DESIGN A WEARABLE TEXTILE ANTENNA TO TRANSMIT REAL-TIME DATA OF AN ATHLETE

C. S. B. M. R. N. L. K. Amunugama
Dept. of Electrical and Information Engineering
Faculty of Engineering, University of Ruhuna
Galle, Sri Lanka
nuwanthika.laky@gmail.com

E. H. Jayatunga
Dept. of Electrical and Information Engineering
Faculty of Engineering, University of Ruhuna
Galle, Sri Lanka
eranda@eie.ruh.ac.lk

L. Helapita,
Dept. of Electrical and Information Engineering
Faculty of Engineering, University of Ruhuna
Galle, Sri Lanka
lalindahelapita@gmail.com

T. H. Nagahawaththa
Dept. of Electrical and Information Engineering
Faculty of Engineering, University of Ruhuna
Galle, Sri Lanka
thnagahawaththa@gmail.com

***Abstract*—In field of wearable technology one challenging improvement is wearable textile antenna. In this project, the wearable textile patch antenna was designed for audience of athletes considering the less radiation towards the body. Pure Polyester was chosen to use as the substrate of the antenna in order to make the antenna more flexible. Antenna simulations done by using the CST simulation software and performances were compared with conventional rigid antenna and textile antenna. In order to decide the best feeding way, three different feeding techniques was studied and one method called inset feeding was selected due to well performance in on-body condition. As the project purpose, in order to monitor the real-time ECG data of an athlete, a user friendly system was designed through a local radio link with the use of the designed antenna. nRF24L01 transceiver module was used to power up the antenna and Arduino Pro-mini board was used as the micro-controller. Lithium Polymer battery was used to energize the wearable device and a desktop application was created to monitor the ECG signal. Finally, the system was authenticated for application by means of radiation pattern distribution**

Keywords-microstrip-patch-antenna;wearable-textile-antenna; feeding-techniques; real-time-communication-system; monitor-the-ECG-signal

I. INTRODUCTION

Communication technology is increasingly pervading everyday life. There is a much interest in body-worn communication systems whether for on-body communication or off body communication to fixed and mobile networks. Such systems are of interest for detecting motion on the body during exercise, monitoring functions such as heart rate and blood pressure. Utilization of textile materials for the development of flexible wearable systems has been rapid due to the recent miniaturization of wireless devices. Therefore, for communication field, it is better to find antenna with wearable textiles. Meanwhile, real-time data monitoring is better to understand the health condition of an athlete. The present work consists of two parts: the development of a suitable body worn antenna, and simultaneous monitoring of player condition by using selected antenna. When the antenna is considered, many types of research done by using microstrip patch antennas for wearable applications, because of the planner structure, simplicity of the implementation, less disturbance to the person who wears the antenna, specially low radiation out to the ground plane side (towards the body), etc. other than the inverted-F type and planer monopole antennas.

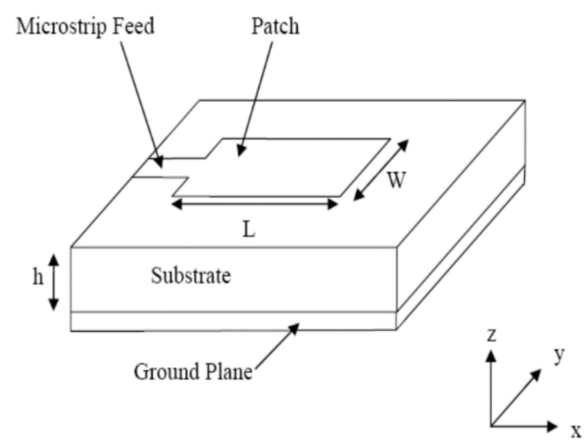

Fig. 1. Rectangular patch antenna

The conventional microstrip patch antenna is as Fig. 1. Textile dielectric materials are used as the substrate of the microstrip patch antenna. There are researches, which done for comparing the performance by changing the substrate dielectric material. As the first part, material selection and best feeding method were studied. For the second part, creation of radio link and system authentication was done.

