International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
IJISAE
ISSN:2147-6799 www.ijisae.org Original Research Paper

Review of Textile Antenna for WBAN: Challenges, Design and Multiple Application

Rudra Bhanu Satpathy[1]*, G. P. Ramesh[2]

Submitted: 30/12/2023 **Revised**: 05/02/2024 **Accepted**: 11/02/2024

Abstract: WBAN -Wearable Body access network has grown up to have cutting edge scope with rise and need of technology along with trending fashion. WBAN system and smart textile/wearables have applications in field of healthcare, sports ,security ,entertainment and communication systems of 5G.Design of textile antennas is becoming an important aspects of studies of antennas and communication system. This article reviews novel works related to design of wearable antennas and their application in different bandwidth like ISM Band, X/Ku Bands, C-Bands and Wi-Max. A vivid study of real-time feasibility and design challenges, application of wearable antennas in smart textiles, design methodologies and outcome parameters evaluation are done. Looking at the conditions that makes the antenna bio-compatible before coming in contact with human body and impact of wave polarization due to folding of antennas that bends with body curvature are some of the key factors to be considered while designing the substrate of antenna. Different types of antennas like Dipole, helictical , E-Shaped and array of antennas integrated were designed by researchers with scopes of application in different sectors and operating in different bandwidth which are evaluated and compared. Several methodologies of fabricating antennas are discussed and evaluated that includes choice of substrate material, designing using Surface integrated waveguides and 3D printing. Outcome based design parameters and choice of materials for radiator and substrate are evaluated considering their reliability, flexibility and efficiencies. Efficiencies of these novel textile antennas are studied, evaluated and compared considering criteria like loss, gain , weight , maintenance, installation cost and consistency in conditions like weather , wash cycles , temperature and proximity of users. Factors affecting performance of antenna including capacity of substrates like tolerability, flexibility, compactness, wave polarization and tangent loss while bending of textile are analyzed. The study of wave polarization and electromagnetic properties of textile antennas due to effects like wave scattering due to motion and environment are evaluated in this article. Dielectric characteristics of textile along with conductive nature of Radiative and substrate element of antennas are considered in subsequent studies. The article focuses on review of existing works in field of wearable antenna design considering applications and problem statements for WBAN applications.

Keywords: *Textile Antenna, Wearable Body Access Network (WBAN), WBAN Applications*

1. Introduction

With emerging technology for communication, data transfer and trending fashion, wearable technology has cutting edge application. According to Technoavio a UK based Technology Media House market segment of Wearable devices is expected to rise to 23 Billions by year 2025, driving growing demand for wearable technology [1]. The 5G communication is the emerging system with high rate of data transmission that will not only confined to mobile technology has applications in ISM band used for WBAN [2]. Advancing research opportunities in WBAN communication emphasizes on development of systematic devices, design of antennas and communication technologies. Wearable antenna have been the subject of discussion, innovation and research in last decade with multiple works by communication engineers. In this article studies and reviews have been made about current novel works in design of antennas. The paper also covers wide range of application of WBAN and design of required textile antennas of different forms like patch, helictical, circular and dipole antennas. Several works related to challenges in design of textile antennas have been persuaded considering the difficulties of flexibility, environmental characteristics, proximity of users, garment life and wash cycles. Substrate materials for antenna to be embedded in textile are carefully chosen and the article discusses the types of material along the dielectric – conductive and non-conductive nature to consider the materials for radiative element and substrate element. Alternative material like Zelt, Flectron and non conductive materials like silk and felt fabric are studied for better choice of substrate materials[3]. Design of radiating materials for antenna are carefully studied to ensure safety and to avoid injury of body tissues due to sharp metallic edges of radiator. Wearable antennas have several usage in WBAN systems used in different sectors which are discussed in this article covering a wide range of applications in frequency bands like C-Band, X/Ku Band, ISM -5G band and Wi-Max applications. With the parallel demand and growth of trending of Fashion, technology and internet of things WBAN system will be single point of user interaction for man with technology, thus motivating us to work ahead to design miniature textile antenna to operate in ISM band for 5G applications.

