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Design of a Skin Implantable Antenna with the Defective Ground Structure Aiming at the Reduction of Specific Absorption Rate

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***Abstract*— The development of Implantable Medical Devices (IMDs) is one of the most important aspects towards establishing an advanced health care system. Nowadays, the devices which are designed to monitor physiological data inside the human body have great promises to provide major contributions to disease prevention, diagnosis and therapy thus reducing hospitalization terms and improving the patient's quality of life.**

The proposed work is to design a Skin Implantable Antenna with the Defective Ground Structure aiming at the reduction of Specific Absorption Rate. The work comprises of a comparison made for three different defective ground geometries, Circular headed dumbbell, Folded structure and U-shaped structure with each of them having a rectangular patch as radiating element. Their performance has been analyzed in terms of Specific Absorption Rate, Effective Isotropic Radiated Power, Voltage Standing Wave Ratio, Return loss and Radiation efficiency by placing the antenna inside the skin model to operate at ISM band of 2.45GHz. The proposed work fulfills the requirements given by the International Telecommunication Union Standards for a Skin Implantable Antenna.

Keywords*— Defective ground structure, Specific Absorption Rate (SAR), Effective Isotropic Radiated Power (EIRP), ISM band, International Telecommunication Union Regulation Standards (ITU-R).

I. INTRODUCTION

The increasing demand for non-invasive surgical operations has made the use of Implantable Medical Devices (IMDs) as part of medical procedures highly attractive. Consequently, current invasive procedures to elicit physiological and biological data may be avoided by using implantable devices. Implantable antennas are electrically small antennas similar to typical antennas used for common wireless applications such as mobile phones, but with the additional complication that the implant will be located in a complex lossy medium. Most of the research on implantable antennas for medical purposes has focused on therapeutic applications such as hyperthermia, balloon angioplasty, etc. or on sensing applications. In both cases, the antennas works in its near field and propagation over a certain distance is not an issue.

In Biomedical Telemetry applications [3]-[16] on the other hand, the system is unlikely to be in the near field therefore it should have the capacity to transmit data over a longer distance. In this case, features like the radiation efficiency and the bandwidth are essential in order to provide transmission over a large enough range with a high enough data rate to be able to operate in wider environments like those experienced in the day-to-day life of the user. Currently, the application of the implantable antenna for building a communication link between the implanted devices and outside the human body is receiving more attention. As already mentioned above, the integrated implantable antenna is a key and critical component of RF-linked implantable medical devices, which enables bidirectional communication with the exterior monitoring/control equipment.

In this paper, the main aim is to reduce the Specific Absorption Rate in the implantable antenna which is a serious issue which is implemented by the Defective Ground structure, a recent ongoing development approach for designing low profile antennas such as microstrip and dielectric resonator antennas [17]-[21]. The paper also focuses on the implantable antenna complying with the antenna less than 1 m (Body area network antenna).

The defect in a ground is one of the unique technique to reduce the overall size of the antenna. So, antenna size with DGS is reduced for a particular frequency as compared to the antenna size without the defect in the ground.DGS is realized by introducing a shape defected on a ground plane thus will disturb the shielded current distribution depending on the shape and dimension of the defect The disturbance at the shielded current distribution will influence the input impedance and the control flow of the antenna. It can also control the excitation and electromagnetic waves propagating through the substrate layer. DGS have the characteristics of the stop band slow wave effect and high impedance. DGS is basically used in microstrip antenna for different applications such as antenna size reduction, cross polarization reduction, mutual coupling reduction in antenna arrays, harmonic suppression etc.

II. PROPOSED METHOD

The proposed work comprises of a comparison made for three different defective ground structure geometries, Circular head dumbbell, Folded structure and U-Shaped structure with each of them having a rectangular patch as radiating element to operate at the ISM band of 2.45GHz using the High Frequency Structure Simulator. SAR has been calculated by placing the antenna inside the skin model consisting of three layers the skin, the muscle and the fat content of thickness 2mm,20 mm and 3mm respectively. The SAR and EIRP values are found to be within the maximum limit provided by the ITU-R standards [2] for a Skin Implantable Antenna.

