WEARABLE FRACTAL ANTENNA DESIGN USING HILBERT TRANSFORM

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ABSTRACT.

Wearable antennas are the type of textile antennas which has flexibility of bending, decorative and transmits the radio signals with the required efficiency. There are lot of applications of theses wearable antennas like defense, medical or healthcare applications, commercial applications. Wearable fractal monopole antenna operating in Ultra High Frequency (UHF) band has been presented. The antenna geometry is a planar fractal patch antenna. Wearable antenna is designed with fractal geometry having plus shaped Hilbert curve as basic shape. Wearable antenna is simulated on different textile materials like Flannel, Cotton, Jeans, Flame Retardant (FR4) substrate. Antenna is simulated using Ansys High Frequency Structure Simulator (HFSS) tool. Simulated antennas are fabricated, tested and verified at anechoic chamber and vector network analyzer. The antenna parameters such as size of antenna, return loss (S11) parameter and radiation efficiency, radiation parameter for different substrate textile materials has been studied and compared. These type of wearable fractal antenna can be used in various UHF band applications.

***Keywords**: Fractal, Wearable antenna. Hilbert transform. Textile antennas. Return loss (S11 parameter). Anechoic Chamber. Vector Network Analyzer (VNA)*

1. INTRODUCTION

Wearable antennas are becoming more important in applications for Wireless Body Area Network (WBAN) for example in medical, defense fields. In wireless systems, the wearable antenna plays an important role in facilitating a reliable communication link between on-body sensors and the control station. The wearable antenna is used in close proximity of physical body with its different curvature radius and complexities

The performance analysis is based on deformation in structure and the attenuation caused by using this as wearable antenna. Textile antennas which are small in size, unobtrusive, mechanically tough and less weight are feasible with different applications. The radiations from these textile antennas which are electromagnetic must have absorption ratio value within specific health and safety limits. The micro strip antennas are suitable for body-worn devices with their conformability, ease of on body integration, low-cost of fabrication. Proper separation between the antenna and the anatomical tissues of physical body has to be achieved. Several micro strips at 2.45GHz have been studied in literature survey.

A compact economical fractal antenna, using Flannel, Cotton, Jeans material as substrate is simulated in Industrial Scientific Medical (ISM) band for WBAN applications. Fractal geometry with defected ground structure is employed to increase the electrical span of radiating material without increasing its dimensions, making the antenna more precise. Textile fractal antenna with omni-directional radiation and linear polarization pattern is designed and validated for different applications.

2. BACKGROUND THEORY

A printed fractal antennas using metamaterial has high efficiency [1]. Split Ring Resonator (SRR) is used to improve the gain and directivity by 2.5dB than patch the antenna without SRR. The fractal antenna gain is having efficiency of 90% with gain of 8dBi. An Ultra-Wideband wearable fractal slot antenna in frequencies ranging from 0.5GHz to 4GHz [1-3] uses a substrate of dielectric constant 1.54 ,enim material and observed that the accuracy of antenna parameter is increased [4-6].

A modified low-profile monopole Koch antenna backed with Electromagnetic Band Gap (EBG) plane [7-9] is designed. The antenna was tested on phantom and gave an efficiency of 78% and gain of 7.8 dB, with same values. This type of antennas are mechanically robust and highly suitable for body worn applications.

An embroidered textile antenna array [10-12] with orthogonal double band polarized linearly in ISM band for wearable applications outperform traditional unidirectional antennas. Antenna with semi-flexible material like RT duroid 5880[13-14] shows that even in bent position, effects of bandwidth, gain, reflection coefficient and efficiency gives bandwidth of 1380 MHz , with center frequency of 2.4 GHz.

