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Flexible wideband antenna for 5G applications

Mohammed Tighezza[1] | **S. K. A. Rahim**[1] | **M. T. Islam**[2]

[1] Wireless Communication Centre (WCC), Universiti Teknologi Malaysia, Johor Bahru, Johor 81310, Malaysia

[2] Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM), Bangi, Selangor 43600 UKM, Malaysia

Correspondence
Mohammed Tighezza, Wireless Communication Centre (WCC), Universiti Teknologi Malaysia, Johor Bahru, Johor 81310, Malaysia.
Email: mtighazza@gmail.com

Abstract

A modified microstrip patch antenna is implemented on Polyethylene terephthalate (PET) substrate with a thickness of 0.125 mm for 5G applications. The wideband antenna of 60 $\times$75 mm^2 total dimensions is fabricated using novel inkjet printer and silver nano-particles as the conductive ink. The designed and fabricated antenna operates within 7 to 13 GHz and exhibits almost omnidirectional radiation pattern with an average gain of 5 dBi. The flexible antenna was also tested under bending conditions and showed good performance within the X-band region. The originality of the work lies in the combination of the antenna's structure, flexibility, and targeted frequency of operation.

KEYWORDS

5G, flexible antenna, PET, wideband, X-band

1 | INTRODUCTION

With the advent of 5G networks, a need to connect most devices and gadgets together and to the internet has become inevitable. The diversity in the interconnected devices rose the idea of designing flexible and robust antennas able to be mounted on curvy shaped or wearable devices. Such antennas must be able to be bent and deformed while maintaining good performance in terms of bandwidth, radiation patter, gain, and efficiency. The shift from rigid to flexible and bendable antennas imposes the employment and investigation of different conductive and substrate materials. Work reported on flexible antennas displayed the use of different substrate material such as article,[1,2] Kapton Polymide,[3] Polydimethylsiloxane (PDMS),[4,5] and Polyethylene Terephthalate (PET)[6–9] However, literature review showed that PET sheets are robust and have relatively low tangent loss compared to other flexible materials. It is also evident that microstrip patch antennas (MPAs) are the most suitable candidates for flexible antennas for their planar form.

MPAs are a category of planar antennas which have been researched and developed extensively in the last three decades. They have been favored among antenna designers and have been used in many applications in wireless communication systems, both in the military and commercial sectors. These planar antennas have shown major advantages being low profile, planar, light, and easy to integrate with circuit elements. However, MPAs suffer from serious drawbacks including a very narrow bandwidth typically less than 5%, high feed network losses, high cross polarization, and low RF power handling capabilities due to the small separation between the radiating patch and its ground.[5,6,8]

Therefore, many researches have been conducted on the conventional MPA to overcome the drawbacks mentioned earlier. For instance, the narrow bandwidth has been improved and increased in comparison with the conventional MPA by using different techniques such as truncated corners of the rectangular patch,[10,11] the employment of different substrate and conductive material with different thicknesses, and the use of partial ground as reported in many ultrawideband antennas.[4,6,10,12–16]

Because flexibility of antennas was not of a major concern until recently due to wearable devices and other medical applications, few are the works done on this field as compared to others. Therefore, in this project a flexible antenna targeting X-band frequencies is designed and fabricated by means of novel inkjet printing technology. The antenna's design in terms of operation, flexibility, size, materials, and technology used is one of its kind to our best knowledge and has yielded satisfactory results within the required specifications.

2 | ANTENNA DESIGN AND CONFIGURATION

The proposed antenna is designed on a 0.125 mm thick PET sheet with permittivity $\varepsilon_r = 3.2$ and a loss tangent $\tan\delta = 0.022$. It has a partial ground printed on the same plane as the patch and the feed using silver nano-particles layer of thickness $T_c = 4$ µm. The coplanar waveguide (CPW) feed is divided into two section joined together to ensure smooth electromagnetic waves transition and good matching. The antenna's initial dimensions are estimated by