A. DESIGN OF RECTANGULAR PATCH ANTENNA AND THE DEFECTIVE GROUND STRUCTURE GEOMETRIES

The Rectangular patch antenna is designed using the formulas from Balanis [22]: The expression for ε_{reff} and change in length (ΔL) is given by Balanis as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\{1+12h/W\}^{-1/2}$$

where

ε_{reff} = effective dielectric substrate

ε_r = dielectric constant of substrate

h = height of the dielectric substrate

W = Width of the patch

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)((W/h) + 0.264)}{(\varepsilon_{reff} - 0.258)((W/h) + 0.8)}$$

The effective length of the patch L_{eff} now becomes,

$$L_{eff} = L + 2\Delta L$$

For a given resonance frequency f_0 , the effective length is given as:

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}}$$

For a rectangular Microstrip patch antenna, the resonance frequency for any TM_{mn} mode is given as:

$$f_0 = \frac{c}{2\sqrt{\varepsilon_{reff}}}\{ (m/L)^2 + (n/W)^2 \}^{1/2}$$

Where m and n are modes along L and W respectively.
For efficient radiation, the width W is given as:

$$W = \frac{c}{2 f_0 \sqrt{(\varepsilon_r + 1)/2}}$$

Table 1 has the proposed patch antenna dimensions and Fig 1 gives the design of the rectangular patch.

TABLE I

PROPOSED PATCH ANTENNA DIMENSIONS

PARAMETERS	DIMENSIONS
Operating frequency	2.45GHz
Width of the radiating patch	37.26mm
Length of the patch	28.83mm
Substrate used	FR4
Thickness of the substrate	1.6mm

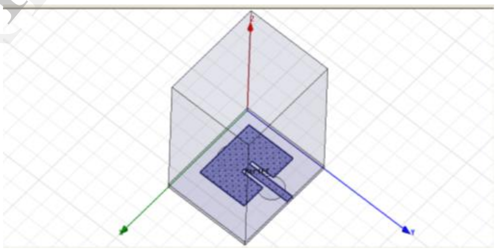

Fig 1. Rectangular patch as radiating element

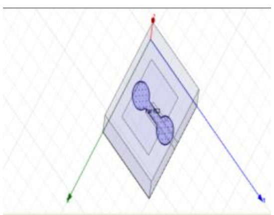

Fig 2. Circular head dumbbell

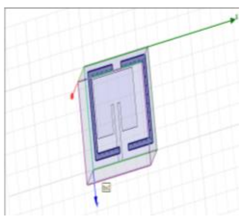

Fig 3. Folded structure

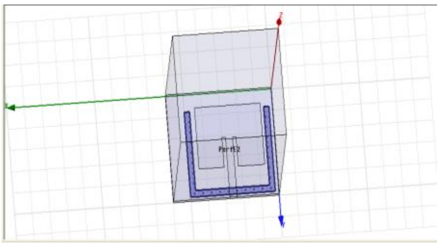

Fig 4 U-Shaped structure

TABLE 2
CIRCULAR HEAD DUMBBELL DGS DIMENSIONS

PARAMETERS	DIMENSIONS
Radius of circle	7mm
X-size and Y-size of the rectangle	5mm,14mm

TABLE 3
FOLDED DGS DIMENSIONS

PARAMETERS	DIMENSIONS
Length of folded DGS	X=2.5mm,Y=40mm
Width of the folded DGS	X=23mm,Y=3mm

TABLE 4
U-SHAPED DGS DIMENSIONS

PARAMETERS	DIMENSIONS
Length of folded DGS	X=2.5mm,Y=40mm
Width of the folded DGS	X=23mm,Y=3mm

The three defective ground structure geometries (Fig 2 ,3 and 4) have been designed with each of them having rectangular patch as an radiating element operating at 2.45GHz.Their dimensions have been tabulated (Table 2,3 and 4).
Step 1: The rectangular patch acts as the radiating element with inset feed provided at the patch (Fig 1).
Step 2:Either of the defects mentioned above is placed as the ground defect. Both the ground and the patch are assigned with the Perfect electric conductors (Perf E1 and Perf E2). (Fig 2,3 or 4).
Step 3: Waveport with the incident power of 1W is assigned at 21mm along the X-axis which is the default value provided by the software tool.
Step 4: Air box of 5cm is placed over the antenna and radiation boundary is assigned to it (Rad 1).
Step 5: Antenn is placed inside the skin model and their performance has been estimated.

