[1] Jyotika Yadav,
[2]Tilak Dhari Singh,
[3]Shivesh Tripathi
[4]Kamal Prakash Pandey
[4]Vijay Shanker Tripathi

A Compact, Wearable Antenna for on-Body WBAN Applications

Journal of Electrical Systems

Abstract: - This paper presented a wearable low-profile compact antenna, which is suitable for on-body wireless body area network (WBAN) applications. This wearable antenna is designed using a widely available polyamide based flexible substrate, with significantly lower cost. The final antenna topology is obtained by placing patch on the substrate with a feedline, having some slots, and a ground structure to achieve compact and lightweight, low cost, easy to integrate with good directivity and radiation efficiency, it operates on the central frequency of the industrial, medical, and scientific bands at 4.8 GHz. The built prototype of this antenna has shown good agreement between theoretical and experimental results. Our design has a compact power factor, with S11 parameter of -25 dB, with a good Specific Absorption Rate (SAR). Its results have revealed extremely good stiffness for both loading and structural deformation of the human body based on theoretical and experimental studies, therefore making it an ideal candidate for applications on the human body.

Keywords: Compact antenna, Microstrip wearable antenna, on-body, specific absorption rate (SAR), wearable antenna, wireless body area network (WBAN).

I. INTRODUCTION

There have been significant improvements in the flexibility of devices and the development of sensors that can play an important role in health monitoring and transmission over the past few decades. Measuring physiological signals in real time and performing continuous, applications of wireless body sensor networks (WBSN) for health monitoring. It has attracted a lot of attention because of its huge potential. Various body-worn applications, such as signaling and rescue or geo-location of military personnel, etc., have led to the foundation of Wireless Body Area Network (WBAN) [1-2].

On-body plays an important role in referring to wireless data exchange, as this mode occurs between devices distributed at different locations on the human body [3-4]. A portable broadband dipole antenna with a simple mechanical structure and very low cost has been proposed. [5]. This includes the advancement of high efficiency and wearable antenna devices, enabling wireless body area networks [6]. As one of the key components that meet modern technology requirements, the wearable antenna plays an essential role in enabling proper communication in the body [7]. Design of tri-band off-body antenna for wearable electronic devices for body area network (BAN) communication, empowering wireless system communication are described in [8]. A wearable broadband antenna has been designed for on-body wireless body, which is application are in wide area network (WBAN) [9-10]. On-body wireless wearable ultra-wideband (UWB) an antenna has been designed, which is applied in area network (WBAN) and Body-Centric Communications has been presented [11-12]. Wearable dual-band high-gain low-SAR antenna and flexible dual-band tree fractal antenna proposed for off-body communication [13-14]. This paper discusses in detail the wearable microstrip patch antenna which is very suitable for medical applications [15]. This paper reports a wearable tri-band half-mode substrate integrated with waveguide (HMSIW) antenna suitable for wireless body area network (WBAN) applications [16-17]. Wearable wireless devices, leading in a rapidly

3 *Corresponding author: [3] Shivesh Tripathi [2]Department of Electronics and Communication Engineering, G L Bajaj Institute of Technology and Management, Gr. Noida.
[1] Jyotika Yadav, [2]Tilak Dhari Singh and [5]V S Tripathi [1,4] Department of Electronics and Communication Engineering,[5]Motilal Nehru National Institute of Technology, Allahabad, Prayagraj.
[4]Kamal Prakash Pandey, [3]Department of Electronics and Communication Engineering, BBS College of Engineering & Technology, Allahabad, Prayagraj.

expanding area of Body-centric Wireless Networks (BCWNs). In-body communications for health monitoring applications utilize an implanted medical device and an external base station to incorporate Body-centric, on-body, off-body and in-body applications in wireless networks for wireless communications. [18-20]. The wearable antenna in the WBSN plays an important role in wireless communications, sensing detection, and energy provision [21-25]. Wearable antennas for WBSN have appeared more and more in recent years. Integrated into various positions of human body, such as arm, chest, leg and foot. These antennas are mainly designed according to the microstrip antenna design principle, which has the advantages of simple structure and easy integration [26-30].

