

Design and Performance Analysis of Low Profile Miniaturized MSPAs for Body Centric Wireless Communication in ISM Band

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Abstract: Body centric wireless communication is emerging and active area of research for many applications as identification, tracking, health care systems and radio frequency linked telemetry. In this paper, On-body performance and analysis of various wearable square shaped spiral cut MSPAs were investigated by measuring reflection coefficient, radiation pattern and impact of human body equivalent model. This antenna is covering the industrial, scientific and medical band (ISM 2.45 GHz) which can be used for wearable applications in field of health care and telemetry. In particular, the designing and analysis focused on the performance of a miniaturized square shaped spiral cut MSPA for body centric wireless communication. The characterization of proposed antenna is analyzed using numerical equivalent of three layered canonical model of skin, fat and tissue. For all types of wearable square shaped spiral cut MSPA the main parameter under study is reflection coefficient and the effect of novel double C structured square shaped spiral cut MSPA with miniaturized designs.

Keywords: Body Centric Wireless Communication, ISM Band, On-Body channel, Wearable Antenna, Layered Tissue Model, Wireless Communication Link.

I. Introduction

Antenna is the most important part in the field of wireless communication. Antennas are being used in many applications with the substantial development in the field of wireless communication. There are many areas where body centric communication systems can be used such as identification, tracking, and health care systems. Wearable antennas also can be applied for youngsters, the aged and the athletes for the purpose of monitoring [1]. Due to growing technology, antennas requirement is also gaining heights. For this particular purpose antennas need to be light weight, low cost and small size [2].

In recent years, there has been increasing concern in the field of wearable electronics for medical, entertainment and military. The main feature of wearable electronics is to allow wireless communication from or to the body via wearable antennas. Therefore, wearable antennas have the main role in wireless on-body centric communication and have more attention in research. Due to growing wireless applications the appropriate antennas requirement is also gaining heights in the field of body centric wireless

communication. For this particular purpose antennas need to be light weight, low cost and small size [3]. Body worn antennas are used in various applications such as health, surveillance, monitoring etc.

Body centric wireless communication systems are becoming the important part for future communication. It consists of three basic communications as shown in Figure 1 i.e. On-body, Off-body and In-body communication [3]. On-body basically refers to the communication between On-body/wearable devices which is the centre of discussion. Off-body refers to the communication from Off-body to On-body devices. In-body by the name itself suggests communication with the implantable device or sensor.

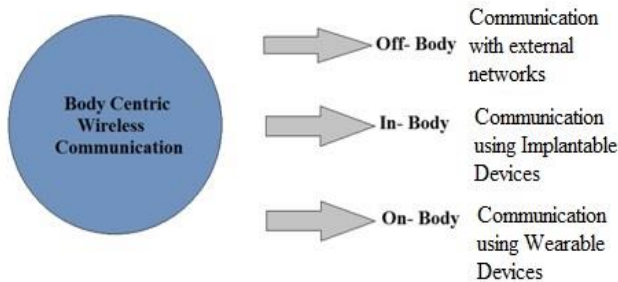


Figure 1. Description of Body Centric Wireless Communication [3]

Body-worn antennas are much more suitable for biomedical telemetry than implantable antenna. Many challenges occur in case of Medical implant devices (IMDs) such as miniaturization, compatibility with the human body and the patient safety [4]. Till date researches on IMDs have not succeeded within the human body. So far, the issue with the size have reached such particular level that it can be inserted into the animals and the results obtained are favorable. But when it comes to the matter of compatibility many materials can be used but can be harmful to the human body. So to overcome these, wearable antennas are being used, which can be easily worn. The main advantage of wearable antenna as compared to implantable is the SAR value. In case of On-body SAR value is reduced and issues related to radiation also decreased.

Body worn antenna so far is capable of size reduction. As in [5] due to body movements, a wearable antenna is constantly changing its direction of maximum radiation, which leads to significant changes in the radio link performance. This antenna helps in medical purpose. Defected ground can be also used for reducing the size of the Microstrip components as in [6]-[8]. For the case of Body worn the design strategies are strict i.e. low power consumption is required for demanding application requiring in medical purpose, surety and safety are necessary for vital application, radiation are subject to regulatory limits for public health and co-existence regions, and size, aspect ratio, and weight should be carefully dimensioned.

In the proposed work, antenna used is of comparatively small size and it is been placed over the layered model of electrical equivalent of human body. This particular

antenna works in Industrial, Scientific and Medical (ISM) band operating at 2.45GHz.

II. On Body Communication

On-body communication is between On-body/wearable devices depicted in Figure 2. In this figure ECG sensor, EMG sensor and motion sensor are using On-body communication and Off-body communication is via the control unit towards external access point. The wearable antennas are worn on the body and the communication can be done wirelessly.

