Progress In Electromagnetics Research Letters, Vol. 98, 55–60, 2021

Surface-Mount PIFA Using Ball Grid Array Packaging for 5G mmWave

Xi Wang[1], Xiubo Liu[1], Wei Zhang[1], Dongning Hao[1], and Yanyan Liu[2, *]

Abstract—In this letter, a surface-mount planar inverted-F antenna (PIFA) is proposed for the 5G mmWave system using ball grid array packaging (BGA). To meet the requirement of cost-effectiveness, the proposed antenna element is designed on a single FR4 layer to achieve low cost. To achieve a compact size, the BGA packaging is used on the proposed antenna element. Finally, the size of the antenna prototype is only 4.5 mm × 4.5 mm × 1.3 mm. Besides, the surface-mount feature allows the proposed antenna to be integrated with other devices in the same system package. The simulation and measurement results are discussed in detail. The measurement results show that the impedance bandwidth of -10 dB is 15.3% (24.7–29.6 GHz), and the peak gain is 5.85 dBi at 28 GHz. The proposed PIFA can be used in the 5G NR bands N257 (26.5–29.5 GHz), N258 (24.25–27.5 GHz), and N261 (27.5–28.35 GHz).

1. INTRODUCTION

5G communication operates in a high carrier frequency with massive bandwidth, which can provide a user experience of high-speed data transmission. The density of equipment, especially the number of antennas, is higher than the previous four generations. The 5G systems need to be highly integrated, cost and energy-efficient. The mmWave antenna is one of the key technologies to the 5G system [1, 2]. Coaxial connectors [3] or waveguide connectors [4] are the simplest and most popular interconnection methods for connecting antennas and RF front-end chipsets. However, the bulky size is difficult to integrate into the system. Besides, the high insertion loss between the antenna and the RF front-end chip will degrade the performance of the RF system. Antenna in package (AiP) and heterogeneous 3-D integration technology is a key technology of 5G [5, 6]. The integration of the antenna and RF front-end chipset into the same package can reduce the feed-line loss and enhance system performance. Most importantly, the interconnection using the surface-mount technique avoids the use of bulky and lossy connections. For example, surface-mount technology was applied to the stamped metal antenna [7] and wideband 3D patch antenna [8].

Planar inverted-F antenna (PIFA) is a popular antenna used for ultrawideband and mobile-phone due to its compact size, light weight, and low cost [9–12]. However, the substrate of the above-mentioned antenna may not be compatible with the system board. Therefore, surface-mount solutions may be more attractive for system applications. Hence, in this letter, we propose a compact PIFA using BGA packaging technology for 5G mmWave system integration. The compact BGA packaged antenna element is suitable for integration with other surface-mount devices (SMD) into the same package. The simulated and experimental results are shown and discussed. The antenna is designed, fabricated, and measured. The proposed antenna achieves a broadband bandwidth and a stable radiation pattern. All the simulation results are given by ANSYS electromagnetics.

Received 2 May 2021, Accepted 5 June 2021, Scheduled 7 June 2021

* Corresponding author: Yanyan Liu (lyytianjin@nankai.edu.cn).

