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Designing of Implantable Patch Antenna for Human Health Monitoring

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Abstract
This work represents the Implantable patch antenna that operates at Industrial and Scientific, as well as medical band (2.4GHz-2.48GHz) for human health monitoring. 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 patch antenna has a compact volume of 50 mm^3 (10mm×10mm×0.5mm). All the Simulations are carried out within homogeneous skin phantom and head scalp phantom. Miniaturization of antenna & Bandwidth enhancement is achieved by using various techniques described in this work. The proposed Implantable patch antenna has wide axial ratio bandwidth of 20.08% and 15.44% inside scalp phantom and homogeneous skin phantom, respectively. 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. Obtained impedance bandwidths are 59.09% and 44.53%, obtained reflection coefficients are -23.34 dB and -31.95 dB, inside scalp phantom and homogeneous skin phantom, respectively. At resonating frequency of 2.45GHz, obtained peak gain is -25.18 dB and -28.12 dB, respectively. For patient safety concerns, simulated maximized SAR values are also investigated and are coming under the IEEE standard limits. The allowable input power is also calculated in this work.
Keywords— *Defective ground structure, Specific Absorption Rate (SAR), Effective Isotropic Radiated Power (EIRP), ISM band, International Telecommunication Union Regulation Standards (ITU-R).*

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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. A Microstrip Patch antenna, in its most simple form, is formed of a radiating patch on one side of a dielectric substrate and a ground plane on the opposite, as shown in Fig.2.1. The patch is typically product of conductive metals like copper or gold and might be manufactured into any shape. 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 [4]-[9] 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 [11]-[15]. 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.

Patch antenna design equations

- ❖ Length of the Rectangular patch: $L = \frac{C}{2fr\sqrt{\varepsilon r}}$
- ❖ Width of the Rectangular patch: $W = \frac{C}{2fr\sqrt{(\varepsilon r+1)/2}}$
- ❖ Relative Dielectric constant: $\varepsilon e = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+\frac{10\hbar e}{W}\right)^{-1/2}$
- ❖ Fringing Length: $\Delta L = 0.412\hbar\,\frac{(\varepsilon eff+0.3)\left(\frac{W}{\hbar}+0.264\right)}{(\varepsilon eff-0.258)\left(\frac{W}{\hbar}+0.8\right)}$
- ❖ Effective Length of the Patch: $L_e = L + \Delta L$

Table 1-Characteristics of the different feed techniques

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture Coupled Feed	Proximity Coupled Feed
Spurious Feed Radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of Fabrication	Easy	Soldering & Drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (With impedance matching)	2-5%	2-5%	2-5%	13%

Table 2-Dimensions of the proposed antenna

Parameters	Value (in mm)	Parameters	Value (in mm)
lg	10	w2	1.6
lp	9.2	w3	1.8
ls	5	w4	0.2
l1	1	df	0.7

l2	0.4	ds	0.5
w1	5.4	(xf,yf)	(-3.05,0)

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.

$$\textbf{SAR} = (1\sigma/2)\,|\,\textbf{E}|^2$$

Where
σ is the electrical conductivity of the tissue (S/m)
E is the RMS electric field
ρ is the sample density (Kg/m3)

IV. SIMULATED RESULTS

All the simulations and results are obtained in the Ansoft HFSS software tool.

