DESIGN AND PERFORMANCE ANALYSIS OF IMPLANTABLE ANTENNA FOR POST-SURGERY TEMPERATURE MONITORING

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Abstract— This abstract offers a method for monitoring post-operative temperature: an implantable antenna. This innovation in medical monitoring technology enables medical staff to continuously and remotely check on patients' core body temperatures without the use of probes or additional equipment. The proposed hexagonal microstrip patch antenna is printed on a biocompatible Alumina 95.99% substrate which has a thickness of 1.5mmThe planned antenna is intended to function in the range of 5.74 – 5.87 GHz in the ISM radio band with -34dB return loss. According to the SAR analysis, the highest SAR values were less than 1.6 W/Kg for 1g of tissue and 2 W/Kg for 10g of tissue , It is the Federal Communication Commission's (FCC) is advised maximum margin.

Keywords- postoperative, implantable , monitoring,SAR.

I. INTRODUCTION

Recent advancements in medical technology have introduced innovative solutions for enhanced patient care and post-surgery monitoring. Among these breakthroughs is the utilization of implantable antennas for monitoring body temperature after surgical procedures. Maintaining the ideal body temperature is crucial for post-surgery recovery, as temperature variations can signal potential complications. This state-of-the-art technology offers a highly effective method for tracking patients' temperature internally. Integrated into the body during surgery, these miniature antennas operate wirelessly, eliminating the requirement for external sensors or cumbersome monitoring devices. One of the challenges with existing solutions for temperature monitoring is that they often rely on external sensors or devices, which can be inconvenient for patients, particularly those undergoing surgical procedures or intensive care. While some solutions use wireless temperature monitoring devices that transmit data externally, they may lack accuracy and reliability, especially when precise temperature monitoring is critical. Additionally, these external methods may not provide continuous monitoring, which could result in gaps in data collection and compromise patient care. Furthermore, the need for frequent manual measurements with traditional methods can be labor-intensive for healthcare providers and may delay the detection of sudden changes in temperature, which could be critical in identifying conditions such as sepsis or hyperthermia.The implantable antenna facilitates uninterrupted and real-time temperature monitoring, seamlessly integrated into the patient's body without causing any discomfort or inconvenience. This advanced technology empowers healthcare providers to closely observe temperature trends, facilitating swift intervention when any irregularities arise. Biomedical engineering demands compact and effective antennas for implantation within or around biomedical devices [5]. Yet, the diverse composition of body tissues [6] can induce attenuation, diminishing both efficiency and bandwidth. The primary hurdle in antenna design lies in achieving small size without compromising radiation performance. Addressing this challenge necessitates striking a balance between size and radiation properties. Particularly for high temperature sensing applications, the primary drawback of invasive temperature sensing addresses is the possibility for high installation and maintenance costs linked to the cable connections. On the contrary, noninvasive ways of monitoring temperature, such acoustic and infrared thermography, enable remote temperature readings without any requirement for direct physical contact.

This study's primary goal is to examine multiple factors influencing the design, optimization, and evaluation of implantable antennas dedicated to monitoring post-surgery temperature. Through a thorough examination of these elements, our goal is to enhance implantable medical device technology and ultimately enhance patient care and outcomes within the healthcare sector.

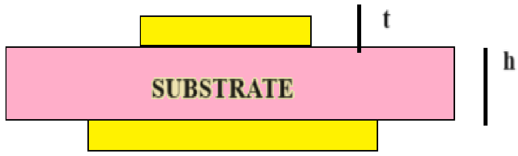

Fig 1. Schemetic view of proposed antenna

I. DESIGN OF ANTENNA

A. SIMULATION TOOL

Antennas customized for biomedical applications can be designed and simulated using a variety of software programs. IE3D software for 3D and planar microwave circuit analysis and design; CST Microwave Suite, a computational tool for electromagnetic design and analysis; Yee's technique, commonly referred to as Finite-Difference Time-Domain (FDTD) or High Frequency Structure Simulator, a popular commercial finite element method solver for electromagnetic structures; and FEKO software for field calculations involving arbitrary-shaped bodies are a few examples of these. In this study, the hexagonal microstrip patch antenna is crafted utilizing CST Microwave Suite.