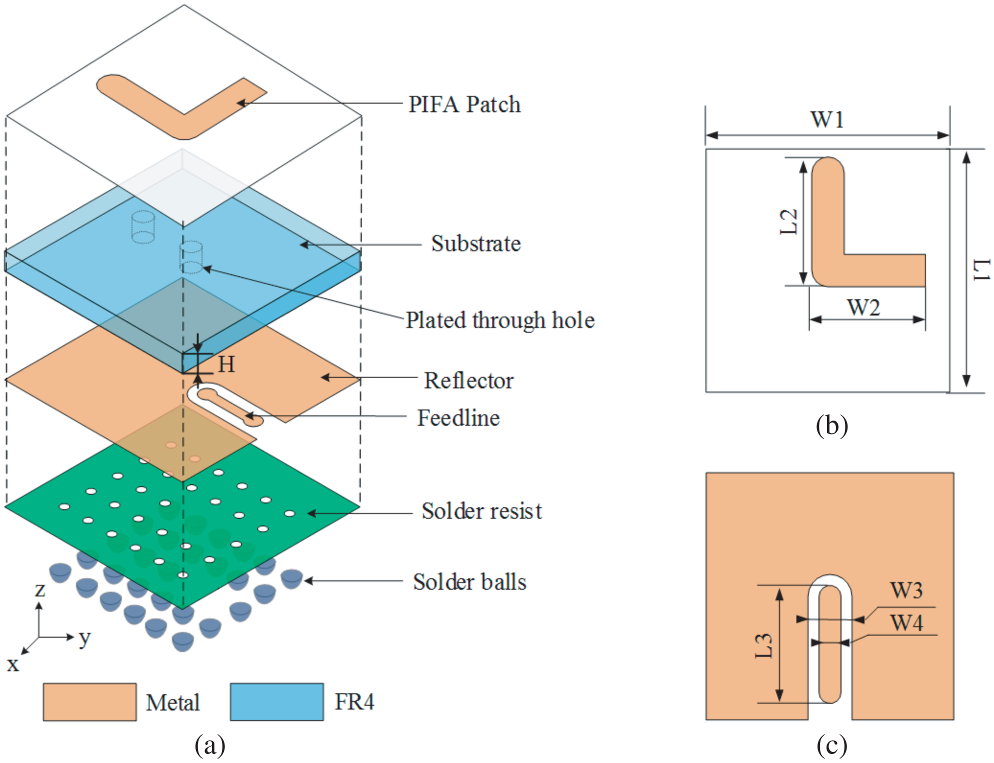
[1] School of Microelectronics, Tianjin University, Tianjin 300072, China. [2] Tianjin Key Laboratory of Photo-electronic Thin Film Devices and Technology, Nankai University, Tianjin 300071, China.

2. ANTENNA GEOMETRY AND DESIGN

Figure 1 shows the geometry of the proposed antenna element. The explored view in (a), the top view in (b), and the bottom view in (c). It can be seen that the PIFA patch is printed on a single-layer FR4 substrate with a permittivity of 4.4 and a dielectric loss of 0.018. The PIFA is fed by plated through holes (PTH) with a diameter of 0.2 mm located on the substrate, and the grounded port is directly shorted to the ground plane through another PTH. A quarter-wavelength feedline is printed on the bottom layer to improve the impedance matching. Furthermore, the grounded bottom metal can be regarded as a reflector for obtaining a directional radiation pattern. The input impedance of the PIFA is the standard 50 Ω, which is easy to integrate with other devices. Solder resist is applied to the surface of the bottom metal. After reflow-soldering, the solder balls with a diameter of 0.3 mm are mounted on the bottom of the proposed antenna element. Table 1 lists the detailed dimension of the proposed antenna element.

Table 1. Dimensions of the proposed antenna element (Units: mm).

Parameters	Values	Parameters	Values
$L1$	4.5	$W2$	2.1
$L2$	2.4	$W3$	0.8
$L3$	2.15	$W4$	0.4
$W1$	4.5	H	1.1



(a)

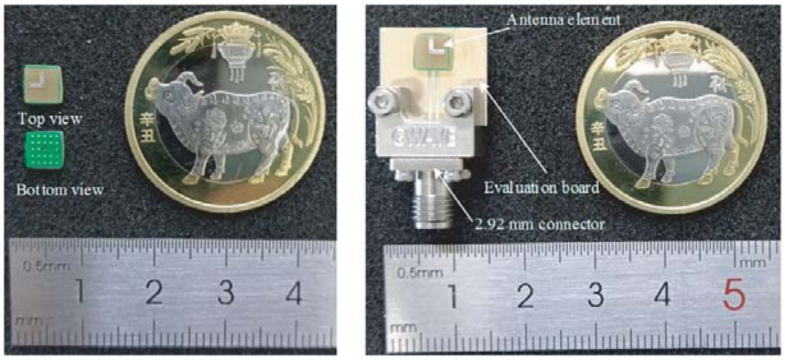
(b)

(c)

Figure 1. Geometry of the proposed antenna element. (a) Explored view. (b) Top view. (c) Bottom view.