In the proposed work, the size is so miniaturized that the antenna can be easily worn with respect to medical application and the communication with the other devices can be easily done. In medical background, several devices are used which store data such as blood pressure, heart beat etc. As shown in Figure 2, wearable antenna is able to communicate the data to the concern physician through access point.

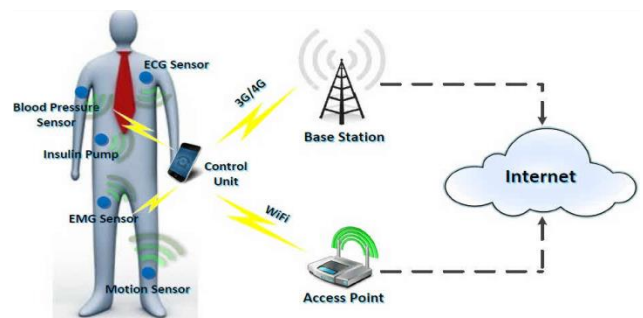


Figure 2. On Body and Off Body communication [9]

III. Design Strategy of Wearable Square Shaped Spiral Cut MSPA

A. Antenna Design

The flowchart of proposed strategy is given in the Figure 3. This flowchart clearly describes the steps followed to design the desired shape. First the high permittivity substrate is selected and then the rectangular patch is designed upon its surface. This Microstrip patch antenna is designed and simulated in computer simulation software i.e. CST Microwave Suite. Simulation is made by using one layer skin model as in [3],[10], but in this paper three layered model (skin, fat, muscle) is used for making it more effective. This electrical equivalent model of human body is more realistic than one layer model for simulations as shown in Figure 4(a) [12],[13].

The substrate used in the spiral cut MSPA is polytetrafluoroethylene (PTFE) which is a fluorocarbon solid. This is a hydrophobic type material and this property is used here for making a water resistant antenna. The vicinity of the antenna would be human body so

water or water containing substances might be present around the antenna. PTFE molecules are non polar and the water molecules are polar hence the PTFE material does not get wet by water content. Due to hydrophobic property the effect of water is negligible on the electrical properties of antenna. PTFE is ideally used for printed circuit board technology due to its high insulating and temperature resistant properties.

The proposed antenna is placed above the human tissue model. Figure 4(b) shows the layers i.e. muscle ($\epsilon_r = 54.417$, $\sigma = 1.882$ S/m), fat ($\epsilon_r = 5.280$, $\sigma = .104$ S/m) and skin ($\epsilon_r = 38.0066$, $\sigma = 1.464$ S/m) which are the electrical equivalent model of human tissue [11].

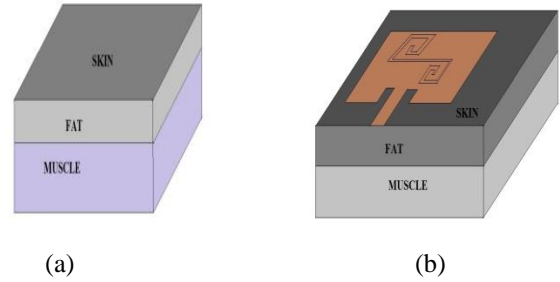


Figure 4. (a) Layered Structure of human Tissue Model (b) Proposed antenna placed on human Tissue Model.

After simulating the rectangular patch antenna in free space box the strategy is to miniaturize and optimize this antenna for achieving minimum Reflection coefficient ($|S_{11}|$). Many optimized designs are simulated for square shaped spiral cut MSPA as double I, L and C structures. Accordingly for the ISM band square-shaped spirals are cut and for more precise results C-shaped mirror image design are drawn horizontally. The initial parameters of MSPA are set manually. Number of turns was taken according to the design as well as spirals were also drawn accordingly. The design was placed over the skin layer as the study of interest is wearable antenna. After the simulation procedure with respect to layered tissue model is over, different results were obtained.

B. Antenna Measurement

The main focus is on S_{11} parameter as it has to lie in the range of ISM band. If $|S_{11}|$ is not less than -10dB, parameters are simultaneously changed for optimizing it. By changing the parameters estimated results are obtained. After this, for the final design the return loss is analyzed and checked whether it is minimum or not, if not the parameters are altered accordingly. Lastly, the other results were observed.

In the measurement of antenna all the design dimensions are in millimeter and the results such as reflection coefficient, gain and radiation pattern are measured with frequency. Various results for square-shaped spirals cut MSPA and double I, L and C structures are obtained in CST Microwave Suite in free space box and on the layered model. The double C structure is showing the perfect results in ISM band and is a resonating structure at 2.45 GHz.