[1] *Research Scholar, St.Peter's Institute of Higher Education and Research, Chennai, India*
[2] *Professor, Department of Electronics and Communication Engineering, St.Peter's Institute of Higher Education and Research, Chennai, India*

Application of WBAN

Wearable technology and network system, WBAN has huge application in healthcare, military, sports, lifestyle, glamour, security and communication.

Healthcare – Healthcare complications have raised the demands of diagonosys and patient vital monitoring. With increases scopes and application of Artificial intelligence in diagonosys smart heath care monitoring systems are on demand. Research has been made to develop wearable sensors for monitoring neo-natal cardiorespiratory functionality [4].

Research has been made to manage anxiety and depression using Artificial intelligence through wearable devices [5]. For the IoT connected healthcare applications, the wireless body area network (WBAN) is gaining popularity as wearable devices spring into the market.Articles have proposed wearable sensor node , with solar energy producing Bluetooth low energy transmission for monitoring patients vitals through WBAN . Multiple sensor nodes are deployed in patients body to monitor body temperature and heart beats. [6]. Numerous application of WBAN in healthcare as apromising area needs developed communication architecture including priorities on development of wearable textile antennas. Several other areas of application of wearable textile antennas in WBAN are proposed that includes both medical and non-medical sectors [7]. As because clothing is the 24 X 7 essential need, people prefer to embed WBAN technology and textile antenna having scopes of security, safety systems and healthcare monitoring which creates wider opportunity of research [8]. The paper segregate the wearable antennas to two types of application a) UWB Wearable antennas for Off Body communication b UWB Wearable antennas for On Body communication. The work describes different types of antennas for Section A i.e Off Body communication in form of (i) Mono Pole /Di Pole Antenna (ii) Antenna with rear dipole plane.For on Body communication a dipole antenna with its radiation in multidirection but wave polarisation in vertical plane of body is ideal choice .

wearable biomedical telemetry applications work includes wideband, low-profile and semi-flexible antenna [9].

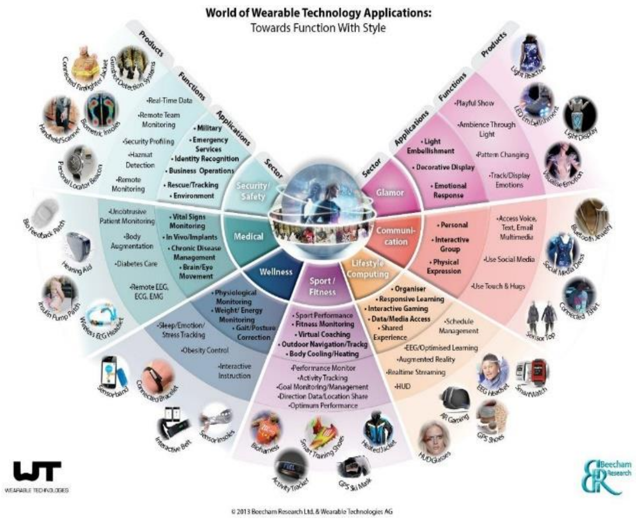


Fig.1: Image of WBAN Application

Challenges in Design of Wearable antennas

As discussed several real time challenges are faced by engineers to design wearable antennas. In this section we have reviewed articles stating difficulties in design of textile antennas which will followed by our further reviews on design methodologies .Bio-compatibility to human body is the first and foremost criteria which includes factors like a) impact of radiation on human body. b) Compartibility of ideal substrate to the skin c) Rigidity and sharpness of radiator expected to cause damage to body tissue are few factors [10]. In the proposed work ahead ISM (Industrial , Scientific & Medical) Band 2.4 GHz is preferred .

Another important challenge in wearable antenna is the consistency across varied environment. Temperature, humidity and the proximity of people and other garments as well as wash cycles, etc are some individual situation that affects gain of textile antennas [11].