3. MEASUREMENT RESULTS AND DISCUSSION

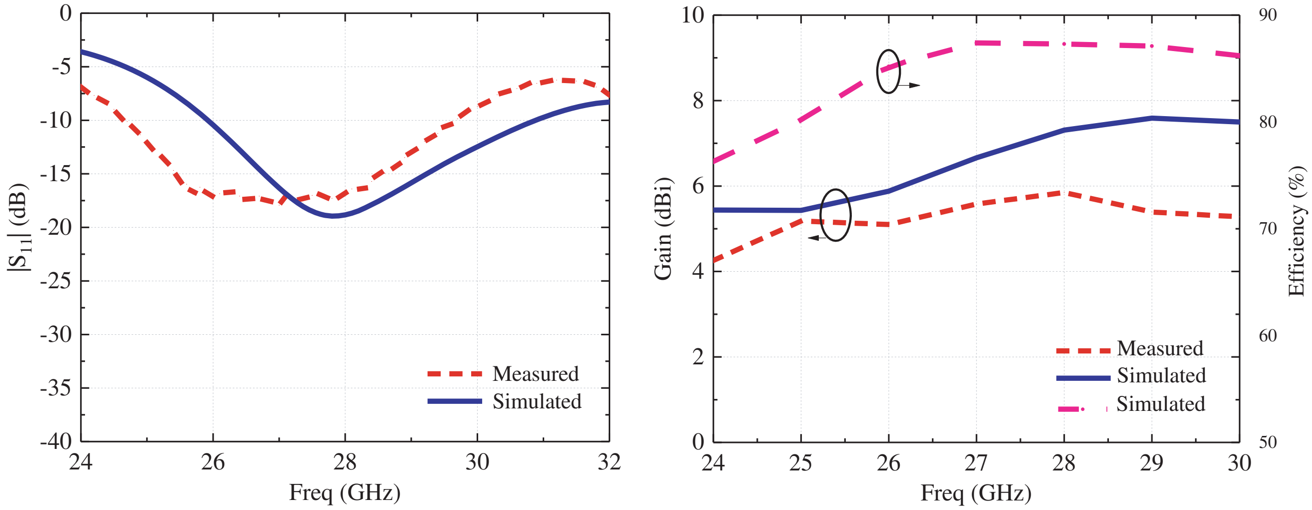
As shown in photographs of Figure 2, a prototype is fabricated to verify the proposed design. The antenna element is shown in Figure 2(a), and the assembly prototype is shown in Figure 2(b). An evaluation board with a 50 Ω coplanar waveguide (CPW) is fabricated on the Rogers4350B with a dimension of 14 mm × 13 mm to verify the proposed antenna element. An end launch 2.92 mm connector is mounted on the edge of the evaluation board to connect the antenna and the instrument. The S-parameters are measured by Rohde & Schwarz Network Analyzer (ZVA40). Furthermore, the radiation patterns are measured in an anechoic chamber.



(a) (b)

Figure 2. Photograph of the PIFA antenna prototype. (a) Antenna element. (b) Assembly prototype.

Figure 3(a) shows the simulated and measured reflection coefficients of the antenna. The simulated $|S_{11}| < -10\,\mathrm{dB}$ is from 26 to 30.8, and the $-10\,\mathrm{dB}$ impedance bandwidth is 16.9%. The measured $|S_{11}| < -10\,\mathrm{dB}$ is from 24.7 to 29.6, and the $-10\,\mathrm{dB}$ impedance bandwidth is 15.3%. As shown in Figure 3(b), The simulated antenna efficiency exceeds 76.3% in the operating frequency band of 24 to 30 GHz. The simulated gain ranges from 5.44 to 7.59 dBi, and the measured gain ranges from 4.26 to 5.85 dBi. A small discrepancy can be observed between the simulated and measured results. Firstly,



(a) (b)

Figure 3. (a) Measured and simulated reflection coefficient of the proposed antenna. (b) Measured and simulated peak gain of the proposed antenna.