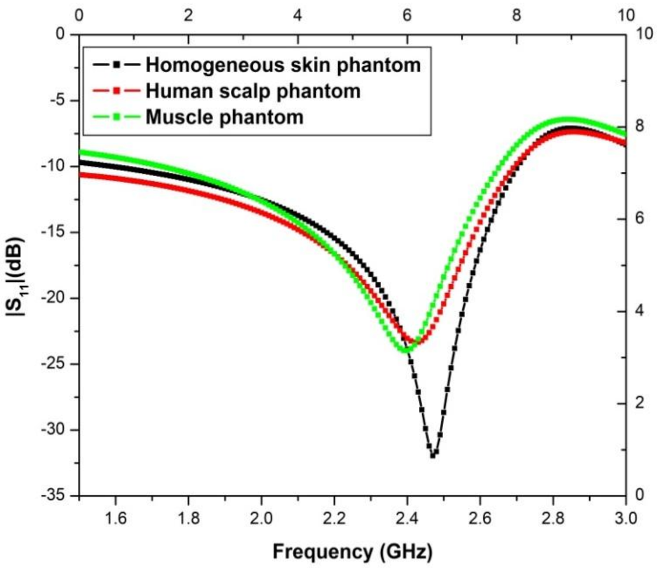

Fig.1 Reflection coefficient (dB) when antenna embedded at 4mm depth

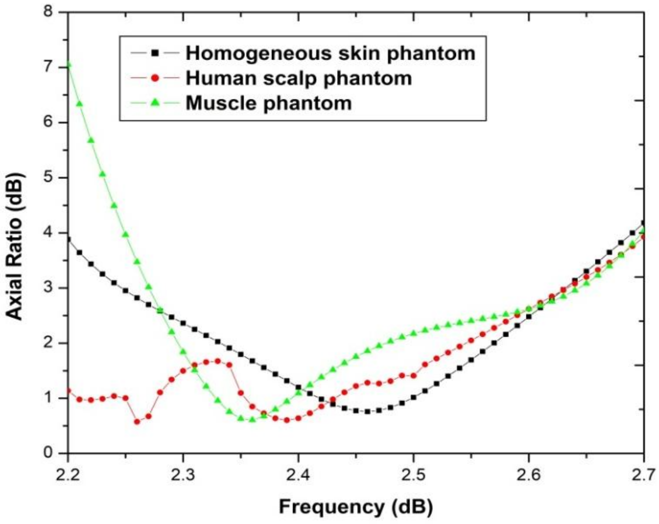

Fig.2 Axial Ratio (dB) when antenna embedded at 4mm depth

The obtained 3dB axial ratio bandwidth is 15.44% and 20.08%, respectively. The proposed antenna has a maximum peak gain of -25.18 dB at a resonant frequency of 2.47GHz inside homogeneous skin phantom and -28.12 dB at a resonant frequency of 2.42GHz in human scalp phantom.

