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Design of 1.4 GHz WMTS Band Implantable Antenna and Performance Measurement for Bio-Telemetric Applications

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ABSTRACT: In this paper, the design and validation of an implantable antenna which is applicable to biotelemetry services is presented. This proposed antenna operates in the wireless medical telemetry service (WMTS) frequency band of 1.39–1.4 GHz. As compared to other contemporary antennas, this design provides better gain of -31 dB and reflection coefficient of -20.2 dB with better safe limit of specific absorption rate (SAR). At the resonating frequency of 1.4 GHz, the intended antenna provides good radiation and gain characteristics. The VSWR parameter for this designed antenna has been obtained as 1.25 which promises for proper impedance match. The designed antenna has been fabricated and validated with tissue mimic liquid-phantom to make sure the suitability for implantation. The simulated measurements have a close agreement with the experimentally measured results.

1. INTRODUCTION

Due to the growing need for continuous and remote patient monitoring of physiological data, implantable medical devices (IMDs) have attracted a lot of interest in research. Among the many uses for IMDs are disease diagnosis, ongoing patient monitoring, athlete performance evaluation, and more [1]. Different kinds of implantable devices with varying uses include temperature monitors, blood glucose sensors, cardioverters, pacemakers, defibrillators, and others. For continuous remote patient monitoring, however, biotelemetry systems must be installed in IMDs and monitoring centers [2]. The biotelemetry system is in charge of transmitting the physiological signal that the IMD has stored and facilitating communication between the IMD and monitoring center. Due to its higher data rate, wider communication range, affordability, adaptability to changing needs, and other advantages, antenna-based biotelemetry systems are becoming more and more common than inductive biotelemetry systems [3]. IMDs use a variety of antenna types, including helical antennas, microstrip antennas, planar inverted-F antennas antennas (PIFAs) [4, 21], and others. Because IMDs are limited in size, the implantable antenna needs to have a smaller construction. Furthermore, the antenna must have strong radiation performance throughout one or more frequency bands designated for biomedical use. The International Telecommunication Union (ITU) recommends almost six frequency bands for implantable antenna design, and the Federal Communication Commission (FCC) subsequently approves these recommendations. The industrial, scientific, medical (ISM) frequency band (433–434.8 MHz, 902–928 MHz and 2.4–2.48 GHz), the WMTS (wireless medicine telemetric service) frequency band (1.39–1.42 GHz), and the MICS (medical implants communication service) frequency band 402–405 MHz, and Med Radio frequency band (401–406 MHz) [5–8]. The WMTS spectrum is utilized for patient health monitoring that is done remotely. Devices that check the vital signs of patients and other significant health metrics like respiration and pulse rate are included in wireless medical telemetry systems. After that, the observed information is sent across a radio link to a distant location — such as a medics' station or to the concerned physician, that is outfitted with a specialized radio receiver. For instance, patients are frequently observed after surgery with wireless cardiac monitors. The antenna performance must be evaluated in both free space and phantom models for biotelemetry and implantation applications. For an antenna to be implanted, it must have both biocompatibility and good radiation performance. The antenna's biocompatibility and patient safety are determined by the specific absorption rate (SAR) computation within the model. This paper proposes an implantable small WMTS band antenna for biotelemetry applications. The suggested antenna is created and analyzed simulatively. Next, taking into account the implantation setting, the antenna's performance is assessed in a liquid phantom model that mimics tissue.

2. DESIGN OF PROPOSED ANTENNA

2.1. Geometry of the Antenna

The computer simulation technology (CST) studio suite software is used to develop and simulate the suggested antenna. The antenna measures $(20.2 \times 14.8)\,\text{mm}^2$. Figure 1 shows the suggested design's front and back views. The substrate layer is a 1 mm thick layer of Rogers RO-3006 that is engraved on a ground plane with a dielectric constant ($\varepsilon_r = 10.2$) and a dielectric loss ($\tan\delta = 0.0035$). The goal of the superstrate layer, which is a 0.635 mm thick layer of Rogers RT 6010 with the same dielectric constant and dielectric loss as of substrate,

