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A Compact Printed Dipole Antenna for Wideband Wireless Applications

Jiangniu Wu[1], Zhiqin Zhao[1, *], Zaiping Nie[1], and Qing-Huo Liu[2]

Abstract—A compact printed dipole antenna with wide impedance bandwidth is proposed in this paper. This antenna consists of a pair of radiation metal arms and a microstrip-to-slotline transition structure. At the end of the feeding slotted line, a beveled slot with stepped connection structure is designed to realize an offset feeding structure for feeding the dipole antenna. By using the beveled offset feeding structure, the bandwidth of the dipole antenna is significantly improved. The microstrip-to-slotline transition is used as an integrated balun to realize a balanced feeding for the dipole antenna. To demonstrate the effectiveness of the proposed design, a prototype of the designed antenna is fabricated and measured. The measured results show that the designed dipole antenna achieves a gain of 2.2–4.4 dBi across a wide impedance bandwidth from 2.65 GHz to 17.5 GHz with a compact size (33 mm × 16 mm). The performance of the proposed dipole antenna is also compared with some similar printed dipole antennas with respect to overall size, substrate dielectric constant, impedance bandwidth and antenna gain.

1. INTRODUCTION

With the rapid development of wireless communication systems, there is an increasing requirement for printed wideband antennas with small size [1, 2]. Among the possible candidates reported in the literature, owing to their many salient features such as light weight, low cost, ease of fabrication, and suitability for integration with microwave integrated circuits [3], printed dipole antennas are considered to be highly prospective and have been widely investigated [4–6].

To widen the bandwidth of a printed dipole antenna, many attempts have been made such as inductively-loaded, double-sided printed method and series-fed technique, et al. [7–12]. Different element geometries have also been researched to improve the operating impedance bandwidth including circular, elliptical, bowtie and so on [13–18]. Antenna miniaturization is an important trend for wireless applications. Thus some small printed dipoles have also been investigated. A wideband low profile dipole fed by coplanar stripline is presented in [19]. A planar wideband balun based on microstrip to coplanar stripline is designed to feed this dipole antenna. Unfortunately, a larger size is required to realize this type balun, which will increase the antenna size. An ultrawideband printed dipole antenna with shorting bridge is designed in [20]. A wideband microstrip balun with three-section transformer is used to feed the printed dipole antenna. However, the bandwidth of the dipole antenna is limited by using this balun. The antenna size is also increased due to the additional balun.

Printed antennas with integrated baluns are able to reduce the occupied area with wideband performance [21]. An integrated balun is designed for half bowtie printed dipole antenna in [22]. The half bowtie printed dipole is shown to have a wide bandwidth of over 47%. A printed dipole antenna with an integrated balun feeding is given in [23]. Dual-band characteristics are achieved and bandwidths

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* Corresponding author: Zhiqin Zhao (zqzhao@uestc.edu.cn).
[1] School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu 611731, P. R. China.
[2] Department of Electrical and Computer Engineering, Duke University, Durham, NC 27708, USA.

of 41.5% and 47.8% are obtained at L- and S-bands, respectively. A tapered slot feeding is also designed as an integrated balun to feed a printed dipole antenna in [24].

In this paper, a printed dipole antenna with an integrated balun is proposed and researched. A beveled slot with stepped connection structure is designed at the end of the slotted line to realize an offset feeding for the proposed dipole antenna. Owing to the beveled offset feeding structure, an extremely wide impedance bandwidth can be achieved with a compact size. The measured results of a fabricated prototype validated the effectiveness of the proposed design.

2. CONFIGURATION OF THE PROPOSED ANTENNA

The rectangular dipole antennas with different feeding mechanisms are shown in Figure 1. Figure 1(a) shows a center-fed rectangular dipole antenna. Usually, such type antenna can achieve a wide impedance bandwidth through increasing the width of the arms. As shown in Figure 1(b), a very effective method to improve the impedance bandwidth is offsetting the feed point [25]. Another effective method is adopting the beveled arms as shown in Figure 1(c) to improve the impedance bandwidth [19, 20]. In this paper, these two techniques are used together to improve the impedance bandwidth of a rectangular dipole antenna. The designed dipole antenna with a beveled offset-fed structure is shown in Figure 1(d). A slotted line is adopted to feed this dipole antenna as in [20].