Moreover motion of antennas because of body parts movement is another factors that affects the performance of antenna. Motion causes wave polarization and scattering creating degradation of signal transmitted which needs careful study to address [12] .

The dielectric characteristics of textile has impact on permittivity and tangential loss caused by substrate of antenna. Novel works has been done to study the conductive and non conductive characteristics of textiles as substrate [13].

2. Taxonomy

Impact of Human body

Human body has tremendous impact on performance of antenna and several researches has been made considering Specific Absorption ratio technique to study the effect and how antenna performance degrades in contact with body surface . Review works in [14][15] states and evaluates impact of real time environment, impact of Human Body interaction , bending wrinkles and washing. All wearable antennas have some unwanted backward radi- ation, which is absorbed by the human tissues. This radiation can be hazardous if it exceeds the standard exposure limit. Therefore, for on-body applications, the SAR guidelines for electromagnetic radiation absorption must be considered and fulfilled.

Design and types of wearable antennas

Several works have been proposed to design conformal wearable antennas for WBAN applications. Design language of these antennas includes some primary characteristics that makes them withstand some real-time requirements like flexibility Bending with clothes, compatibility with human body. Dual band antennas and UWB antennas for WBAN application and designs are reviewed in the article. Several types of. Wearable antennas are proposed – (i)On body textile antenna (ii)-Dual band diamond textile wearable antenna (iii)Polygon shaped slotted dual band antenna [16].

A permittivity Customizable Ceramic Doped Silicon substrate shaped with 3-D printing to design flexible and conformal antenna was proposed [17]. Two important criteria's has been addressed by designing the antenna through the work a) Platform tolerability , flexibility and compactness b) study of significant tangential loss due to bending. The work investigates the possibilities to join the potential of ceramic dopped polymeric substrate with the advantage of 3-D printing to design fully controllable electromagnetic structure in terms of permittivity , low loss , cost effectiveness, flexibility and form factor.

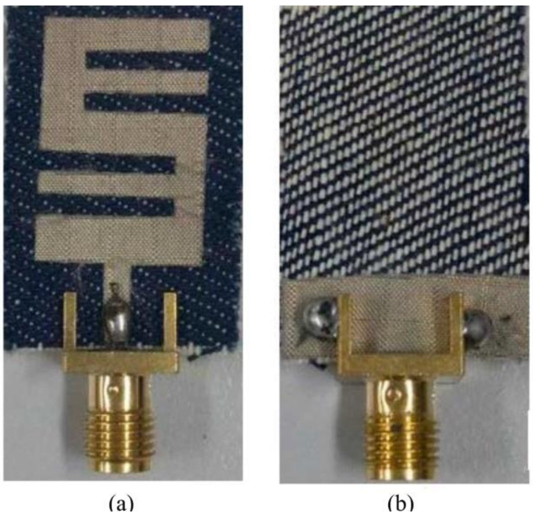


Fig. 2: A typical E type Antenna showing a denim substrate and metallic radiator

Study of Bending factor of Antenna

The study proposes the effect of bending of antenna due to body curvature and its impact on a rectangular patch textile antenna operating at ISM Band-2.4 GHz [18]. The substrate of the antenna was made up of Denim material and conducting layer was created by Copper and Nickel plated textile fabric.

The performance of antenna was evaluated through bending in respect of length and width. The antenna was placed and bent over body curvatures like chest, hand, legs and wrist looking at WBAN applications and requirement. Results were obtained from bench and anechoic chamber measurements and compared with simulation results. The prototype presents a maximum gain of approximately 4 dBi and 70° of half-power beamwidth (HPBW) in the flat position.It was observed that bending of wrist causes decrease of gain upto 2dB where as HPBW (half power beam width) increase by 25 degree.