The crossed dipole antenna array of size 2×2 and the 4×4 microstrip antenna with normal aperture [14-16] has simulated bandwidth of 38.1% at S-band and 34.5% at L-band . This type of antenna is best suited for the satellite navigation service. The patch antenna fitted onto the curved surface of the aircraft as conformal antenna is more beneficial for the armed forces vehicles especially aircraft's application. The consistent designs [15-18] may be incorporated into any other curved surface to cut down the drags and extra aerodynamic impacts.

In [18-19], the framework of rectangular patch antenna (RPA) with zero value having slots at 7.96 GHz is designed at safety applications that come under the X-band area. Rectangular shaped meander lines prolonged is designed with FR4 substrate. This parasitic component edge of projected antenna with defected ground structures, works out for tri band frequencies at 8GHz, l0.2 GHz and 14.23GHz supporting defense communications.

The patch antenna and ground conducting planes are constructed using copper tape [20]. This reverberates at wavelengths from 1.8GHz to 23.8 GHz with low permittivity better impedance matching is realized. This type of antenna bending gives improved impedance match.

3. METHODOLOGY

A monopole textile fractal antenna is chosen and designed. A planar conglomerate fractal antenna based upon the plus-shaped fractal geometry and Hilbert curve with defected ground structure has been agglomerated and simulated on HFSS software. By changing the substrates, the antenna dimensions also change due to its dielectric constant value. The substrates which have been chosen are Flannel, Cotton, Jeans, and thin FR4. The dimension, dielectric constant and electrical size of each substrate are mentioned in Table1.

Table 1: Dimensions of monopole Fractal Antenna design with different dielectric substrates

Sl. No	Substrate (thickness)	Dimension (lxwxh) in mm	Dielectric constant	Electric size
1	Flannel (1mm)	11.33 x 13.52 x 1	1.7	0.48λ x 0.32 λ
2	Cotton (1mm)	54.78 x 48.66 x 1	1.67	0.438 λx 0.389 λ
3	Jeans (1mm)	14.39x 16.85 x 1	1.6	0.432 λx 0.381 λ
4	FR4 (1.57mm)	29.61x38.01x 1.57	4.4	0.236 λx 0.304 λ

After the simulation next step is to convert the design into a Gerber file. The next step is the fabrication process. In fabrication, firstly antenna design which is converted into a Gerber file is to be printed on a butter sheet or transparency sheet. Then the materials are laceration according to their sizes. Next, the screen printing is done. For screen printing, one spoon of the coating solution is mixed with 3-4 drops of sensitizer. Next screen preparation will be done and then remove the photosensitive in the darkroom and take the screen mesh, here 110 mesh silkscreen is taken. Then place the photo-sensitive film now take the coating solution mixture and pour it on top of the film spread the whole film by squeezer. Now take the butter sheet and place it on film and expose that to sunlight for 1-minute next screen printing will be done. Take one spoon of pattern emulsion and add token reducer for required quantity and mix it well then spread it over FR4 through the screen. The same steps are repeated for fabrics using conductive ink which is spread over the fabrics. Next, the etching process will be done only for FR4. Then the proposed antenna is ready for testing. The complete procedure is depicted in the flowchart of Figure 1.

