Performance Analysis of Wearable Horn Shaped Antenna

Mayank Dixit[1], Dr. Sheena Gaur[2], Dr Pooja Tripathi[3]
[1]*Research Scholar, Mewar University*
[2]*Professor, Electronics and Communication Engineering, Mewar University*
[3]*Professor, Information Technology, Indraprastha Engineering College*

***Abstract*—This research presents the design and development of a wearable horn-shaped textile antenna for medical and wireless applications in the ISM (Industrial, Scientific, and Medical) band. The antenna is constructed using a denim substrate with a thickness of 0.56 mm, ensuring flexibility and user comfort. The study explores the effects of slot modifications and substrate size variations to optimize resonance frequencies, impedance matching, and gain performance.**
A meta-material-based unit cell structure is incorporated at the back of the antenna to minimize electromagnetic radiation absorption by the human body, thereby improving Specific Absorption Rate (SAR) values. Simulations and experimental measurements confirm the antenna's resonance at 2.45 GHz (WiFi and ISM band), 3.04 GHz, 3.9 GHz (WiMax), and 6.56 GHz (C-band). The antenna achieves a peak gain of 4.74 dB at 2.45 GHz and demonstrates stable radiation characteristics in both on-body and off-body environments.
Compared to existing textile antennas, the proposed design offers superior multiband performance while maintaining a compact and flexible form factor. The findings indicate that the antenna is well-suited for wearable healthcare monitoring, wireless body area networks (WBANs), and IoT-based medical applications.

***Index Terms*—Wearbale devices, antenna design, horn speed antenna, ISM Band Antenna, Microstrip Patch Antenna, Denim Substrate Antenna, Multiband Antenna,Wireless Body Area Networks(WBANs)**

I. INTRODUCTION

The antenna is developed for medical applications in the ISM band in this chapter. Various studies have been conducted in order to compare the best suited design for specific purposes. The desired bands are achieved by using the horn shaped antenna by designing an antenna in the form of horn. The slots produce interruptions in the electric current flow, which aids in the introduction of new resonant frequencies. Due to addition of slots, the horn shaped antenna is appropriate for desired ISM band [1,2]

The findings of the simulations and the measurements are very close to each other. The remaining chapter of the text is divided into different parts. In Section II, antenna design geometry is discussed.

II. ANTENNA DESIGN AND CONFIGURATION

2.1 Antenna Design

Wearable microstrip patch antenna design geometry with textile material is the antenna design concept. The equations used to calculate the antenna patch dimensions based on the resonating frequency. The wearable antenna is made from a substrate made of denim substrate [3,4,5]. The material thickness of the denim is 0. 56mm.Based on the formulae, the dimensions of the patch are

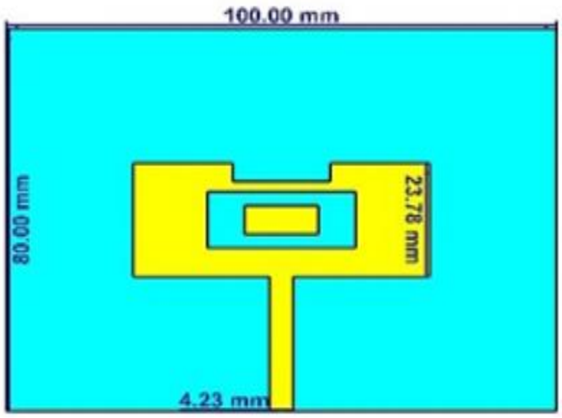
24.008 x 53.675 mm^2[126].

An antenna with a slotted design on a rectangular patch is intended to resonate at the correct frequencies. The thin substrate and feedline make up the compact design, which works well as a downsized arrangement for multiband applications. The dimensions of the microstrip feedline (50 ohm) are 2.113 x 13 mm^2. Various antenna properties can be implemented based on the needs by changing the feedline impedance [155].

