DESIGN, SIMULATION AND FABRICATION OF WEARABLE ANTENNA FOR BODY AREA NETWORK USING JEANS AS SUBSTRATE

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Abstract *:* This paper presents a wearable textile microstrip patch antenna operating for wireless body area network (WBAN) at the center frequency, *fc* of 2.40 GHz. Textile materials are suitable for design due to their flexibility and low relative permittivity. In this project, jeans fabric with the relative permittivity, Ɛr = 1.70 and thickness of 1.00 mm is chosen as a substrate attached to Conductive Copper Foil Tape as a conductive material with the thickness of 0.06 mm and conductivity of 6.67×10^5 S/m, respectively. In the first stage, a microstrip patch antenna layout with an line feeding technique is designed and simulated by using High Frequency Simulation Software (HFSS). In the second stage, a wearable textile microstrip patch antenna is fabricated and optimized. Simulation and fabrication measurement results show that the designed antenna characteristics are suitable for an industrial, scientific, and medical radio (ISM) band, which is at the *fc* = 2.40 GHz. Moreover, relative permittivity, Ɛr and thickness, *h* of the developed textile-based substrate affect significantly a wearable microstrip patch antenna radiation performance.

Index Terms – **Wearable antenna; jeans fabric; wearable antenna; microstrip patch antenna; wireless body area network; Conductive copper foil tape**

I. INTRODUCTION

Conventional antennae are found to be quite rigid in its structure & hard to implement in places with low availability of spaces. The complexity of the device could be far more intensive in nature depending on the requirement & nature of its design. The Body Area Network (BAN) Antennas are considerably suitable in any scenario like health monitoring , in sport, and even in military prospective due to its considerable light weight , low power, and sensing capability. BANs provide cheap, reliable, and scalable system for monitoring daily activities for short to long period of time. The application of WBAN has been intensifying in various fields including medical, military, navigation, entertainment, and sport. Several frequency bands have been assigned for WBAN systems, such as the Industrial Scientific Medical band (ISM: 2.40 GHz and 5.80 GHz), and the Ultra-wideband (UWB: 3.00-10.00 GHz), respectively. Furthermore, a wearable microstrip patch antenna can overcome limitations of a conventional microstrip patch antenna. It is difficult to integrate and hide a conventional microstrip patch antenna inside clothing due to its physical structure. Contrariwise, textile wearable microstrip patch antenna can be a better alternative for various types of WBAN applications since it is lightweight, small, flexible, compact, and easily to be integrated also hidden inside clothing [4].

II. ANTENNA STRUCTURE & DESIGN

A.TYPES OF TEXTILE MATERIAL

Copper Foil Tape with Adhesive Double-Sided Conductive Tape is used for the fabrication of antenna for patch and ground plane. Witha thickness, *t*, of 0.06 mm, conductivity of $6.67 \times 10_5$ S/m and a surface resistivity, R_s less than 0.5 Ω/sq. Tape application temperature range is 10 ℃ -35 ℃, when the surface is not recommended to use paste below 10 ℃. Otherwise vulnerable colloid is too hard, and cannot be bonded firmly affixed to reduce adhesion tape, If you have the right to paste the sticker, usually does not affect the holding relatively low adhesion effect. When the tape is used in a low state of the natural environment, the need to tape warmed to room temperature (about 20 ℃) more than three hours re-use. When the tape is heated at high temperatures using state of the environment, instantaneous temperature do not exceed 120 ℃, working temperature is below 80 ℃, if sustained heating should not exceed more than 10 minutes to prevent damage to the tape functions and features.

TABLE I
FEATURES OF TEXTILE MATERIAL

Material	Thickness, mm	Permittivity (Ɛr)	Conductivity, S/m
Jeans Fabric	1.00	1.7	-
Copper Tape	0.06	-	6.67×10^5