1) *Modeling the antenna*

For modeling purpose following equations are used.

$$L = [\, C / (2 \times Fr \times \mathrm{sqrt}(\varepsilon_{r,eff}))\,] - 2 \times \Delta L \quad (1)$$

$$W = [C / 2 \times Fr\,] \times \mathrm{sqrt}(\, 2 / (\, \varepsilon_r + 1)\,) \quad (2)$$

$$\varepsilon_{r,eff} = [(\varepsilon_r+1)/2]+[(\varepsilon_r-1)/2] \times [\mathrm{sqrt}(1/(1+(12\times h)/W)] \quad (3)$$

Capacitance C

Area of copper plates(electrodes) A

Plate spacing d

$$\Delta L=0.412\times h\times[(\varepsilon_{r,eff}+0.3)/(\varepsilon_{r,eff}-0.258)] \times [((W/h)+0.264)/\ (W/h)+0.8] \quad (4)$$

$$L_e = L + 2 \times \Delta L \quad (5)$$

$$L_g = 6 \times h + L \quad (6)$$

$$W_g = 6 \times h + W \quad (7)$$

Here,

Length of the patch	L
Speed of the light	C
Resonant frequency	Fr
Width of the patch	W
Dielectric constant	ε_r
Effective dielectric constant	$\varepsilon_{r,eff}$
Height of the dielectric substrate	H
Extension length	ΔL
Effective patch length	Le
Length of the ground plane	Lg
Width of the ground plane	Wg

Therefore, the values are in Table. 1.

1) *Calculating the dielectric constant of tetile material*

As required by the above equations, the dielectric constant, ϵ_r of fabric has to be calculated before modeling the patch antenna. As shown in the Fig. 2, a measuring arrangement was used to calculate the capacitance value of the specimen (Fig. 3) by LCR data-bridge.

After taking an average value for the capacitance, the dielectric constant of the textile material can be calculated using (8) and (9).

$$C = \varepsilon \times A / d \quad (8)$$

$$\varepsilon_r = \varepsilon / \varepsilon_0 \quad (9)$$

1) PARAMETER FOR ANTENNA DESIGN

Patch length, L	52.26 mm
Patch width, W	56.41 mm
Height of substrate, h	0.35 mm
Dielectric constant of substrate, ε_r	1.356
Resonant frequency, Fr	2.45 GHz
Length of ground plane, Lg	54.36 mm
Width of the ground plane, Wg	58.51 mm
Thickness of copper patch	0.1 mm

Fig. 2. Capacitance measuring arrangement

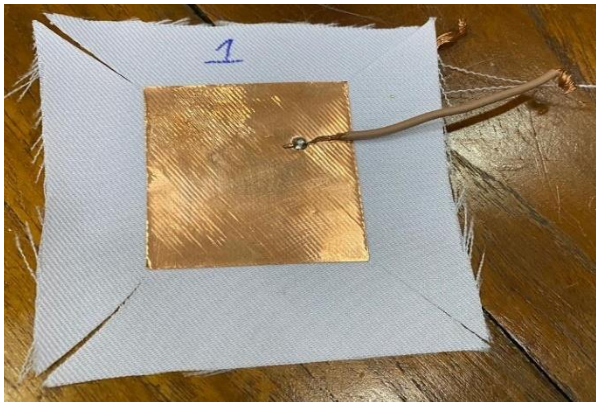

Fig. 3. Capacitor specimen with Polyester dielectric material

The area of the copper electrodes and the thickness of the dielectric fabric piece are known. Using the average capacitance value, ϵ_r was calculated (Table II).

II. TEXTILE MATERIAL SELECTION

Polyester(100%) material is taken as the substrate material of microstrip patch antenna because of low dielectric constant and no stretch. Low dielectric constant reduces the surface wave losses which tries to guide wave propagation within the substrate.

DIELECTRIC CONSTANTS OF DIFFERENT TEXTILES

Textile Material	**Dielectric Constant**
Single Jersey	3.14
Cotton Lycra Thick	2.29
Polycot	1.919
Polyester	1.356