B. ANTENNA STRUCTURE

Implanted antennas must be designed to be as tiny as feasible while maintaining biocompatibility and minimal intrusion, due to the restricted space within the human body. The geometrical configuration of the proposed hexagonal patch biocompatible antenna, fed by 50-ohm microstrip line, is displayed in Fig 1. The incorporation of two rectangular strips allows for operation at the specified frequency. The essential idea behind antenna shrinking is that a lower directed wavelength, or smaller size and narrower bandwidth, are caused by a high relative permittivity of the substrate Hence, the hexagonal patch is constructed using a biocompatible Alumina 95.99% substrate with a thickness of 1.5 mm and a dielectric constant of 9.8.

Proposed antenna is small enough for medical applications, measuring 28x24x1.57 mm^3. The figure shows the specific specifications of the suggested implanted antenna. The surrounding medium is taken into account throughout both the modeling and measurement operations because of its intended implantation within human skin. To determine the specific absorption rate, the antenna is positioned inside the human body in a manner similar to the phantom model depicted in Figure 10 and is simulated in CST. The antenna's hexagonal patch has a radius of R, while Table I lists the other dimensions. The suggested hexagonal microstrip patch antenna's step-by-step process is depicted in Figs. 3(a) through 3(c).The corresponding S11 plot that was obtained at each phase is also included.

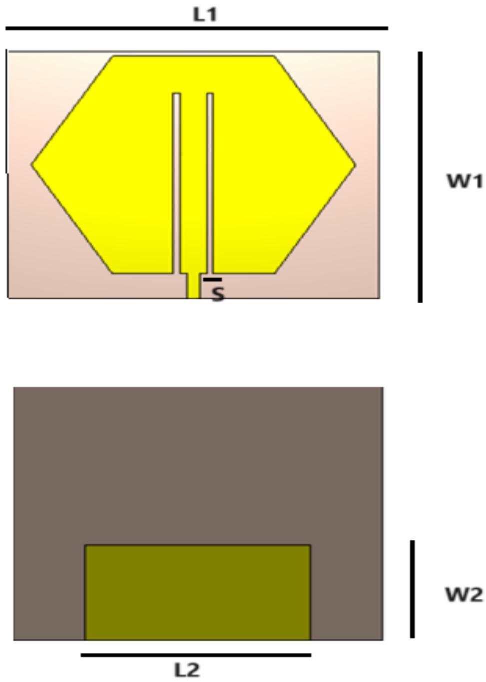

Fig 2. Front view and Back view of the proposed antenna.

TABLE I. DIMENSIONS OF PROPOSED ANTENNA DESIGN

PARAMETER	*VALUE (mm)*	*PARAMETER*	*VALUE (mm)*
W1	24	R	12.2
L1	28	S	0.5
W2	9	t	0.035
L2	17	h	1.5

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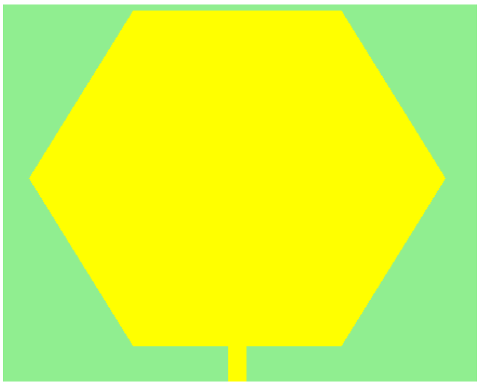