Materials Used

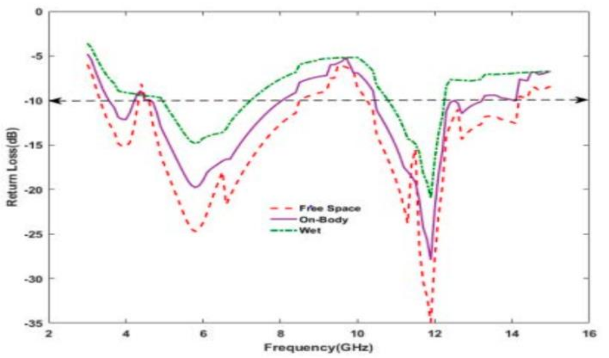
For design of wearable antennas two types of substrates were used in the different methods of design as common that includes conductive section and the substrate part . The preferred materials for conductive sections are copper , silver and aluminum with a plethora of materials characterizing the textile nature as antenna .Several researches have been made to opt flexible material as a conductive substitutes like CNT , Graphene and Graphite .Similarly design and choice of materials for substrate has been a due course of study with option of flexible substrate made up of paper, polymer , rubber and foam . Researches has been made to design printed circuit board by using Roger ,FR4 and TEFLON [19]. Conductive materials used are for top Radiator and Ground , so characteristics of conductive materials needs to abide resistivity , conductivity , deformability , weather proof , textile strength and ability to integrate with flexible materials . Various preferred conductive smart textile materials are used for wearable antennas including zelt , nylon and nickel plates [20]. Moreover polymers are low lossy materials and have high stability in wet condition because of high moisture absorption rate which makes them suitable for wearable application [21].

Study of characteristics of Substrate

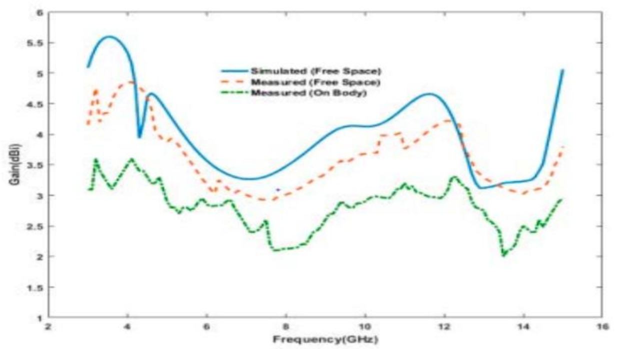
Substrate is the base of fabric on which the radiator of antenna is mounted. Research has been done for design of smart textile, garment tracking and e- fabric since twentieth century when [22] designed the conductive polimer as textile in 1977 and earned Novel Prize after thirty years. Inclusion of antennas in smart textiles and apparels without user discomfort in several domains have been studies and reviewed [23]. Therefore, the design and demon- station of a miniaturized textile antenna (denim substrate) shows in Fig. 1 for ISM band application at 2.4 GHz are presented [24].

Table 1: Comparison of choice of flexible materials as substrate

Properties	***Polymer***	***Textile***	***Fluidic***	***Paper***
Dielectric Loss	Low	Low	Medium	High
Tensile strength	High (167) MPA	Low (25.) MPA	Low (30)MPA	Low (3.9) MPA
Flexural Strength	High	Low (8900 psi)	Low (7200 psi)	Low (650 psi)
Deformability	Low	High	High	High
Thermal Stability	High	Low	Low	Low
Fabrication complexity	Simple	Complex	Simple	complex
Cost of Fabrication	Medium	Low	Low	High



(a)



(b)

Fig. 3: Jeans textile antenna's simulated and measured (a) S11 & (b) gain

3. Related Works

DUAL MODE WEARABLE ANTENNA WITH SIW (SURFACE INTEGRATED WAVE GUIDE)

A novel dual band wearable textile antenna with Surface integrated waveguide is proposed in this article [25].A miniature square type wave guide is created and embedded within the textile substrate and by minimizing square cavity size 1/8 times with eight mode SIW configuration .The antenna covers frequency band of UHF LoRa (Low Range) application.