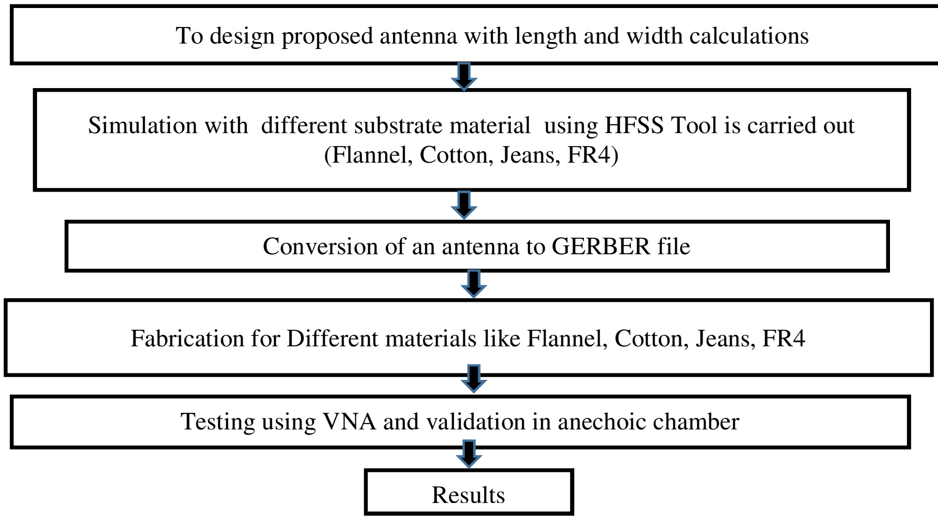


Figure 1: Flow chart of the developing a Monopole Fractal antenna methodology

3.1 Design equations

To design the antenna with width (W)of the patch and length (L) is given by equation (1) and (4) respectively

$$W = \nu_0/2\ f\ \sqrt{}(2/\ \varepsilon_r+1) \tag{1}$$

where 'ε_r' is dielectric constant of the material. If 'H' is height of the substrate, the effective dielectric constant is calculated using equation (2).

$$\varepsilon_{ref} = (\varepsilon_r+1/\ 2) + (\varepsilon_r-1/\ 2)\ [1 + 12\ H/W]^{\ 1/2} \tag{2}$$

Calculate ΔL using equation (3)

$$(\Delta L)/h = 0.412((\varepsilon_{ref} + 0.3)\ (W/H + 0.264))/((\varepsilon_{ref}-0.258)\ (W/H+0.8)) \tag{3}$$

Calculate length of the patch using equation (4) with c_0 is speed of light in free space.

$$L = c_0/\ (2f\sqrt{\varepsilon_{ref}}) - 2\Delta L \tag{4}$$

3.2 Calculation of feed dimensions:

Step-1: The input impedance of the patch is calculated using equation (5)

$$R_{in} = 1 / (2(G1 \pm G2)) \qquad (5)$$

Where the conductance of two slots are given by G1 and G2, If the resonant voltage distribution beneath the patch and between the slot is odd then it is represented by + sign, while for even resonant voltage distribution – sign is used in equation (5).

Step-2: Having L as the length of patch, using equation (6) find y_0, by assigning $R_{in}(y=y_0)$ as 50Ω and $R_{in}(y=0)$ from the above equation. The calculated value of y_0 will be between 0 and L/2.

$$R_{in}\ (y = y_0) = R_{in}\ (y = 0) \cos^2 ((\pi/2)\ y_0) \qquad (6)$$

The width of feed is calculated using equation (7) or (8) for the microstrip line:

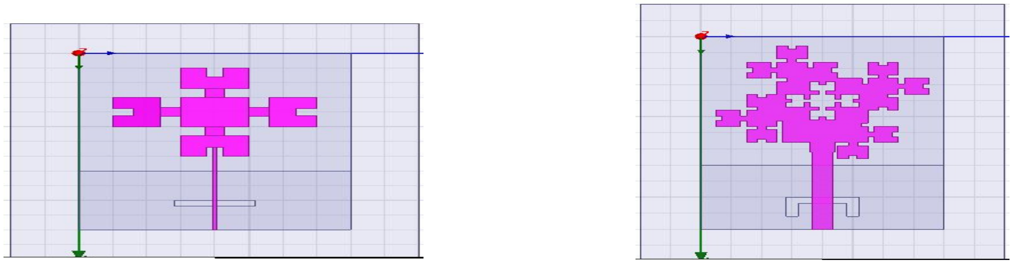
$W/H \leq 1$:

$$\varepsilon_{reff} = (\varepsilon_r+1)/2 + (\varepsilon_r-1)/2 \ \{ \ [1 + 12\ (H/W)]^{-1/2} + 0.04(1 - W/H)\} \qquad (7)$$

$W/H \geq 1$:

$$\varepsilon_{reff} = (\varepsilon_r+1)/2 + (\varepsilon_r-1)/2 \ \ [1 + 12\ (H/W)]^{-1/2} \qquad (8)$$

Using the above calculated dimensions of the antenna design, Hilbert equation with 2nd and 3rd iteration are simulated as shown in the Figure (2).



