A Biodegradable Textile-based Graphene Antenna for 5G Wearable Applications

Anikó Német[1], Shaker Alkaraki[2], Qammer H. Abassi[3], Syeda Fizzah Jilani[1,2]

[1]Department of Physics, Physical Sciences Building, Aberystwyth University, Aberystwyth, UK, SY23 3BZ*

[2]School of Electronic Engineering and Computer Science, Queen Mary University of London, London, UK, E1 4NS

[3]School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK

**ann23@aber.ac.uk*

***Abstract*—This paper presents a textile-based antenna for the currently deployed fifth-generation (5G) wireless bands. The proposed antenna consists of a coplanar-waveguide (CPW)-fed patch with truncated sides and a pair of L-shaped stubs as a part of ground geometry. The antenna has a bandwidth of 3.3-3.8 GHz, a peak gain of 3.17 dBi at 3.7 GHz and an efficiency of 64%. The antenna is designed on denim fabric and offers desired flexibility and ease of integration as a part of a garment, environmentally friendly and biodegradable attributes of graphene due to non-metallic nature, and affordability in terms of manufacturing cost.**

***Keywords*—5G; antenna; graphene; textile; wearable; wireless.**

I. Introduction

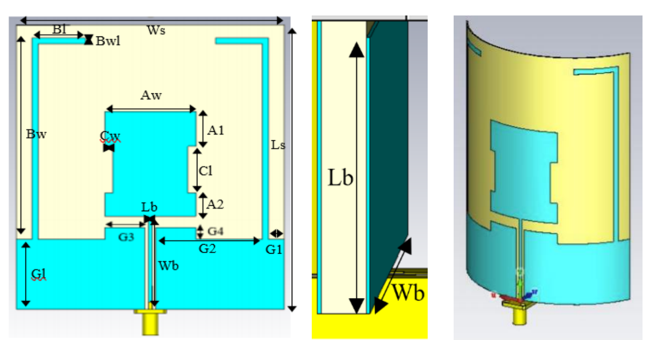
With the world moving towards a more sustainable future, the emphasis is on biodegradable materials and waste reduction. The 5G network is ready to be used in many countries and the preparations of the 6G networks are progressing [1]. In the past few years, several aspects related to wireless communication such as data rates, connectivity, bandwidth, coverage along the reduction of energy consumption have shown enormous progress. A drastic increase in the development of compact and miniaturized wireless devices for on-body gadgets is observed [2, 3]. Wearable devices with integrated antennas prove to be important in areas such as security, automation, electronic systems; tracking devices, navigation systems and body measurement or scanning devices [4]. Such antennas require high-performance attributes along with miniaturization, conformity and ease of integration into a garment [5].

Several aspects need considerations to acquire desired performance characteristics. For instance, reasonable bandwidth can be achieved by a wideband or a multiband design. A reliable and consistent gain profile over the entire bandwidth is highly desirable with decent radiation efficiency. It is also important to examine the flexibility of the antenna structure while bending along the non-planar surface of a human body that may result in performance degradation [6]. Factors that can impact the optimal functioning of a wearable antenna are humidity, temperature, high electrical, mechanical, thermal, and chemical properties of the materials. Key features of a potential antenna solution integrated with wearables for modern 5G wireless applications are low cost, lightweight, low loss, flexibility and high resolution/accuracy in fabrication [7].

Graphene is a highly conductive 2-D nanomaterial where carbon atoms are bound in a honeycomb shape hexagonal lattice. It exhibits a mechanical strength of 130 GPa, excellent conductivity for a single layer, reasonable conductivity up to a few layers and biocompatibility that fit well with miniaturization of antennas and body-centric communications [9]. In this paper, a textile antenna with graphene paper has been proposed that offers performance stability, flexibility, eco-friendly due to non-metallic conductive parts as the washing of copper-based wearable antennas could be hazardous, and affordable in terms of cost [10]. The emphasis of this work is on delivering an efficient and eco-friendly antenna targeting the currently deployed 5G band of 3.3-3.8 GHz for body-centric applications.