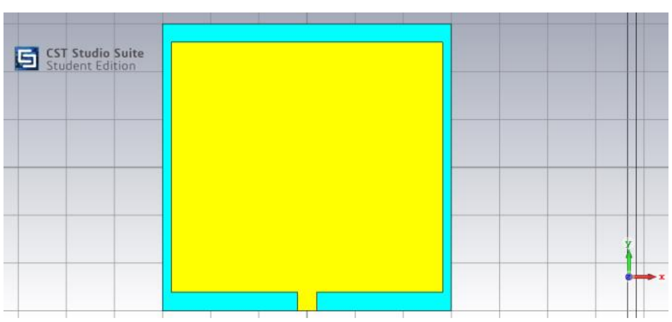

Fig. 4. Line fed antenna front view

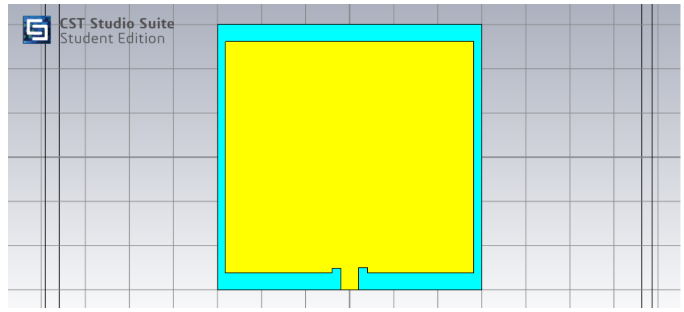

Fig. 5. Inset feed antenna front view

Permittivity	ε
Dielectric constant of the substrate	ε_r
Permittivity of free space	ε_0

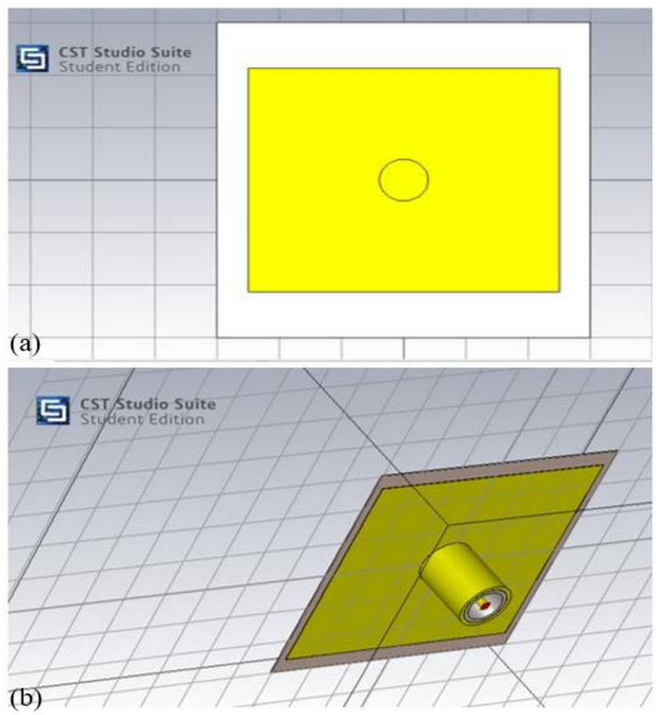

Fig. 6. Coaxial feed antenna (a) Front view, (b) Perspective view

III. FEEDING TECHNIQUE SELECTION

In order to transmit the maximum power, feeder impedance and input impedance of the antenna should be matched. For that, antenna feeding techniques play major role. In this project, three feeding techniques (line, inset and coaxial) were studied under contacting feeding section

.

1) Microstrip line feeding

In line feeding method, feeding line is connect to the patch edge as in Fig. 4 [4]. Feeding line should be much smaller than the width of the patch, W [6]. Impedance matching can be done by shifting the feeding line along the patch edge.

2) Inset feeding

Inset feeding method is an improved version of line feeding technique. Here, feeding line is connected to the patch with two inset cuts as in Fig. 5. The depth of the inset cut towards the center of the patch can change the input impedance[8]. By using Inset cuts, we can control the feeding position to match the transmission line impedance and the input impedance. Both line feeding and inset feeding are easy in fabrication.

3) Coaxial feeding

Coaxial feeding (or probe feeding) is the most commonly used patch antenna feeding method. The inner conductor of the coaxial cable is extended through the dielectric material and soldered to the patch plane. The ground plane is connected to the ground terminal of the coaxial cable[5]. The position (Fig.6) of feeding is taken from following equations [7]. This position is used to match input impedance(Fig. 7).

$$Xo = L / \mathrm{sqrt}(\varepsilon_{r,eff}) \quad (10)$$

$$Yo = W / 2 \quad (11)$$

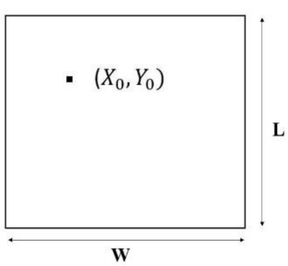

Fig. 7. Coaxial cable feeding position

Accordingly, Table III gives parameter changes of different feeding techniques.