(a) (b)

Figure 2: (a) Simulated antenna with 2^{nd} iteration with Hilbert curve geometry (b) Simulated antenna with 3^{rd} iteration

Figure 2, is the simulated Hilbert geometry Fractal antenna using HFSS tool, showing second and third stages of iterations. Figure 3, represents the fabricated version of Hilbert Fractal antenna on different wearable materials like Jeans Figure (3a), Cotton Figure(3b) using conducting ink and thin FR4 with copper as conducting material Figure (3c and 3d)

(a) (b) (c) (d)

Figure 3: Images of Fabricated antennas (a)Jeans wearable antenna (b) Cotton fabric wearable antenna (b) and (d) FR4 wearable antenna

4. RESULTS AND DISCUSSION

These four types of textile-based antennas are fabricated as shown in Figure 3. Each of these antennae was tested and validated at Center of Excellence facility –Center for Antenna Testing and RF circuitry –CARFS at RIT, Bangalore. The following results obtained are plotted in the graphs Figure 4 to Figure 8. Figure 4 shows the simulation results of S11 parameter for fabricated fractal antenna on cotton and FR4 material. Figure 5 show the simulation results of fractal antenna on Flannel material and Jeans material.

Fabricated Wearable antennas were tested using VNA and Anechoic chamber to get the measured results. Figure6 show the S11 parameter response of Flannel material. Figure7 shows the measured results of cotton material, Figure 8 showing the measured results of Jeans and Figure 9 showing the measured results of FR4 material.