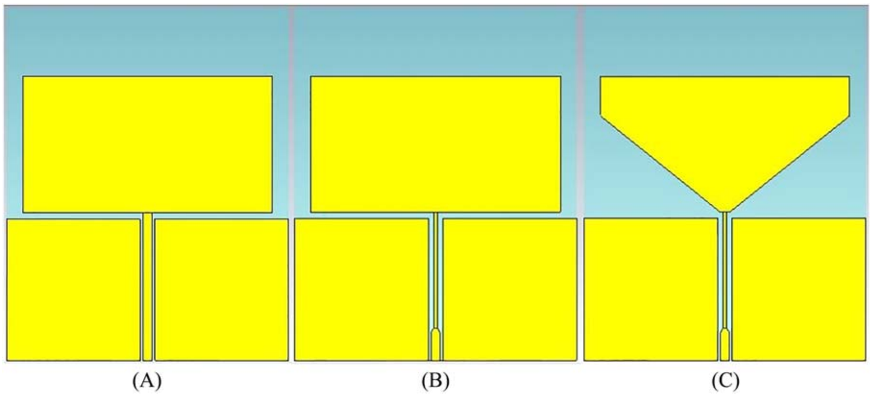

(A) (B) (C)

FIGURE 1 Evolution of the proposed antenna structure. [Color figure can be viewed at wileyonlinelibrary.com]

$f_L(\text{GHz}) = \frac{300}{p\sqrt{\varepsilon_{\text{eff}}}}$, where p is the perimeter of the patch (L × W) and ε_{eff} is given as $\varepsilon_{\text{eff}} = \frac{(\varepsilon_r+1)}{2}$.[12] However, the final antenna dimensions are obtained by using the CST microwave studio's optimization tool to obtain the final optimized structure of the proposed antenna as shown in Figure 1C. Figure 1 also demonstrates the evolution of our antenna from conventional rectangular patch and normal CPW feed in (a) to the final structure shown in (c). For better matching, the