Wearable on-body antenna for WBAN applications has been designed and proposed to cover 4.8 GHz. The antenna design steps, specifications, simulated and measured results, comparison with other existing works and conclusions are explained respectively in the next section of the paper.

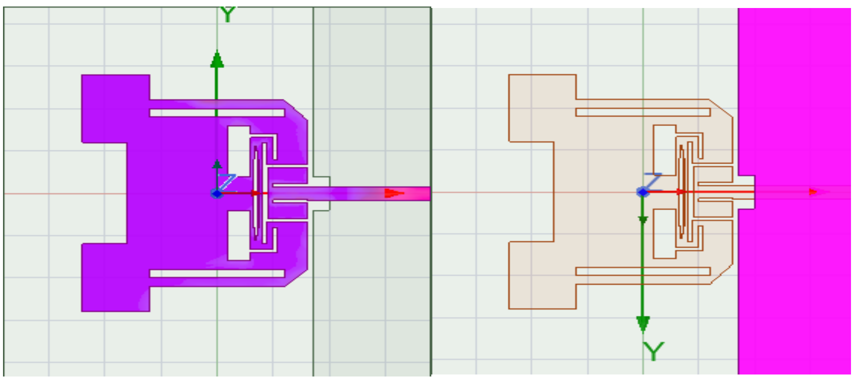
II. ANTENNA DESIGN AND METHODOLOGY

A wideband wearable microstrip patch antenna based on metasurface with a microstrip feedline technique at a resonance frequency of 4.8 GHz. The geometry of the proposed antenna is shown in Fig. 1. Schematic structure of Microstrip rectangle shape slot patch antenna (a) Top view (b) Bottom View (c) Fabricated prototype [17].

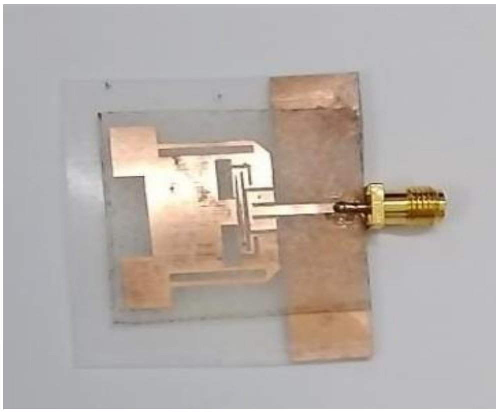
The overall dimensions of an antenna are 16×22×1 mm3. Table I shows the dimensions of the antenna parameters. A rectangular microstrip patch antenna is designed, and an inverted u shape along with a rectangle shape slot is etched at the top of the patch [18]. The overall dimensions of an antenna are 16×22×1 mm3. Table I shows the dimensions of the antenna parameters. A rectangular microstrip patch antenna is designed, and an inverted u shape along with a rectangle shape slot is etched at the top of the patch [18].

Table I Antenna Dimension

Substrate Dimensions	Ground	Patch Size
X=38 mm	X=10.5 mm	X=16 mm
Y=44mm	Y=44mm	Y=22mm
H=0.4mm	-	-



(a) (b)



(c)

Fig. 1. Schematic structure of Microstrip rectangle shape slot patch antenna

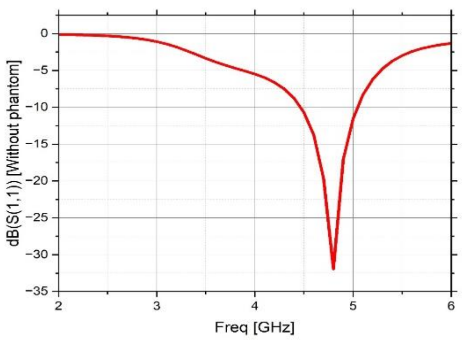
(a) Top view (b) Bottom View (c) Fabricated prototype.

