Dual Band Circular Patch Flexible Wearable Antenna Design for Sub-6 GHz 5G Applications

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In this paper, a dual band wearable antenna for 5G applications that resonates at 3.63 GHz and 4.95 GHz covering sub-6 GHz 5G-NR bands such as n48, n77, n78, and n79 is presented. The antenna consists of slotted circular ring patch as radiating element, polyester as wearable substrate, and a partial ground plane on the bottom. The designed antenna is sized at 55×46×0.4 mm^3, achieving a bandwidth of 300 MHz from 3.50 to 3.80 GHz and a bandwidth of 160 MHz from 4.86 to 5.02 GHz. Besides, the antenna shows realized gain of 4.2 dBi at 3.63 GHz and 5.78 dBi at 4.95 GHz whereas efficiency is found 90.5 % and 82.3 % respectively.

Index Terms — wearable antenna, 5G application, polyester

I. INTRODUCTION

Wearable computing devices which are integrated in wireless body area networks (WBAN) have seen enormous developments in recent years, specifically in the sports and medical fields. Wearable computing devices can be used in hospitals to monitor patients' health on a regular basis, allowing health professionals to make critical decisions in life-threatening situations [1]. Moreover, athletes can use this device to track and receive real-time feedback during their training, which eventually helps them to improve their own performances, besides being coached by trainers [2]. Wearable antenna plays a significant role in wearable computing device to efficiently transmit and receive the wireless signals [3]. Realizing this, tremendous research efforts have been channeled toward designing efficient wearable antennas to enhance the performance of wearable computing devices.

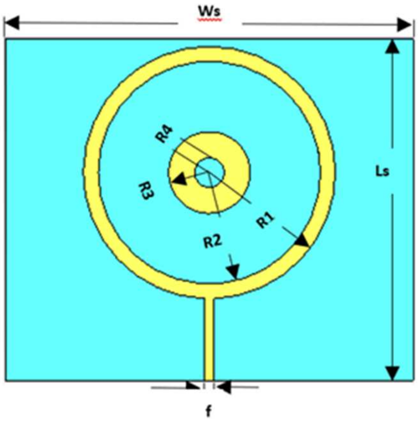
Wearable antennas can be classified into two categories: rigid antennas, which exhibits more stability in radiation pattern performance and flexible antennas, which offers advantages such as lightweight and convenient attachment, both which are important for human comfort [4]. The fabric textile materials with low dielectric constant (ε_r) are the most commonly used substrates for flexible antenna designs due to their capability in achieving wideband and good radiation pattern characteristics. Besides this, other commonly used substrate materials for flexible antenna designs are wool felt [5]-[6], felt [7]-[8], and felt textile [9]. These materials, however, are thicker than fabric textile, which increases manufacturing cost and reduces the comfortability of the wearer. Therefore, flexible wearable antenna designs preferably embraces fabric textile materials as substrate due to their thinness and low dielectric constant value ($\varepsilon_r < 2$), besides being comfortable to wear [10]. Polyester fabric is an excellent choice for flexible wearable antenna design since it is thin and has lower dielectric value. The dielectric characteristics property of polyester fabric makes it preferable as it has improved dielectric characteristics in comparison with other available textile materials including linen, cotton, and silk [11].

Besides that, lower values of dielectric constants are preferred to achieve higher bandwidth since bandwidth is inversely proportional to permittivity or dielectric constant [12]. Nevertheless, attaching multiple layers of polyester fabrics makes the substrate thicker [11], and thus complicates the fabrication process [11]-[13].

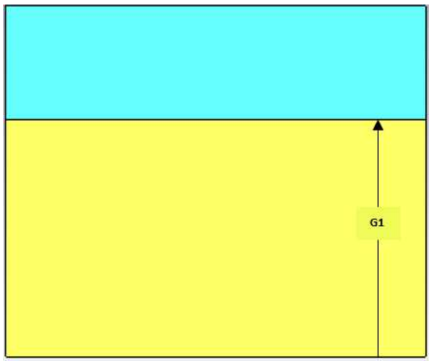
The Third Generation Partnership Project (3GPP) recently has released various Fifth Generation New Radio (5G-NR) frequency bands in sub- 6 GHz region that can be utilized for 5G applications. Among these bands, 3.5 GHz becomes one of most important one as it is being widely utilized in 5G for various applications such as medical, sports, education and etc. [14]. Furthermore, 3.5 GHz band has received the most attention in the World Radio Communication Conference (WRC) due its widespread use in most of the countries across the world when compared to other 5G-NR sub – 6 GHz bands [15]. In addition, another prominent 5G-NR sub–6 GHz band n79 was covered with second resonance frequency at 4.95 GHz.