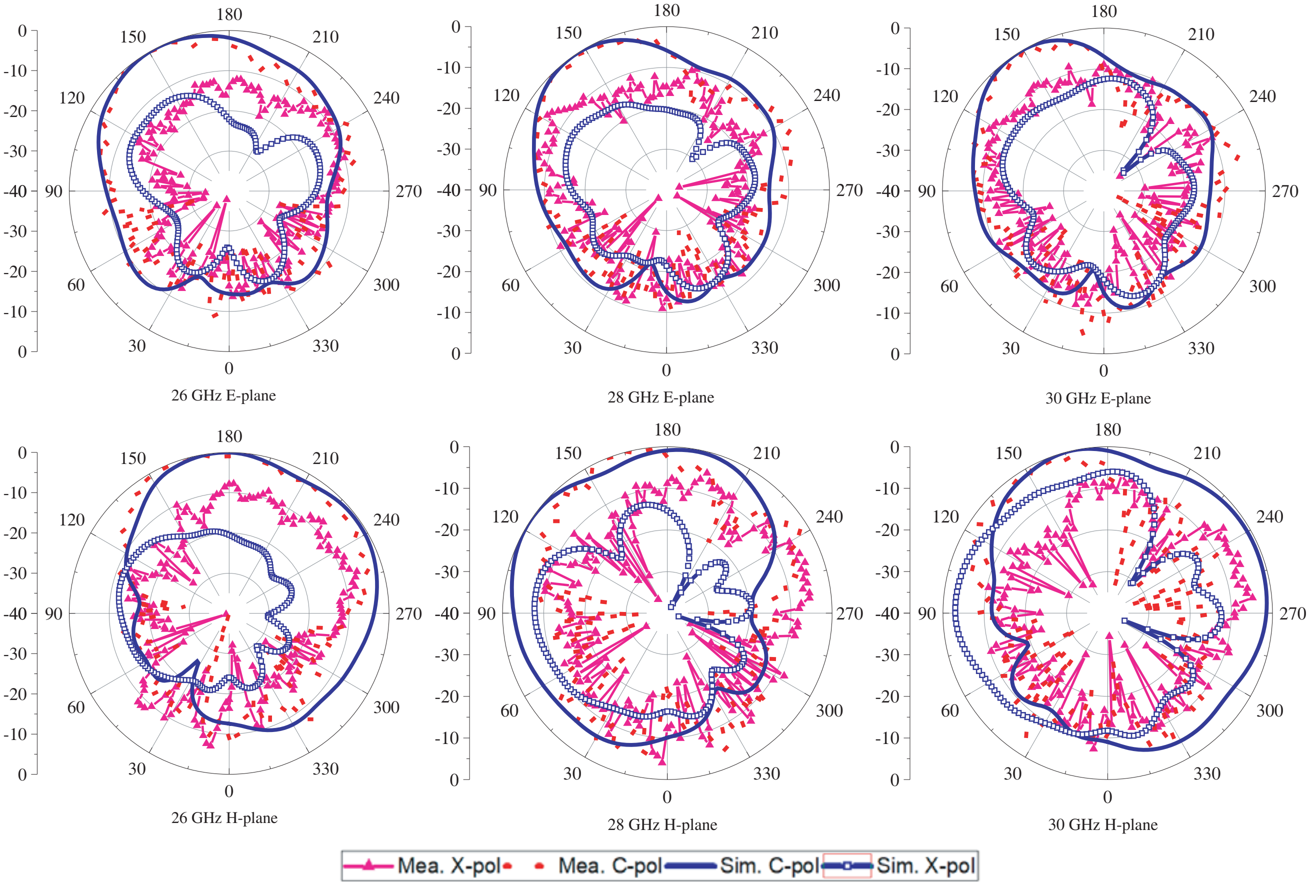

26 GHz E-plane
28 GHz E-plane
30 GHz E-plane
26 GHz H-plane
28 GHz H-plane
30 GHz H-plane

Figure 4. Simulated and measured *E*-plane and *H*-plane normalized radiation patterns at 26 GHz, 28 GHz and 30 GHz.

the difference is mainly due to the fabrication tolerance of the antenna dimension. Compared with the design, the value caused by the tolerance is slightly different. Secondly, the permittivity of FR4 varies with frequency, which also influences the reflection coefficient. Figure 4 presents the measured and simulated normalization radiation patterns at 26, 28, and 30, respectively. It can be seen that the measured results are in good agreement with the simulated ones. Some small difference occurs at the

Table 2. Comparisons between the proposed and reported antennas.

Ref.	Antenna type	Fc	Imp. BW (−10 dB) (%)	Measured peak gain (dBi)	Dimensions of single element (mm^3)	Material	Interconnection
[3]	Huygens source	27.91	2.14	4.54	$2.4 \times 2 \times 1.143$	Rogers5880	Coaxial line
[4]	Patch	27.9	8.6	7.41	$19.9 \times 30 \times 0.79$	TLY-5	Waveguide
[7]	PIFA	28.62	2.4	13.78 #	$3.5 \times 3 \times 0.7$	Stainless steel	Surface-mount
[8]	Patch	34.25	21.9	8	$5 \times 4.25 \times 0.5$	Copper	Surface-mount
This work	PIFA	27.15	15.3	5.85	$4.5 \times 4.5 \times 1.3$	FR4	Surface-mount

1 × 8 array

H-plane which is mainly caused by the 2.92 mm end launch connector. The connector can be regarded as the external reflector to tilt the radiation pattern.