DESIGN OF MIMO TEXTILE ANTENNA

A dual mode MIMO (Multiple input and Multiple output) antenna for wifi sensing application is proposed [26]. The MIMO technology for antenna is mixed with Orthogonal frequency division multiple access (OFDM) used in Wifi 6/6E to increase the throughput. The details of the design and its performance in a sample indoor MIMO setting are provided. The MIMO antenna is proposed for WiFi tracking and sensing applications. The performance of the MIMO antenna in an indoor setting is examined. The article shows the application of wearable antennas in WLAN system to connect with WiFi and WiFi devices. There is a need of wearable antenna that can seamlessly integrate into human clothing and operate in WiFi band .Such antennas are expected to small and small antennas radiate in omni-direction thus degrading the SAR value with section of radiation reflected bqck towards body .On the other hand, the radiation toward the body can cause a high specific absorption rate (SAR), requiring a reduction in the input power to comply with the standard SAR levels .The priority of the work is to design a small antenna with maximum possible isolation from human body . Wifi application are expected to be of following category (i) Detection (ii) Recognition (iii) estimation. In many of these applications, multiple antennas are required or provide a more accurate result. Therefore, we are looking for a multiple input multiple output (MIMO) system comprised of largely separated textile antennas, distributed on the body. The study produces a comparative analytics of different type of textile antenna by comparing the substrate material, respective gain and efficiency.

Researchers in [27] have used embedded conductive fibers in a polymer substrate to design flexible , robust and frequency tunable wearable antenna . The problem is the these type of development were prone to stretch and damage due to deformity of fibers embedded in polymer . In further course of research and development high stretchability materials [28][29].Further researches suggested another problem stating stretchable antennas have low radiation rate when stretched and pulled .

SAR ANTENNA DESIGN

An wearable dual band high gain low SAR antenna design is proposed for Off-Body Communication [30]. A wearable dual-band folded-ring antenna, haves a directional radiation pattern and offers high-gain, high-efficiency, and low-specific absorption rate (SAR) performance, is presented for 2.45/3.45 GHz off-body communication. The proposed antenna is comprised of two substrates; a folded-ring antenna as a main radiator is printed on a low-loss rigid substrate and a conductive textile is attached to a felt substrate. The conductive textile is used as the ground plane and as a protective shield to prevent incidental electromagnetic waves from propagating toward the human body.

WEARABLE ANTENNAS IN 5G APPLICATIONS: REVIEW OF DESIGN AND METHODOLOGIES

5G Network is in verge of development across many countries focusing on faster wireless data rates, connectivity, bandwidth, low energy consumption and latency. IoT -Internet of things is the smartest and emerging technology that integrates devices across the network , this prioritized the connectivity of Wearable devices as well.

4. Discussion

Ongoing recent researches and development were studied and evaluated to understand further challenges and scopes of development for textile antennas . The key areas to be addressed were choice of materials that suits the compatibility for on body application and better efficiency along with feasibility . Realtime conditions and characteristics of antenna resembling the properties of textile is the most important factor to be evaluated .In further studies different design languages we reviewed that includes dual band folded ring antennas that has directional radiation pattern with high gain , efficiency and low SAR. Dual mode MIMO -Multiple Input Multiple Output antenna was also studied that includes technology of Orthogonal frequency division multiple access (OFDM) for Wifi application . Dual mode antenna which perform with Surface integrated waveguide is also studies and discussed where a miniature square wave guide is created to increase efficiency with eight mode SIW configuration . The article also discusses about several designs and 5G application of wearable antennas which includes sports , entertainment , health care , communications and security.

5. Conclusion

Researches towards development of smart textile has a tremendous growth in last decade , still there is the need of further works that includes development of wearable antennas to perform at 5G frequency band by overcoming the challenges and difficulties discussed in this article . When the communication system is shifting to 5G band , it is the need of hour to develop wearable antennas with higher performance and efficiency to encompass the application of Wearable Technology.