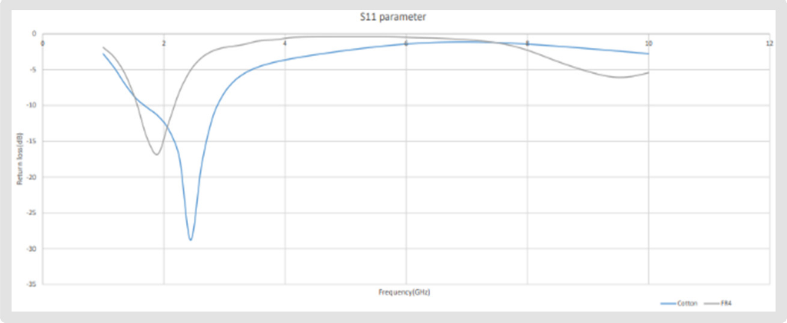


Figure 4: S11 Simulation result of Cotton and FR4

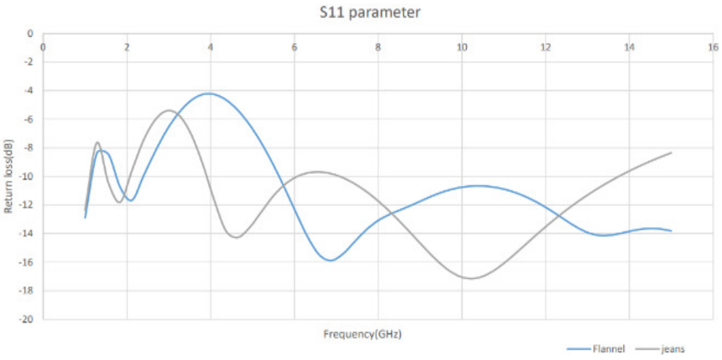


Figure 5: S11 Simulation result of Flannel and Jeans

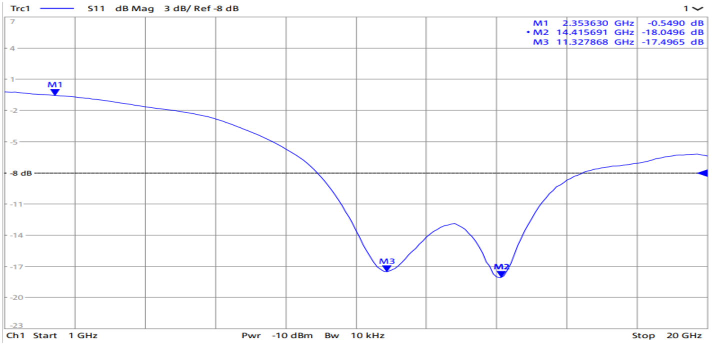


Figure 6: S11 measured result of Flannel

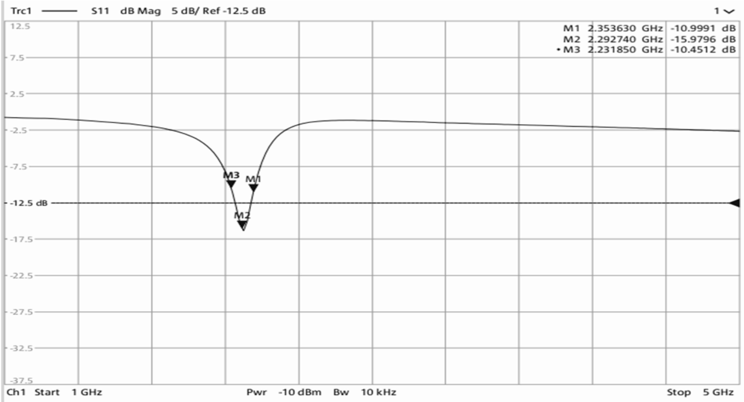


Figure 7: S11 measured result of Cotton

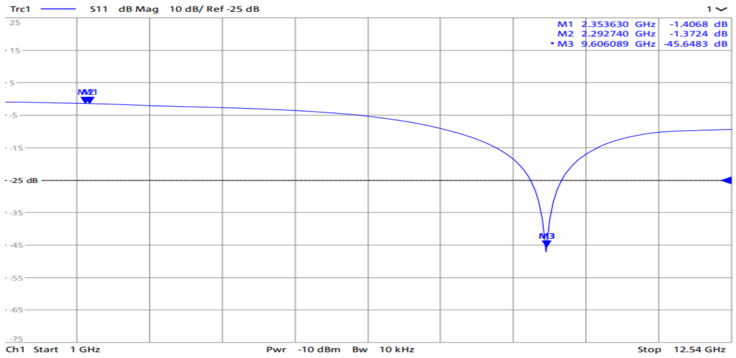


Figure 8: S11 measured result of Jeans

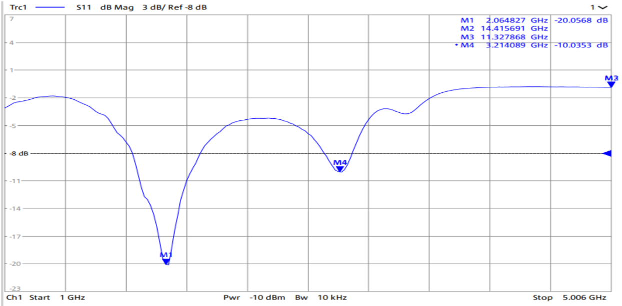


Figure 9: S11 measured result of FR4

From the graphical representation we observe that these wearable antennas which were designed for ISM band had the variations with the theoretical calculation, simulated values and measured values of resonant frequencies as shown in the Table 2 and Table 3.

Table 2: Comparison of resonant frequency of different Textile fractal antennas.