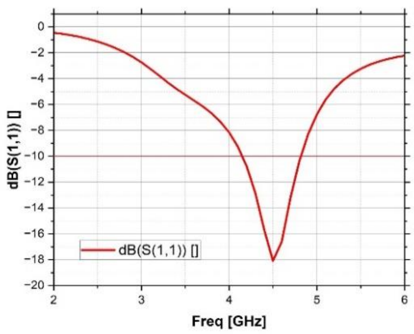
Ansys HFSS version 23 software is used to design and simulate the antenna and measure its performance. Antenna design begins with the standard design of a microstrip patch antenna which has a very narrow bandwidth (130MHz). The upper edges of the patch and the degraded ground structure are cut away and an inverted U-shape is carved out of the patch. Due to which its bandwidth has increased. This increased the value of S11 and bandwidth. Bandwidth increased by 39% and S11 is -36.91 dB. Common choices for flexible antenna substrates include Polyimide (PI), Kapton, PDMS (Polydimethylsiloxane), etc. This work is done using polyamide substrate [(εr=4.3), (δ=0.004)].

III. RESULT AND DISCUSSION

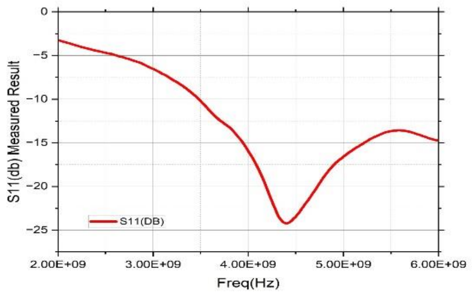
A. Characterization of antenna

Measurement setup used to characterize the antenna's performance. VNA and an anechoic chamber measured frequency for accurate return loss, radiation pattern, and Bandwidth measurements. A 50-ohm SMA connector is used for feeding. Fig. 2 (a) shows the S11 without phantom. (b) shows shows S11 with phantom, (c) Measured Results of S11 Fig.3 shows the combined result of S11. Fig. 4 shows the arm, wrist, chest results of rectangle shape slot patch antenna.





(a) S11 without phantom (b) S11 with phantom



(c) Measured Results of S11

Fig. 2 shows (a) S11 without phantom (b) shows S11 with phantom

(c) Measured Results of S11

The effect of antenna loading on human body and performance are discussed in this section. The performance of the antenna was measured by loading it on different parts of the body (arm, wrist, and chest) of the human. From Fig. 4 it is observed that the value of S11 is varied and resonant frequency is shifted When antenna is displaced to different places on the body. It is also observed that resonant frequency is shifted towards the lower side when the antenna is loaded on the human body. It happened due to the high permittivity of the human body. The shifts in resonance frequency for the chest are 4.96 GHz and S11 is – 19.0486 dB, for the arm is 4.64 GHz and S11 is – 31.1441 dB, and for the wrist 4.82 GHz and S11 is -30.2261 dB. while in all situation's antenna covers a 4.8 GHz.

