the chamber’s size and spurious radiation of the fixed bracket and SMA connectors. The measured radiation patterns further indicate the correctness of the design of the balun structure.



 Fig.9 Reaction coefficient (S11) of the balun-integrated dipole antenna.



(a) in the H-plane



(b) in the E-plane

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

# **4 Conclusions**

In this paper, a novel balun for dipole antenna was designed and fabricated. Theoretical and simulation analysis on current distribution, and 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 more than 25%, which can be regarded as a wideband structure. Overall, the balun has advantages of simple structure, low fabricated cost and wide bandwidth, which make it promising in engineering applications such as 4G communications.

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