Fig 3a (i) Step 1

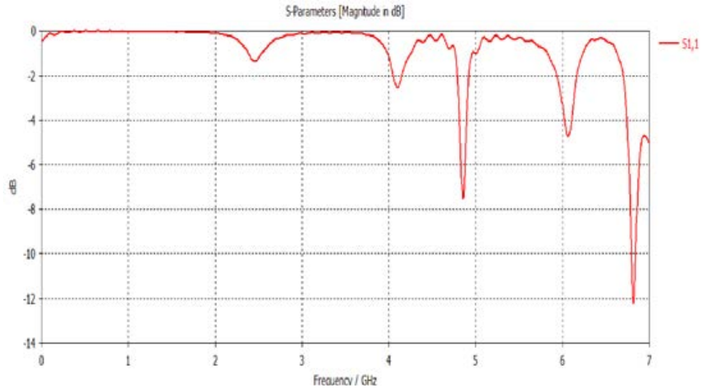

Fig 3a (ii) Result 1

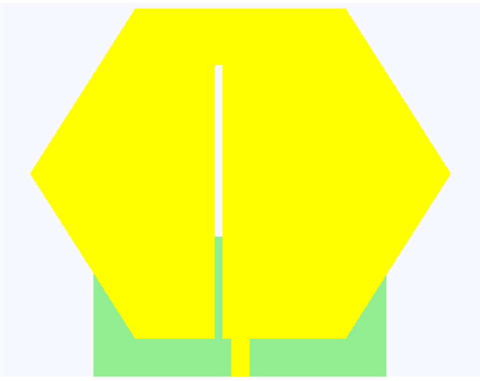

Fig 3b (i) Step 2

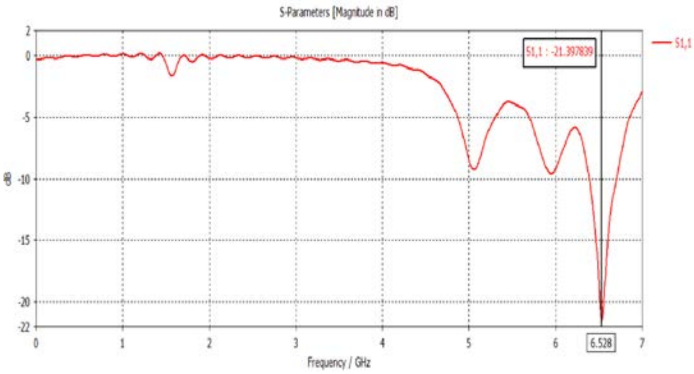

Fig 3b (ii) Result 2

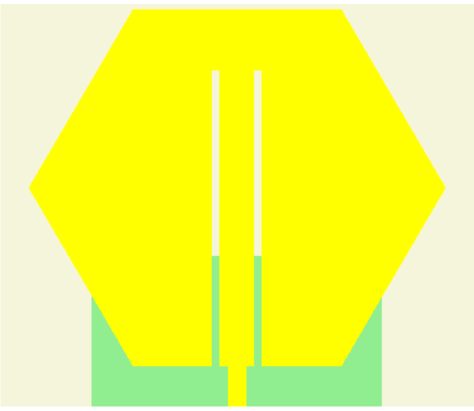

Fig 3c (i) Step 3

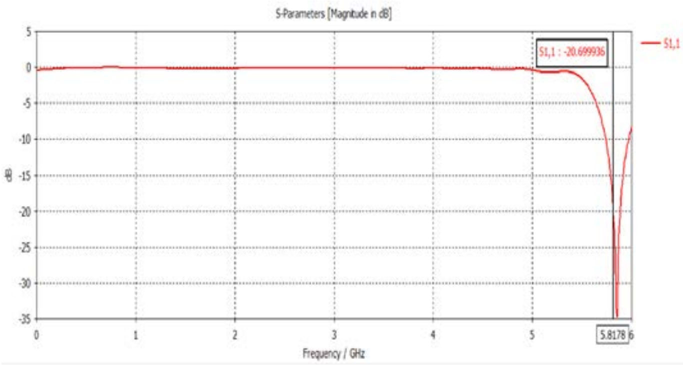

Fig 3c (ii) Result 3

The antenna's design progression, as depicted in Figures 3(a)-3(c), underwent iterative enhancements. Initially, resonance challenges occurred at the intended frequency due to a full ground plane. To mitigate this issue, the length of the ground plane was decreased, and additional strips were gradually

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incorporated from step 3a to step 3c. Ultimately, the third iteration achieved the desired frequency response within the range of 5.74-5.87GHz.

II. SIMULATION RESULTS

A. RETURN LOSS

To gain a deeper understanding of the proposed Hexagonal microstrip patch antenna, a parametric investigation was conducted by adjusting several antenna parameters [4]. The analysis focused on substrates with a permittivity value below 10.2, and the comparison is illustrated in Fig. 5. Taconic (εr = 10), Alumina 95.99% (εr = 9.9) (as used in the proposed work), Rogers R03010 (εr = 11.2), FR-4 (εr = 2.2), and Rogers R03210 (εr = 10.8) were selected for this examination. As depicted in Fig. 4, the calculated S11 values for the aforementioned substrates are -41dB, -34dB, -22dB, -0.7dB, and -26dB, respectively. On the basis of feasibility and performance analysis Alumina 95.99% is selected as substrate.