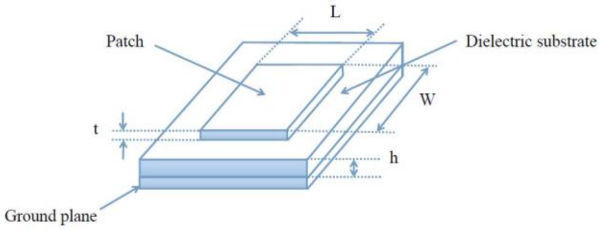

Fig. 1: Microstrip Patch Antenna Structure

B. Patch Antenna Design

i. Calculation of Microstrip Patch Antenna

Fig. 1 shows the rectangular microstrip patch antenna structure consists of conductive, substrate and ground planes. The patch size is generally dependent upon the resonant frequency, f_r and substrate dielectric constant, $\mathcal{E}_r$ [10]. The f_r in this study is the center frequency, f_c = 2.40 GHz where the width of the patch, W is calculated using (1):

$$W = \frac{c}{2f_r\left(\sqrt{\frac{\varepsilon_r+1}{2}}\right)} \quad (1)$$

According to (1), c is the speed of light where the increment of $\mathcal{E}_r$ will decrease the size of the antenna patch. The actual length of the patch is computed as in (2):

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} = 2\Delta L \quad (2)$$

Based on (2), the effective dielectric constant, $\mathcal{E}_{reff}$ is defined as in (3):

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r+1}{2}\right) + \left(\frac{\varepsilon_r-1}{2}\right) + \left(1+\left(\frac{12h}{W}\right)\right)^{\frac{1}{2}} \quad (3)$$

Moreover, the length extension, ΔL is calculated as shown in (4) below:

$$\Delta L = 0.412\left[\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\right]\left[\frac{\left(\frac{W}{h}+0.264\right)}{\left(\frac{W}{h}+0.8\right)}\right] \quad (4)$$

ii. Calculation of Microstrip Line Feed

Then, the microstrip synthesis, H with characteristic impedance, Z_0 equals to 50 Ω is generated using (5):

$$H = \left[\frac{Z_0\sqrt{2\varepsilon_r+1}}{119.9}\right] + \frac{1}{2}\left[\frac{\varepsilon_r-1}{\varepsilon_r+1}\right]\left[\ln\left(\frac{\pi}{2}\right) + \frac{1}{\varepsilon_r}\ln\left(\frac{4}{\pi}\right)\right] \quad (5)$$

Based on (5), the width of microstrip line feed, W_f is computed as in the following (6):

$$W_f = \left[\left(\frac{e^H}{8} - \frac{1}{4e^H}\right)^{-1}\right] \times 1.6mm \quad (6)$$

Moreover, the length of microstrip line feed, L_f is obtained through (7) below:

$$L_f = \theta \times \frac{\lambda}{360^o} \quad (7)$$

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_{reff}}} \quad (8)$$

iii. The Ground Dimension for the Antenna

The length of the ground plane is calculated using the following (9):

$$L_g = L + 6h \quad (9)$$

Moreover, the width of the ground plane is computed as shown below (10):

$$W_g = W + 6h \quad (10)$$

After finding the microstrip patch antenna, line feed and ground dimension values through calculations using (1) - (10), the design of the wearable microstrip patch antenna schematic and layout is made using the High Frequency Simulation Software (HFSS).

In this project, the wearable antenna is given line feed. The main advantage of line feed is that it's easy to fabricate and simulate. The Table II shows us the values of the parameters before and after undergoing optimization using HFSS. Fig. 4 displays the Copper foil tape as a textile conductive after being attached to the jeans fabric as a textile substrate. The wearable textile microstrip patch antenna is then soldered with a 50 Ω impedance subminiature version A (SMA) probe connector so that the Antenna can be connected to a vector network analyzer (VNA) via a radio frequency (RF) coaxial cable for performance measurements.

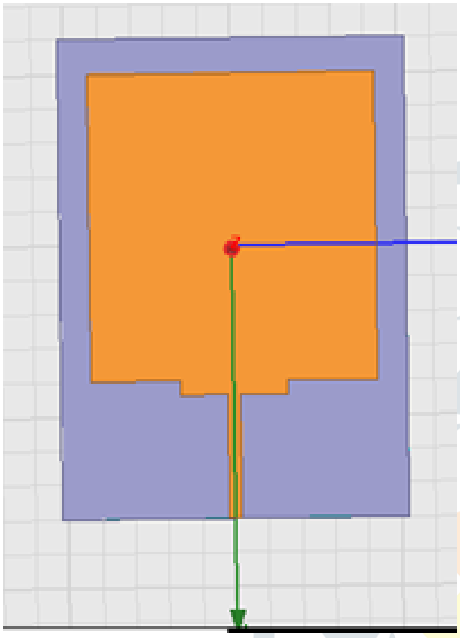

Fig.2: Simulated wearable antenna.