III. ITU-R STANDARDS FOR A SKIN IMPLANTABLE ANTENNA

Wireless implantable devices operate in several frequency bands depending on the data rate, working range, power transfer capability, and the different standards of different countries. This project focuses on the EM radiation occurring in the 2.45 GHz ISM band. EIRP limitations and frequency spectrum allocations are reported based on the information available from ITU [2]. Power limitations are also set to prevent hazardous heating of the biological tissue. The maximum power for the transmission from any implantable device must comply with the peak spatial-average SAR limitations.

In the presence of biological tissues, the main drawback of the power dissipation in the lossy surrounding media is the generated heat which may be hazardous. The Specific Absorption Rate has therefore been introduced for the analysis of EM waves in biological tissues. The evaluation of SAR is a way to compute the dissipation of EM power per unit mass (with different averaging techniques or peak values),in order to estimate the heating of the tissues that may have harmful effects.

$$SAR = \frac{1}{2}\frac{\sigma}{\rho}|E|^2$$

Where
σ is the electrical conductivity of the tissue (S/m)
E is the RMS electric field
ρ is the sample density (Kg/m^3)

It depends on various factors such as

- The radiation characteristics (frequency, polarization, intensity),
- The characteristics of the biological object, geometry (size and shape) and the internal structure,
- The distance of the emission source of radiation and biological objects (near or far field) and
- The properties of the surrounding area.

The limitations of a skin implantable antenna operating at 2.45GHz are

- EIRP should be 20 dBm or 100 mW
- SAR per 1-g averaging should not be more than 1.6W/Kg according to the FCC limit.
- SAR per 10-g averaging should not be more than 2W/Kg according to the European union limitation.