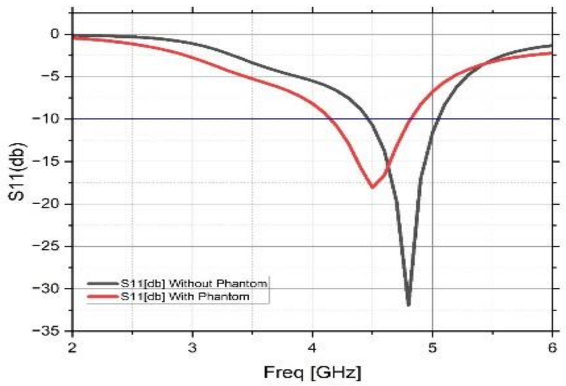


Fig. 3 shows S11 combined without phantom and with phantom

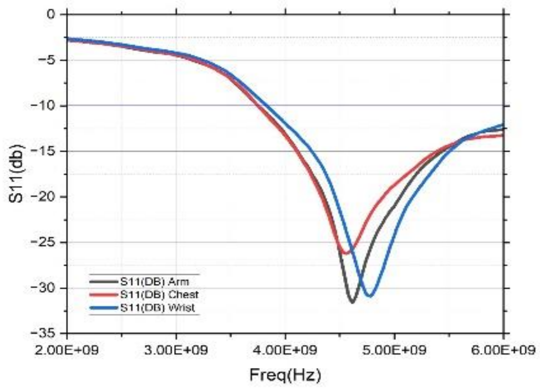


Fig. 4 shows the arm, wrist, chest

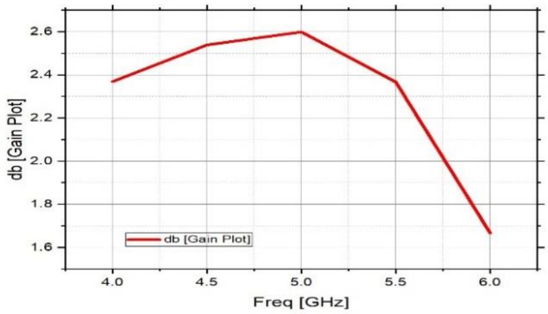


Fig. 5 shows the measured antenna gain

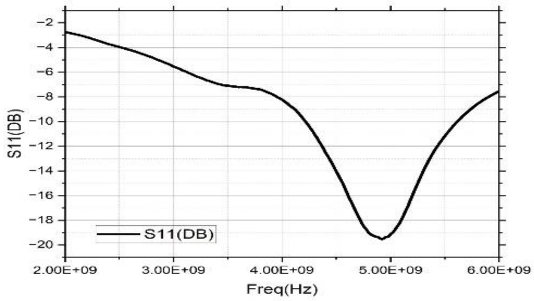


Fig. 6 SWR measured results

The measured gain of the proposed antenna is shown in Fig. 5. Fig. 6 shows the SWR measured results of the rectangular shape slot patch antenna. Fig. 7 shows the surface current distribution at the bottom of the antenna. Fig. 8 shows the proposed slotted patch antenna measurement setup. Fig. 9 shows the measured far-field radiation patterns (E-plane and H-plane) of the antenna at 4.8-GHz which is end fire type pattern. The polar plot of the proposed antenna shows in Fig.10. For WBAN applications, analysis of measurement data shows that the proposed antenna can be used as an on-body subsystem. Table II shows a comparison of proposed antenna with other reported works available in the open literature.