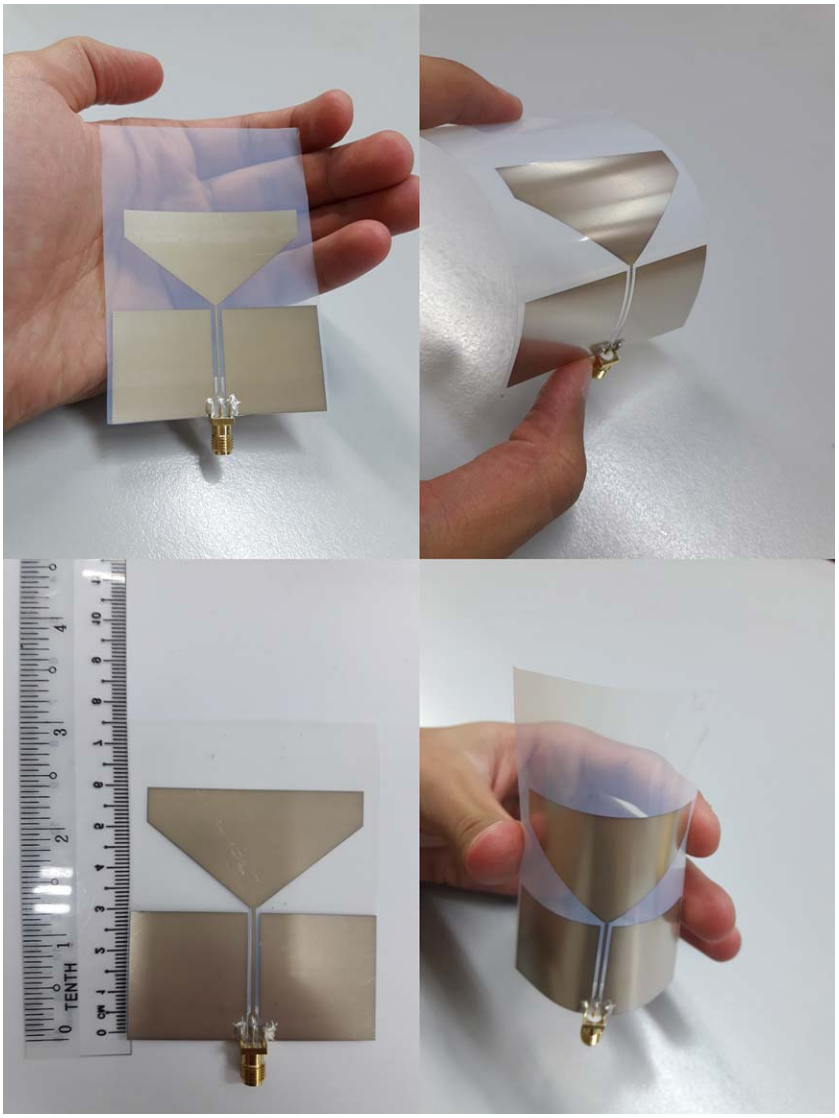


FIGURE 2 Fabricated antenna. [Color figure can be viewed at wileyonlinelibrary.com]

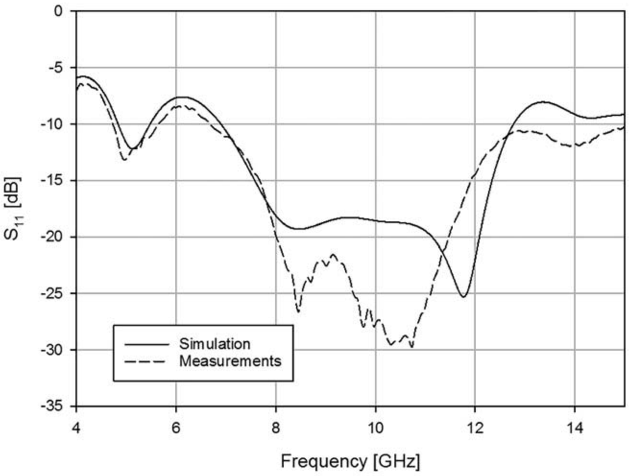


FIGURE 3 Simulated and measured return loss

feed was modified as shown in Figure 1B to ensure broader bandwidth within the frequency region of interest. Lastly, the patch's two bottom corner of the antenna are curtailed to further improve the bandwidth breadth towards covering the whole X-band region. Furthermore, the evolution process was done in parallel with parameter optimization in CST Studio. Brother MFC-J430W printer is used to fabricate the antenna which propels droplets of silver nano-particles on the shiny surface of the PET substrate coated with a special substance that ensures instant drying of the conductive ink, making this technology very simple to use and very time efficient. Lastly the antenna it attached to a SMA connecter by means of silver glue and a hardening substance mixed together to ensure a solid bond.

3 | RESULTS AND DISCUSSION

The fabricated prototype of the flexible antenna is depicted in Figure 2. The antenna was measured to verify its operation conformation with that of the simulated results. Figure 3 illustrates the simulated and measured return loss (S_{11}) results which appear to be in close proximity. The results showed a fractional bandwidth of 60% extending from 7 to 13 GHz. The bandwidth results are taken with respect to the −10 dB line ensuring at least 90% of non-reflected power. However, the slight discrepancies are attributed to the port mismatch due to the gluing process as well as the flexibility nature of the antenna. Nevertheless, the bandwidth achieved by the antenna covers completely the X-band which is a good candidate for future 5G networks due to its closeness to existing cellular frequencies.[17] Furthermore, the radiation pattern results measured at 10 GHz are revealed by Figure 4 indicating almost omnidirectional characteristics that makes the antenna suitable for mobile application as well as fixed devices. Finally. the gain and the efficiency of the proposed antenna are illustrated in Figure 5. The measured results showed an average gain value of 5 dBi and a maximum efficiency value of 38% which is higher than that reported in previous work done on some inflexible UWB antennas of similar design principle.[12-14] However, the deflection in the measured results from simulation is mainly due to imperfections in the fabrication process of the antenna, the flexibility nature of the antenna, and the flawed measurement chamber.