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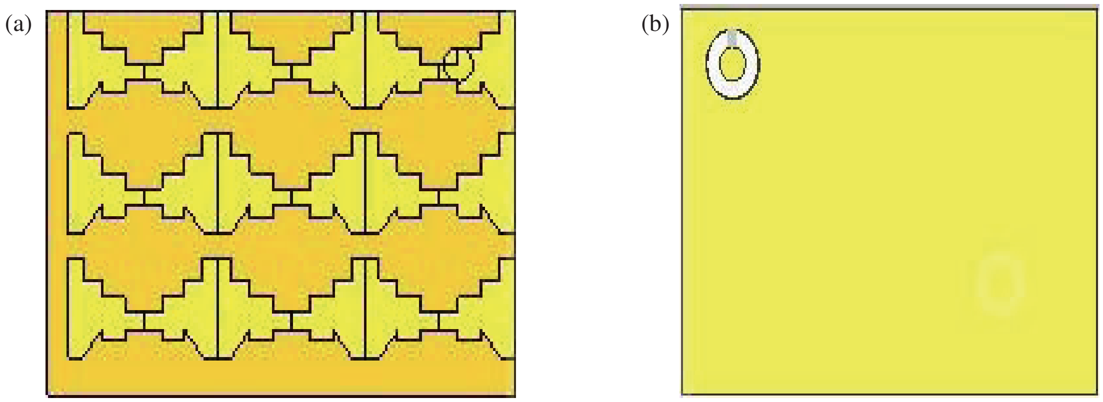


FIGURE 1. Design of the antenna (a) Front view and (b) Back view.

TABLE 1. Dimensions of the design.

Label	Dimension (mm)	Label	Dimension (mm)
l	14.8	f	0.4
b	20.2	g	5.2
a	3.6	h	0.4
c	0.9	i	1.2
d	0.6	j	1.6
e	0.8	k	1.4 (diameter)

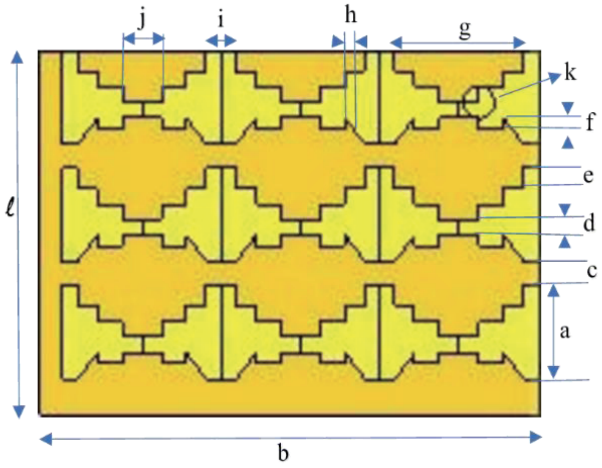


FIGURE 2. Label for the dimensions of the antenna.

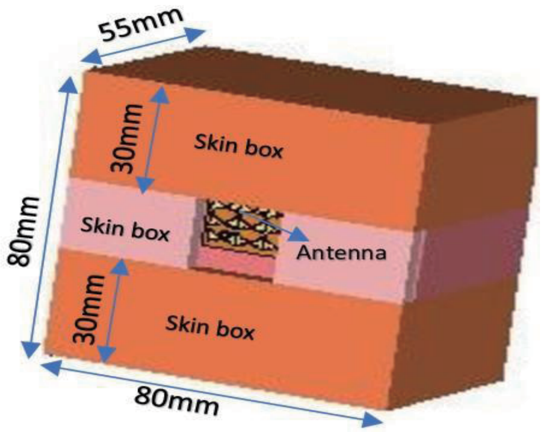


FIGURE 3. Skin box environment for antenna design.

is to prevent short circuiting with the human body's tissues after implantation.

Radiofrequency and commercial microwave applications are a great fit for Rogers RO3006 laminates. Dielectric constants do not need to be adjusted because of their superior mechanical and electrical qualities. Engineers can create multi-layer boards with several layers since they are also superior insulators. For radiofrequency (RF) and microwave applications, this makes it an excellent option.

By this way, the design of proposed antenna was done in CST software with the proper dimensions as shown in Table 1, and Figure 2 shows the label for such dimensions.

2.2. Design Environment

In the CST tool, first, a cubic radiation box $(90 \times 90 \times 90)\,\text{mm}^3$ was taken in which a skin box of volume $(80 \times 80 \times 55)\,\text{mm}^3$ was selected. Second, the above said antenna design was done in the middle of skin box as shown in Figure 3. The dielectric constant of skin tissue at 1.4 GHz is 39.6, and the conductivity is 1.036 s/m [23]. This arrangement of design inside the skin box is to replicate the behavior of implantation of antenna in human body. Finally, a feed line or port (labeled as 'k' in Figure 2) was set at the back side of design which is for connecting to the measuring device. For biometric applications, the design of antenna in a skin or bio-tissue environment is quite suitable.