A. Practical implementation of simulated antennas

For the purpose of conducting the laboratory experiments, the antennas were fabricated with above features as in Fig. 8 and Fig. 9. Polyester textile material is used as the dielectric substrate material, Adhesive copper tape is used for the conductive patch plane and ground plane. Both textile material and the copper tape was cut manually from a pair of scissors.

PARAMETERS FOR DIFFERENT ANTENNA FEEDING TECHNIQUE

Feeding Technique	**Description**	**Value** in mm
Line	Width of the feeding line	3
	Length of the feeding line	10
Inset	Width of the feeding line	3
	Length of the feeding line	10
	Insert Length of the feed from patch edge	8.5
	Gap between inset feed line and patch	1.74
Coaxial	Displacement of Feed Along Length Axis, X0	44.98
	Displacement of Feed Along Width Axis, Y0	28.20
	Inner Radius of Coaxial Prob	1.024
	Outer radius of Coaxial Prob	6.86

Coaxial cable core was soldered to the patch and the outer ground terminal of the coaxial cable was soldered to the ground plane of the patch antenna.

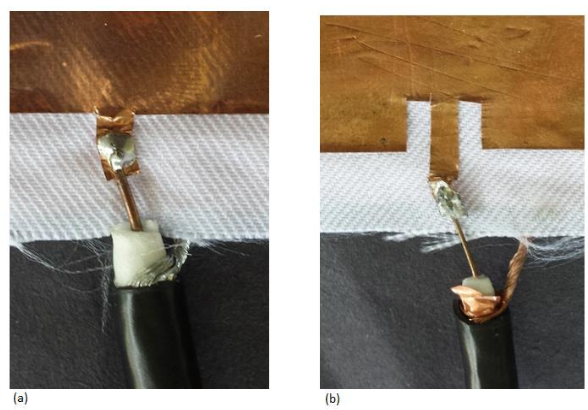

Fig. 8. Fabricated antennas for (a) Line feeding and (b) Inset feeding

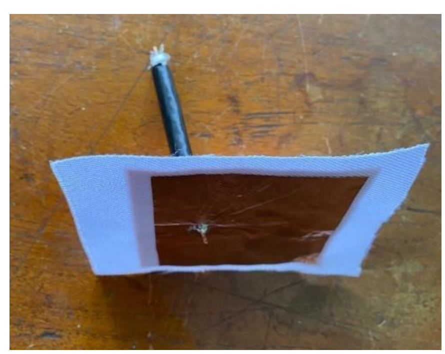

Fig. 9. Fabricated antenna for coaxial feeding

B. Simulation results

1) Microstrip line feeding

For line feeding antenna -19.934 dB return loss is achieved at 2.42 GHz (Fig. 10). Angular width is 73.2 degrees and the main lobe magnitude is 7.91 dBi.