Fig.3: Fabricated wearable antenna.

TABLE II
OPTIMAL ANTENNA PARAMETER

Parameters	Non-optimal valve	Optimal value
Length of Patch Antenna, *L*	48.785mm	48.016mm
Width of Patch Antenna, *W*	51.012mm	50.057mm
Length of Line Feed, *Lf*	30.652mm	30.033mm

III. RESULT AND DISCUSSION

In this section, both simulation and actual measurements of the wearable microstrip line feed patch antenna performance in the free space is discussed. The simulation is performed by using Anritsu Vector Network Analyer (VNA) Master 2024B. The antenna performance is simulated and measured precisely in terms of return loss (S_{11}), impedance matching, three dimensional (3D) radiation pattern and gain. S_{11} in an antenna is a parameter that states the total of power that is lost to the load and does not return as a reflection. Ideally, the antenna should achieve the $S11$ of the antenna lower than -10 dB to obtain a good performance [3]. Fig. 5 depicts the S_{11} parameter simulation in terms of magnitude in dB and phase in degree of the designed wearable microstrip patch antenna. In simulation the S_{11} parameter in terms of magnitude in dB is shown in fig.5. At frequency

f_c=2.40GHz the value of S_{11} parameter is -13.22 dB. The simulated result is better than the fabricated result where S_{11} is -11.47 dB at f_c=2.40GHz. The maiximum S_{11} paramete -34.24 dB is obtained in fabrication at f_c =2.28GHz & -14.84dB in simulation.

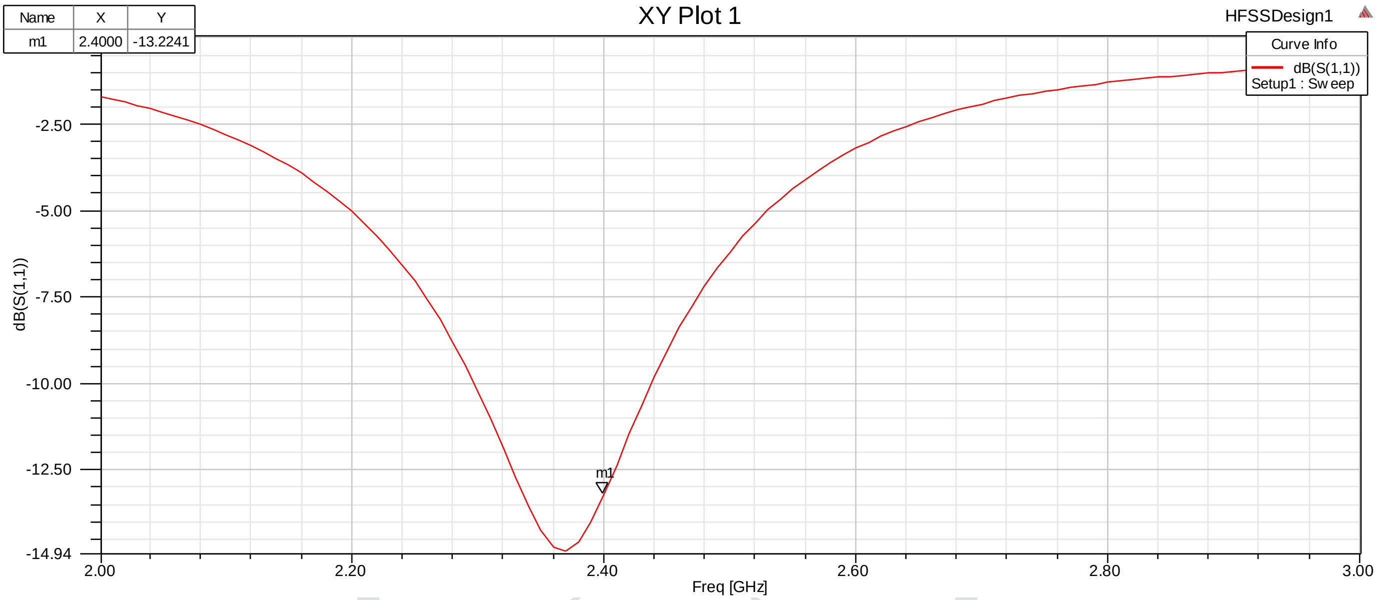

Fig.3: Simulated Return Loss Using HFSS.