Owing to the symmetrical currents on the inner edges, the slotted line is always used as a balanced feeding for balanced antennas. Many microstrip-to-slotline transitions used as baluns have been widely

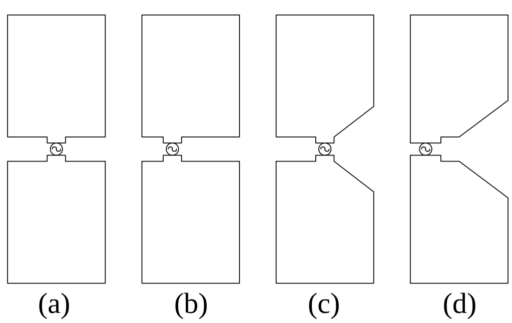


Figure 1. The printed dipole antenna with different feeding mechanisms, (a) center-fed, (b) offset-fed, (c) beveled center-fed, and (d) beveled offset-fed.

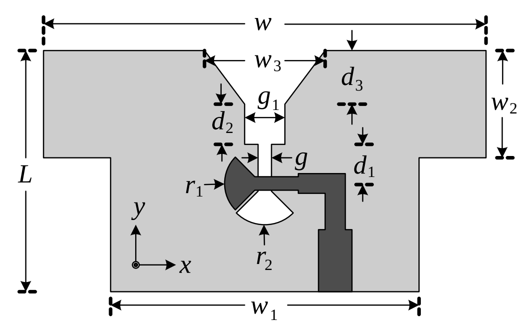


Figure 2. Geometry of the proposed printed dipole antenna.

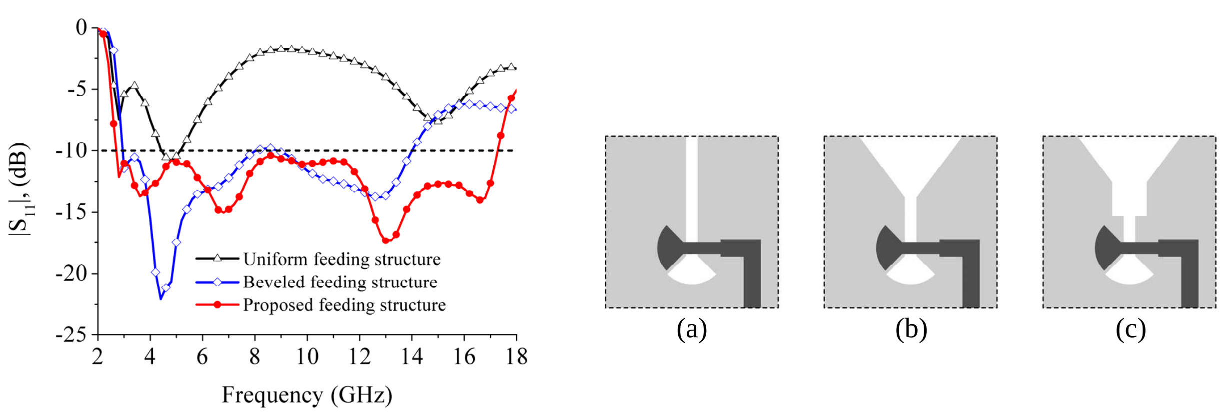


Figure 3. Comparisons of the simulated reflection coefficients of the printed dipole antenna with three feeding structures, (a) uniform feeding structure, (b) beveled feeding structure, and (c) proposed beveled offset feeding structure.