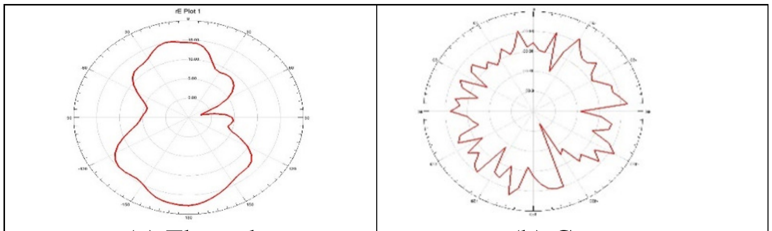
Type of wearable fractal antenna	Theoretical value using the design equations	Simulated result using HFSS	Measured results in anechoic chamber
Flannel	9.5 GHz	8.88 GHz	10.32 GHz
Jeans	7.8 GHz	7.98 GHz	8.60 GHz
Cotton	2.4 GHz	2.4 GHz	2.29 GHz
FR4	2.4 GHz	1.9 GHz	2.0 GHz

The refection co-efficient (S11) of simulated antenna using HFSS and fabricated antennas are compared and is shown in the Table 3, below. The values are good enough to have an application as Textile fractal antennas for WIFI-based applications (2.4Ghz), Military and Navigation applications (X band).

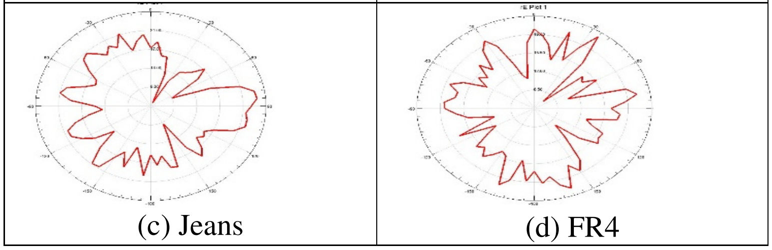
Table 3: Comparison of S11 parameter of different Textile Fractal antennas

Substrate	Simulated results of S11 parameter	Fabricated results of S11 parameter
Flannel	-15.887 dB	-17.4965 dB
Cotton	-28.132 dB	-15.9796 dB
Jeans	-14.27 dB	-45.6483 dB
FR4	-16.81dB	-20.0568 dB

The E-plane and H-Plane radiations for these four type of wearable Fractal antennae are measured using vector network analyzer. The radiations are as shown in the Figures 10 and Figure 11. Flannel Textile fractal antenna shows Bi-directional radiation, Cotton and Jeans Textile Fractal antenna has omnidirectional radiation with few directional nulls. FR4 Fractal antenna also shows omnidirectional pattern with good gain factor. Wearable fractal antenna can be placed on a Phantom material having a good absorption at these resonant frequencies in opposite direction, towards the body. Hence these designed antennas can be used for various commercial and defense applications.