Considering all these requirements, a simple dual ring circular patch antenna placed on a single-layer polyester substrate is proposed in this paper. The research work presented in this paper advances the flexible wearable antenna design by utilizing thin substrate material with low dielectric value that potentially provides desired resonant band and good radiation pattern. In addition, besides being comfortable to wear, the thin and soft fabric material also reduces the manufacturing costs. This paper is organized as follows. Section II describes the antenna design and the dimension details, followed by results and discussion in section III. Finally, section IV concludes the research work.

II. ANTENNA DESIGN



(a)



(b)

Fig 1: Configuration of the designed antenna (a) Top View (b) Back View

Fig 1 shows the modeled dual-ring circular patch antenna design. This antenna was modelled and simulated in CST Microwave Studio software. Two circular ring patches (inner and outer) with a thickness of 3.5 and 2 mm respectively, are designed on top of a polyester fabric substrate (55 mm x 46 mm x 0.4 mm) as shown in Fig 1(a). The polyester substrate is with a relative dielectric constant (ε_r) of 1.40 and loss tangent (tanδ) of 0.005. Furthermore, a 50 Ω microstrip feedline is attached to the outer circular ring patch to feed RF power. A partial ground plane with the size of 55 mm x 31 mm is introduced on the bottom of substrate to obtain wider bandwidth. The dimensions of the proposed antenna are summarized in Table 1.

TABLE 1 The dimension details of the proposed antenna

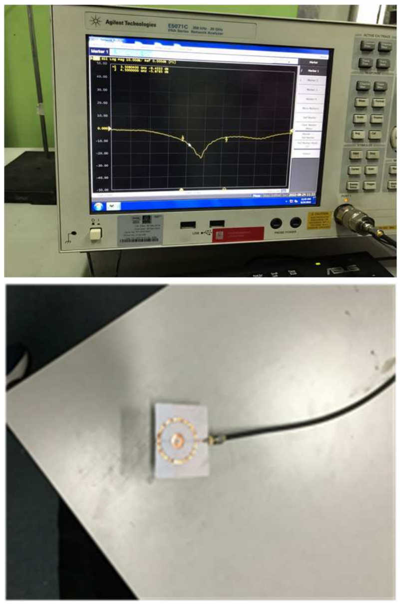
Parameter	**Description**	**Dimensions (mm)**
Ws	Width of Substrate	**55**
Ls	Length of Substrate	**46**
R1	Outer Radius of Circular Patch	**17**
R2	Inner Radius of Circular patch	**15**
R3	Outer Radis of Inner Circle	**5.5**
R4	Inner Radius of Inner Circle	**2**
f	Width of Feedline	**1.3**
G1	Ground Height	**31**

III. RESULT AND DISCUSSION

The top and bottom view of the fabricated prototype of the proposed antenna are shown in Fig 2 (a) and (b), respectively.

(a)

(b)



(c)

Fig 2: Configuration of the Fabricated antenna **(a)** Top View **(b)** Back View **(c)** Measurement Setup

The patch and ground plane of the antenna were fabricated using copper tape which is 0.05 mm thick. A 50 Ω SMA connector is attached to the microstrip feedline. Fig. 2(c) on the other hand, shows the setup during the s-parameter measurement using vector network analyzer (VNA) in the laboratory. Both simulated and measured results (reflection coefficient) will be discussed in the following subsections.

A. *Reflection Coefficient Results*

Fig 3 presents the simulated and measured reflection coefficient results of dual ring circular patch antenna. From the figure, it can be observed that the measured result is comparable to the simulation. The dual ring circular patch antenna successfully achieved resonances at 3.63 and 4.95 GHz with at least S11 < -10 dB. This translates to two 10 dB bandwidth of 300 MHz (from 3.50 to 3.80 GHz) and 160 MHz (from 4.86 to 5.02 GHz), covering sub-6 GHz 5G-NR bands such as n48, n77, n78, and n79.