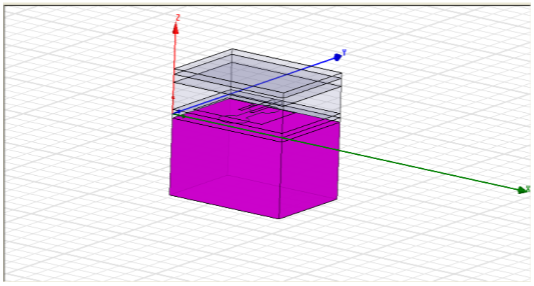

Fig 5 Muscle content of 20 mm thickness below the antenna design

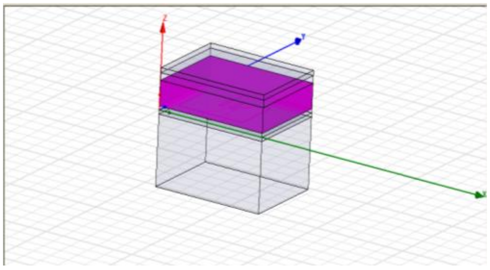

Fig 6 Muscle content of 10 mm thickness above the antenna design

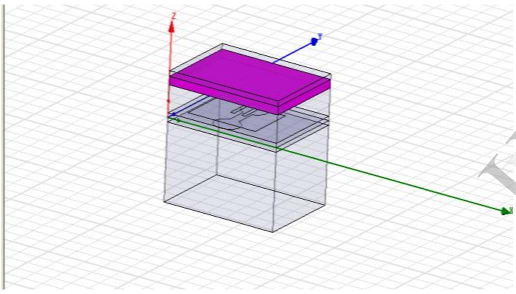

Fig 7 Fat content of 3 mm thickness

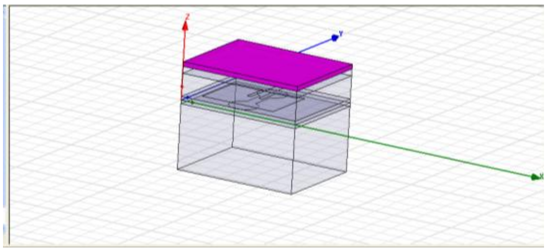

Fig 8 Skin content of 2 mm thickness

IV. PERFORMANCE ANALYSIS OF SKIN IMPLANTABLE ANTENNA WITH THREE DIFFERENT DEFECTIVE GROUND STRUCTURES

The performance of the antenna has been estimated in terms of SAR, EIRP, Return loss, VSWR and Radiation efficiency.

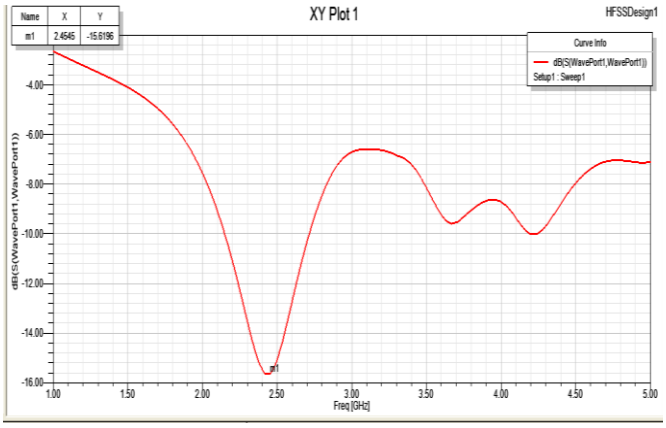

Fig 9 Return loss of folded structure as defective ground

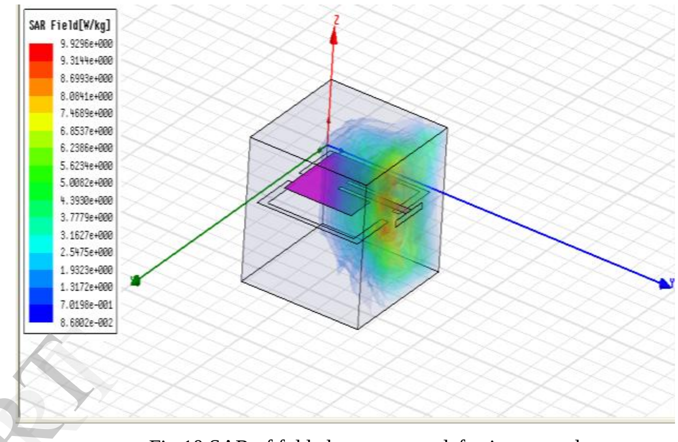

Fig 10 SAR of folded structure as defective ground

TABLE 5
RESULTS OF FOLDED STRUCTURE AS DEFECTIVE GROUND

PARAMETERS (at 2.45GHz)	VALUES
SAR	0.39 W/Kg
EIRP	22 dBm
RETURN LOSS	-15.61dB
VSWR	1.39
RADIATION EFFICIENCY	83.48%

Folded DGS placed beneath the patch perturbs the electromagnetic fields around them so that the trapped electric fields give rise to Capacitive effect(C) while the surface currents around the defect cause an Inductive effect(L) in turn results in resonant characteristics of a DGS. The folded DGS follows the boundary of the patch resulting in the rejection of the TM_{02} mode which is responsible for producing the XP radiations in the rectangular patch. It signifies suppressing the XP radiations in H-plane while leaving the primary radiation relatively unaffected. Thus providing a good return loss, VSWR < 2,SAR is low when compared to the maximum limit given by the European Union. EIRP of 22dBm which is 2dBm greater than the ITU-R standards for a skin implantable antenna.