The fig.4 shows us the S_{11} parameter of the fabricated antenna. It can be clearly seen that the return loss is higher in fabricated which is -34.06 for f_c= 2.27GHz , which is acceptable since it's value is lower than -10.00 dB.

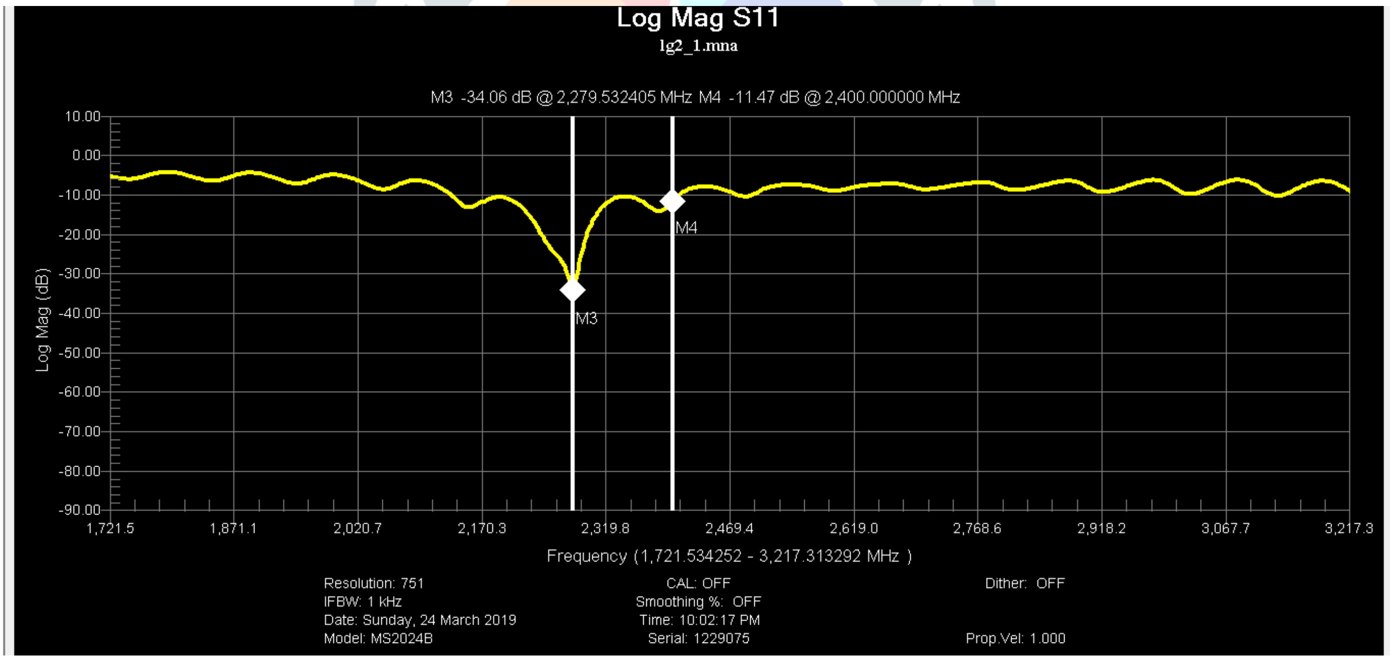

Fig.4: Return Loss Measurement using VNA

Impedance matching in antenna design is where the input impedance Z_{in} of the antenna should be practically near to the characteristics impedance Z_0 , which is 50Ω in this study. In the Fig.5 we can see that at f_c=2.40 GHz the impedance is 0.65-0.12i Ω is shown by placing a marker on the Smith Chart of the simulated result. Which when multiplied by 50 Ω gives an impedance of 33.00 + j6.39 Ω Ω which is approximate result.