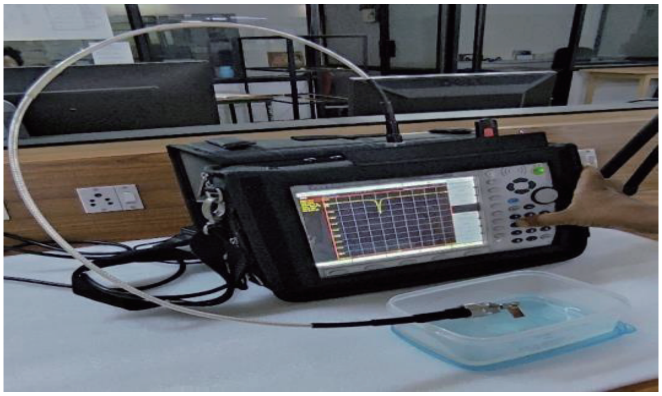


FIGURE 4. Reflection coefficient measurement using VNA.

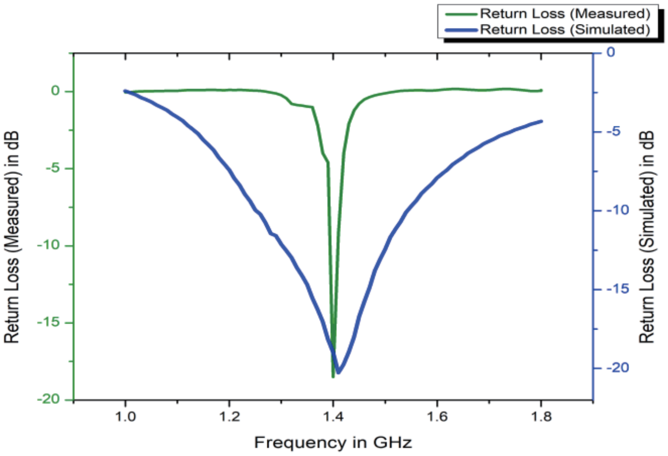


FIGURE 5. Reflection coefficient of the proposed antenna.

3. SIMULATION AND EXPERIMENTAL MEASUREMENT

The CST studio suite software tool has been employed for simulative measurement of the antenna parameters such as reflection coefficient, radiation pattern, bandwidth (BW), realized gain, and voltage standing wave ratio (VSWR).

For experimental measurements, first, the fabrication of our designed antenna was done. Second, a tissue mimic liquid phantom was prepared by mixing agarose (1%), sugar (39%), salt (1%), and distilled water (59%). This liquid phantom is considered as an equivalent to muscle tissue, and so with the proper replication behavior inside the human body, the validation of our implantable antenna could be done [9, 10]. High water content tissues, such muscles and other bodily parts, have highly electrical characteristics. Using water as the primary source of high permittivity in materials used to create artificial tissue phantoms is one method of closely imitating such tissues by using it as the foundation for liquid mixtures [11]. Along with this, a vector network analyzer (VNA) (Anritsu-MS2027C) was used as the measuring device. Now, let us discuss the simulative and experimental measurement of specific designed antenna's parameters in this section.

3.1. Reflection coefficient and BW

The prepared tissue mimic liquid was taken in a beaker of 500 mm^3. The fabricated antenna's port was connected to the VNA through a probe, and the antenna was immersed in that beaker containing liquid phantom as shown in Figure 4. Now the frequency tuning was made to fix at the desired WMTS frequency band.

The reflection coefficient or return loss is denoted by $|S_{11}|$, which stands for how much the power or energy reflected from the utilized antenna. When $|S_{11}| = 0$ dB, the antenna radiates nothing and so no loss of power. The suggested antenna's performance is assessed in CST simulation. The proposed design resonates at the 1.4 GHz frequency WMTS band, and at that frequency, the simulative reflection coefficient is -20.2 dB. Here, a -10 dB impedance bandwidth of 234 MHz between 1.302 GHz and 1.536 GHz has been attained. Figure 5 shows the curve of the reflection coefficients (simulated and measured) versus frequency. By this curve, it is observed that the simulated reflection coefficient value of -20.2 dB is almost close to the measured reflection coefficient value of -19 dB.