References

[1] https://www.technavio.com/content/about-us

[2] M. Agiwal, A. Roy and N. Saxena, "Next generation 5G wireless networks: A comprehensive survey", *IEEE Commun. Surveys Tuts.*, vol. 18, pp. 1617-1655, 3rd Quart. 2016.

[3] Rais, N. & Soh, Ping Jack & Abdul Malek, Mohamed Fareq & Ahmad, Sahadah & Mohd Hashim, Nur Baya. (2009). Wearable Antennas using Conductive Textiles.

[4] Grooby, E., Sitaula, C., Chang Kwok, T. *et al.* Artificial intelligence-driven wearable technologies for neonatal cardiorespiratory monitoring: Part 1 wearable technology.*Pediatr Res* 93, 413–425 (2023). https://doi.org/10.1038/s41390-022-02416-x

[5] Abd-alrazaq A, AlSaad R, Aziz S, Ahmed A, Denecke K, Househ M, Farooq F,Sheikh J

[6] T. Wu, F. Wu, J. -M. Redouté and M. R. Yuce, "An Autonomous Wireless Body Area Network Implementation Towards IoT Connected Healthcare Applications," in *IEEE Access*, vol. 5, pp. 11413-11422, 2017, doi: 10.1109/ACCESS.2017.2716344.

[7] Yadav, Ashok, et al. "A review on wearable textile antenna." *Journal of Telecommunication, Switching Systems and Networks* 2.3 (2015): 37-41.

[8] S. Yan, P. J. Soh, and G. A. E. Vandenbosch, ‘‘Wearable ultrawideband technology—A review of ultrawideband antennas, propagation channels, and applications in wireless body area networks,’’ *IEEE Access*, vol. 6, pp. 42177–42185, 2018.

[9] A. Smida, A. Iqbal, A. J. Alazemi, M. I. Waly, R. Ghayoula and S. Kim, "Wideband Wearable Antenna for Biomedical Telemetry Applications," in *IEEE Access*, vol. 8, pp. 15687-15694, 2020, doi: 10.1109/ACCESS.2020.2967413.

[10] A Akbarpour and S. Chamaani, ‘‘Ultrawideband circularly polarized antenna for near-field SAR imaging applications,’’ *IEEE Trans. Antennas Propag.*, vol. 68, no. 6, pp. 4218–4228, Jun. 2020.

[11] M.ElGharbi,M.Martinez-Estrada,R.Fernández-García,S.Ahyoud,and I. Gil, ‘‘A novel ultra-wide band wearable antenna under’’ *J. Textile Inst.*, vol. 112, no. 3, pp. 437–443, Mar. 2021.

[12] M. Klemm and G. Troester, ‘‘Textile UWB antennas for wireless body area networks,’’ *IEEE Trans. Antennas Propag.*, vol. 54, no. 11, pp. 3192–3197, Nov. 2006.

[13] S.ZhuandR.Langley,‘‘Dual-bandwearabletextileantennaonanEBG substrate,’’ *IEEE Trans. Antennas Propag.*, vol. 57, no. 4, pp. 926–935, Apr. 2009

[14] Yan, Sen, Ping Jack Soh, and Guy AE Vandenbosch. "Performance on the human body of a dual-band textile antenna loaded with metamaterials." *2015 9th European Conference on Antennas and Propagation (EuCAP)*. IEEE, 2015.

[15] Sultan, Kamel Salah, Haythem Hussien Abdullah, and Esmat Abdel-Fatah Abdallah. "Low-SAR

miniaturized handset antenna using EBG." *Microstrip Antennas: Trends in Research on* 1 (2017): 127.

[16] Wang, J. C., et al. "Conformal wearable antennas for WBAN applications." *Proceedings of the international multiconference of engineers and computer scientists*. Vol. 2. 2016.