C. Wireless Communication Link Establishment

Practically the wearable On-body antennas act as transmitting antenna and external device act as receiver antenna. The link between wearable and external device is called Uplink and the link between external and wearable is called Downlink. Assuming the far field wireless communication,

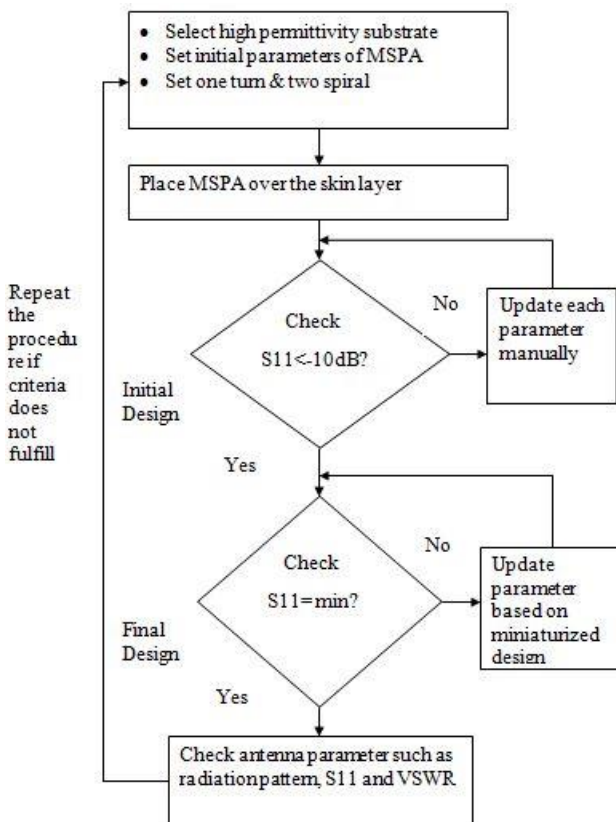


Figure 3. Proposed strategy for designing the Antenna.

According to the Flow graph in Figure 3, first high permittivity substrate is taken but due to other requirements of this antenna as body centric wireless communication applications the PTFE material is chosen. Spiral structure is made for the basic design to get the maximum impedance matching at 2.45 GHz frequency range. Here one turn and two spirals with appropriate dimensions are chosen for the basic antenna structure.

$$\begin{aligned} \text{Link Margin (dB)} &= \text{Link C/N}_0 - \text{Returned C/N}_0 \\ &= P_t + G_t - L_f + G_r - N_0 \end{aligned} \quad (1)$$

Where P_t is transmitted power, G_t is transmitting antenna gain, L_f is the path loss, G_r is receiving antenna gain and N_0 is noise power density [3].

According to a simple communication model using a transmitter and receiver the path loss is given as

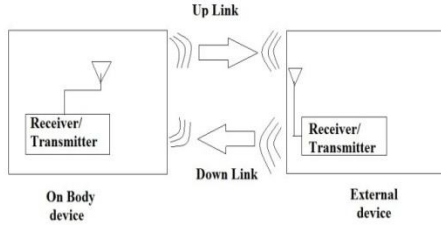


Figure 5. Wireless Communication link between Transmitter and Receiver [3].

$$L_f(\text{dB}) = 20 \log(4\pi d/\lambda) \quad (2)$$

Where d is the distance between transmitter and receiver.

If impedance mismatch loss is considered then

$$L_{\text{imp}}(\text{dB}) = -10 \log(1 - |r|^2) \quad (3)$$

Here r is approximate reflection coefficient

The received power is calculated as

$$P_r = P_t + G_t + G_r - L_f - L_{\text{imp}} - e_p \quad (4)$$

Where e_p is polarization mismatch

$$P_r = (G_t G_r \lambda^2 / (4\pi d)^2) (1 - |S_{11}|^2) e_p P_t \quad (5)$$

Above equations are for the wireless communication in air as a medium. In this paper On-body communication is the major concern so the above model is applicable for ECG sensor, EMG sensor and control unit as a transmitter or receiver both.