Table 2 shows the comparison between the proposed antenna and reported antennas. It can be noted that the antennas in [3] and [4] must be connected to the system using coaxial cables or waveguide connectors. They are very difficult to integrate into the system. The surface mount antennas can be easily integrated into the same package with the RF chipsets, as shown in [7] and [8]. Compared with [7] and [8], the proposed antenna was fabricated on a low-cost FR4 substrate by using the standard printed circuit board (PCB) techniques. The cost-effective feature is more attractive than metal antennas. The BGA packaging enables the proposed antenna to be integrated with the chipsets into the same package to achieve high integration.

4. CONCLUSIONS

A surface-mount PIFA with BGA packaging has been presented in this letter. The BGA packaging technique has been introduced to achieve a compact size and easy to integrate it into the 5G mmWave system. A prototype has been fabricated to verify the performance. The measured results show that -10 dB impedance bandwidth is 15.3%, covering 24.7 to 29.6 GHz, and the peak gain is 5.85 dBi at 28 GHz. The compact dimension of $4.5\,\mathrm{mm}\times4.5\,\mathrm{mm}\times1.3\,\mathrm{mm}$ is very suitable to integrate into the system package. The proposed antenna is a very promising candidate for 5G millimeter-wave applications.

ACKNOWLEDGMENT

This work was supported by the Tianjin Research Innovation Project for Postgraduate Students under Grant 2020YJSB008.

REFERENCES

1. Andrews, J. G., et al., "What will 5G be?" *IEEE J. Sel. Areas Commun.*, Vol. 32, No. 6, 1065–1082, Jun. 2014.
2. Hong, W., K. Baek, and S. Ko, "Millimeter-wave 5G antennas for smartphones: Overview and experimental demonstration," *IEEE Trans. Antennas Propag.*, Vol. 65, No. 12, 6250–6261, Dec. 2017.
3. Tang, M., T. Shi, and R. W. Ziolkowski, "A study of 28 GHz, planar, multilayered, electrically small, broadside radiating, huygens source antennas," *IEEE Trans. Antennas Propag.*, Vol. 65, No. 12, 6345–6354, Dec. 2017,.
4. Park, J., J. Ko, H. Kwon, B. Kang, B. Park, and D. Kim, "A tilted combined beam antenna for 5G communications using a 28-GHz band," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 15, 1685–1688, 2016.
5. Zhang, Y. and J. Mao, "An overview of the development of antenna-in-package technology for highly integrated wireless devices," *Proc. IEEE*, Vol. 107, No. 11, 2265–2280, Nov. 2019.
6. Watanabe, A. O., M. Ali, S. Y. B. Sayeed, R. R. Tummala, and M. R. Pulugurtha, "A review of 5G front-end systems package integration," *IEEE Trans. Compon. Packag. Manuf. Technol.*, Vol. 11, No. 1, 118–133, Jan. 2021.
7. Park, J., D. Choi, and W. Hong, "Millimeter-wave phased-array antenna-in-package (AiP) using stamped metal process for enhanced heat dissipation," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 18, No. 11, 2355–2359, Nov. 2019.
8. Ahmad, Z. and J. Hesselbarth, "High-efficiency wideband surface-mount elevated 3-D patch antenna for millimeter waves," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 16, 573–576, 2017.
9. Rowell, C. and E. Y. Lam, "Mobile-phone antenna design, *IEEE Antennas Propag. Mag.*, Vol. 54, No. 4, 14–34, Aug. 2012.
10. Kearney, D., M. John, and M. J. Ammann, "Miniature ceramic PIFA for UWB band groups 3 and 6," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 9, 28–31, 2010.

11. Kearney, D., M. John, and M. J. Ammann, "Miniature ceramic dual-PIFA antenna to support band group 1 UWB functionality in mobile handset," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 1, 336–339, Jan. 2011.
12. Abdelgwad, A. H. and M. Ali, "Capacity and efficiency improvement of MIMO antenna systems for 5G handheld terminals," *Progress In Electromagnetics Research C*, Vol. 104, 269–283, 2020.