4 | BENDING ANALYSIS

To investigate the performance of the proposed antenna under bending conditions, the antenna is positioned around a virtual cylinder ($\varepsilon_r = 1$) in four different positions as demonstrated in Figure 6. As it can be seen, the antenna is first attached vertically to a cylinder with its structure facing outwards of the cylinder as in (a) and inwards as in (b). Similarly, the antenna is mounted horizontally on the cylinder with its structure facing outwards and inwards as shown in

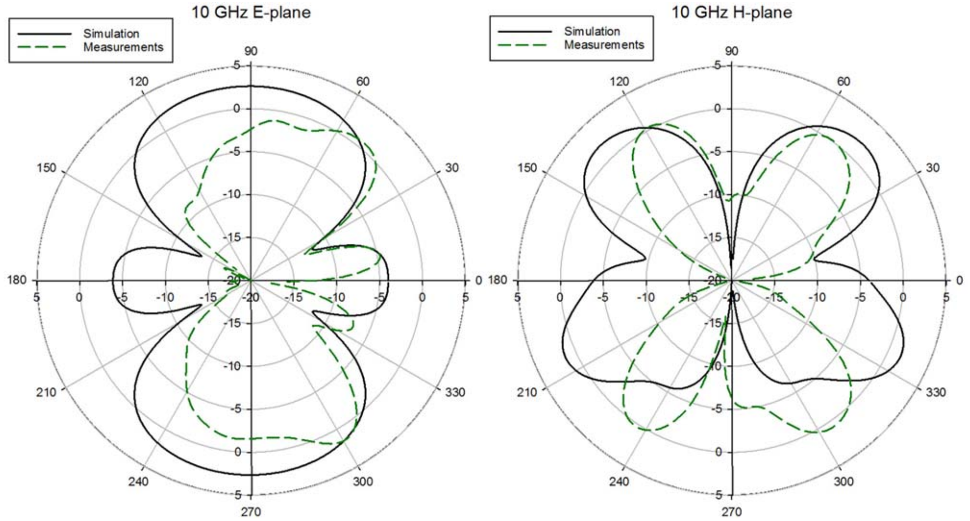


FIGURE 4 Radiation pattern. [Color figure can be viewed at wileyonlinelibrary.com]