2.2 Stages of Antenna design and analysis

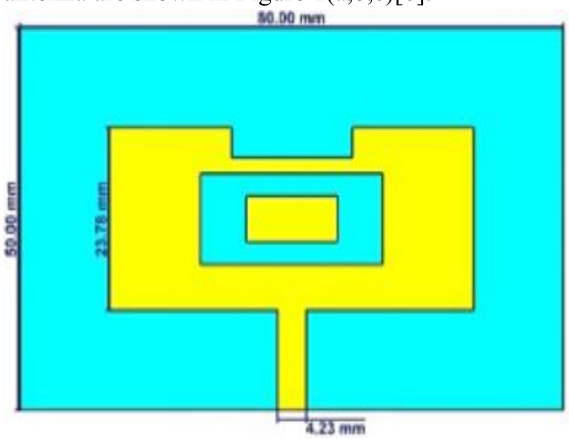
The denim textile based wearable antenna used in this study is specifically developed to show resonance in ISM band. The antenna design performance is heavily influenced by the substrate material and size.

2.2.1 Working on improving the antenna substrate size



a)

Antenna was designed with denim substrate of 1.12mm height. The textile antenna design with dimensions 80x100mm^2, 50x80 mm^2, and 50x70 mm^{2}of the substrate used to simulate the textile antenna are shown in Figure 1(a,b,c)[6].



(b)

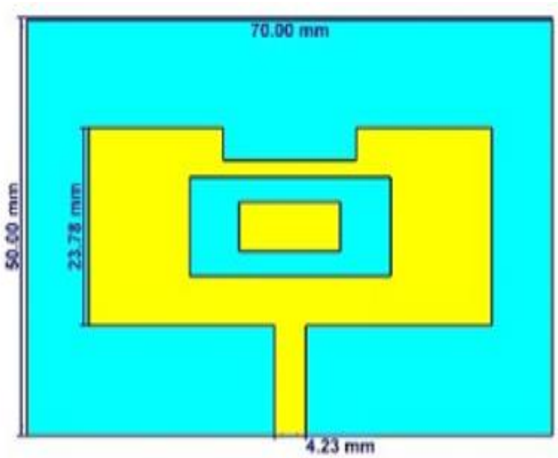
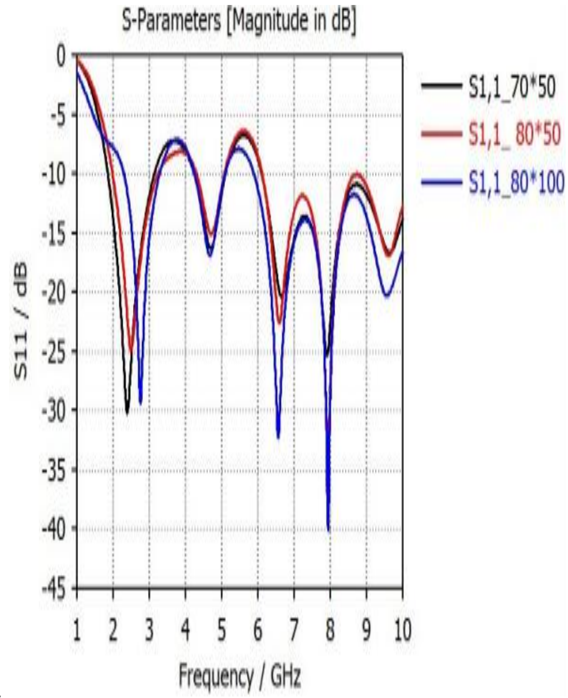


Figure 1: Varying substrate dimensions with hs (height of substrate)1.12mm antenna design a) 80 x 100mm2 b) 50x80 mm2 and c) 50x70mm2



.

Figure 2: Comparison of antenna S-Parameters with hs=1.12mm for 100 x 80 mm2, 80 x 50 mm2, and 70 x 50 mm2.

The Figure 2 describes S11 characteristics of different antenna designs. The antenna with dimensions of 80x 50x 1.12 mm^3 is the best for use in ISM band and multiband applications.

2.2.2 Optimizing the slot positions

The slot adjustments can alter the resonance frequency. The Figure 6-3 describes various antenna designs as stages in development of proposed multiband antenna. The patch dimensions of the Antenna 1 are 24.008 x 53.675 mm^2 and the length of the feedline is 4.226 mm. The ground plane is carved with a 54.68 x 25.01 mm^2 slot. A rectangular slot measuring 12 x 26.84 mm^2 is cut from the center of the patch[7.8]. Then slot of 26.04 x 4 mm^2 is cut from the top of the patch of microstrip antenna. The different antennas are designed with varying substrate heights and different dimensions of slots carved in the patch.

