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Ultra-wideband bilateral tapered slot-line antenna fed by coplanar waveguide

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Abstract: In order to broaden the bandwidth of a tapered slot-line antenna (TSA), a bilateral tapered slot-line antenna (BTSA) with a new feeding structure of coplanar waveguide (CPW) is developed. Based on the fact that the bandwidth limitation of TSA mainly depends on its feeding structure, an improved CPW-based feed structure etched on the backboard of the BTSA is adopted to perform traveling-wave transition. Both the simulation results and measurement data verify that the proposed feeding structure results in "high-pass" frequency response for antenna impedance matching. The voltage standing wave ratio (VSWR) is less than 2∶1 when the frequency is higher than 3 GHz. The antenna gain exceeds 7 dBi with good radiation patterns when the bandwidth is from 4 to 16 GHz. This ultra wideband (UWB) antenna with a compact size is specially available for the electronic systems of counter-measure and microwave imaging.

Key words: ultra wideband (UWB); tapered slot-line antenna (TSA); feeding structure; coplanar waveguide (CPW)

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The tapered slot-line antenna (TSA) has been widely used in phased arrays[1], electronic counter measurments[2], mobile communication[3], and radio telescopes[4] due to its features of low profile, low cost, printed technology in structure and with a wide frequency band and a moderate gain in performance. For improving the properties of the TSA, Langley et al. [5] proposed an ultra wideband balun broadening its impedance matching bandwidth, and Zhang et al. [6] proposed the grating loading to enhance its gain. Now as a traveling-wave antenna, the TSA also receives much interest for medical imaging[7] due to its wideband features and appropriate gains. The bandwidth for impedance matching of the TSA depends on both the feed transition and the slot termination[8–11]. However, for an ultra-wideband antenna, the realization of the bandwidth for impedance matching is not enough, and the consideration of the bandwidth for radiation pattern and gain is also very important. The radiation properties of the TSA depend on the structural parameters such as length, width, and taper profile, and the effective dielectric thickness t_e defined by the dielectric constant r and physical thickness t of the substrate[8]. In Ref. [12], the optimum range of t_e normalized to the wavelength in free space for qualified patterns is summarized as

$$0.005 \leqslant \frac{t_e}{\lambda} = (\sqrt{\varepsilon_r} - 1)\frac{t}{\lambda} \leqslant 0.03 \tag{1}$$

and its alternative form is

$$\frac{0.005c}{(\sqrt{\varepsilon_r} - 1)t} \leqslant f \leqslant \frac{0.03c}{(\sqrt{\varepsilon_r} - 1)t} \tag{2}$$

where c is the velocity of light in free space. From Eq. (2), it can be obtained that the frequency coverage f_{max}/f_{min} is less than 6∶1.

Usually, the TSA is fed by a microstrip-line (MSL) crossed to the slot-line (SL) printed on the other side of the substrate. The unavoidable structure of the open-circuited MSL-stub and the short-circuited SL-stub results in additional frequency sensitivity. On the other hand, a bilateral TSA (BTSA) can be fed by a fin-line inside a rectangular waveguide in millimeter waves[13], which avoids the stub structure but is inconvenient for lower frequency bands with coaxial feed lines.

In this paper, a novel balanced feeding technique using coplanar waveguide (CPW) is proposed. Its simulation and measurement results are in good agreement. The frequency coverage for impedance matching (VSWR less than 2∶1) of the proposed antenna is 6.6∶1, while the frequency coverage for good radiation patterns is 4∶1. So the common bandwidth is 4∶1.

1 Antenna Design

The layout of an antenna prototype shown in Fig. 1 includes two parts: the CPW feeding structure etched on one side of an FR4 microwave substrate (ε_r = 4.4 and t = 1.6 mm) serves as a backboard[6, 14] for suppressing the backward radiation; and the bilateral tapered slot-line structure etched on two sides of a Duroid dielectric substrate (ε_r = 2.2 and t = 0.5 mm) serves as a radiator. The root of the radiator is inserted into the central slits excavated in the backboard and connected to the backboard by welding. The exponential taper profile of tapered slot-line is defined as

$$y(x) = \pm[0.156\exp(0.06x) - 0.106] \tag{3}$$

In addition, a pair of quarter-elliptical corner slots (with semi-major axis a and semi-minor axis b) are etched at the base of both the upper-half and the lower-half of the radiator for avoiding the currents directly flowing from the CPW structure (central strip of the lower part and ground plane of the upper part coated on the backside of backboard). The CPW connects downward to an unbalanced coaxial feed line, and forward to a balanced BTSA. In detail, its central strip surrounded by a Π-shaped slot connects to the lower-half of the BTSA, and its ground plane at the upper-part