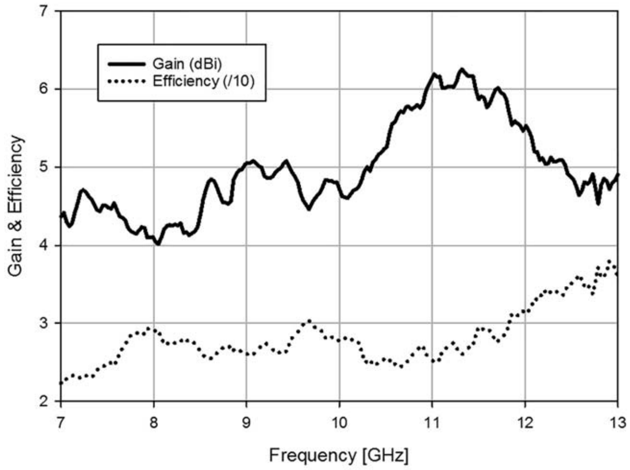
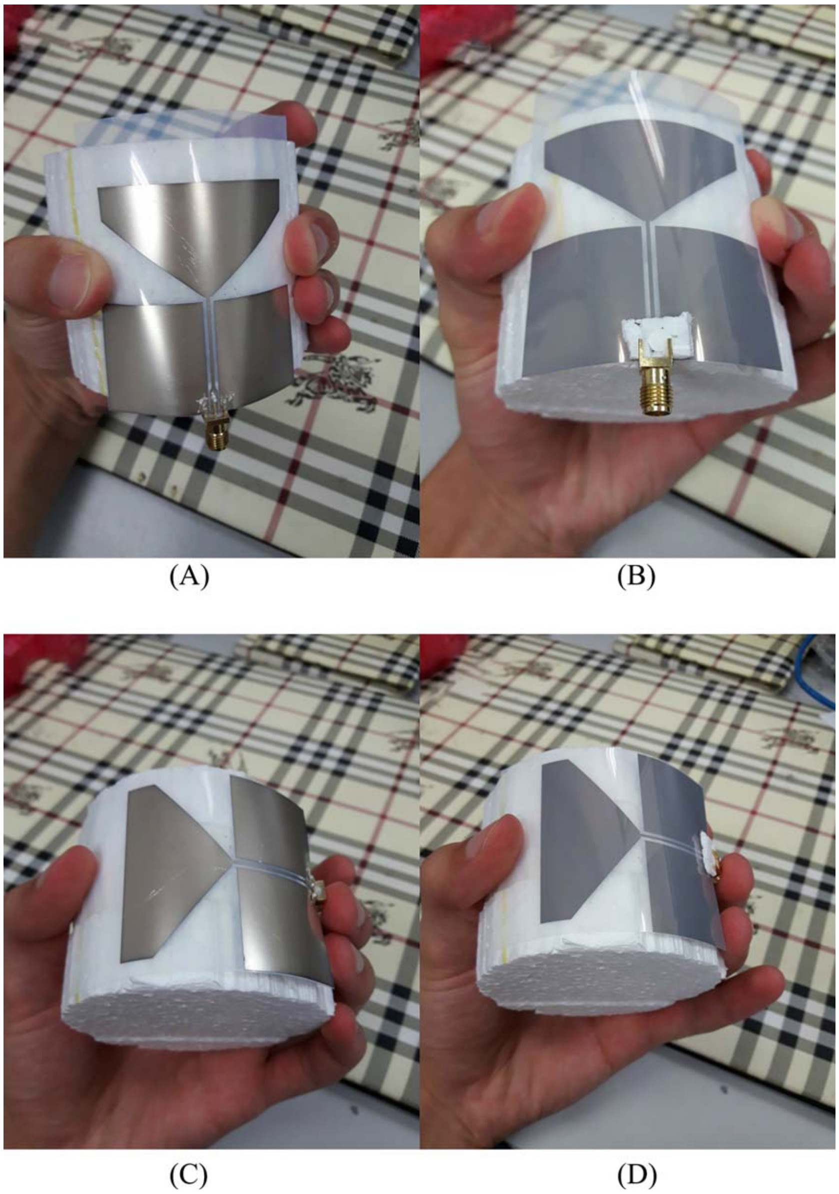