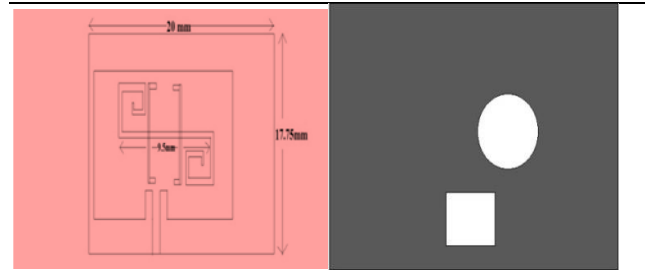
IV. Design Configuration of Wearable Square Shaped Spiral Cut MSPA

The proposed design parameters are being given in the tabular form. The material used in the patch region is lossy copper as given below in Table 1. Substrate used in wearable square shaped spiral cut MSPA is polytetrafluoroethylene (PTFE) with relative dielectric constant 2.1 and conductivity 1 and tangent delta 0.00022. The dimensions are so chosen to be reasonable for body worn devices. Volume of antenna is $(20 \times 17.75 \times 1.9 = 674.5 \text{ mm}^3)$ which is miniaturized enough to be used for On-body applications in ISM band for body centric wireless communication. Front and back view of proposed antenna is shown in Figure 6(a), (b). Here in Figure 7(a), (b), (c),

(d) front view of the square shaped spiral structure, double I cut, double L and double C cut are shown and it is simulated in CST Microwave Suite using FDTD (Finite-Difference Time-Domain).

Table 1. Parameter value of proposed antenna

Parameter	Value(mm)
Length of rectangular Patch (L)	17.75
Width of rectangular Patch (W)	20
Length of slot (L1)	9.5
Square slot on ground length (l)	3
Square slot on ground width (w)	3
Circle slot on ground(r)	2



(a)

(b)

Figure 5. (a) Front View of Double C structure in proposed square shaped spiral cut MSPA (b) Back View of Double C structure in proposed square shaped spiral cut MSPA.

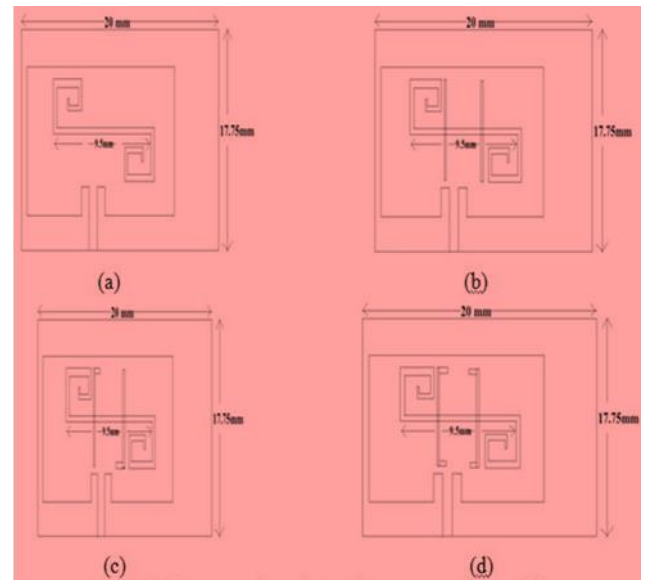


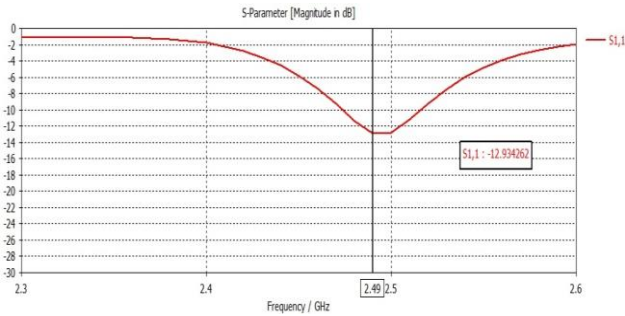
Figure 6. Front view of (a) Square shaped spiral cut MSPA (b) Double I structure (c) Double L structure (d) Double C structure.

V. Results and Analysis

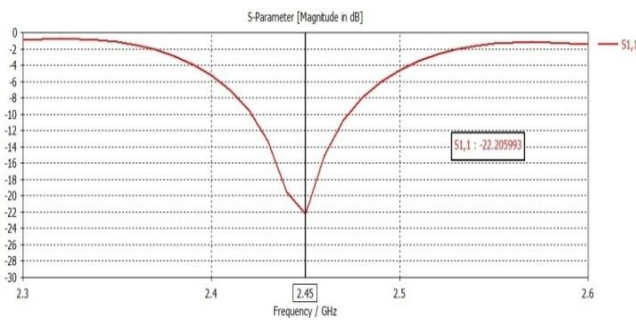
A. Reflection Coefficient Vs Frequency performance

In case of two square spiral shapes resonant frequencies are 2.49 GHz and 2.45GHz, 2.49GHz and 2.45 GHz for double I cut, double L and double C cut structures