The Antenna 2 and Antenna 3 are designed by varying the slot dimensions and positions. In Antenna 2, slot cut from the ground is of dimensions is 8.11 x 4mm ^{2}

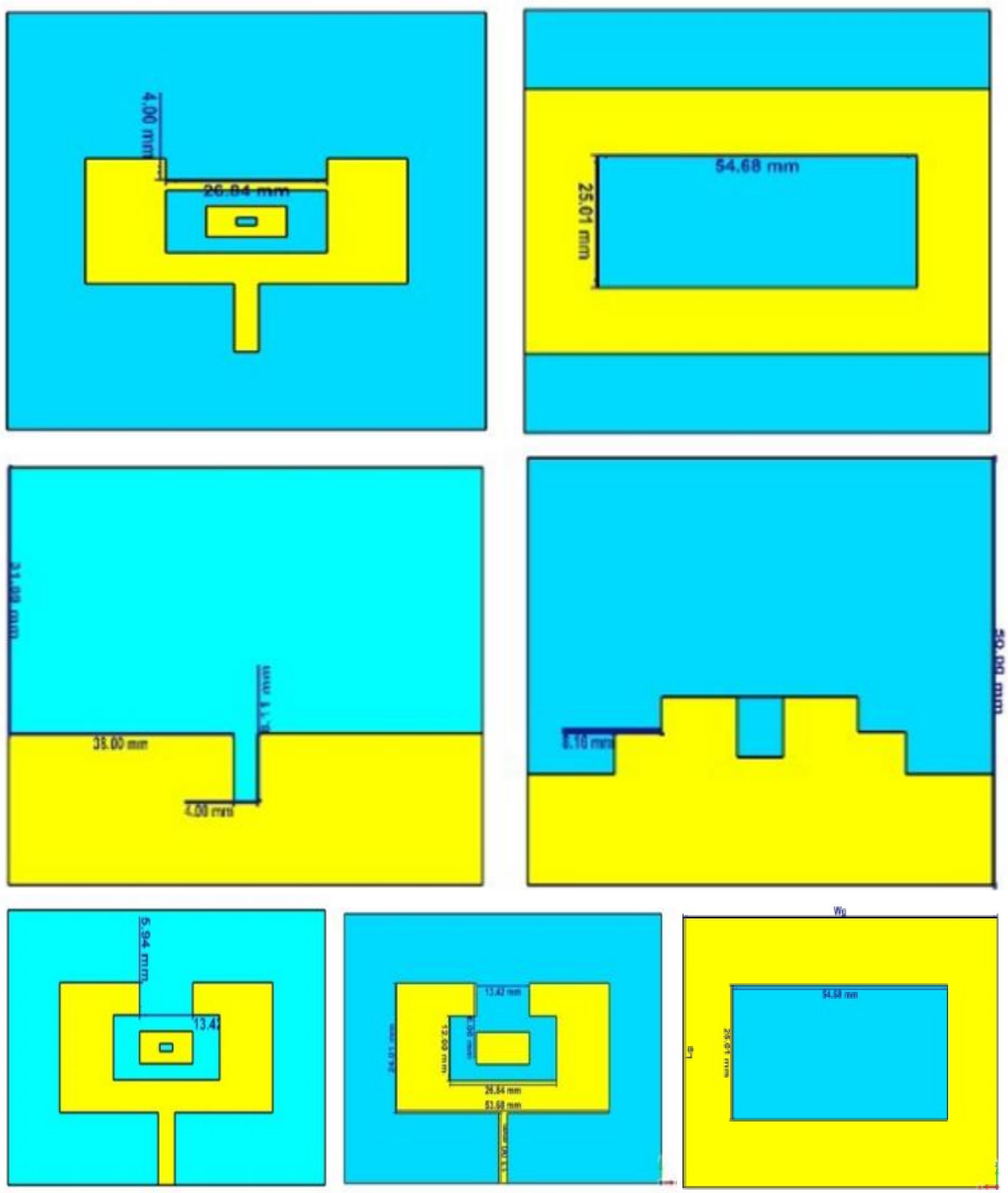


Figure 3: Geometries for wearable textile antenna design(a,b,c,d,e,f,g,h)

In Antenna 3 the dimensions of slot is 6 x 13.42 mm^2 which carved from top of the patch and staircase shaped slot carved from ground. As seen in Figure 4, three designed antennas are not resonating in the ISM band. The substrate dimensions of proposed wearable antenna design geometry are 50 x 80 x 0.56 mm^3, slot etched from top dimensions is 6 x 13.42 mm^2. The gain values are shown in Figure 5.