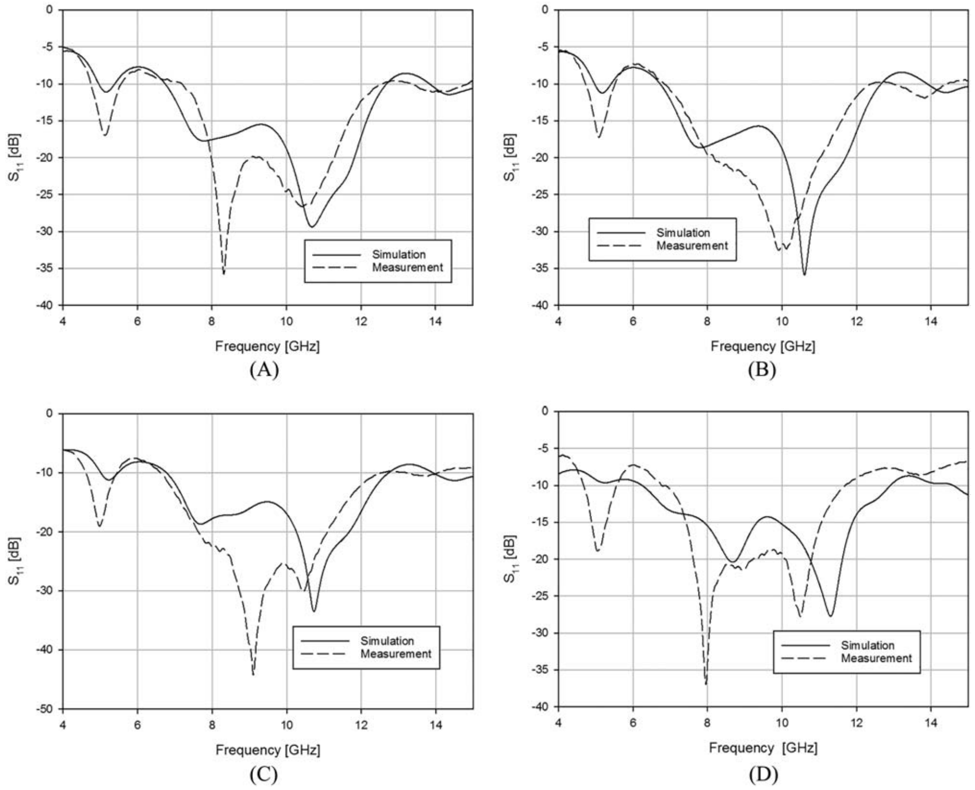
FIGURE 5 Measured gain and efficiency

(c) and (d) respectively. To match the simulated air cylinder in practical measurements, the antenna is bent around a Styrofoam cylinder having close permittivity to that of air ($\varepsilon_{\text{Styrofoam}} = 1.03$). The S_{11} results of the bent antenna around horizontally and vertically positioned cylinders of different diameters are shown in Figures 7–10. It was observed during the bending tests that the resonant frequencies are significantly affected by the bent antenna structure. However, despite the deflection between measured and simulated results, the antenna proved able to operate well throughout X-band frequencies and the targeted bandwidth was preserved. The design and tests done on few fabricated prototypes have shown that the shift in bandwidth is mainly attributed to the fabrication process which involves the structure printing out of very thin silver layer as well as the gluing process of the SMA connector. Conversely, the deflection in


(A) (B)

(C) (D)

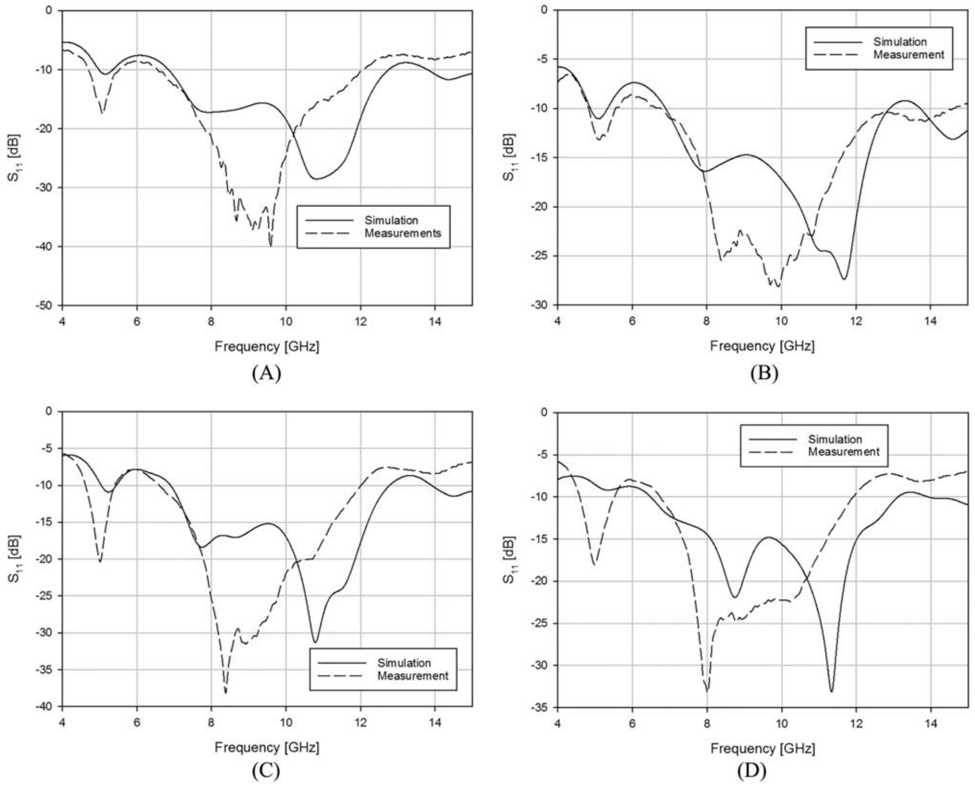
FIGURE 6 Bending positions. [Color figure can be viewed at wileyonlinelibrary.com]