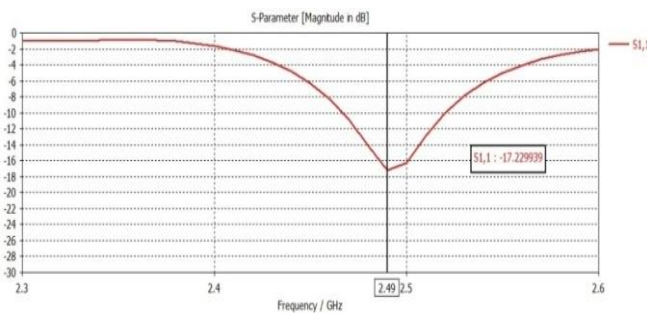
respectively as in Figure 8(a), (b), (c), (d). All frequency bands are lying in ISM band. Impedance bandwidth of antenna is (40MHz) in case of Square shaped spiral cut MSPA (Figure 8(a)).The impedance bandwidth is now increased to 60MHz (Figure 8(d)). It is increased by 20 MHz compared with simple Square shaped spiral cut MSPA.



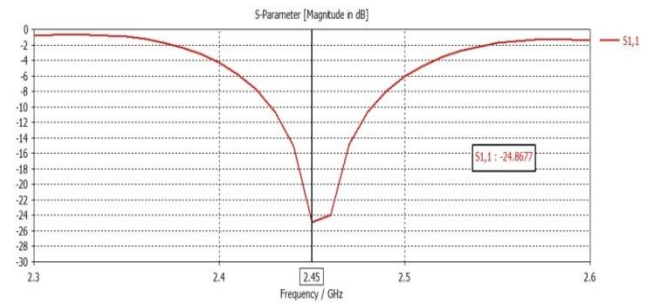
(a) Reflection coefficient Vs Frequency performance of Figure 7(a)



(b) Reflection coefficient Vs Frequency performance of Figure 7 (b)



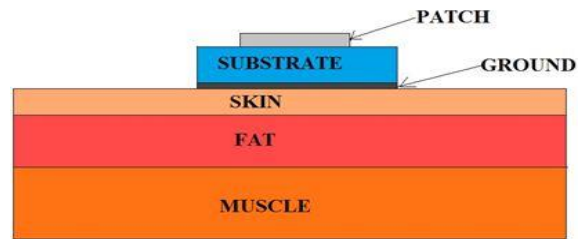
(c) Reflection coefficient Vs Frequency performance of Figure 7 (c)



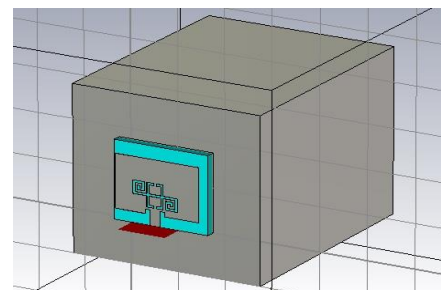
(d) Reflection coefficient Vs Frequency performance of Figure 7 (d)

Figure 7. Reflection coefficient Vs Frequency performance of Figure 7 (a), (b), (c) and (d).

The reflection coefficient is -12.93dB,-22.20 dB,-17.22 dB and -24.8 dB, for Square shaped spiral structure, Double I, Double L and Double C structures respectively. It is observed that Double C structure is showing the best results on comparison basis of reflection coefficient.



(a)



(b)

Figure 8. (a) Placing of proposed antenna over layered tissue model (b) Proposed antenna in CST microwave studio suite placed over the layered tissue model.

All results shown in above figures are produced after placing the antenna on layered tissue model of human body. By placing this antenna on human model the results are more consistent in typical conditions. The advantage of placing this antenna on human body is that the impedance is matched well and the electrical size of antenna is also reduced in comparison with the results in free space [5], [14].

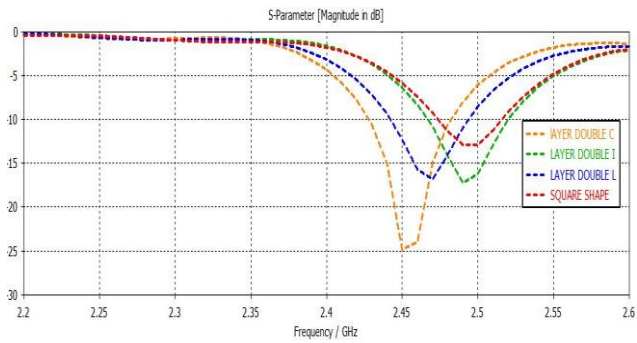


Figure 9. Comparison graph of S parameter of all four designs.

A comparison graph is produced in simulator for Square shaped spiral structure, Double I, Double L and Double C structures depicted in Figure 10. In this comparison double C structure is showing the resonating structure at 2.45 GHz frequency and the least value of reflection coefficient -24.8 dB. Other antennas as Double I, Double L and Double C structures are resonating at other frequencies with lesser values of reflection coefficient.