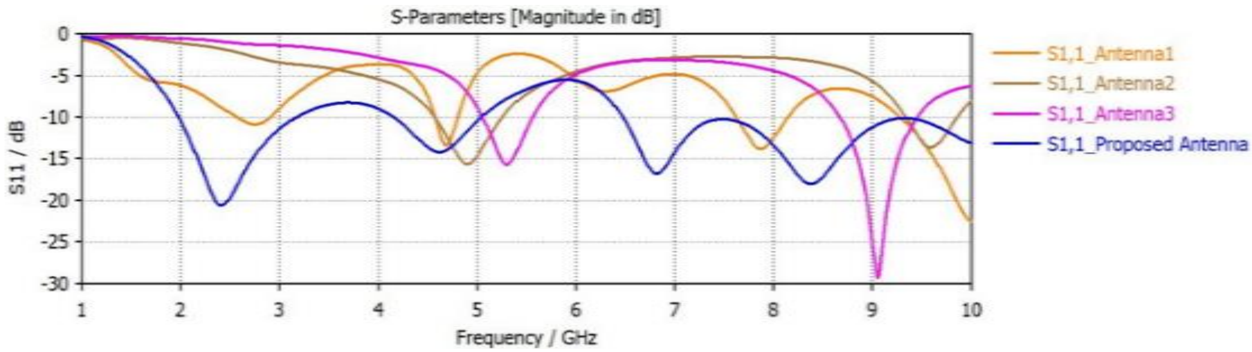
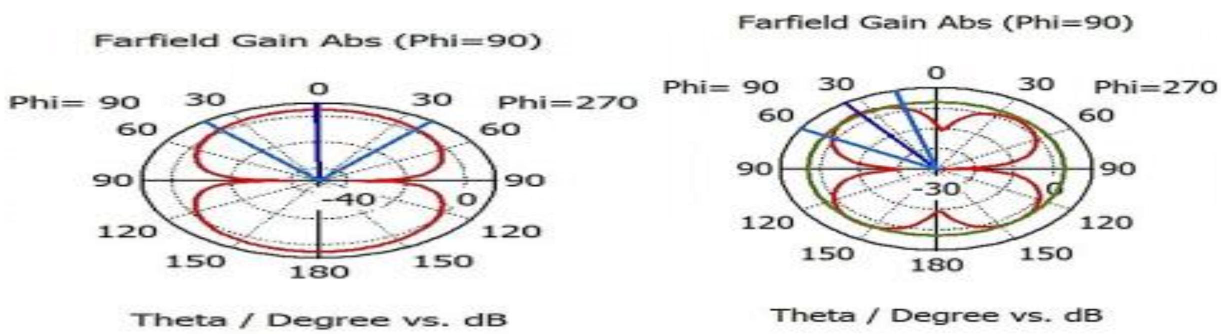


Figure 4: S-parameters with minor modifications for various antenna configurations



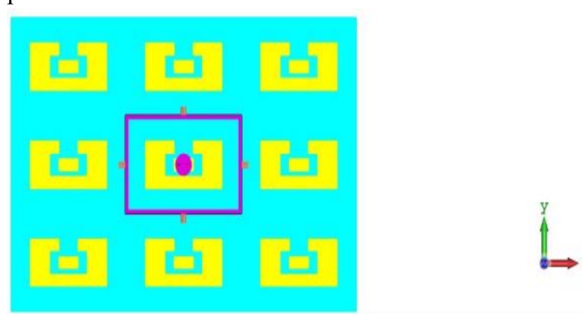
a) b)

Figure 5: Gain values provided at a) 2.45 GHz b) 5GHz frequencies

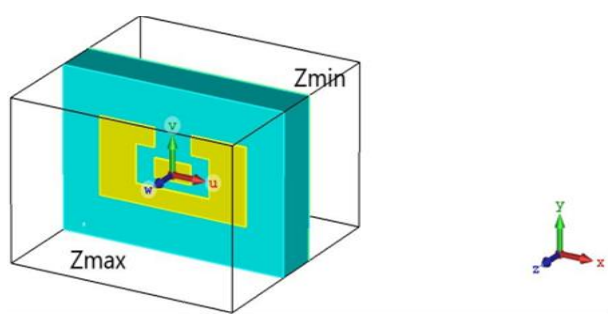
2.2.3 Unit Cell Structure

In antenna designs, meta material structures are designed after the design optimization and are incorporated at the backside of antenna design to make it immune to human body effects. The unit cell mm structure is useful in reducing electromagnetic radiation absorption by human being and so improving the SAR results. The meta material is a collection of structures that results negative refractive index and permittivity. They help to achieve great levels of miniaturization. The unit cell structure is designed by meta material geometry component[9,10].