3.2. Radiation Pattern and Gain

The radiation pattern of the antenna points how energy or power is received by it or radiated out. Figure 6 displays the radiation pattern of proposed simple geometrical implantable antenna measured in an anechoic chamber which is a room for electromagnetic measurements without any unwanted reflections or echoes. Such measured omnidirectional pattern suggests that the antenna can cover a wide range of signal locations.

The antenna's gain quantifies or forecasts its performance [12]. The capacity to efficiently guide the quantity of radiated power when the antenna is pointed in a certain direction is known as the gain. Human bodily tissues are a lossy material that creates tight closeness and, as a result, negative gain. The radiation detected when the antenna is mounted on the phantom model points in the direction of the body because of the negative gain brought on by the dissipative behavior of the surrounding human tissue. As seen in Figure 7, the realized gain achieved in the planned antenna is -31.4 dBi. Additionally, the structure's compactness results from the negative gain and satisfies the implantation needs. Figure 8 represents the 3D pattern of the simulated realized gain. Figure 9 shows the measurement of gain experimentally in an anechoic chamber. Such measured gain vs frequency curve is shown in Figure 10 in which the -33 dB gain of designed antenna is observed at 1.4 GHz. Hence, the observed and simulated gain parameters are closely matched.

3.3. VSWR and SAR

The evaluation of a power source's radio frequency power transmission efficiency is done using the voltage standing wave ratio, or VSWR. The voltage ratio of the signal induced by a

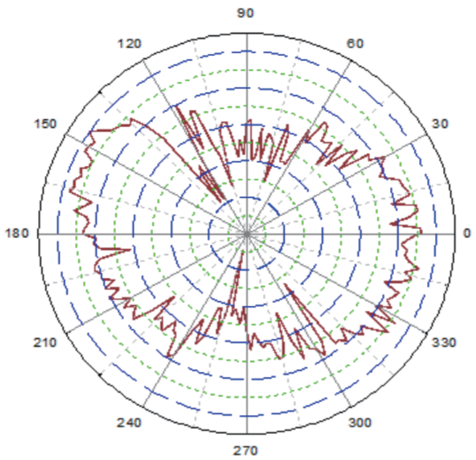
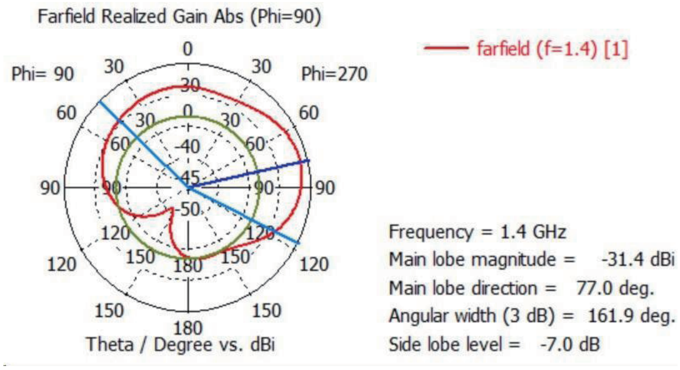


FIGURE 6. Radiation pattern (measured).



Frequency = 1.4 GHz
Main lobe magnitude = -31.4 dBi
Main lobe direction = 77.0 deg.
Angular width (3 dB) = 161.9 deg.
Side lobe level = -7.0 dB

FIGURE 7. Realized gain pattern (simulative).

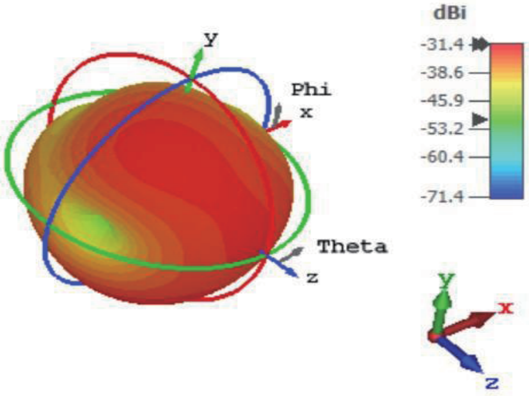


FIGURE 8. Realized gain 3D-pattern (simulative).