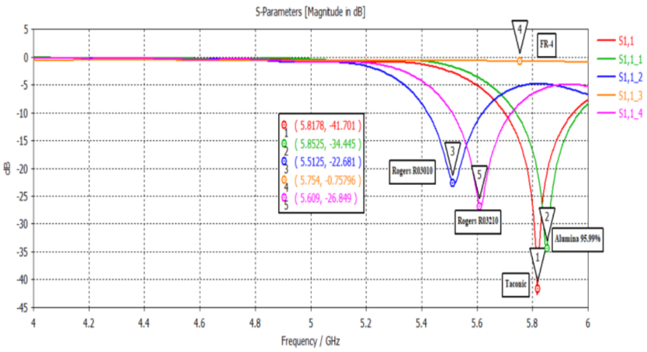

Fig 4. Simulated S11 for the proposed microstrip antenna for different Substrates.

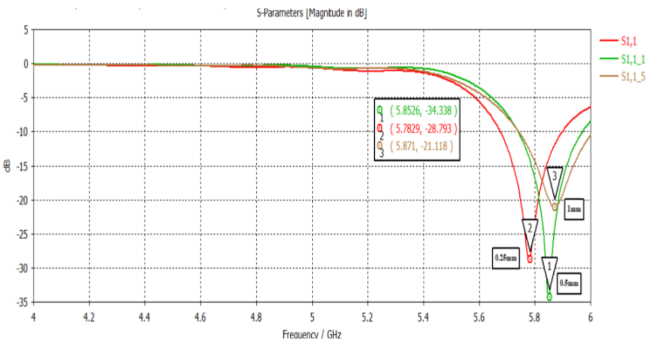

Fig 5. Simulated S11 for the proposed microstrip antenna for different S values .

The simulated S11 for the suggested microstrip antenna across a range of S values is shown in Fig. 5. S values of 0.5mm (as used in the suggested work), 0.25mm, and 1mm were investigated for analysis. Results show that a rectangular strip cut width of S = 0.5mm produces a return loss of -34dB together with the intended frequency response.

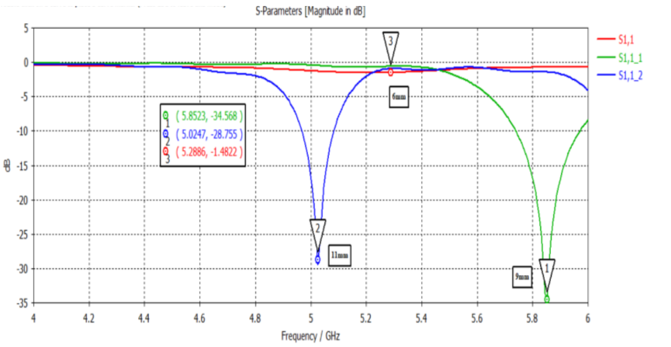

Fig 6. Simulated S11 for the proposed microstrip antenna for different W2 values.

The Ground width W2 analysis performed for values of 6mm, 11mm, 9mm (proposed work).As illustrated in the Fig 6 ,the W2 = 9mm produces the required frequency response at 5.85 GHz.

B. VSWR

Implantable antennas for medical devices typically operate with a 2:1 VSWR (Voltage Standing Wave Ratio), optimizing power transfer efficiency and mitigating signal loss caused by reflection. While attaining a perfect 1:1 VSWR entails expensive and intricate manufacturing processes, opting for a 2:1 VSWR provides resilience to human body variations and facilitates practical design and fabrication. The achieved VSWR for the designed hexagonal microstrip antenna is depicted in Fig 7.