designed for balanced antennas such as bowtie antennas, Vivaldi antennas, et al. In this paper, a broadband microstrip-to-slotline transition structure is adopted as an integrated balun for feeding the proposed dipole antenna. The broadband microstrip-to-slotline transition structure is previously reported in [26]. The geometric structure and parameters of the designed dipole antenna with the integrated balun are shown in Figure 2. This antenna is printed on a FR-4 substrate with a dielectric constant of 4.4 and a thickness of 0.8 mm, respectively. The dipole arms are printed on the bottom layer of the substrate and directly connected to the slotted line of the microstrip-to-slotline transition structure. The microstrip feeding line of the transition feeding is printed on the top layer of the substrate. The input impedance of the microstrip feeding line is set to be 50-Ω for easily matching to a coaxial line. A stepped microstrip feeding line is adopted to realize a better mode transition between the slotted line and the microstrip line. The gap of the slotted line is extended step by step in order to further improve the impedance matching. The antenna without stepped slot structure is used as a reference antenna for comparison.

Figure 3 shows the comparisons of the simulated reflection coefficients of the printed dipole antenna with three feeding structures. Due to the beveled structure at the end of the slotted line shown in Figure 3(b), the impedance matching of the dipole antenna is significantly improved so that a wide impedance bandwidth is obtained. After designing a stepped connection structure between the beveled slot and the feeding slotline as shown in Figure 3(c), an additional resonance is introduced in the high frequency band. The bandwidth of the dipole antenna is further increased. The simulated impedance bandwidth defined by $|S_{11}| < -10$ dB of the dipole antenna with the stepped beveled offset feeding structure ranges from 2.65 to 17.3 GHz. A relatively wide impedance bandwidth is achieved.

The main parameters of the proposed dipole antenna are g_1, d_2, d_3 and W_3. From EM parametric study, we find that the impedance bandwidth in the high frequency band is mainly decided by the parameter W_3. The parameters W and d_3 have large effect on the impedance matching at the low frequencies. The impedance matching can be improved through slightly changing g_1, d_2 and W_2. In the practical application, misalignment between the bottom and the top layers is always inevitable. Thus the effect of the misalignment between the bottom and top layers are also studied. The effect of misalignment is shown in Figure 4. As shown in Figure 4(a), we find that the impedance matching is getting worse when the parameter S_1 increases to 0.3 mm. However, the reflection coefficient is still acceptable when the variation of S_1 is lower than 0.2 mm. The various S_2 has a relatively small effect on the impedance matching as shown in Figure 4(b). The impedance matching changed slightly when the parameter S_2 varies. From the above discussions, it can be summarised that the misalignment between bottom and top layers has a very small effect on the impedance matching when the variations of S_1 and S_2 are lower than 0.2 mm. Thus the effect of the misalignment between the bottom and the top layers can be ignored.

During the optimization phase, the optimization process is aimed at obtaining a wideband impedance matching. Parameter optimization is mainly obtained by means of parametric analysis

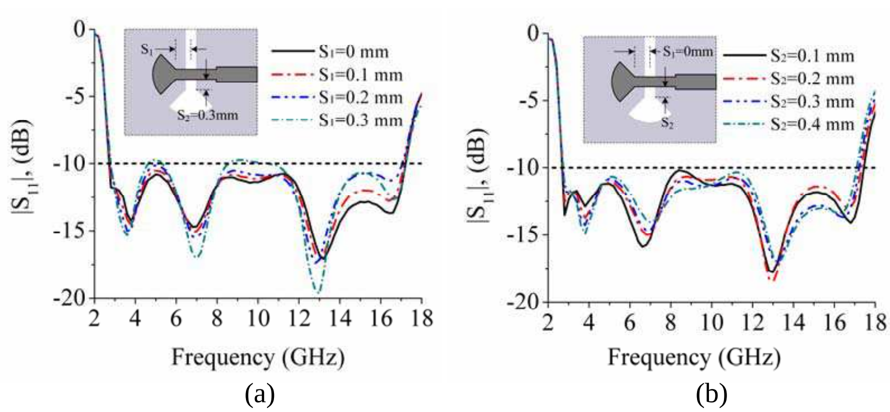


Figure 4. Effect of the misalignment between the bottom and the top layers on the reflection coefficients of the designed dipole antenna, (a) S_1, and (b) S_2.