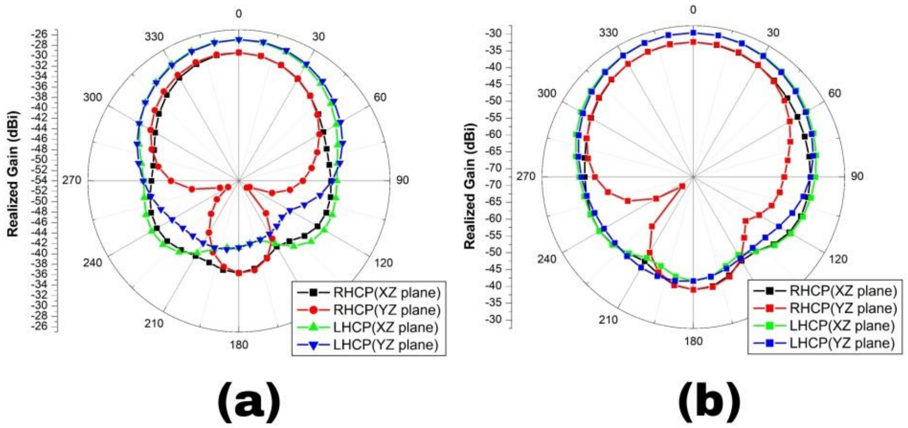

Fig. 3 Simulated Realized gain pattern (a) Skin phantom (b) Scalp phantom

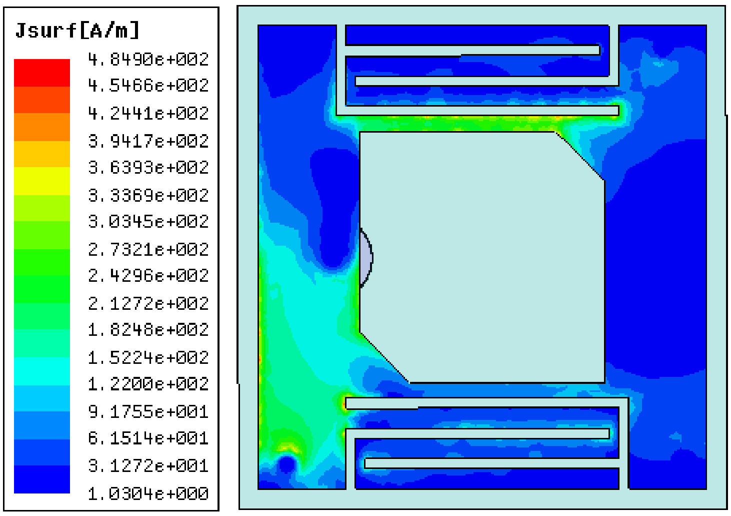

Fig. 4 Surface current density at 2.41GHz

According to IEEE standards, the maximum allowable SAR is 1.6W/Kg and 2W/Kg for 1g and 10g of human tissue, respectively. By maintaining the input power of 1W, simulated SAR values are 795.94W/Kg and 839.06 W/Kg for 1g of homogeneous skin phantom and human scalp phantom, respectively.

Table 3- SAR and input power for proposed antenna

Tissue	Frequency (GHz)	SAR(W/Kg)	Input power(mW)
Skin	2.41	795.94	2.01
Scalp	2.67	839.06	1.90

The measured percentage impedance bandwidth is 45.86% and the measured reflection coefficient is 30.19 dB in skin-mimicking solution. It shows the good agreement between the simulation results and measurement for the reflection coefficient and percentage impedance bandwidth.

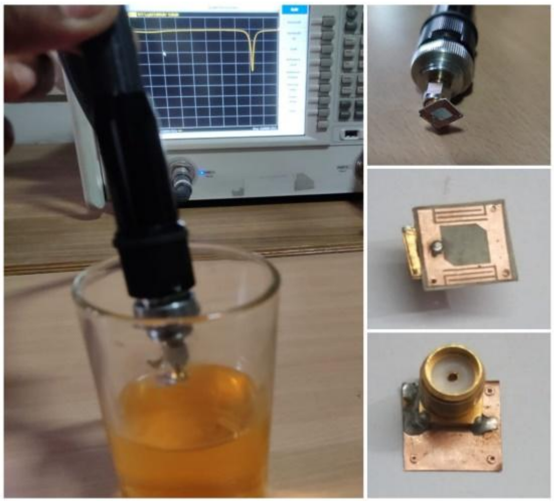

Fig.5 Measurement setup and environment for measuring the proposed antenna

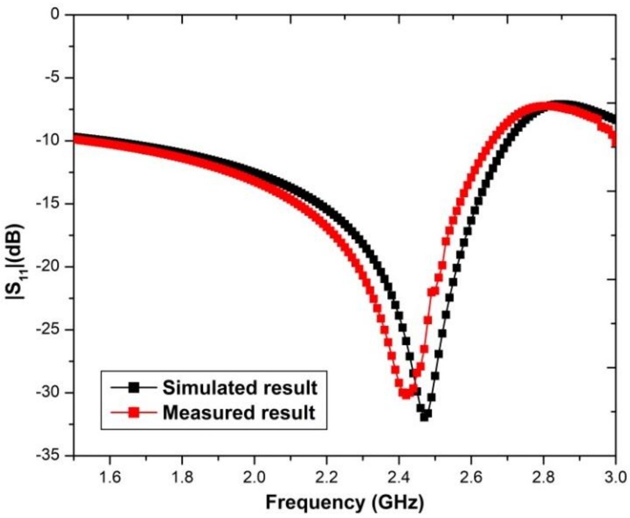

Fig. 6 Simulated and measured results (reflection coefficient)

V. CONCLUSION

A circularly polarised patch antenna, which is embedded into homogeneous skin phantom and human scalp phantom, operating in the ISM band (2.4GHz-2.48GHz)is presented in this paper. The miniaturization and bandwidth amplification are achieved by patch meandering, slot cut, introducing shorting pins. The proposed antenna has a stable radiation pattern and good impedance matching. A wide impedance bandwidth of 44.53% and 59.09% is achieved, for homogeneous skin phantom and human scalp phantom, respectively. The proposed antenna is encapsulated with a biocompatible material. Regarding patient safety, observations of SAR analysis concluded that SAR is under the limits of the IEEE standard, and the calculated input power for the proposed patch antenna is much greater than 25 μW considerable for biomedical implantable antenna applications.

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