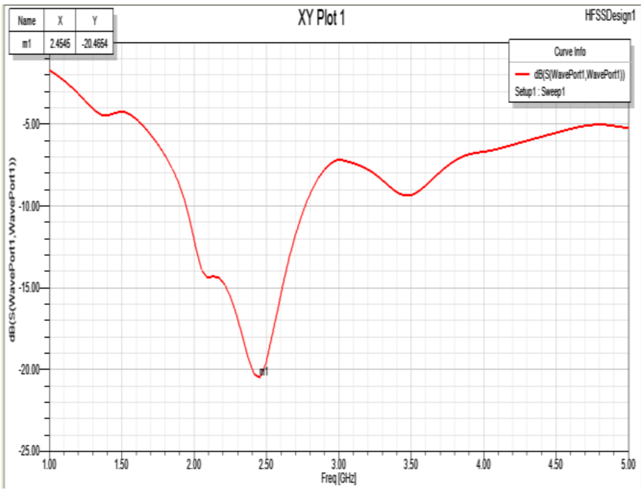

Fig 11 Return loss of the U-Shaped defective ground

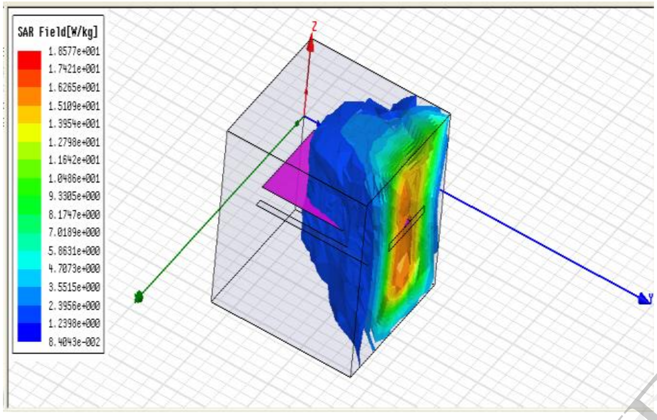

Fig 12 SAR of the U-Shaped defective ground

TABLE 6
RESULTS OF U-SHAPED STRUCTURE AS DEFECTIVE GROUND

PARAMETERS (at 2.45GHz)	**VALUES**
SAR	0.66 W/Kg
EIRP	16.9 dBm
RETURN LOSS	-20.46dB
VSWR	1.209
RADIATION EFFICIENCY	85%

Similar to the Folded DGS, the U-Shaped DGS placed beneath the patch perturbs the electromagnetic fields around the defect so that the trapped electric fields gives rise to the Capacitive effect(C),while the surface currents around the defect cause an Inductive effect(L) in turn results in resonant characteristics of a DGS. The folded DGS encloses the patch boundary completely but U-Shaped DGS encloses the boundary of the patch along the length completely and partially along the width so that the electric fields are not trapped together vey closely. It provides a return loss of -20.46 dB, VSWR < 2,SAR and EIRP satisfying the limit of ITU-R standards for a skin implantable antenna.