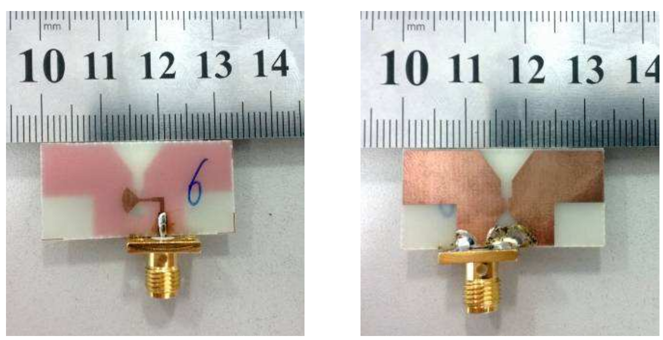
in which one parameter is studied while the others are kept fixed. By optimization, the final design dimensions are specified as: $W_1 = 16\,\mathrm{mm}$, $W_2 = 8.8\,\mathrm{mm}$, $W_3 = 9\,\mathrm{mm}$, $d_1 = 2\,\mathrm{mm}$, $d_2 = 2.8\,\mathrm{mm}$, $d_3 = 5\,\mathrm{mm}$, $g = 0.5\,\mathrm{mm}$, $g_1 = 1.7\,\mathrm{mm}$, $r_1 = 3.3\,\mathrm{mm}$, $r_2 = 2.7\,\mathrm{mm}$. The overall size of the substrate is $33\,\mathrm{mm} \times 16\,\mathrm{mm}$ ($W \times L$).

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

To demonstrate the effectiveness of the proposed design, a prototype of the designed antenna is fabricated and measured. Figure 5 shows the photographs of the fabricated antenna. A 50-Ω SMA connector is used to excite the fabricated antenna for measurement. The impedance matching is measured by using an Agilent E8363B Performance Network Analyzer (PNA) and the radiation performance is obtained by using SATIMO antenna measurement system. The *xoy*-plane and *yoz*-plane are referred to as the E-plane and H-plane, respectively.

Figure 6 shows the measured and simulated reflection coefficients of the designed dipole antenna. It is observed that the experimental results are in good agreement with the simulation results. As shown in Figure 6, only a small difference occurs between the measured and the simulated results. The simulated impedance bandwidth defined by $|S_{11}| < -10\,\mathrm{dB}$ is from 2.65 to 17.3 GHz and the measured impedance bandwidth defined by $|S_{11}| < -10\,\mathrm{dB}$ is from 2.65 to 17.5 GHz. Clearly, the designed dipole antenna with the proposed feeding structure provides a wide measured impedance bandwidth ratio of 6.6 : 1 with a compact size ($33\,\mathrm{mm} \times 16\,\mathrm{mm}$).

The measured and simulated antenna gains of the designed dipole antenna are shown in Figure 7.



(a) (b)

Figure 5. Photographs of the fabricated antenna, (a) top layer, (b) bottom layer.

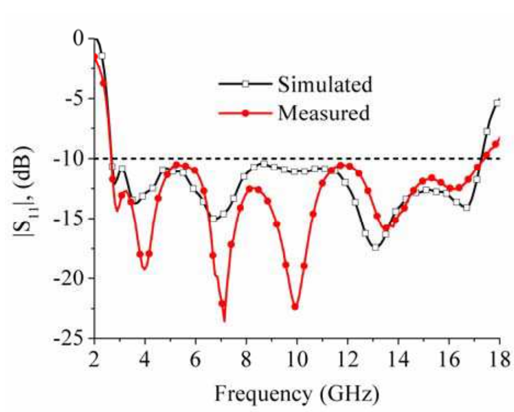


Figure 6. Measured and simulated reflection coefficients of the designed dipole antenna.