[17] L. Catarinucci, F. P. Chietera and R. Colella, "Permittivity-Customizable Ceramic-Doped Silicone Substrates Shaped With 3-D-Printed Molds to Design Flexible and Conformal Antennas," in *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 6, pp. 4967-4972, June 2020, doi: 10.1109/TAP.2020.2969748.

[18] D. Ferreira, P. Pires, R. Rodrigues and R. F. S. Caldeirinha, "Wearable Textile Antennas: Examining the effect of bending on their performance," in *IEEE Antennas and Propagation Magazine*, vol. 59, no. 3, pp. 54-59, June 2017, doi: 10.1109/MAP.2017.2686093.

[19] Salvado R, Loss C, Gonçalves R, Pinho P. Textile Materials for the Design of Wearable Antennas: A Survey. *Sensors*. 2012; 12(11):15841-15857. https://doi.org/10.3390/s121115841

[20] P. Salonen, Y. Rahmat-Samii, M. Schaffrath and M. Kivikoski, "Effect of textile materials on wearable antenna performance: a case study of GPS antennas," *IEEE Antennas and Propagation Society Symposium, 2004.*, Monterey, CA, USA, 2004, pp. 459-462 Vol.1, doi: 10.1109/APS.2004.1329673.

[21] Trajkovikj, J.; Zurcher, J.-F.; Skrivervik, A.K. PDMS, A Robust Casing for Flexible W-BAN Antennas. *IEEE Antennas Propag. Mag.* 2013, *55*, 287–297

[22] H. Shirakawa, E. J. Louis, A. G. MacDiarmid, C. K. Chiang, and A. J. Heeger, ‘‘Synthesis of electrically conducting organic polymers: Halogen derivatives of polyacetylene, (CH)x,’’ *J. Chem. Soc., Chem. Commun.*, vol. 16, pp. 578–580, Jan. 1977

[23] M. M. H. Mahfuz *et al*., "Wearable Textile Patch Antenna: Challenges and Future Directions," in *IEEE Access*, vol. 10, pp. 38406-38427, 2022, doi: 10.1109/ACCESS.2022.3161564

[24] A. Y. I. Ashyap, Z. Z. Abidin, and S. H. Dahlan, ‘‘Inverted E-shaped wearable textile antenna for medical applications,’’ *IEEE Access*, vol. 6, pp. 35214–35222, 2018

[25] G. A. Casula, G. Montisci and G. Muntoni, "A Novel Design for Dual-Band Wearable Textile Eighth-Mode SIW Antennas," in *IEEE Access*, vol. 11, pp. 11555-11569, 2023, doi: 10.1109/ACCESS.2023.3242602.

[26] Noghanian, Sima. "Dual-Band Wearable MIMO Antenna for WiFi Sensing Applications." *Sensors* 22.23 (2022): 9257.

[27] Simorangkir,R.B.V.B.;Yang,Y.;Esselle,K.P.;Zeb,B.A .AMethodtoRealizeRobustFlexibleElectronically Tunable Antennas Using Polymer-Embedded Conductive Fabric. *IEEE Trans. Antennas Propag.* 2018, *66*, 50–58

[28] Kumar, A.; Saghlatoon, H.; La, T.-G.; Honari, M.M.; Charaya, H.; Abu Damis, H.; Mirzavand, R.; Mousavi, P.; Chung, H.-J. A highly deformable conducting traces for printed antennas and interconnects:Silver/fluoropolymer composite amalgamated by triethanolamine

[29] Salleh, S.M.; Jusoh, M.; Ismail, A.H.; Kamarudin, M.R.; Nobles, P.; Osman, M.N.; Jais, M.I.; Soh, P.J.; Rahim, M.K.A.; Sabapathy, T. Textile Antenna With Simultaneous Frequency and Polarization Reconfiguration for WBAN. *IEEE Access* 2017, *6*, 7350–7358

[30] Le, Tu Tuan, and Tae-Yeoul Yun. "Wearable dual-band high-gain low-SAR antenna for off-body communication." *IEEE Antennas and Wireless Propagation Letters* 20.7 (2021): 1175-1179.