The unit simulations are run with the CST Microwave Studio software's frequency-domain solver and boundary conditions. Open boundary conditions were implemented in the z-direction. The Meta surface geometry depicted in Figure 6(a) is made up of 3x3 lattices to express the boundary conditions. The unit cell's geometrical dimensions are 8x5x1.6mm3, as seen in Figure 6(b). The reference distance is divided by two. The S-parameters aid in the analysis of the material's behavior[11,12]. Figure 7(a) depicts the Meta material's S11 and S21 parameters, whereas Figure 7(b) depicts the cross-polarization and co-polarization.



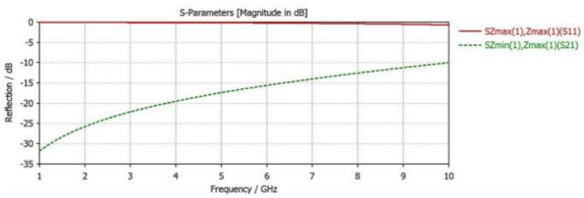
a)



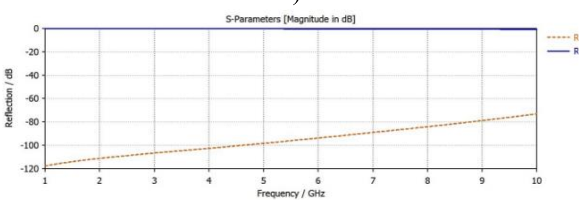
b)

Figure 6: Boundary conditions are expressed by the construction of a 3x3 square lattice b) floquet ports Zmax and Zmin

After reflection of the material surface, the incident x-polarized wave becomes a y-polarized wave and vice versa. When x-polarized incident wave meets y-polarized reflected wave, the reflection coefficient is Ryx. When a y-polarized incident wave meets an x-polarized reflected wave, the reflection coefficient is Rxy [23].The Figure 7 describes the material characteristics of the meta surface with a 1.6mm substrate thickness. Figure 6-7(a) depicts the refractive index vs frequency. Figure 76 (b) shows the permittivity and permeability values of meta material. At 2.45 GHz, there are negative values of refractive index and permittivity.

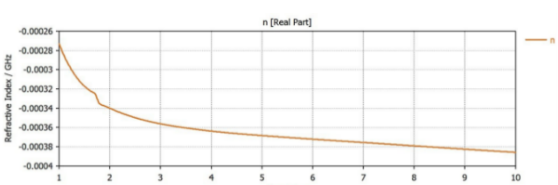


a)

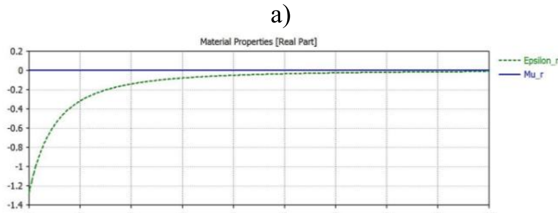


b)

Figure 7: The unit cell S-parameters: a) S11 and S21 reflection coefficients b) co-polarization (solid line) and cross-polarization (dotted line) reflection coefficients.



a)



b)

Figure 8: The unit cell's material properties are as follows: a) refractive index, b) permeability represented by dotted line and permittivity by dashed line

2.3 Results and Discussions

The proposed antenna provides resonance for WiFi (2.45 GHz), ISM band (2.4 to 2.48 GHz), 4.4GHz (INSAT & Radio altimeters), and C-band (6.57 to 6.8 GHz), as shown in Figure 9.