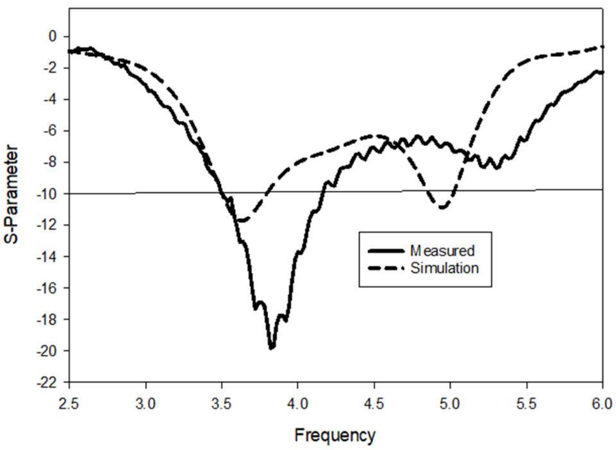
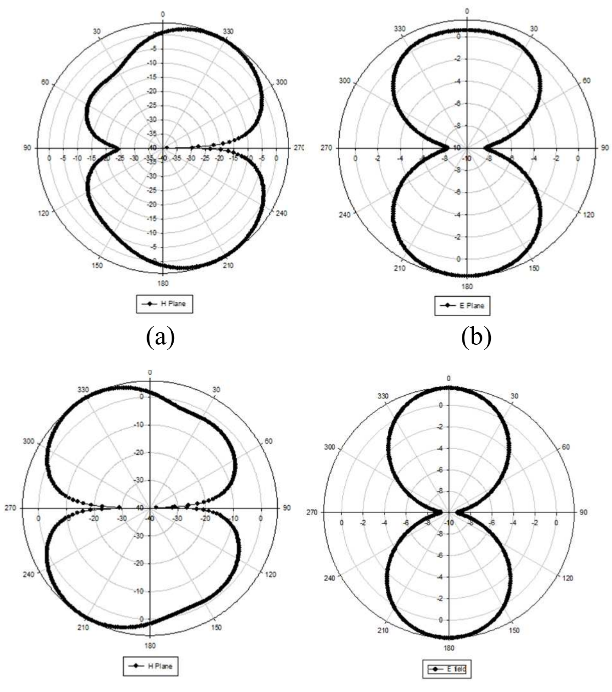


Fig 3 : Simulated and Measured Reflection Coefficient

B. *Radiation Pattern Result*



(a) (b)

(c) (d)

Fig 4: Radiation pattern at 3.63 (a) E-Plane (b) H-Plane at 4.95 (c) E-plane (d) H-Plane

The proposed antenna's radiation patterns observed at 3.63 GHz are illustrated in Fig 4(a) and (b), respectively in E-plane and H-plane and at 4.95 GHz in Fig 4(c) and (d), respectively in E-plane and H-plane. It can be noticed that the proposed antenna has a dipole-shaped radiation pattern at resonant frequency due to the dual circular ring patch design with a partial ground plane.

C. *Gain and Efficiency Results*

The simulated realized gain and total efficiency of the proposed antenna are illustrated in Fig 5. The proposed antenna achieved a realized gain of 4.2 and 5.78 dBi at 3.63 and 4.95 GHz respectively, with a total efficiency of 90.5% and 82.3%.

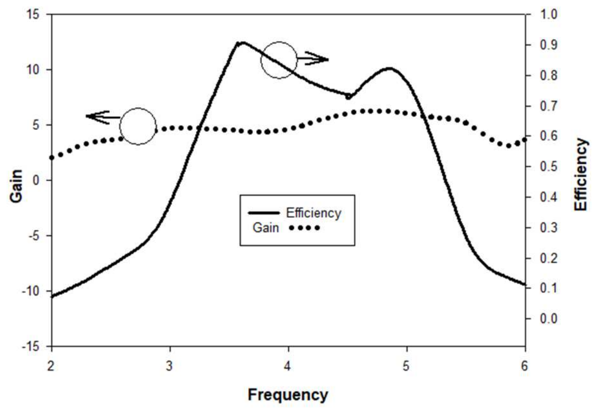


Fig 5: Gain and Efficiency Vs Frequency Curve

IV. CONCLUSION

In this paper, a dual circular ring patch antenna is designed on flexible materials for sub-6 GHz 5G application. The proposed antenna is made using a thin polyester fabric substrate and copper tape. It exhibited a dual band characteristic centered at 3.63 GHz and 4.95 GHz with a dipole-like radiation pattern. It featured a satisfactory realized gain of 4.2 and 5.78 dBi indicating suitability for 5G sub- 6 GHz wearable antenna applications.