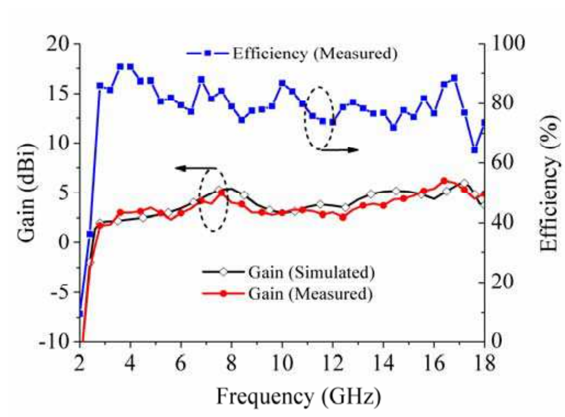


Figure 7. Measured and simulated antenna gains and measured radiation efficiency of the proposed dipole antenna.

It is observed that a good agreement between the measured and simulated results is achieved. The measured antenna gain ranges from 2.2 to 4.4 dBi. The average gain is around 3 dBi in the band of 2.95–18 GHz. The measured radiation efficiency of the fabricated antenna is also shown in Figure 7. The radiation efficiency value includes the mismatch loss and dielectric loss. According to the measured result, the measured radiation efficiency of the proposed printed dipole antenna is around 80% within the effective operating bandwidth.

In order to demonstrate the radiation performance of the fabricated antenna, its radiation patterns are also measured. The measured and simulated radiation patterns in E-plane (xoy-plane) and H-plane (yoz-plane) at 4, 8, 12 and 16 GHz are depicted in Figures 8 and 9, respectively. It is observed from the plots that the measurement results are in good agreement with the simulation results. As one can see from the plots, the radiation patterns of the designed dipole antenna exhibit bidirectional radiation characteristics in the xoy-plane and omnidirectional radiation characteristics in the yoz-plane at 4 and 8 GHz, which are comparable to that of a conventional dipole antenna. The main deviation from the radiation patterns of a conventional dipole antenna is the asymmetry of antenna structure. At 12 and 16 GHz, the radiation patterns of the designed antenna exhibit endfire radiation characteristics. This is because the radiation patterns of the proposed antenna are mainly affected by the balun and the beveled tapered slot at the high frequencies. The balun reduce the back radiation and the tapered slot increases the directivity of the antenna in the high frequency band. Anyhow, the main lobes of the radiation patterns are approximately fixed toward the endfire direction (y-axis direction) within the operating frequency bandwidth. Stable radiation patterns are still observed.