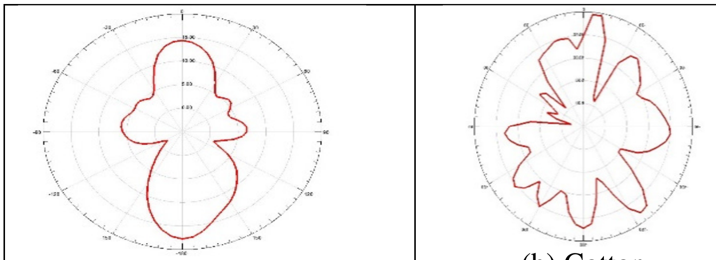


(a) Flannel (b) Cotton

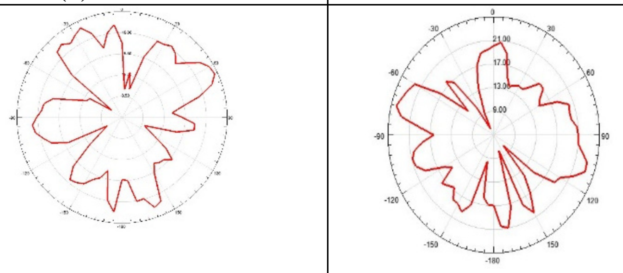


(c) Jeans (d) FR4

Figure 10: 2D E-Plane radiation of Textile Fractal antennas



(a) Flannel (b) Cotton



(c) Jeans (d) FR4

Figure 11: 2D H-Plane radiation of Textile Fractal antennas

The proposed wearable fractal antenna is theoretically designed for 9.5Ghz, 7.8Ghz, 2.4Ghz and 2.4Ghz and it resonates at frequency 10.32GHz, 8.6GHz,2.29GHz, and 2.0GHz for Flannel, Jeans, Cotton and Fr4 respectively after fabrication. The return loss of simulated antennas is -15.887 dB, -28.132 dB, -14.27 dB and -16.81dB for Flannel, cotton, Jeans and FR4 respectively. The fabricated antennas have reflection co efficient of -17.49 dB for flannel, -15.9dB for cotton , -45.64dB for jeans and -20dB for FR4 as shown in Table 3. The results have closer values of simulated results and measured results after fabrication. Figure 10 shows the 2D radiation pattern in E plane with Flannel material having bidirectional radiation pattern with wide half power beam width, while cotton, jeans and FR4 has almost omni directional radiation pattern with considerable nulls in between. Figure 11 shows the 2D radiation pattern in H plane with Flannel material having bidirectional radiation pattern with narrow half power beam width, while cotton , jeans and FR4 has directional radiation patterns with considerable nulls.

5. CONCLUSION

Applications of fractal geometry in designing of Wearable antennas are increasing in the fields of Science and Antenna engineering. This paper gives an overview of design and fabrication of wearable fractal antenna which contributes to the research area in Wearable or Textile Antenna engineering. Wearable Fractal antennas with different textile materials like Flannel, cotton, jeans and thin FR4 material using Hilbert transform geometry is designed, simulated and fabricated. The antennas are verified in anechoic chamber under ideal conditions and using precision Vector Network analyzer (100Khz -40Ghz). Validation of the results are carried at Center of excellence for Antennas and Radio Frequency systems at Ramaiah Institute of Technology, Bangalore.

Wearable textile s flannel, cotton , jeans and thin FR4 can be used at WIFI frequency application of 2.4 Ghz and 5G applications in Sub 6Ghz band. Return loss is much greater than -10dBi inferring it is suitable for many applications of data communication. Radiation patterns reveal that these antenna radiate with certain directional properties, having considerable propagation in restricted directions. Hence a secured transmission and reception of information can be communicated by these wearable antennas.

The antenna size is optimized with different materials, commonly available in market. The compact size is more suitable as wearable antenna applications. Here we notice that there is a difference in the resonating frequencies of simulated and fabricated antennas. This is mainly due to limited constraints like using connectors with adhesives, available material thickness, conducting ink used to fabricate the antennas, to measure various parameters. This could be improvised with more accuracy by fabricating wearable antenna with conducting threads stitched on to the textiles and using better soldering techniques and use more precise accurate connectors.

References

1. A. Sabban, Small New Wearable Antennas for IoT, Medical and Sports Applications, 2019 13th European Conference on Antennas and Propagation (EuCAP), 2019, pp. 1-5.

2. K. Wang and J. Li, Jeans Textile Antenna for Smart Wearable Antenna, 2018 12th International Symposium on Antennas, Propagation and EM Theory (ISAPE), 2018, pp.1-3.

3. A. Arif, M. R. Akram, K. Riaz, M. Zubair, and M. Q. Mehmood, Koch Fractal Based Wearable Antenna Backed with EBG Plane 2020 17th International Bhurban Conference on Applied Sciences and Technology (IBCAST), 2020, pp. 642-646.