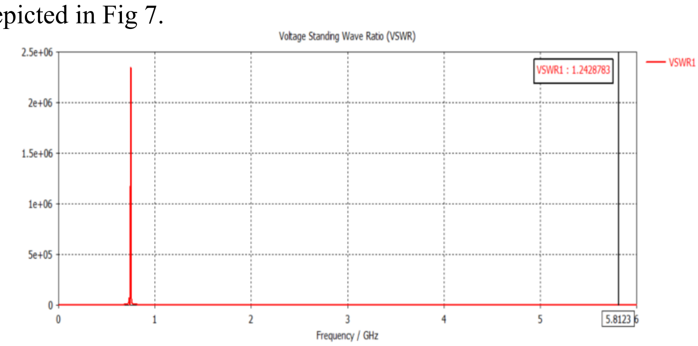

Fig 7. VSWR

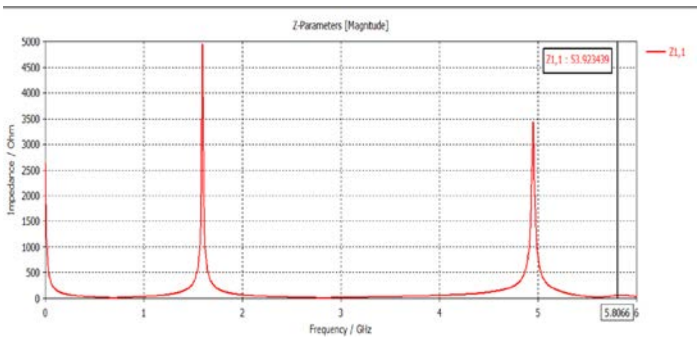

Fig 8.Z11 PARAMETER

C. Z11

The antenna's impedance parameters play a vital role in determining its radiation efficiency. When there's a mismatch between the proposed SC4antenna's impedance and the system's impedance, it can result in energy losses and decreased radiation efficiency. At the desired frequency, the antenna's impedance (Z11) is measured at 53 ohms, which closely aligns with the ideal impedance match of 50 ohms. This close match facilitates maximum power transfer from the feeding system to the antenna, optimizing its performance.

D. GAIN

The hexagonal microstrip patch antenna, designed to operate within a tissue model, achieves consistent far-field gain across its entire bandwidth, as depicted in Figure 9. This performance is observed at a frequency of 5.8 GHz.The proposed antenna attains gain value of 4.7dBi at 5.8GHz and a bandwidth of 280MHz.

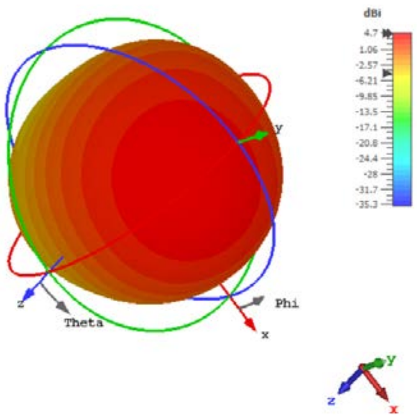

Fig 9a. 3D Radiation pattern

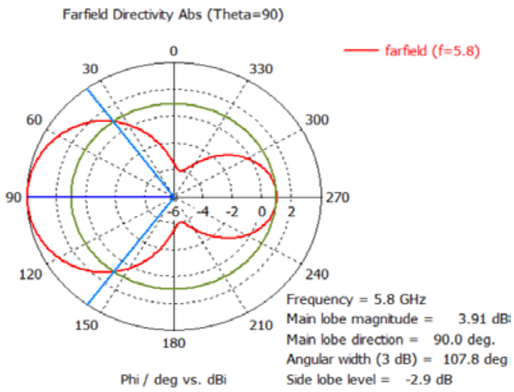

Fig 9b. Polar Radiation pattern (theta=90)

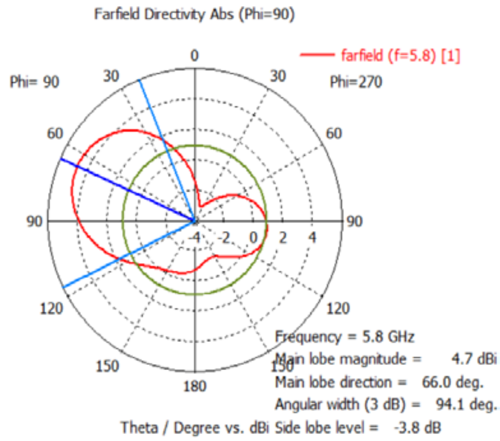

Fig 9c. Polar Radiation pattern (phi=90)

III. SAR ANALYSIS

It is essential to perform Specific Absorption Rate (SAR) evaluations while building implantable antennas to monitor post-surgery temperature in order to guarantee that the electromagnetic energy absorbed by tissues is safe. For this reason, Computer Simulation Technology (CST) is an invaluable tool that makes it easier to do SAR analysis to assess the safety of the implantable device. To simulate the anticipated environment of the designed antenna within the human body, a homogenous tissue model is used in CST Microwave Studio. Figure 10 shows the three-layered tissue model; Figure 10 also shows the simulation environment and a side view of the tissue model [3]. The tissue model's overall dimensions are 45 mm x 45 mm x 16 mm³.