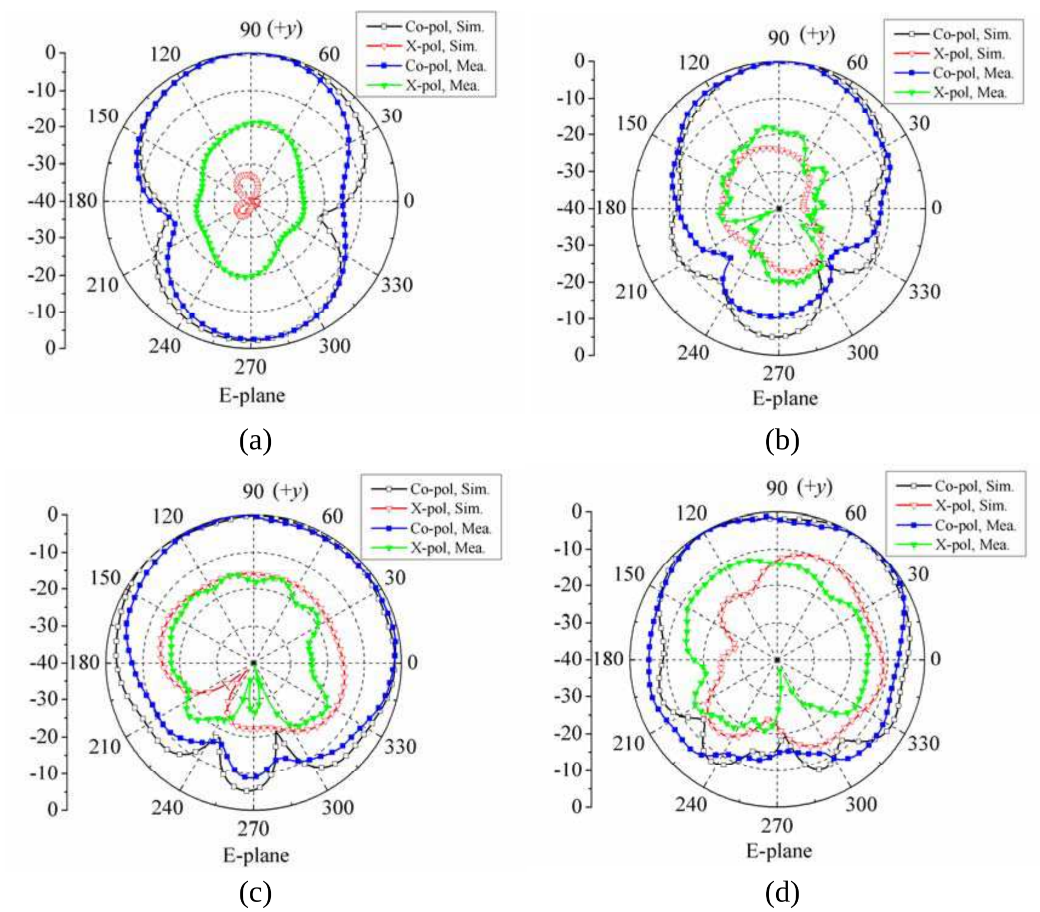


Figure 8. Simulated and measured radiation patterns of the proposed antenna in E-plane (xoy-plane) at the different frequencies, (a) 4 GHz, (b) 8 GHz, (c) 12 GHz, (d) 16 GHz.