4. C. Mao, D. Vital, D. H. Werner, Y. Wu and S. Bhardwaj, Dual-Polarized Embroidered Textile Armband Antenna Array With Omnidirectional Radiation for On-/Off-Body Wearable 8 Applications in IEEE Transactions on Antennas and Propagation, vol. 68, no. 4, pp. 2575-2584, April 2020.

5. 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,

6. Y. Y. Zheng, C. C. Liu, and Y. R. Ding, A Shared-Aperture Broadband Circularly Polarized Antenna for Satellite Communications and Navigation, 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, 2019, pp. 1755-1756.

7. B. Chauhan, M. Bhatia, A. Chakraborty, P. S. Sharma, and A. Sharma, Cylindrical Conformal Antenna Arrays Theory for Military Aircraft Antenna, 2020 IEEE International Conference on Computing, Power and Communication Technologies (GUCON), 2020, pp. 77-82.

8. A. F. Miligy, M. E. Morsy, and A. M. Soliman, Investigation of a Compact ITC-2021 ADC Shape Slotted Patch Antenna with Return Loss Improvement For X-Band Military Applications, 2021, International Telecommunications Conference (ITC-Egypt), 2021, pp. 1-5.

9. U. Lakshmi Madhavi and T. J. Swamy, A Novel Triple-band Meander Monopole Antenna Design for Military Applications, 2021 International Conference on Computer Communication and Informatics (ICCCI), 2021, pp. 1-5.

10. M. S. Mahmud and S. Dey, Design and performance analysis of a compact and conformal super wideband textile antenna for wearable body area applications,2012 6th European Conference on Antennas and Propagation (EUCAP), 2012, pp. 1-5.

11. 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, in IEEE Transactions on Antennas and Propagation, vol. 67, no. 10, pp. 6378-6388, Oct. 2019

12. K. Sumathi, K. S. Bharathi, D. V. Sreeram and S. Swetha, Textile MIMO Antenna for Ultra-Wide Band Applications 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS), 2021, pp. 743-747.

13. R. Raihan, M. S. A. Bhuiyan, R. R. Hasan, T. Chowdhury, and R. Farhin, A wearable microstrip patch antenna for detecting brain cancer, 2017 IEEE 2nd International Conference on Signal and Image Processing (ICSIP), 2017, pp. 432-436, DOI: 10.1109/SIPROCESS.2017.8124578.

14. H. -K. Nie et al., Wearable Antenna Sensor Based on EBG Structure for Cervical Curvature Monitoring, in IEEE Sensors Journal.

15. J. Zhong, A. Kiourti, T. Sebastian, Y. Bayram, and J. L. Volakis, Conformal Load-Bearing Spiral Antenna on Conductive Textile Threads, in IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 230-233, 2017, DOI: 10.1109/LAWP.2016.2570807.

16. D. Bonefačić, J. Bartolić, B. Ivšić, and M. Katalenić, , Wideband Textile Planar Monopole Antenna, 2019 European Microwave Conference in Central Europe (ECE), 2019, pp. 175-178.

17. H. Li, J. Du and X. -X. Yang, Compact Triple-Band Wearable Circular Patch Antenna for WLAN/WiMAX Applications; 2021 International Symposium on Antennas and Propagation (ISAP), 2021, pp. 1-2, doi: 10.23919/ISAP47258.2021.9614587.

18. Chaht, M. Zhadobov, L. Le Coq and R. Sauleau, Wearable Endfire Textile Antenna for On-Body Communications at 60 GHz, in IEEE Antennas and Wireless Propagation Letters, vol. 11, pp. 799- 802, 2012.

19. A. Sabban, New fractal compact printed antennas, 2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2017, pp. 2197-2198.

20. J. Qiang, F. Xu, and W. Fan, Reducing Mutual Coupling of Millimeter Wave Array Antennas by Fractal Defected Ground Structure, 2018 12th International Symposium on Antennas, Propagation and EM Theory (ISAPE), 2018, pp. 1-3.