II. Antenna Design and Methodology

The proposed 5G antenna (dimensions: 107×122.2 mm^2) is designed on a denim substrate (thickness: 0.5 mm) and the conductive part is created with a graphene paper (thickness: 0.4 mm and conductivity of 1×10^4 S/m). The structure is comprised of a coplanar waveguide (CPW)-fed rectangular patch with rectangular notched trimmed-off on both sides to incorporate longer radiating length in a smaller footprint. The appropriate impedance matching is achieved by a step-rise geometry of the ground plane instead of a typically flat ground plane. The height of the step introduced in the ground is represented by G4 and represented in Fig. 1 along with all other dimensions. The CPW ground is also augmented by two L-shaped stubs which act as reflectors to converge the radiation of the antenna towards the top and bottom side. The simulation is conducted in CST Microwave Studio Suite and the optimized dimensions of the antenna are provided in Table 1. For conformal analysis, the antenna is bent at different radii from 50 mm to 90 mm.



(a) (b) (c)

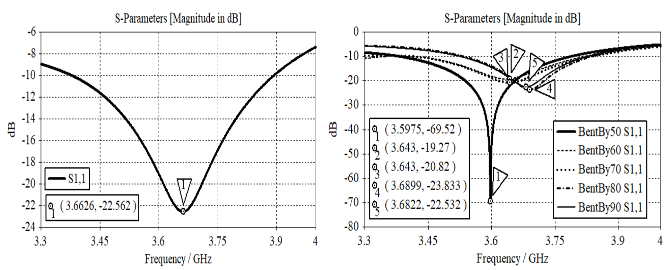
Fig. 1. Simulation model of the proposed graphene antenna for wearables: (a) front view, (b) side view, (c) conformal view.

TABLE I. OPTIMIZED DIMENSIONS OF THE GRAPHENE ANTENNA

Antenna (mm)		Feedline (mm)		Backside (mm)		Stub (mm)		Ground (mm)	
Aw	36.5	Wb	40	Wb	107	Bw	86.5	Gl	30
A1	15	Lb	1.6	Lb	3	Bl	21.3	G1	6.2
A2	10					Bwl	2.5	G2	42.6
Cw	3.2							G3	16
Cl	20							G4	5

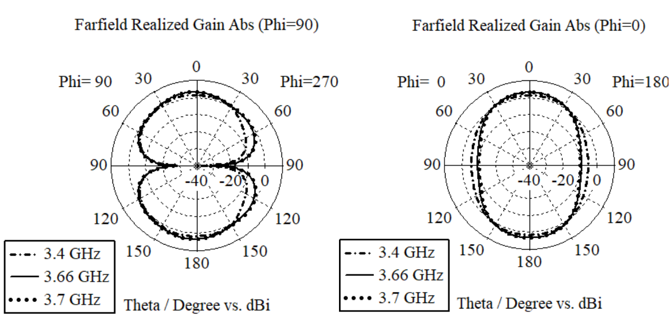
III. RESULTS AND ANALYSIS

The antenna performance is analyzed in the CST simulation. Parametric analysis on all the design parameters is carried out to achieve optimal performance. The reflection coefficient (S11) plots on Fig. 3. (a) shows the resonant frequency of 3.66 GHz with an impedance bandwidth of 0.43 GHz taking -10 dB as a reference, which covers the entire range recently being deployed for the 5G applications. In order to investigate the conformity, the bending of the antenna was observed along different radii. The plots in Fig. 3 (b) show S11 for different bending radii that depict bending has a slight impact on the bandwidth and reduced it to 0.41 GHz. This is completely acceptable as most of the wearable applications are short-range and -6 dBi is an acceptable limit. In Fig. 3, E and H-plane cuts of the radiation pattern show an omnidirectional pattern though the L-shaped stubs act as reflectors and converge the beam towards the front and back of the antenna. The peak gain is 3.169 dBi at 3.685 GHz as shown in Fig. 4. The simulated antenna efficiency is 64%.