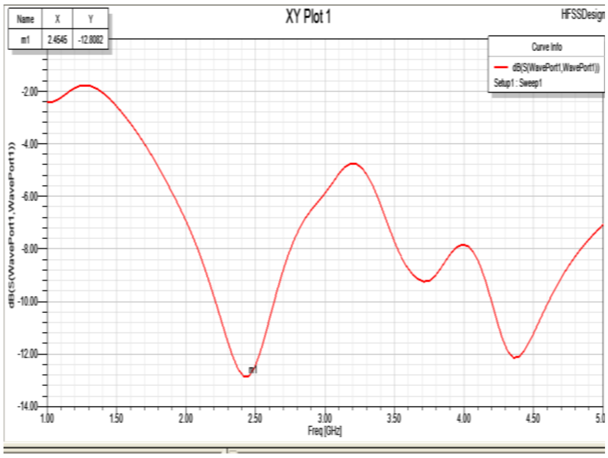

Fig 13 Return loss of the Cicular head dumbbell defective ground

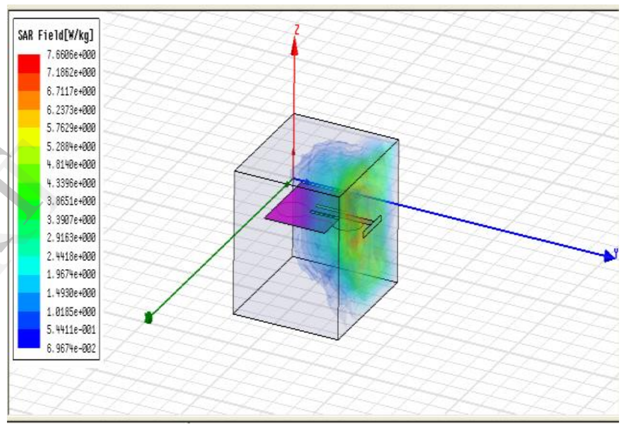

Fig 13 SAR of the Circular head dumbbell defective ground

TABLE 7
RESULTS OF CIRCULAR HEAD DUMBBELL STRUCTURE AS DEFECTIVE GROUND

PARAMETERS (at 2.45GHz)	**VALUES**
SAR	0.30W/Kg
EIRP	21 dBm
RETURN LOSS	-12.08dB
VSWR	1.59
RADIATION EFFICIENCY	85.2%

Similar to the Folded DGS, the Circular head dumbbell shaped DGS placed beneath the patch perturbs the electromagnetic fields around the defect so that the trapped electric fields gives rise to the Capacitive effect(C),while the surface currents around the defect cause an Inductive effect(L) in turn results in resonant characteristics of a DGS. The Circular head dumbbell area occupied is very less compared to the patch and the current distribution is only over that small area and the electric fields are not trapped together tightly across the boundary of the patch affecting the Capacitive effect in turn affecting the resonant characteristics. By viewing the return loss output(Fig 13) of the antenna is affected by unwanted distortions and not able to satisfy the band stop characteristics of a DGS. It results in high return loss in negative and the EIRP is not within the limit of the ITU-R standards for a skin implantable antenna.

V. COMPARISON OF RESULTS WITH THE ITU-R STANDARDS

Comparing the results of the three different defective ground structures, U-Shaped DGS, Folded DGS and Circular head dumbbell DGS, the comparison result shows that the U-Shaped defect which encloses the patch boundary along the length completely and partially enclosing the width of the patch tends to operate at ISM band of 2.45GHz without any unwanted distortions at the operating frequency thus providing a good return loss (Fig 11) and acceptable VSWR and the SAR (Fig 13),EIRP values lying within the limit of ITU-R standards for a skin implantable antenna.

TABLE 8
COMPARISON OF SAR BETWEEN DIFFERENT DGS SYSTEMS

PARAMETERS(at 2.45GHz)	ITU-R STANDARD (maximum limit)	FOLDED DGS	U-SHAPED DGS	CIRCULAR HEAD DUMBBELL
SAR (W/Kg)	2	0.39	0.66	0.30
EIRP (dBm)	20	22	16.9	21

VI. CONCLUSION

Skin Implantable Antennas with the three different defective ground structure geometries, Circular head dumbbell, Folded structure and U shaped structure are designed to operate at ISM band of 2.45GHz. The proposed antenna has measured dimensions of 37.26 X 28.83 X 1.6 mm. Their performance have been analyzed in terms of SAR, EIRP, VSWR, Return loss and Radiation efficiency to match the limit provided by the European Union given in the ITU-R standards for a skin implantable antenna.

Comparing the results of the three above mentioned ground defects the U shaped structure appears to be good for the skin implant as it gives SAR of 0.66W/Kg less than the maximum limit of 2W/Kg provided by the European Union given in the ITU-R standards, EIRP of 16.93dBm less than the maximum limit of 20dBm,VSWR of 1.209 less than the maximum value 2 ,Return Loss of -20.46 dB and 85% of Radiation Efficiency.

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