(A) (B) (C) (D)

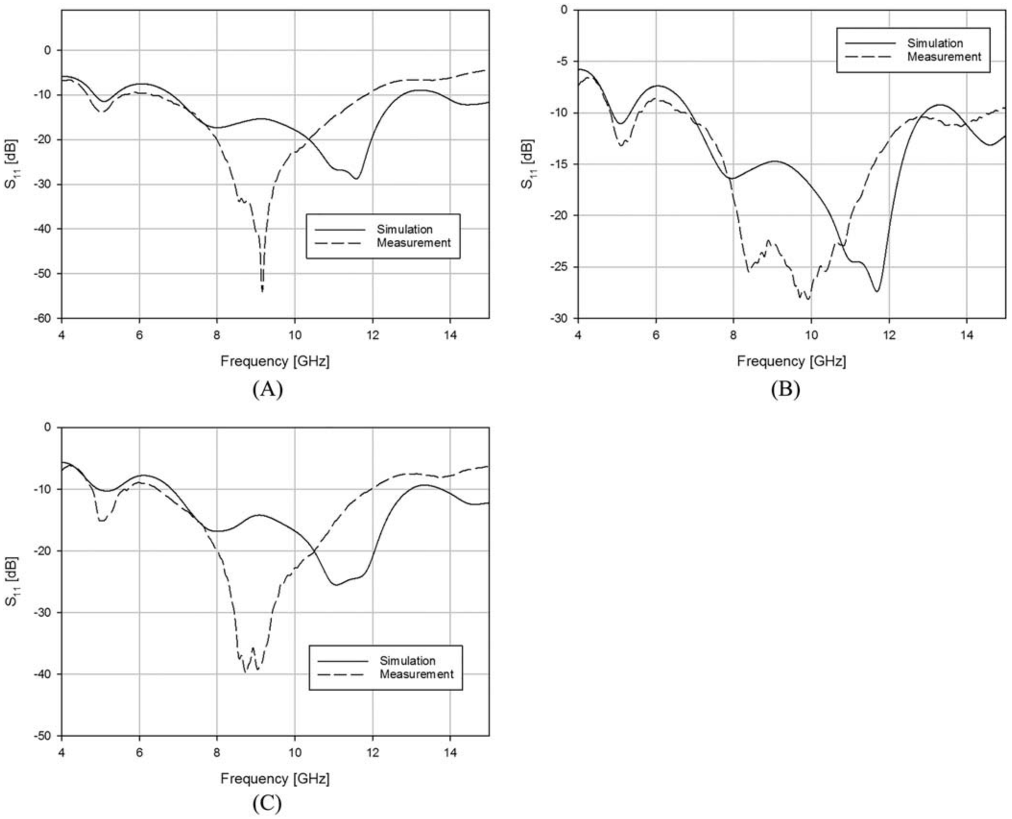
FIGURE 7 S_{11} results when structure is bent outwards around vertical cylinder with diameter of: (A) 80 mm (B) 60 mm (C) 40 mm (D) 20 mm

terms of resonant frequencies is expected to be a result of the imperfection in the surface of the fabricated Styrofoam cylinders. Nevertheless, the antenna has shown great flexibility features and robustness that meet the requirements of many current wearable applications and future 5G devices.