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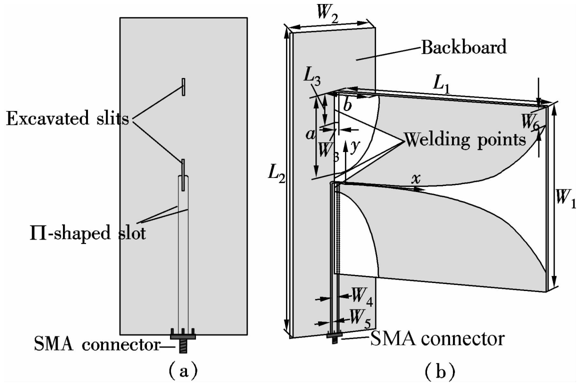

Fig. 1 Design prototype of CPW-fed BTSA. (a) Backboard; (b) Assembly with BTSA radiator

connects to the upper-half of the BTSA. This feeding structure provides perfect function of balun without frequency-sensitive discontinuity, and is designed for a 50 Ω impedance to avoid any transition to coaxial cable. It works in a traveling-wave operation with a very wide bandwidth of impedance matching.

Preliminary simulation results validate the effectiveness of the CPW feeding structure. Then a set of optimized structure parameters are chosen from a great number of simulation routines by using the CST microwave studio. The optimized parameters are listed in Tab. 1.

Tab. 1 Optimized values of design parameters

Parameters	Size/mm
L_1	93
L_2	100
L_3	10
W_1	60
W_2	40
W_3	2
W_4	3
W_5	0.35
W_6	6
a	27
b	20

2 Simulation Results and Measurement Data

The calculated current distribution on the radiator at 10 GHz is shown in Fig. 2. From Fig. 2, it can be seen that the current density concentrates at the tapered edges of the slot-line and then gives most contribution to the radiation; the current density along the tapered slot-line decreases with distance far away from the feeding point.

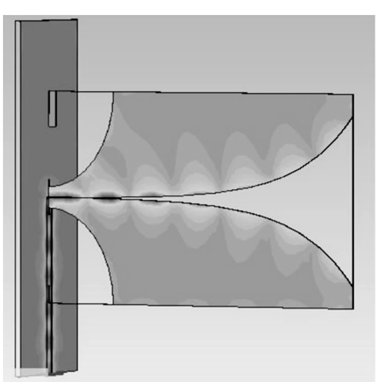

Fig. 2 The calculated current distribution at 10 GHz

An experimental prototype of the antenna (see Fig. 3) is fabricated and tested. The curve of return loss vs. frequency is measured by using an Agilent N5230A vector network analyzer. The measurement data are in good agreement with the simulation results as shown in Fig. 4, in which the measured frequency coverage exceeds 6.6 : 1 (3 to 20$^+$ GHz), and the simulated coverage exceeds 4 : 1 (5 to 20$^+$ GHz) for VSWR less than 2 : 1 ($S_{11} \leqslant -10$ dB). The errors in relative permittivity of FR4 substrate (4.4 ± 0.4) and imperfect fabrication (especially in the bonding process) result in the discrepancy between the simulated and the measured results.

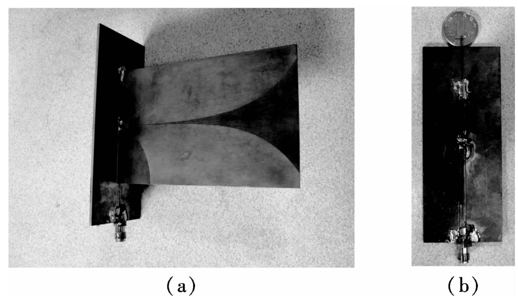

Fig. 3 Fabricated prototype of CPW-fed BTSA. (a) Front view; (b) Side view

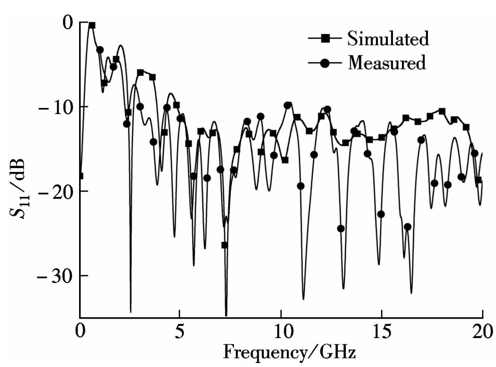

Fig. 4 Simulated and measured S_{11}

The simulated and measured curves of antenna gain vs. frequency are also shown in Fig. 5. The gain is higher than 6 dBi in the whole band and the peak value approaches 13.7 dBi. The radiation properties are measured in an anechoic chamber. The simulated and measured radiation patterns in both E- and H-plane at 4, 10, 16 GHz are compared in Fig. 6, respectively. The antenna holds end-fire patterns