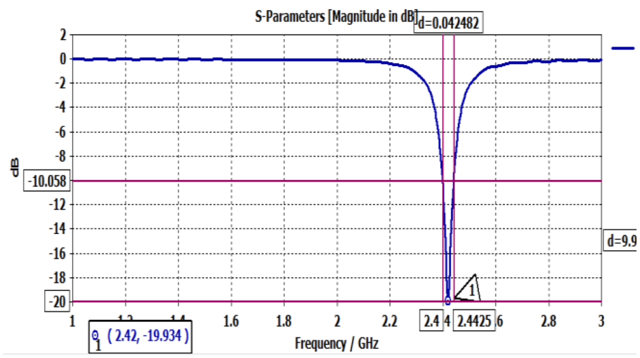

Fig. 10. S11 graph for line feeding

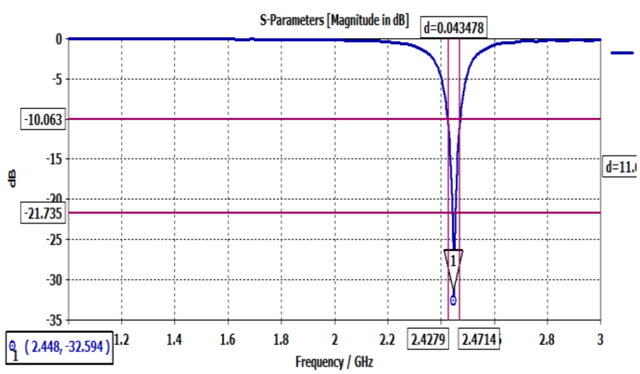

Fig. 11. S11 graph for inset feeding

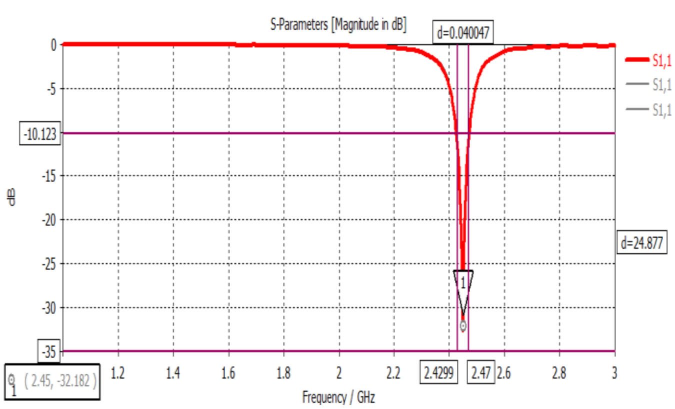

Fig. 12. S11 graph for coaxial feeding

i Inset feeding

For inset feeding antenna -32.594 dB return loss is achieved at 2.44 GHz (Fig. 11). Angular width is 78.5 degrees and the main lobe magnitude is 7.35 dBi.

1) *Coaxial feeding*

For coaxial feeding antenna -32.182 dB return loss is achieved at 2.45 GHz (Fig. 12). Angular width is 49.7 degrees and the main lobe magnitude is -4.66 dBi.

C. Laboratory experiment results

These fabricated antennas were tested from the vector network analyzer (VNA) and the results are shown below(Fig. 13, 14, 15)

The S11 graphs obtained for fabricated antennas from VNA are mostly similar to the simulated results in the previous section. According to the VNA results, line feeding and inset feeding antennas have higher return loss than coaxial feeding antenna. But coaxial feeding antenna shows a narrower bandwidth than other two antennas.