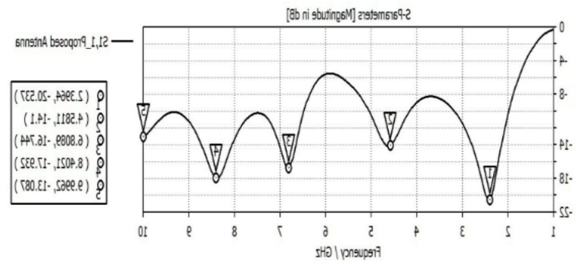


Figure 9: S11 results of Horn shaped Antenna

Figure 10 a) Front side

a) b)

Figure 10: b) back side of fabricated antenna prototype

Figure 10 depicts a fabricated horn-shaped textile antenna prototype. The S11 characteristics vs frequency graph of simulated and measured reflection coefficient values is shown in Figure 6-10. Simulations using CST Microwave Studio were used to determine the off-body simulated values. At 2.32 GHz, 2.4 GHz, 3.042 GHz, 3.9 GHz, and 6.56 GHz, the proposed wearable antenna has reflection coefficient values of -25.85 dB, -22.30 dB, -26.33 dB, -25.40 dB, and -24.19 dB, respectively. The reflection coefficient values for on-body antenna tests are -23.38 dB, -24.28 dB, -18.15 dB, -16.96 dB, and -26.68 dB, respectively, at 2.32 GHz, 2.4 GHz, 3.042 GHz, 3.9 GHz, and 6.56 GHz. For the ISM band, the antenna tested results produce almost identical, if not superior, return loss values (2.4 to 2.48GHz) as shown in Figure 11. However, simulated results reveal that off-body provide resonance at lower frequency values [13]. The antenna is also tested by being placed on the body to determine how it performs in on-body conditions. The measured values fluctuate as a result of some practical losses caused by the unsteady environment. It is quite pleasant to embed the antenna in the garment because of its compact and flexible geometry.

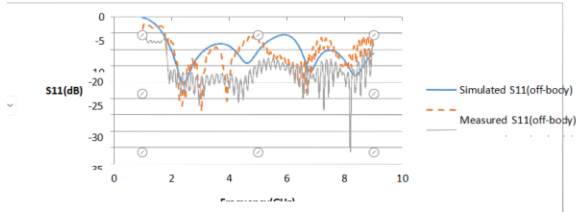


Figure 11: Comparative S11 graph of measured and simulated results

The antennas discussed in the comparison are the textile-based antennas but they are not applicable for the desired ISM band. Moreover, these antennas are not multiband antennas except the antenna designed in [156]. The proposed antenna resonates in the ISM band and act as multiband antenna.

Table 1: Proposed Horn shaped Antenna Design comparison with literature

References	Size (mm)	Material Used	Frequency	Area of Applications	Gain(dB)
[3]	40 x 40x 1	Deni m	3.01–5.30 GHz, 8.12–12.35 GHz	WiMax , WLAN	5.685 at 13.2 GHz
[8]	162.25x 109.5x 3	Felt	2 GHz	WBAN	3.061 at 2 GHz
[14,15]	40x40x 1.5	Felt	5.5 GHz, 8 GHz	WBAN	4.76 at 5.5GHz 8 at 1.61GHz
[16]	70x70x3	Felt	1.76–1.83 GHz, Band 3, 2.36–2.76 GHz	4G LTE, WLAN, ISM	3.2 at 2.45 GHz
Proposed Design	50x80x0.56	Deni m	2.45 GHz, 3.04 GHz, 3.9 GHz and 6.56 GHz	ISM, WiFi, WiMAX and C-Band	4.74 dB at 2.45 GHz, 3.71dB at 5GHz

III. CONCLUSION

The proposed antenna operates in the ISM band between 2.4 and 2.48 GHz, WiFi at 2.45 GHz, WiMax from 3.3 and 3.9 GHz, and C-band from 6.57 and 6.8 GHz. It works as multiband antenna. The antenna has gain values of 4.74 dB and 3.71 dB at 2.4 GHz and 4.6 GHz. At 2.4 GHz, it achieves 44.3 percent percentage impedance bandwidth, and at 4.6 GHz, it achieves 18.35 percent. At 2.45GHz, the VSWR is 1.21, and for frequencies larger than 3 GHz, the VSWR is less than 2. The antenna on-body performance is assessed by mounting it on a human body and observing it in open space. The proposed textile wearable horn shaped antenna is suited for the intended ISM band and other wireless applications.

REFERENCES

[1] A. K. Skrivervik, M. Bosiljevac, J. Trajkovikj, B. Fuchs, and Z. Sipus, “Design considerations for wearable antennas,” 2016 URSI Int. Symp. Electromagn. Theory, EMTS 2016, pp. 524–527, 2016.