B. Radiation Patterns

The radiation pattern is depicted here in two parts; two dimensional and three dimensional radiation patterns. In Figure 11 (a), (b), (c), (d) the radiation patterns are depicted and the required condition for wearable antennas is higher value of front to back ratio. It can be achieved when the antenna is radiating in front direction substantially. This requirement is fulfilled by Double C structure depicted in Figure 11(d).

aforesaid limitations Double C structure is the best result. Angular width is also an important aspect of wearable antennas and 3 db angular widths is 146.3 degrees. More value of angular width will provide better coverage to this Double C structure antenna as well as a good front to back ratio value.

The three dimensional radiation patterns is the actual radiation provided by this antenna in free space. In Figure 12 (a) and (b) the radiation pattern is favorable for Off-body wireless communication in wearable conditions.

The radiation patterns achieved at 2.45 GHz in Figure 12(a), (b) are showing unidirectional radiation patterns which are desired to provide wireless link for On-body and Off-body communication and minimum radiations toward the user’s body. It is highly desirable for wearable antennas [20], [21].

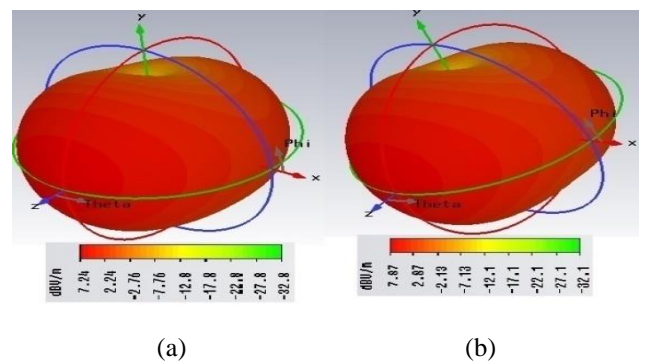


Figure 11. Three-Dimensional Radiation Pattern of antenna (a) Double L (b) Double C structure at 2.45 GHz.

C. Surface current distribution at resonant frequency (2.45 GHz)

The surface current distribution profile at resonant frequency of the proposed antenna geometry is shown in Figure 13. Figure 13(a) shows the direction of maximum current distribution which towards the Square shaped spiral cut on the antenna patch geometry (shown by red spots). The maximum amount of the current occurs at the boundaries of the cutting slots from ground plane depicted in Figure 13(b).

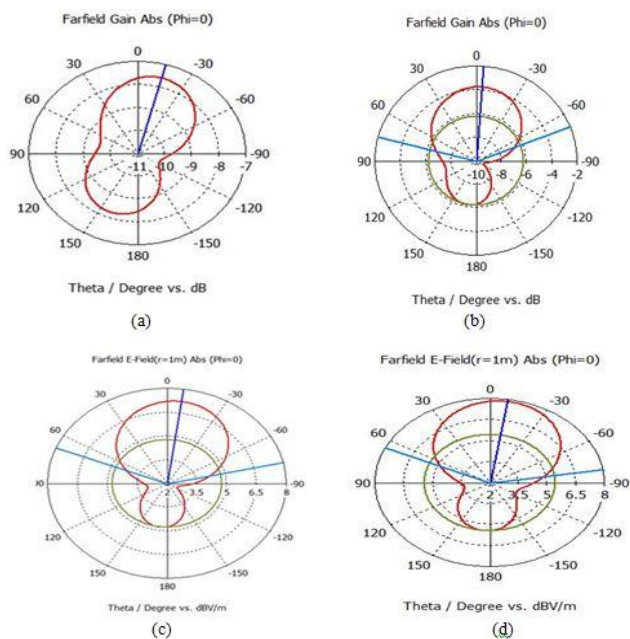


Figure 10. Two-Dimensional Radiation Patterns at 2.45 GHz (a) Square shaped spiral structure (b) Double I (c) Double L (d) Double C structures.

Antennas used for On-body communication are assumed to radiate in one direction substantially so that it can affect the least to the human body [15]-[22]. So based on both

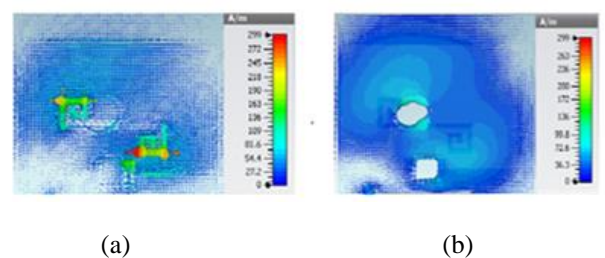


Figure 12. Surface current distribution profiles of square shape spiral at resonant frequency (2.45GHz) (a) On antenna patch geometry (b) On antenna ground plane.