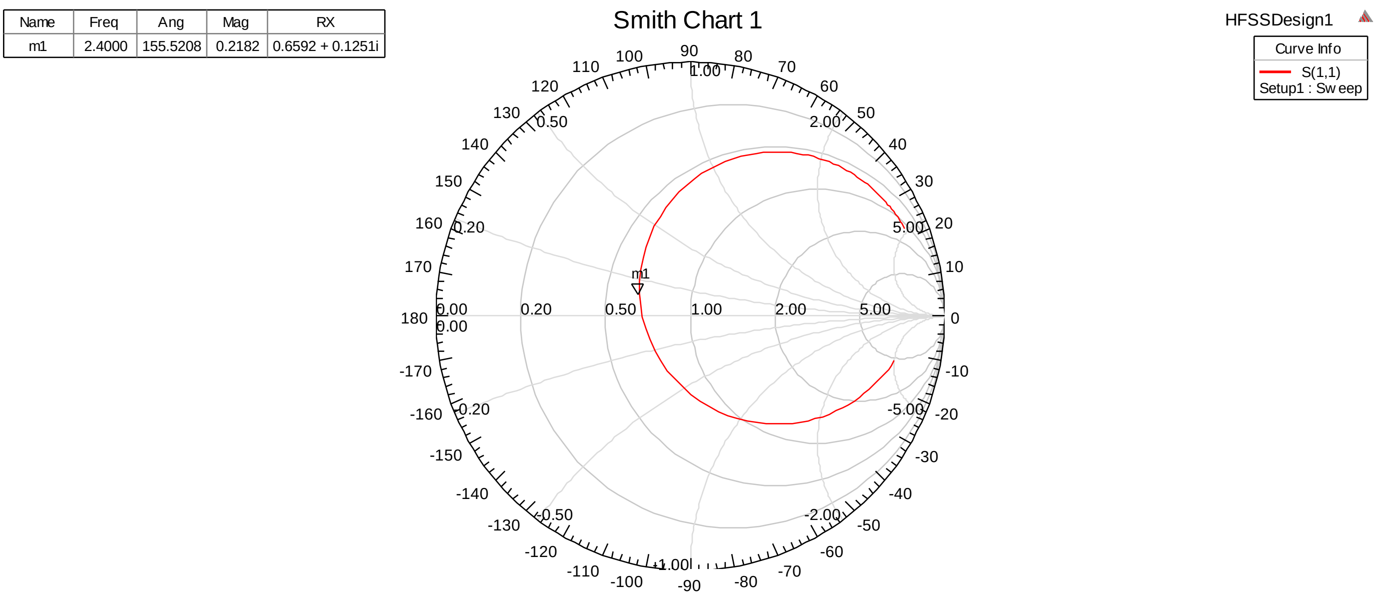

Fig.5: Impedance Matching using HFSS

In fig.6 the results of fabricated antenna observed on VNA is shown. It can be seen that at f_c=2.4GHz the impedance is (34.685Ω, 9.245 Ω), is acceptable value.