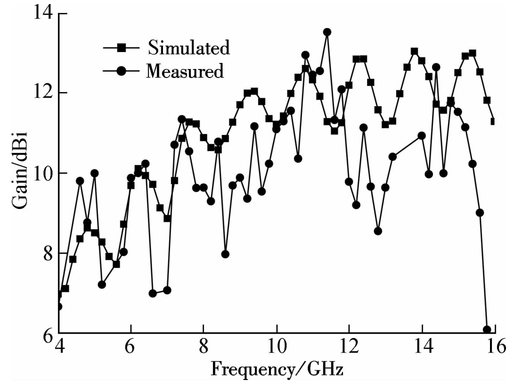

Fig. 5 Simulated and measured gain

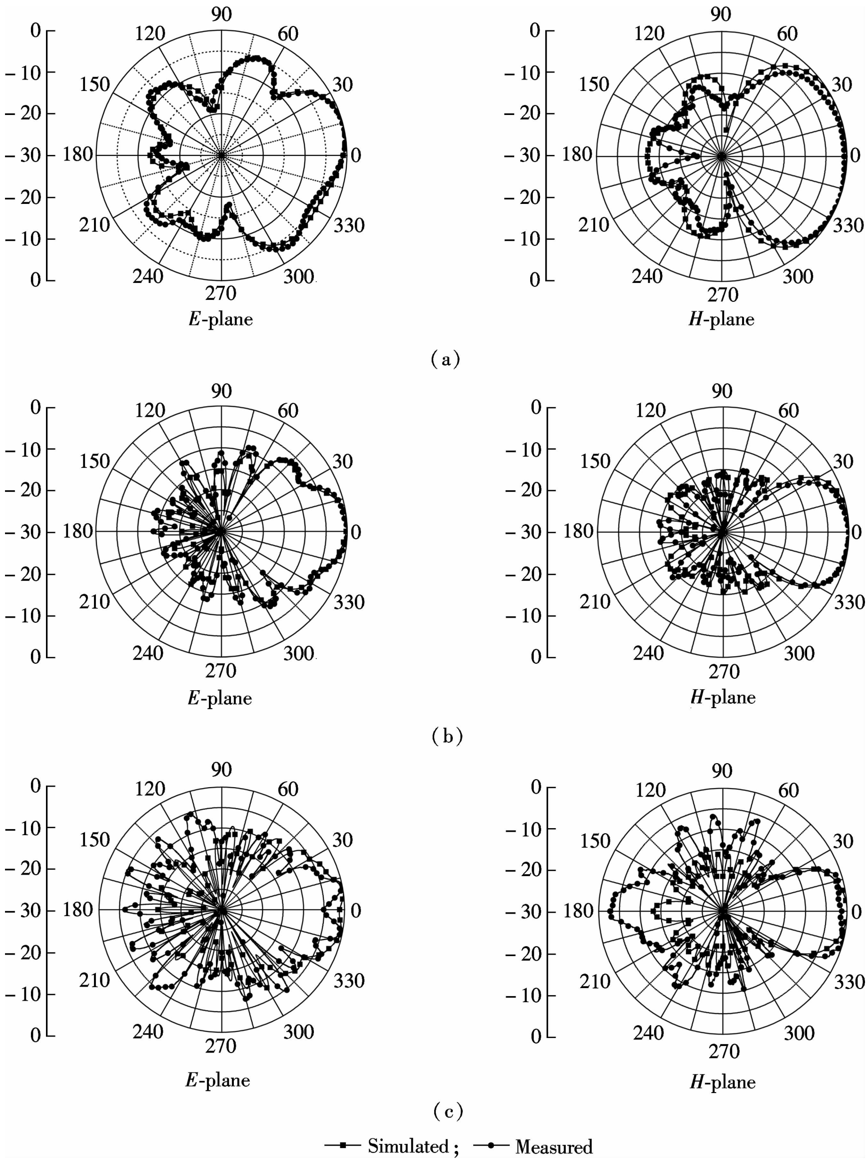

Fig. 6 Simulated and measured radiation patterns. (a) 4 GHz; (b) 10 GHz; (c) 16 GHz

within 4 to 16 GHz. When the frequency rises to over 16 GHz, the main lobe breaks up and then the gain drops down sharply. Therefore, the common frequency coverage of the antenna is just the same as that of the gain of 4∶1 (4 to 16 GHz).

3 Conclusion

A UWB CPW-fed bilateral tapered slot-line antenna is developed. It has a frequency non-sensitive balun structure for the transition from the balanced radiator to an unbalanced coaxial line. Its common bandwidth for both the VSWR less than 2∶1 and the gain higher than 6 dBi covers 4 to 16 GHz. This antenna with its compact size is specially available for the electronic counter-measure and microwave imaging systems.

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使用共面波导馈电的超宽带双侧渐变槽线天线

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摘要:为了拓展渐变槽线天线的工作频带,提出一种采用共面波导新型馈电结构的双面印刷对跖型渐变槽线天线. 基于对渐变槽线天线之宽频带特性受限于现有馈电方式的分析,改用蚀刻于背板的共面波导至双面印刷对跖渐变槽线的行波式转接. 其仿真和实验结果一致表明:该馈电方式使天线的阻抗具有高通频响特性,且保持较好的辐射方向性图,在 3 GHz 以上的频域内,驻波比小于 2∶1;在 4 ~ 16 GHz 频带内,定向增益高于 7 dBi. 这种体积很小的特宽频带天线尤其适用于电子对抗和微波成像等系统.

关键词:超宽带;渐变槽线天线;馈电结构;共面波导

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