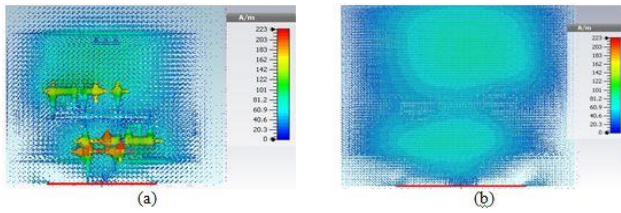


Figure 13. Surface current distribution profile of L shape at resonant frequency (2.45GHz) (a) On antenna patch geometry (b) On antenna ground plane.

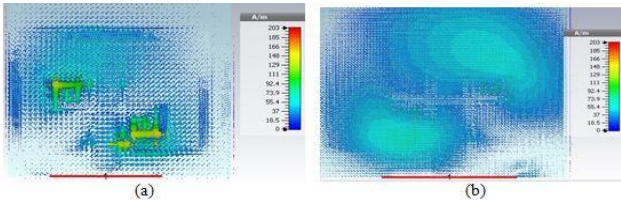


Figure 14. Surface current distribution profile of I shape at resonant frequency (2.45GHz) (a) On antenna patch geometry (b) On antenna ground plane.

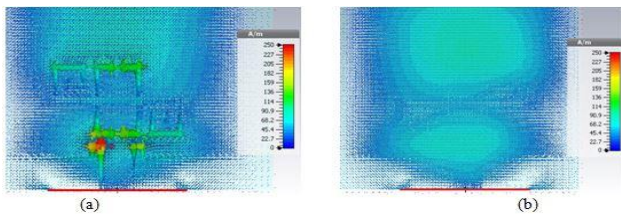


Figure 15. Surface current distribution profile of C shape at resonant frequency (2.45GHz) (a) On antenna patch geometry (b) On antenna ground plane.

Figure 14, 15 and 16 are the surface current distribution of Double L, Double I and Double C structures. It is revealed from the above figures that Double C structure is showing the dominant surface current distribution on the antenna patch geometry and on ground plane also. It is observed by denser red and green area on the surface.

D. Electric field & Magnetic field profile at resonant frequency (2.45 GHz)

The maximum E field directed towards the boundary of the both Square shaped spiral cut MSPA and the rectangular cut from the antenna patch geometry depicted in Figure 17(a) while the maximum H field occurs at the square spiral shaped slot is shown in Figure 17(b).

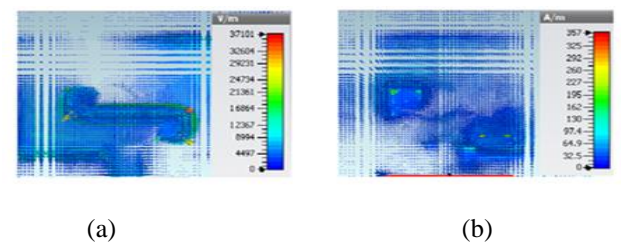


Figure 16. (a) & (b) Electric field & magnetic field Profile respectively of Square shape spiral cut at resonant frequency (2.45GHz).

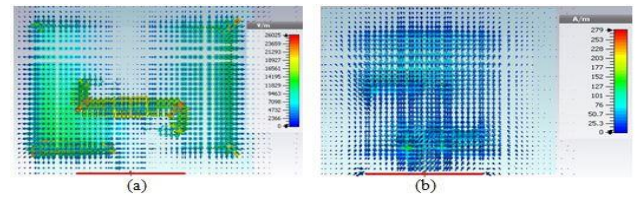


Figure 17. (a) & (b) Electric field & magnetic field Profile respectively of L shape at resonant frequency (2.45GHz).

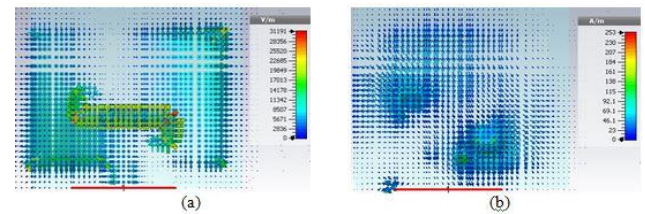


Figure 18. (a) & (b) Electric field & magnetic field Profile respectively of I shape at resonant frequency (2.45GHz).