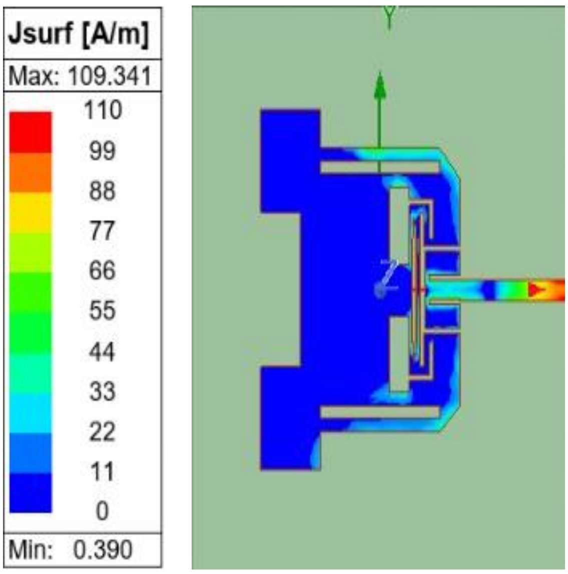


Fig. 7 Surface current density on Radiating Patch

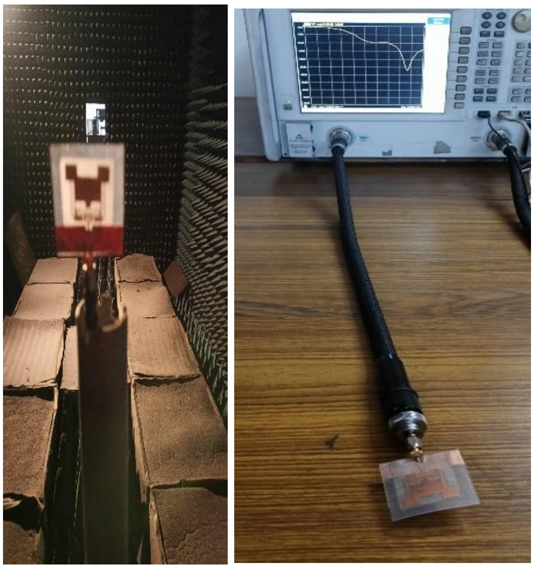


Fig. 8 Measurement setup of Antenna

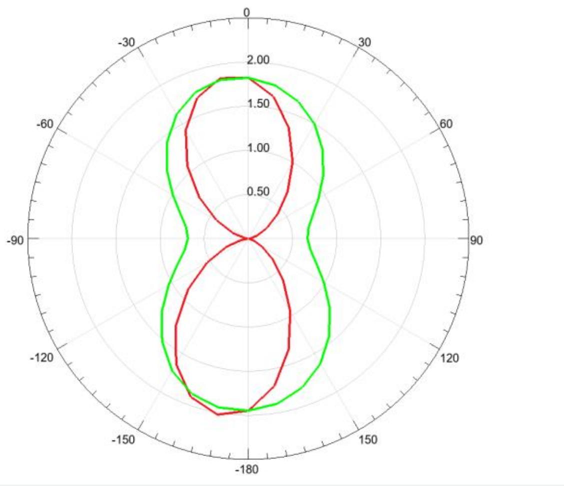


Fig 9 Radiation Pattern

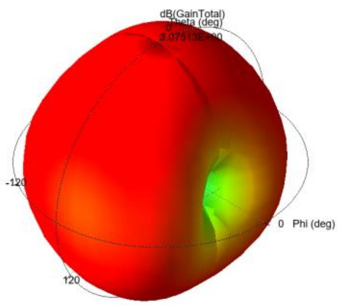


Fig 10 Polar Plot

Table II

Ref.	SUBSTRATE PERMITTIVITY (ϵ_r)	DIMENSIONS (MM^3)	FREQUENCY RANGE (GHZ)	BANDWIDTH	Gain (dB)
[1]	Polymer Substrate	39×39×0.503	2.55	0.9 GHz	2.6

[6]	RT Duroid 5880 (2.2)	47×47×1.575	2.4	320 MHz	3.67
[7]	jeans material (1.7)	58×68×0.2	2.6	200 MHz	5.76
[9]	RT Duroid 5780	45×30×0.787	5.2	320 MHz	2.3
[18]	FR-4 (4.4)	60×53×1	2.55	155 MHz	2.22
This Work	**Polyamide (4.3)**	**16×22×1**	**4.8**	**500MHz**	**2.6**

IV. CONCLUSION

The wideband microstrip antenna in this paper presents a flexible one with good performance in terms of bandwidth, flexibility, and gain. The antenna has been designed on a Polyamide substrate with a size of 16×22×1 mm3. The measured result shows S11 of -36.91 dB at resonance frequency 4.8 GHz band. The frequency range of the proposed antenna is 4.8 GHz and bandwidth of 500MHz. The measured peak gain is obtained about 2.6 dBi with an average SAR of 0.261 W/Kg. terms of bandwidth, flexibility, and gain. The antenna has been designed on a Polyamide substrate with a size of 16×22×1 mm3. The measured result shows S11 of -36.91 dB at resonance frequency 4.8 GHz band. The frequency range of the proposed antenna is 4.8 GHz and bandwidth of 500MHz. The measured peak gain is obtained about 2.6 dBi with an average SAR of 0.261 W/Kg. Measurement results and simulated results are showing the good matching with each other in the proposed antenna. This antenna is small enough to easily integrate into wearable devices, such as smartwatches and smart glasses. This antenna is designed on a very flexible substrate and it can be adapted to different shapes.

ACKNOWLEDGMENT

The authors are thankful to CST UP for supporting this research work under grant number CST/D-3740.

REFERENCES

[1] Arif, A., Zubair, M., Ali, M., Khan, M. U., & Mehmood, M. Q "A compact, low-profile fractal antenna for wearable on-body WBAN applications", *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 5 pp.981-985. May 27, 2019.