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REFERENCES

[1] M. El Atrash, M. A. Abdalla, and H. M. Elhennawy, “A wearable dual-band low profile high gain low SAR antenna AMC-backed for WBAN applications,” IEEE Transactions on Antennas and Propagation, vol. 67, no. 10, pp. 6378–6388, 2019.

[2] P. K. Patnaik, M. Malijeddi, and D. C. Panda, “Wearable microstrip patch antenna for disease detection and WiMAX application,” 2021 2nd International Conference on Range Technology (ICORT), 2021.

[3] T. Le and T.-Y. Yun, “Wearable dual-band high-gain low-SAR antenna for off-body communication,” IEEE Antennas and Wireless Propagation Letters, vol. 20, no. 7, pp. 1175–1179, 2021

[4] J.-P. Xu, L.-J. Xu, L. Ge, Z. Duan, and Y.-M. Tang, “Flexible wearable antenna based on MIMO technology,” 2019 IEEE MTT-S International Wireless Symposium (IWS), 2019.

[5] G. P. Gao, C. Yang, B. Hu, R. F. Zhang, and S. F. Wang , ‘”A wearable PIFA with an all-textile metasurface for 5 GHz WBAN

applications", IEEE antennas and wireless propagation letters, 18(2), 288-292, 2018.

[6] G. P. Gao, B. Hu, S. F. Wang, & C. Yang, "Wearable circular ring slot antenna with EBG structure for wireless body area network", IEEE Antennas and Wireless Propagation Letters, 17(3), 434-437, 2018.

[7] H. Li, S. Sun, B. Wang and F. Wu, "Design of compact single-layer textile MIMO antenna for wearable applications", IEEE Transactions on Antennas and Propagation, 66(6), 3136-3141, 2018.

[8] T. T. Le and T. Y. Yun, "Wearable dual-band high-gain low-SAR antenna for off-body communication", IEEE Antennas and Wireless Propagation Letters, 20(7), 1175-1179, 2021.

[9] H. A. Mashagba, H. A. Rahim, I. Adam, M. H. Jamaluddin, M. N. M. Yasin, M. Jusoh,... and P. J. Soh, "A Hybrid Mutual Coupling Reduction Technique in a Dual-Band MIMO Textile Antenna for WBAN and 5G Applications", IEEE Access, 9, 150768-150780, 2021

[10] C. Hertleer, A. Tronquo, H. Rogier, and L. Van Langenhove, "The use of textile materials to design wearable microstrip patch antennas," Textile Research Journal, vol. 78, no. 8, pp. 651–658, 2008.

[11] S. B. Roshni, M. P. Jayakrishnan, P. Mohanan, and K. P. Surendran, "Design and fabrication of an E-shaped wearable textile antenna on PVB-coated hydrophobic polyester fabric," Smart Materials and Structures, vol. 26, no. 10, p. 105011, 2017.

[12] A. Khan and R. Nema, "Analysis of five different dielectric substrates on microstrip patch antenna," International Journal of Computer Applications, vol. 55, no. 14, pp. 40–47, 2012.

[13] Y. Li, R. Torah, S. Beeby, and J. Tudor, "Fully direct‐write dispenser printed dipole antenna on woven polyester cotton fabric for wearable electronics applications," Electronics Letters, vol. 51, no. 17, pp. 1306‐1308, 2015.

[14] S.-H. Li, K.-A. Cheng, W.-H. Lu, and T.-C. Lin, "Developing an active emergency medical service system based on WiMAX Technology," Journal of Medical Systems, vol. 36, no. 5, pp. 3177–3193, 2011.

[15] N. Ferdous, G. Chin Hock, S. Hamidah A.Hamid, M. N. Raman, T. Sieh Kiong, and M. Ismail, "Design of a small patch antenna at 3.5 GHz for 5G application," IOP Conference Series: Earth and Environmental Science, vol. 268, no. 1, p. 012152, 2019.