[2] S. Sankaralingam and B. Gupta, “Development of textile antennas for body wearable applications and investigations on their performance under bent conditions,” Prog. Electromagn. Res. B, vol. 22, no. 22, pp. 53–71, 2010.

[3] V. K. Singh, S. Dhupkariya, and N. Bangari, “Wearable Ultra Wide Dual Band Flexible Textile Antenna for WiMax/WLAN Application,” Wirel.

Pers. Commun., vol. 95, no. 2, pp. 1075–1086, 2017.

[4] 9H. Yalduz, T. E. Tabaru, V. T. Kilic, and M. Turkmen, "Design and analysis of low profile and low SAR full-textile UWB wearable antenna with metamaterial for WBAN applications," AEU - Int. J. Electron. Commun., vol. 126, no. September, p. 153465, 2020.

[5] 22-23G. Li, G. Gao, J. Bao, B. Yi, C. Song, and L. A. Bian, "A Watch Strap Antenna for the Applications of Wearable Systems," IEEE Access, vol. 5, pp. 10332–10338, 2017.

[6] K. H. Wang and J. S. Li, "Denim Textile Antenna for Smart Wearable Antenna," 2018 12th Int. Symp. Antennas, Propag. EM Theory, ISAPE 2018 - Proc., pp. 1–3, 2019.

[7] 35-38A. K. Horestani, Z. Shaterian, J. Naqui, F. Martin, and C. Fumeaux, "Reconfigurable and tunable S-shaped split-ring resonators and application in band-notched UWB antennas," IEEE Trans. Antennas Propag., vol. 64, no. 9, pp. 3766–3776, 2016.

[8] 36E. F. N. M. Hussin, P. J. Soh, M. F. Jamlos, H. Lago, A. A. Al-Hadi, and M. H. F. Rahiman, "A wideband textile antenna with a ring-slotted AMC plane," Appl. Phys. A Mater. Sci. Process., vol. 123, no. 1, pp. 1–7, 2017.

[9] D. Mandal and S. S. Pattnaik, "Quad-band wearable slot antenna with low SAR values for 1.8 GHz DCS, 2.4 GHz WLAN and 3.6/5.5GHz WiMAX Applications," Prog. Electromagn. Res. B, vol. 81, pp. 163–182, 2018.

[10] M. E. Jalil, M. K. A. Rahim, N. A. Samsuri, N. A. Murad, N. Othman, and H. A. Majid, "On-body investigation of dual band diamond textile antenna for wearable applications at 2.45 GHz and 5.8 GHz," 2013 7th Eur. Conf. Antennas Propagation, EuCAP 2013, pp. 414–417, 2013.

[11] 46-47 S. Agneessens, "Coupled eighth-mode substrate integrated waveguide antenna: Small and wideband with high-body antenna isolation," IEEE Access, vol. 6, pp. 1595–1602, 2017.

[12] G. Indumathi and J. Bhavithra, "Wearable textile antenna for indoor applications," Proc. Int. Conf. Inven. Commun. Comput. Technol. ICICCT 2017, no. Icicct, pp. 30–34, 2017.

[13] 50M. Sharma, V. Dhasarathan, S. K. Patel, and T. K. Nguyen, "An ultra-compact four-port 4 × 4 superwideband MIMO antenna including mitigation of dual notched bands characteristics designed for wireless network applications," AEU - Int. J. Electron. Commun., vol. 123, p. 153332, 2020.

[14] 155-157 Y. Hu, D. R. Jackson, J. T. Williams, S. A. Long, and V. R. Komanduri, "Characterization of the input impedance of the inset-fed rectangular microstrip antenna," IEEE Trans. Antennas Propag., vol. 56, no. 10, pp. 3314–3318, 2008.

[15] N. F. M. Aun, P. J. Soh, M. F. Jamlos, H. Lago, and A. A. Al-Hadi, "A wideband rectangular-ring textile antenna integrated with corner-notched artificial magnetic conductor (AMC) plane," Appl. Phys. A Mater. Sci. Process., vol. 123, no. 1, 2017.

[16] E. A. Mohammad, H. A. Rahim, P. J. Soh, M. F. Jamlos, M. Abdulmalek, and Y. S. Lee, "Dual-band circularly polarized textile antenna with split-ring slot for off- body 4G LTE and WLAN applications," Appl. Phys. A Mater. Sci. Process., vol. 124, no. 8, pp. 1–10, 2018.