[2] Zhu, X. Q., Guo, Y. X., & Wu, W. "A compact dual-band antenna for wireless body-area network applications". *IEEE Antennas and Wireless Propagation Letters*, vol. 15, no.1 pp., 98-101, May 12, 2015,

[3] Zhang, K., Jiang, Z. H., Hong, W., & Werner, D. H. "A low-profile and wideband triple-mode antenna for wireless body area network concurrent on-/off-body communications", *IEEE Transactions on Antennas and Propagation*, vol. 68, no.3 pp.1982-1994, October 28,2019.

[4] Zhang, C., Zhao, Z., Xiao, P., Liu, Q., Wang, N., & Li, G. (2024). "A Miniaturized Wearable Annular Slot Antenna based on Designer LSPs for Telemedicine Communication". *IEEE Transactions on Antennas and Propagation*. voL. 72, no. 9, pp.7293-7298, June 21, 2024.

[5] Amani, N., Jafargholi, A., & Pazoki, R. "A broadband VHF/UHF-loaded dipole antenna in the vicinity of a human body", *IEEE Transactions on Antennas and Propagation,* vol.65, no.10, pp. 5577-5582, August 10, 2017.

[6] Waly, M. I., Smida, A., AlJarallah, N. A., Ghayoula, R., Negm, A. S., Muhammad, S., & Iqbal, A. "Advancement of a high-efficiency wearable antenna enabling wireless body area networks", *IEEE Access*. vol. 11, pp. no.4 138325-138335, December 5, 2023.

[7] Mallavarapu, S., & Lokam, A. "A fully flexible, high gain saw-tooth-shaped boundary fractal wearable patch antenna for WBAN applications". *International Journal of Microwave and Wireless Technologies*, vol.15, no. 5, pp.826-835, July 15, 2022.

[8] Shakib, M. N., Moghavvemi, M., & Mahadi, W. N. L. B. W. "Design of a tri-band off-body antenna for WBAN communication", *IEEE Antennas and Wireless Propagation Letters*, vol 16, no. 6 pp.210-213, May 17, 2016.

[9] Khan, M. A., Rahim, A. A., & Sethi, W. T. Design of Low-Profile Broadband Wearable Antenna for On Body WBAN Applications. *In 2023 18th International Conference on Emerging Technologies (ICET)* pp. 202-206, November 2023.

[10] Grimm, M., & Manteuffel, D. "On-body antenna parameters" *IEEE Transactions on Antennas and Propagation*, vol.63, no. 12, pp.5812-5821, September 25, 2015.

[11] Mahmood, S. N., Ishak, A. J., Ismail, A., Soh, A. C., Zakaria, Z., & Alani, S. "ON-OFF body ultra-wideband (UWB) antenna for wireless body area networks (WBAN)": a review, *IEEE Access*, vol.8, pp.150844-150863, August 10, 2020.

[12] Puskely, J., Pokorny, M., Lacik, J., & Raida, Z. "Wearable disc-like antenna for body-centric communications at 61 GHz", *IEEE Antennas and Wireless Propagation Letters*, vo.14, pp.1490-1493, November 6, 2014.

[13] Le, T. T., & Yun, T. Y. "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, April 21, 2021.

[14] Alkhafaji, A. N., Abdulsatar, S. M., & Ali, J. K. "Design of Flexible Dual-Band Tree Fractal Antenna for Wearable Applications", *Progress in Electromagnetics Research* vol. 125, pp.51-66, October 4, 2022.

[15] Younes, S., & Jaouad, F. "Wearable Patch Antenna with Rectangular Slots and Defected Ground for Biomedical Applications" *In 2023 IEEE International Conference on Contemporary Computing and Communications (InC4)* Vol. 1, pp. 1-6, April 21-22, 2023.

[16] Liu, W., Zhang, K., Li, J., & Yan, S. "A wearable tri-band half-mode substrate integrated waveguide antenna," *IEEE Antennas and Wireless Propagation Letters*, vol.20, no. 12, pp.2501-2505, September 28, 2021.