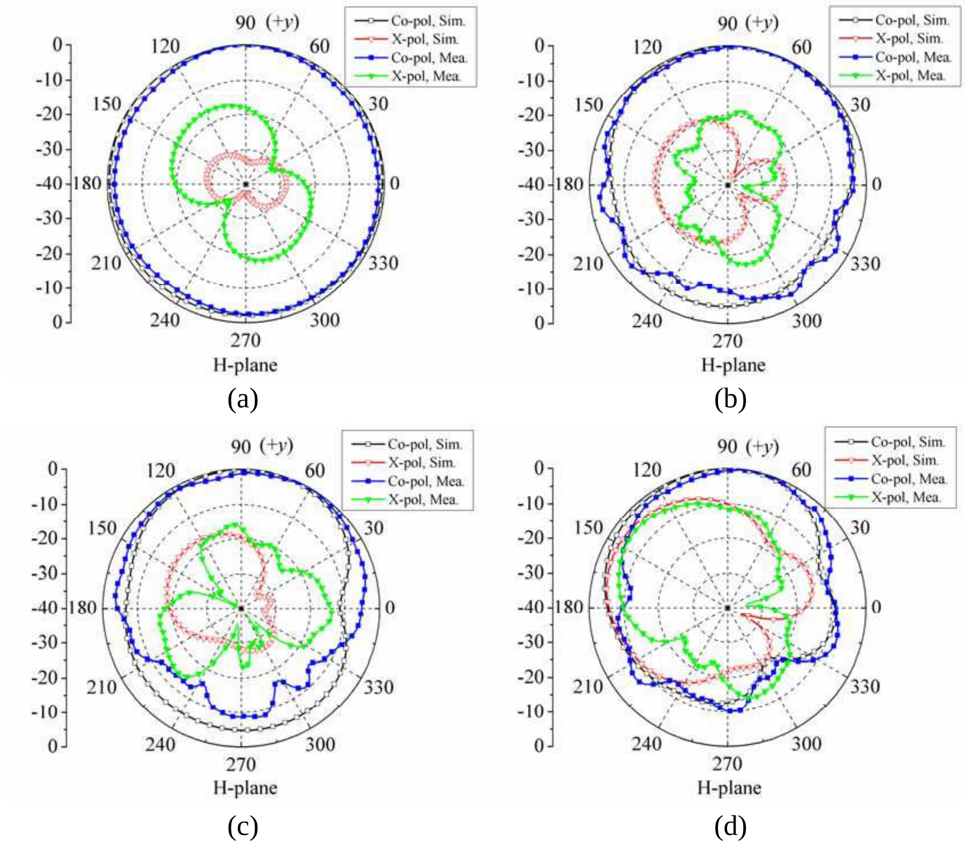


Figure 9. Simulated and measured radiation patterns of the proposed antenna in H-plane (yoz-plane) at the different frequencies, (a) 4 GHz, (b) 8 GHz, (c) 12 GHz, (d) 16 GHz.

4. COMPARISON WITH OTHER SIMILAR DESIGNS

For illustrating the performance of the proposed dipole antenna, comparisons between the proposed dipole antenna and other similar small printed dipole antennas in terms of bandwidth, antenna gain and antenna size are given in Table 1. According to the table, the proposed antenna and the antennas in [9, 17] can cover wide impedance bandwidth with low-profile structures. However, the antennas in [9, 17] have larger size compared with the proposed antenna. Though the size of the antennas in [9, 17] could be miniaturized by using a substrate with a higher dielectric constant, the proposed antenna can easily provide a wider impedance bandwidth. The antennas in [19, 20] can realize 2.8 : 1 and 3.89 : 1 impedance bandwidth, respectively. However, the additional baluns will increase the

Table 1. Comparisons between the proposed and reference antennas.

Antennas	Bandwidth (GHz)	Substrate (ε_r)	Gain (dBi)	Size (mm $\times$ mm)
Proposed	2.65–17.5	4.4	2.2–4.4	33×16
Ref. [9]	3.1–16	2.17	-	45×51
Ref. [17]	2.56–10.4	2.64	-	55×55
Ref. [19]	2.12–6	2.55	2.2–3.8	54×13
Ref. [20]	2.8–10.9	3.38	2.4–6.2	40×18
Ref. [22]	2.27–3.36	2.2	About 1.7–2.3	36.5×19
Ref. [24]	3.1–10.6	2.2	About 0.5–6.5	71×86

antenna size compared with the proposed antenna. The antenna in [22] has a similar size compared with the proposed antenna. The bandwidth of the designed antenna far exceeds that of the antenna in [22]. The performance of the presented dipole antenna also exceeds the performance of design in [24]. In contrast with the similar small printed dipoles with wideband performance and antenna size, the proposed dipole antenna achieves a wider impedance bandwidth under a small overall area. A relatively flat gain response is also obtained in the operating bandwidth.

5. CONCLUSION

A planar printed dipole antenna with wideband performance is presented in this paper. Beveled offset feeding structure has been introduced between the dipole arms to achieve a wideband impedance bandwidth. A wideband integrated balun based on microstrip-to-slotline transition has been employed to excite the proposed dipole antenna. A prototype of the designed dipole antenna is also fabricated and measured to validate the effectiveness of the proposed design. The measured results are in good agreement with the simulation results. The fabricated dipole antenna provides a wide impedance bandwidth defined by $|S_{11}| < -10\,\text{dB}$ from 2.65 to 17.5 GHz and a flat gain response. The measured radiation efficiency of the proposed antenna is around 80% within the effective bandwidth. In contrast with other printed dipole antennas, the designed dipole antenna has successfully achieved a wider impedance bandwidth with a compact size. The proposed method is simple in comparison with the other techniques that have been used for bandwidth enhancement.

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