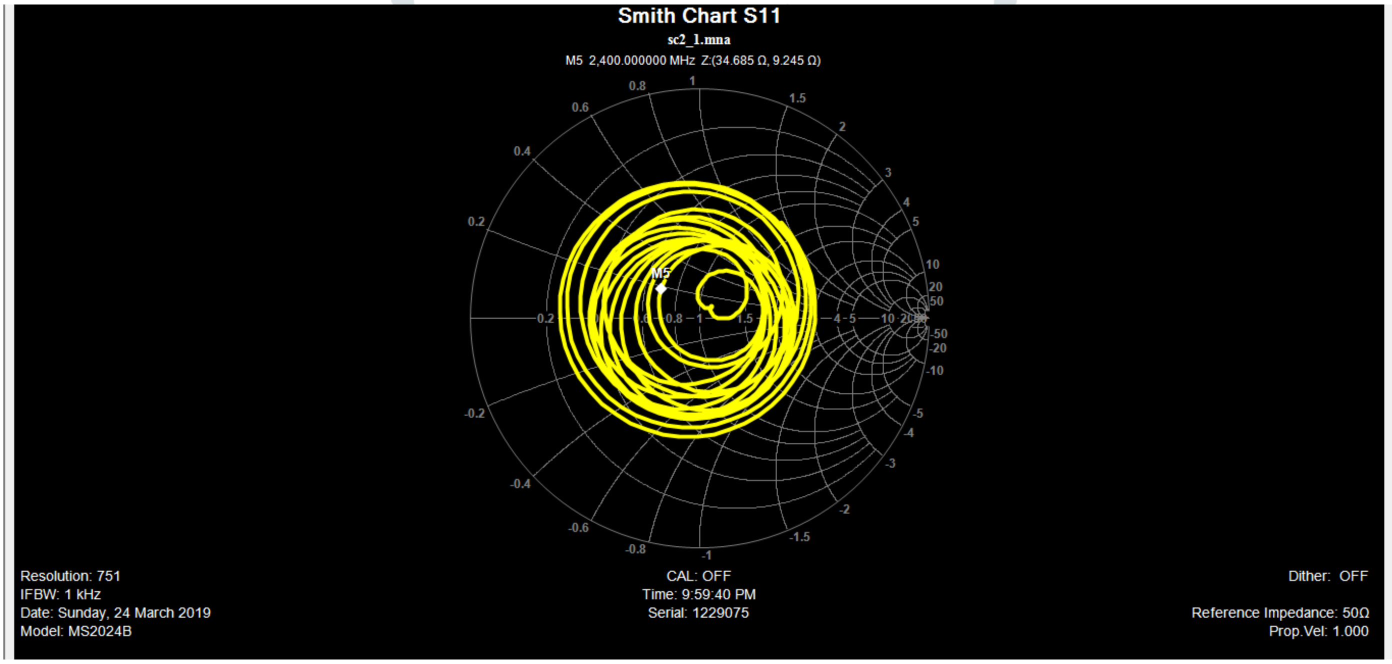

Fig.6 Impedance Matching Measurement using VNA

Radiation pattern is the directional dependence of the strength of radio waves from the antenna. As shown in Fig. 7, the developed wearable microstrip patch antenna generates simulated 3D omnidirectional patterns where equal power of radio wave is radiated in all directions perpendicular to the antenna. The omnidirectional pattern are compatible to human body since human body have a unique posture and flexible. Hence, omnidirectional pattern is required in wearable textile microstrip patch antenna design.

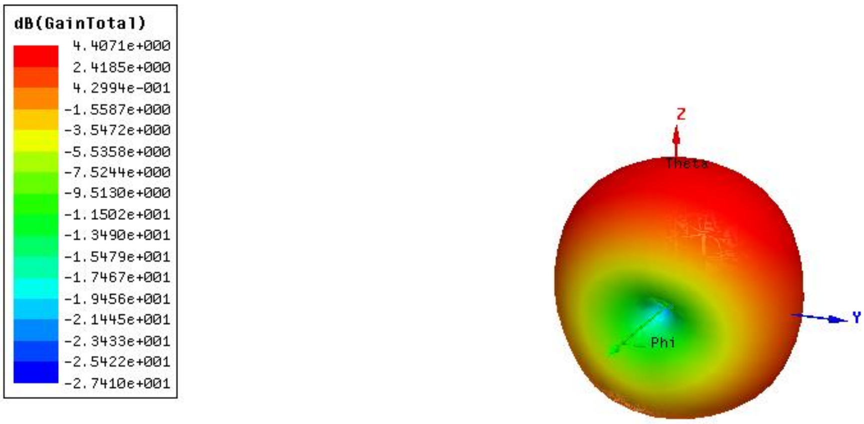

Fig.7: Radiation Pattern Simulation using HFSS.

IV. CONCLUSION AND FUTURE WORK

Thus we can conclude that using jeans as substrate and copper tape as an alternate conductive layer in the wearable microstrip antenna design gives acceptable results. However there is a deviation in S_{11} parameter where the fabricated antenna gives better result than the simulated antenna. We get -11.47 dB is at f_c =2.400GHz which is acceptable. Similarly there is a wide deviation in the Impedance matching between simulated and fabricated antenna. The impedance matching at f_c=2.4GHz the impedance is (34.685Ω, 9.245 Ω).

For future work, this provides a base for WBAN antenna. The objective was show that jeans substrate and copper tape is better than the commonly used Fr4 substrate. In addition, an improvement can be done also by designing the wearable microstrip patch antenna in smaller size, which has less bend compared to the bigger ones. Moreover, smaller wearable microstrip patch antenna is preferable for many recent communication applications. Besides, the developed textile wearable antenna potentially can be applied for harvesting the radio frequency (RF) energy in the free space.

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After designing the antenna on the HFSS software, here are some of the output results for the same design. Here VSWR graph and Smith Chart, Return Loss, 2D& 3D both Radiation Pattern,

VI. REFERECES

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