[17] Tripathi, S., Pathak, N. P., & Parida, M. "A dual feed PIN diode based switchable multiband planar meandered antenna for intelligent transportation system application", *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 29 no.11, pp.1-11, August 20, 2019.

[18] Raj, S., Mishra, P. K., Tripathi, S., & Tripathi, V. "A Defected Ground Structure Based Compact Circular Patch Antenna Design for mm Wave Application." *Defence Science Journal*, vol. 72, no. 4, pp. 592-599, July 2022.

[19] Tripathi, S., Pathak, N. P., & Parida, M. "Microwave front-end subsystems design for ITS/GPS applications", *Engineering Science and Technology, an International Journal*, vol. 19, no. 4, pp.1815-1825, September 2016.

[20] Raj, S., Tripathi, S., Upadhyay, G., Tripathi, S. S., & Tripathi, V. S. "An electromagnetic band gap-based complementary split ring resonator loaded patch antenna for glucose level measurement. *IEEE Sensors Journal*, vol. 21, no. 20, pp.22679-22687, August 24, 2021.

[21] Tripathi, S., Pathak, N. P., & Parida, M., "Concurrent Dual-Band Double-Layer High Gain Planar Antenna for WAICs/ITS Application*". In Computing, Communication and Signal Processing: Proceedings of ICCASP 2018* pp. 37-46, Springer Singapore, Available: https://link.springer.com/chapter/10.1007/978-981-13-1513-8_5

[22] Tripathi, S., Pathak, N. P., & Parida, M., Dual-band dual-beam microstrip patch antenna for intelligent transportation systems application. *In 2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, November 02-04, 2018 pp. 1-5.

[23] Tripathi, S., Pathak, N. P., & Parida, M., "Symmetrical double-comb multi-slotted large bandwidth antenna for intelligent transportation systems," *International Journal of RF and Microwave Computer-Aided Engineering*, vol.29, no.1, pp. 1-10, October 09, 2018.

[24] Velan, S., Sundarsingh, E. F., Kanagasabai, M., Sarma, A. K., Raviteja, C., Sivasamy, R., & Pakkathillam, J. K., "Dual-band EBG integrated monopole antenna deploying fractal geometry for wearable applications", *IEEE antennas and wireless propagation letters*, 14, pp.249-252, September 29, 2014.

[25] Z. Hamouda, J. L. Wojkiewicz, A. A. Pud, L. Koné, S. Bergheul, and T. Lasri, "Magnetodielectric nanocomposite polymer-based dual-band flexible antenna for wearable applications," *IEEE Trans. Antennas Propag.* vol. 66, no. 7, pp. 3271–3277, Jul. 2018.

[26] R. B. V. B. Simorangkir, A. Kiourti, and K. P. Esselle, "UWB wearable antenna with a full ground plane based on PDMS-embedded conductive fabric," *IEEE Antennas Wireless Propag.* Lett., vol. 17, no. 3, pp. 493–496, 24 Mar. 2018.

[27] S. J. Chen et al., “A compact, highly efficient and flexible polymer ultra-wideband antenna,” *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 1207–1210, February 2, 2015.

[28] G.-P. Gao, B.-K. Zhang, J.-H. Dong, Z.-H. Dou, Z.-Q. Yu, and B. Hu, “A compact dual-mode pattern-reconfigurable wearable antenna for the 2.4-GHz WBAN application,” *IEEE Trans. Antennas Propag*., vol. 71, no. 2, pp. 1901–1906, Feb. 2, 2023.

[29] M. Wagih, G. S. Hilton, A. S. Weddell, and S. Beeby, “Millimetre-wave power transmission for compact and large-area wearable IoT devices based on a higher order mode wearable antenna,” *IEEE Internet Things J.*, vol. 9, no. 7, pp. 5229–5239, Apr. 25,2022.

[30] L. Zhang, J. Li, Y. Wang, S. Yan, K.-D. Xu, and H. Luyen, “A compact dual-band wearable button antenna design for WBAN applications,” IEEE Trans. Antennas Propag., vol. 71, no. 10, pp. 8284–8289, Oct.10, 2023.