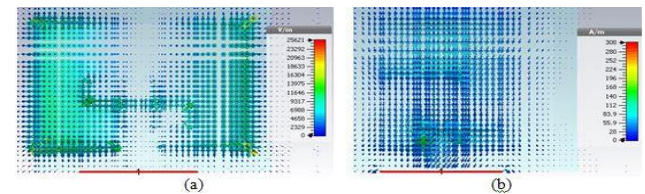
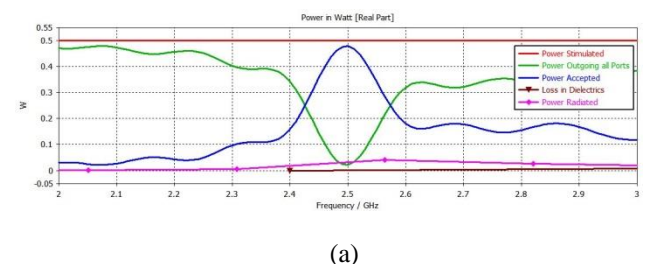


Figure 19. (a) & (b) Electric field & magnetic field Profile respectively of C shape at resonant frequency (2.45GHz).

Electric and magnetic field revealed from figure 17, 18, 19 and 20, it is clear that the results are validating the current distribution shown in figure 13,14,15 and 16.

E. Power profile of modeled antenna

The power profile of modeled antenna geometry is depicted in Figure 21(d). Accepted power of such geometry is maximum at resonant frequency (2.45GHz) while just opposite for outgoing power. The power radiated by the antenna is maximum at 2.56GHz approx. close to 2.45GHz depicted by the mark.



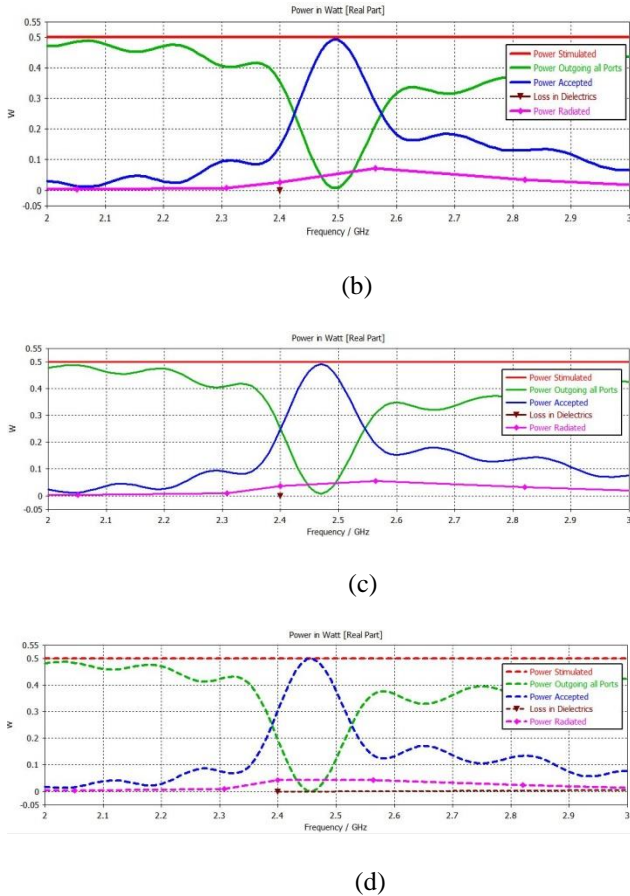


Figure 20. Power profile of (a) Square shaped spiral cut (b) Double I (c) Double L and (d) Double C.

The power profile as depicted in Figure 21 (a), (b), (c) and (d) are showing the power distribution on the port, power accepted and the power radiated by the antenna. The maximum values of power accepted and radiated are lying in frequency band of 2.4 GHz to 2.5 GHz, which is purely the part of ISM band.

VI. Conclusion

A complete strategy of ISM band antenna design for body centric wireless communication is developed. Starting from a wearable Square shaped spiral cut MSPA then after many other modified designs the précised and miniaturized Square shaped spiral cut MSPA with double C structure is achieved. Theoretical results are showing the good agreement with the simulated results. This antenna is showing -24dB reflection coefficient at 2.45 GHz (ISM band) for On-body communication in layered tissue model of electrical equivalent of human body. The volume of antenna is miniaturized (674.5 mm³) so that it can be easily used in body centric wireless communication devices. Square shaped spiral MSPA with double C structure is showing desired unidirectional radiation pattern and the main lobe magnitude is 7.84dbV/m with beam width 146.3⁰.

The impedance bandwidth of Square shaped spiral MSPA with double C structure is 60 MHz in ISM Band (2.4 to 2.5 GHz). Surface current distributions, E field, H field and power profile of proposed antennas are also analyzed in this paper. The miniaturized square shaped spiral

MSPA and its modified variations shows appropriate antenna properties for body centric communication in wearable applications.

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