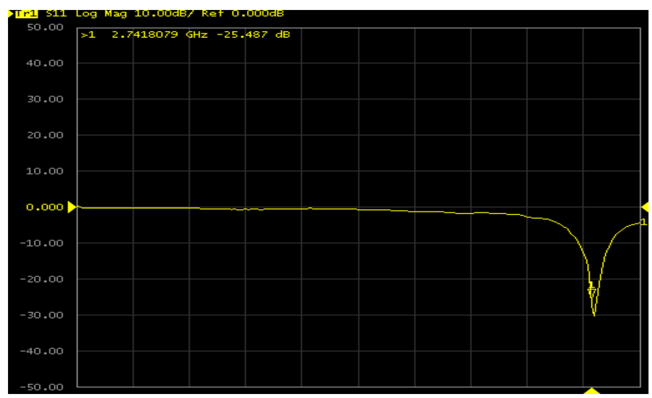

Fig. 13. S11 graph for line feeding

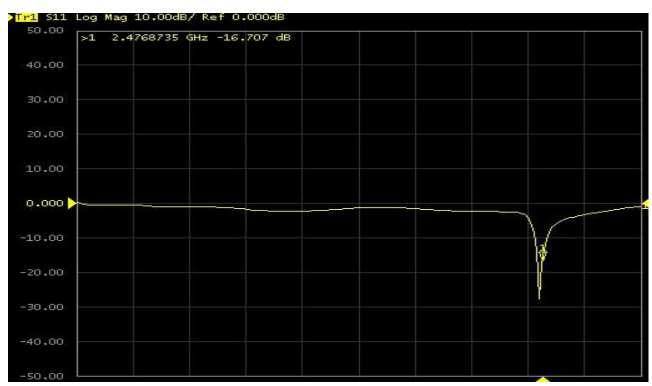

Fig. 14. S11 graph for inset feeding

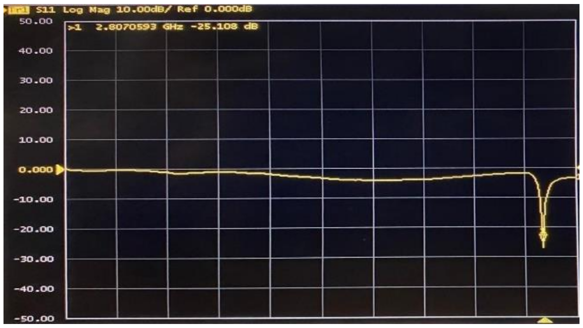

Fig. 15. S11 graph for coaxial feeding

D. Result comparison

According to Table IV, bandwidth of three antennas, all have nearly the same bandwidth (low bandwidth of 2%). Therefore, all these feeding techniques can be used for narrow bandwidth applications. When observing the simulated S11 graphs related to each feeding method, it can be seen that inset feeding and coaxial feeding have higher return loss than the line feeding. Inset feeding has the highest radiation efficiency and lower VSWR measurement. Therefore, it can be concluded that the inset feeding technique provide successful impedance matching than that of line feeding and coaxial probe feeding.

IV. IMPLEMENTATION OF COMMUNICATION LINK AND PRODUCT

The whole wearable device has to be built in small size and lightweight. A micro-controller board has to be used to get the signals from the ECG sensor (AD8232 ECG Sensor module) and generate the signal to give to the transceiver module. Arduino platform is used and the nano Arduino board was selected as it is planar and small scale. nRF24L01 transmitter module with wearable antenna was used as the transmitter and nRF24L01 receiver module with default antenna (a conventional mono-pole antenna that having 2.45 GHz frequency) used on the receiver side. The received data are shown on the computer by using a windows application. The block diagram is shown in Fig 16. Final product is as in Fig 17.

COMPARISON OF RESULTS

	Line feeding	**Inset feeding**	**Coaxial feeding**
Bandwidth/ GHz	0.04248	0.04347	0.0400
Return loss	-19.934	-32.159	-32.182
VSWR	1.78	1.29	1.82