The image gives general idea of the structure of the skin, muscle, and fat, among other layers, each of which has unique electrical characteristics. Additionally, it displays a study on Specific Absorption Rate (SAR), highlighting the negative effects of placing an antenna within a person. The SAR analysis is important as it plays vital role in performance of the antenna. The permittivity, thickness, and conductivity of every tissue layer are shown in Table II. SAR analysis is shown in Fig. 11 when the antenna is left inside the phantom tissue. The results indicate that the maximum SAR obtained for 10g and 1g tissues, respectively, is 0.914W/Kg and 1.3W/Kg, meeting the FCC limit of 2W/Kg for 10g and 1.6W/Kg for 1g [1].

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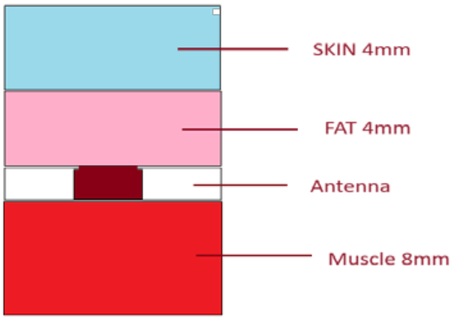

Fig 10. Represents placement of proposed antenna inside the Tissue layers

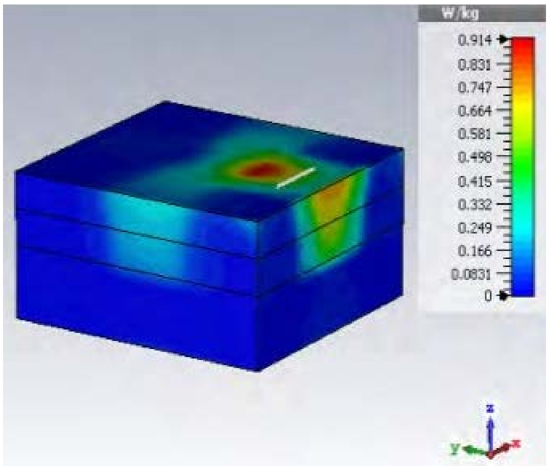

Fig 11. SAR analysis

TABLE II. ELECTRICAL PROPERTY OF DIFFERENT LAYERS OF HUMAN BODY

Tissue Layer	***Permittivity value***	***Conductivity value***	***Thickness (mm)***
SKIN	37.02	2.02	4
FAT	5.18	0.16	4
MUSCLE	51.45	2.56	8

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V. CONCLUSION AND DISCUSSION

The process of creating a miniaturized antenna is described, which involves analyzing factors such as ground analysis and substrate selection, including its permittivity. Through experimentation, it is determined that the proposed antenna functions effectively within the 5.74-5.87 GHz ISM band. The obtained VSWR value 1.24 and Z11 value 53 states that the reflection of power from antenna is less and better overall system performance. The designed hexagonal antenna provides a gain of 4.7 dB. Simulation tests are conducted using a tissue model, demonstrating consistent results both with and without the tissue phantom, indicating accurate performance. By analyzing the Specific Absorption Rate values averaged over 1g and 10g of tissue, human safety concerns are taken into account. For 10g and 1g of tissue, the measured SAR values were 0.914W/Kg and 1.3W/Kg, respectively ,affirms that the designed hexagonal patch antenna can be used for biomedical applications.

A. COMPARE WITH EXISTING SYSTEM

III. COMPARISON WITH EXISTING SYSTEM

Ref	Substrate	Dimensions	Operating frequency	Bandwidth	SAR(1g) W/Kg
[15]	FR-4	20x30x0.536	2.4GHz	93.7MHz	0.662
[16]	RT6010	5x5x0.528	2.4GHz	65MHz	340.4
Proposed System	Alumina	28x24x1.57	5.8GHz	280MHz	0.914
[19]	FR-4	54.5x50.1x1.67	2.4GHz	190MHz	unknown

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