(a) (b)

Fig. 2. Simulated S11 of the proposed graphene antenna: (a) planar antenna, (b) bent antenna



(a) (b)

Fig. 3. Simulated radiation pattern of the proposed graphene antenna: (a) E-plane cut, (b) H-plane cut.

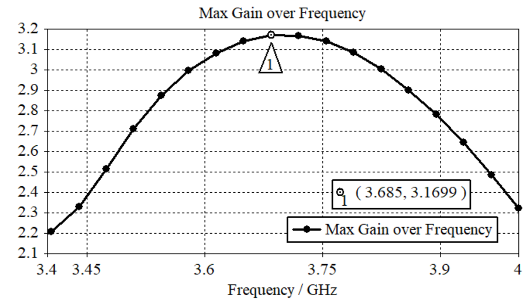


Fig. 4. Maximum gain vs. frequency of the proposed graphene antenna: (a) E-plane cut, (b) H-plane cut.

IV. CONCLUSION

The paper has presented a textile-based biodegradable and eco-friendly antenna as a desirable choice for recent 5G wearables. The use of fabrics as substrates make it a feasible choice to be integrated with garments. To avoid metal residuals in water supplies after washing the electronic wearables, graphene paper is used instead of conventional copper or other typical metals in this antenna. The proposed antenna has shown stable performance in conformity analysis when subjected to different bending curvatures. The high conductivity and substantial thickness of the graphene sheet control the bandwidth and efficiency of the proposed antenna. The impedance bandwidth of 0.41 GHz ranging from 3.4-3.9 GHz, the directivity of 3.34 dBi, the peak gain of 3.169 dBi and efficiency of 64% are key features of this textile-based antenna.

REFERENCES

[1] S. M. Ali, C. Sovuthy, M. A. Imran, S. Socheatra, Q. H. Abbasi and Z. Z. Abidin, "Recent advances of wearable antennas in materials, fabrication methods, designs, and their applications: state-of-the-art," Micromachines, vol. 11, no. 10, 2020.

[2] S. Mumtaz, A. Bo, A. Al-Dulaimi and K. Tsang, "Guest editorial 5G and beyond mobile technologies and applications for industrial IoT (IIoT)," IEEE Trans. Industrial Informatics, vol. 14, no. 6, pp. 2588-2591, 2018.

[3] H. Sun, Z. Zhang, R. Q. Hu and Y. Qian, "Wearable communications in 5G: challenges and enabling technologies," IEEE Vehicular Technology Magazine, vol. 13, no. 3, pp. 100-109, 2018.

[4] G. A. Akpakwu, B. J. Silva, G. P. Hancke and A. M. Abu-Mahfouz, "A survey on 5G networks for the internet of things: communication technologies and challenges," IEEE Access, vol. 6, pp. 3619-3647, 2018.

[5] M. Rahimi, F. B. Zarrabi, R. Ahmadian, Z. Mansouri and A. Keshtkar, "Miniaturization of antenna for wireless application with difference metamaterial structures," Progress in Electromagnetic Research, vol. 145, pp. 19-29, 2014.

[6] A. Y. I. Ashyap et al., "Inverted E-shaped wearable textile antenna for medical applications," IEEE Access, vol. 6, pp. 35214-35222, 2018.

[7] C. Vallés, J. D. Nuñez, A. M. Benito and W. K. Maser, "Flexible conductive graphene paper obtained by direct and gentle annealing of graphene oxide paper," Carbon, vol. 50, no. 3, pp. 835-844, 2012.

[8] K. Rubrice, X. Castel, M. Himdi, P. Parneix, "Dielectric characteristics and microwave absorption of graphene composite materials," Materials, vol. 9, no. 10, 2016.

[9] S. N. H. Sa'don *et al*., "Analysis of graphene antenna properties for 5G applications," Sensors, vol. 19, pp. 4835, 2019.

[10] S. G. Kirtania, et al., "Flexible antennas: a review," Micromachines, vol. 11, no. 9, pp. 847, 2020.