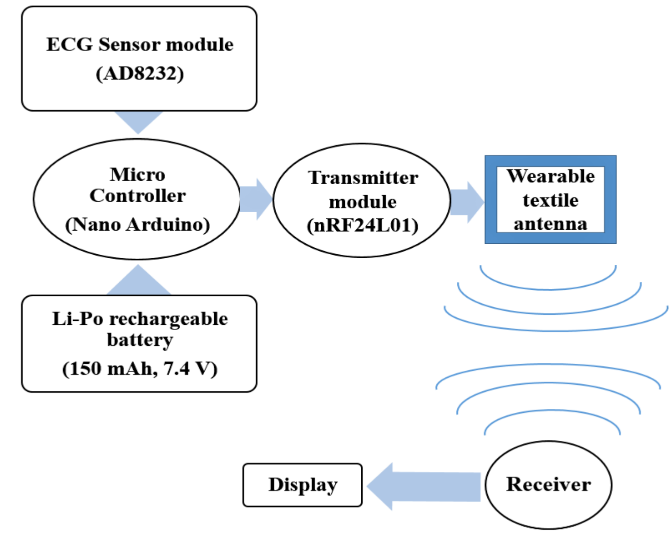

Fig. 16. Block diagram for the project

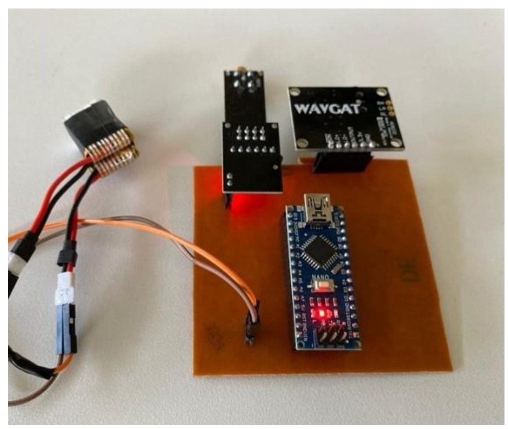

Fig. 17. Final product of the project

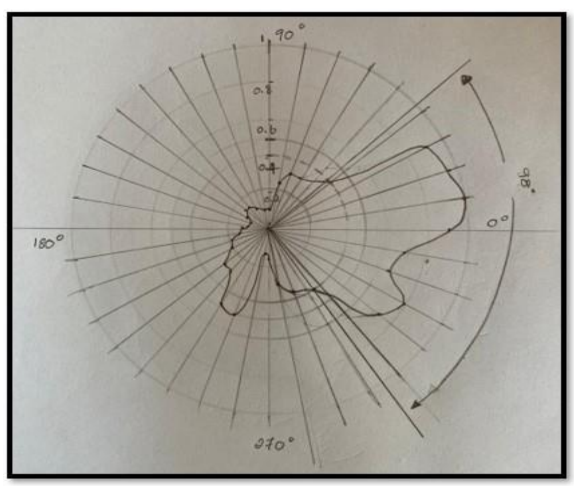

Fig. 18. Radiation distribution of the textile antenna

Fig. 19. Jacket and two antennas on (a) Front side, (b) Back side

V. SYSTEM AUTHENTICATION

In order to check the suitability of the product to wear and for sport activities, field work was done.

A. *Radiation pattern distribution*

According to Fig. 18, ground plane side (left half of Fig. 18) emits low radiation. Therefore, the condition stated as low radiation towards the body is satisfied.

B. *Effect of postural changes*

Due to postural changes (various movements) of the body, the line of sight will not be continued. Therefore, two antennas are mounted on the jacket as in Fig. 19.

C. *Effectiveness of the antenna*

After the completion of the device, the performance of the wearable device was tested in an open field (playground). Device was tested by the means of successful communication distance with various movements of the person who is wearing it.

Final device without any antenna : 8 m

Final device with textile antenna : 51 m

Final device with default antenna : 56 m

VI. CONCLUSION

In this paper, we have selected a textile material, compared three different feeding techniques and implemented a communication link. Polyester textile material was selected due to less stretchability and low dielectric constant value for sport wear application. Observing the simulated S11 graphs related to each feeding method, inset feeding and coaxial feeding are selected due to high return loss than the line feeding. Inset feeding has the highest radiation efficiency and lower VSWR measurement. Therefore, inset feeding technique provide successful impedance matching than other methods. Finally implemented antenna shows less radiation towards the body and hence applicable to on-body conditions and due to considerable transmission distance with our textile antenna it is applicable to on-field (playground) condition also.

REFERENCES

[12] C. Balanis, Antenna theory-analysis and design. John Wiley & Sons, New Jersey: 2005.

[13] S. chakravarthy, N. Sarveshwaran, S. Sriharini and M. Shanmugapriya, “Comparative study on different feeding techniques of rectangular patch antenna” Hyderabad, India: 2016 Thirteenth International Conference on Wireless and Optical Communications Networks (WOCN), 2016.

[14] A. Mohammed, A. Yauri and A. Kabir, ”Review of Feeding Techniques for Microstrip Patch Antenna”, International Journal of Computer Applications, vol. 178, no. 27, pp. 39,40,41,42,43, 2019.

[15] A. Bansal and R. Gupta, ”A review on microstrip patch antenna and feeding techniques”, International Journal of Information Technology, vol. 12, no. 1, pp. 149-154, 2018. Available: 10.1007/s41870-018-0121-4.

[16] H. Varshney, M. Kumar, A. Jaiswal, R. Saxena and K. Jaiswal, ”A Survey on Different Feeding Techniques of Rectangular Microstrip Patch Antenna”, International Journal of Current Engineering and Technology, vol. 4, no. 3, pp. 1418-1423, 2014. [Accessed 3 February 2020].

[17] G. Singh and J. Singh, ”Comparative Analysis of Microstrip Patch Antenna With Different Feeding Techniques”, International Conference on Recent Advances and Future Trends in Information Technology, pp. 18,19,20,21,22, 2012. [Accessed 3 February 2020].

[18] A. Kumar, J. Kaur and R. Singh, ”Performance Analysis of Different Feeding Techniques”, International Journal of Emerging Technology and Advanced Engineering, vol. 3, no. 3, pp. 884-890, 2013. [Accessed 3 February 2020].

[19] P. Bevelacqua, ”Antenna-Theory.com - Rectangular Microstrip (Patch) Antenna - Feeding Methods”, Antennatheory.com, 2020. [Online]. Available: http://www.antennatheory.com/antennas/patches/patch3.php. [Accessed: 03- Feb- 202