(A) (B) (C) (D)

FIGURE 8 S_{11} results when structure is bent inwards around vertical cylinder with diameter of: (A) 80 mm (B) 60 mm (C) 40 mm (D) 20 mm

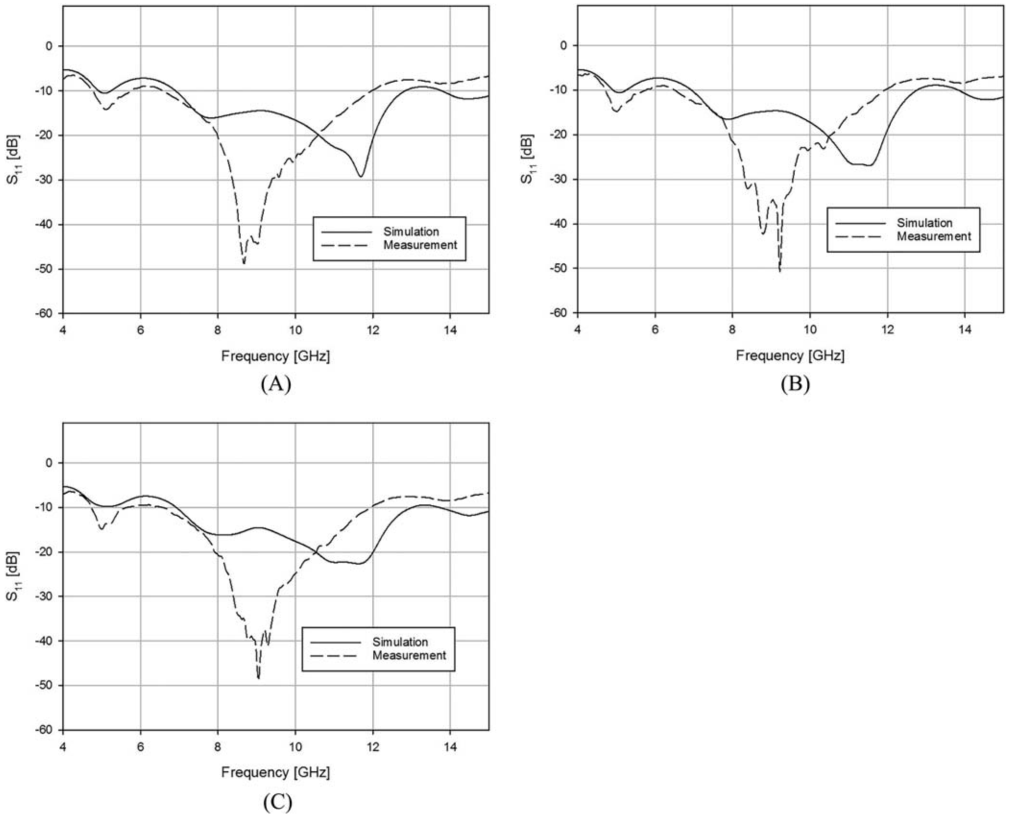


(A)

(B)

(C)

FIGURE 9 S_{11} results when structure is bent outwards around horizontal cylinder with diameter of: (A) 80 mm (B) 60 mm (C) 40 mm



(A)

(B)

(C)

FIGURE 10 S_{11} results when structure is bent inwards around horizontal cylinder with diameter of: (A) 80 mm (B) 60 mm (C) 40 mm

5 | CONCLUSION

In this article, a flexible antenna implemented on PET substrate for 5G applications is presented. The antenna showed good performance in terms of gain, efficiency and radiation pattern throughout the X-band region; a good candidate band for 5G technologies. The antenna's tests under bending conditions showed also satisfactory results in maintaining good performance while bent which makes it best suitable for flexible and wearable applications. The work done in this article contributes greatly to the study of flexible antennas, the printing technologies, and the flexible substrate and conductive materials.

ORCID

Mohammed Tighezza http://orcid.org/0000-0001-8002-1976

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Wide stopband miniaturized "I"-typed EBG with DGS

Hongying Rong | **Qian Wang** | **Shuo Chen** | **Yajie Cao** | **Huiping Tian**

Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications, Beijing 100876, P. R. China

Correspondence
Huiping Tian, Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications, P.O.BOX 90, No.10, Xitucheng Road, Haidian District, Beijing 100876, P. R. China.
Email: hptian@bupt.edu.cn

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Abstract

An electromagnetic band-gap (EBG) structure which combines a tapered surface structure and a tapered defected ground structure is proposed in this article. "I"-typed EBG