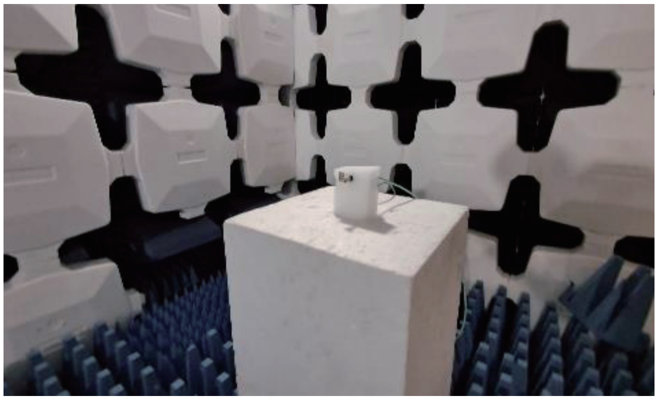


FIGURE 9. Measurement at anechoic chamber.

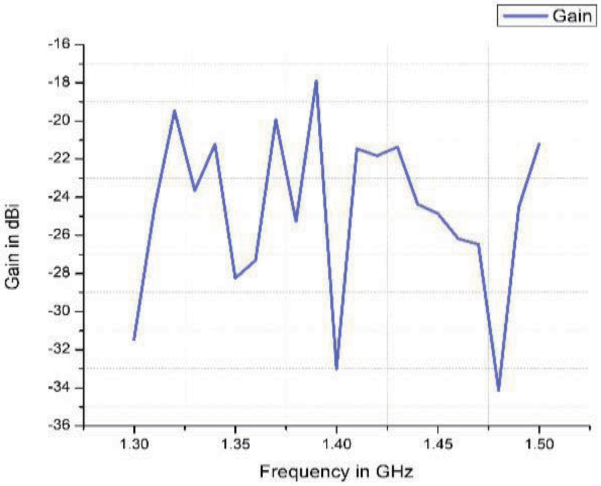


FIGURE 10. Observed gain at anechoic chamber vs frequency.

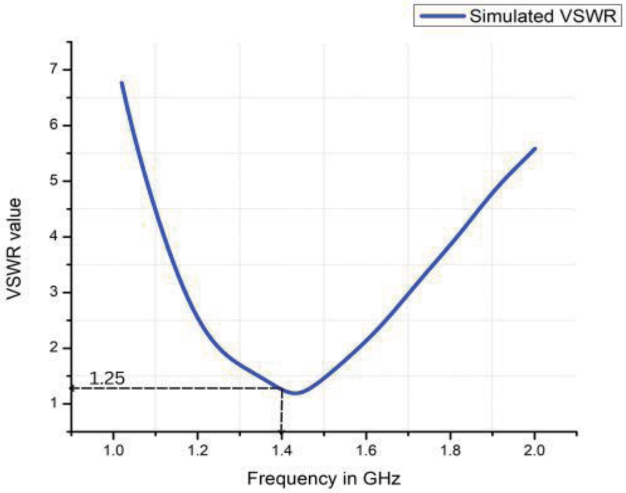


FIGURE 11. VSWR vs Frequency in GHz curve.

transmission line is the mathematical definition of VSWR.

$$\mathrm{VSWR} = V_{\max}/V_{\min}$$

When the source, characteristic impedance, and load impedance are more closely aligned, 100% of the energy is transferred in an ideal scenario. However, in reality, mismatches are caused by a reflection of some portion of the power. The value of VSWR should be minimum of 1 and less than 2 for improved antenna performance and appropriate for the antenna applications, taking into account some reflections.

TABLE 2. Comparison with recent reported literature.

Ref.	Freq. (GHz)	BW (MHz)	VSWR	Gain (dBi)	SAR 1g Avg. (W/Kg)	Size of antenna (mm)
[15]	0.402 (MICS)	52	-	-34.9	284.5	$23 \times 16.4 \times 1.27$
[16]	2.4 (ISM)	540	-	-33	486	$9.8 \times 9.8 \times 1.27$
[17]	1.4 (WMTS)	3.57	-	-37	215	$10 \times 10 \times 0.635$
[18]	0.412 (MICS)	120	-	-35	94	$1.4 \times 12 \times 12$
[19]	0.402 (MICS)	-	-	-43.6	99.5	$11 \times 20.5 \times 1.8$
[20]	2.45 (ISM)	-	1.8	7.81	-	90×90
[21]	2.4 (ISM)	-	1.4	5.2	-	30×37
This Work	1.4 (WMTS)	234	1.25	-31.4	537	20.2×14.8

The VSWR for the antenna proposed is displayed in Figure 11 where the good VSWR value of 1.25 is achieved at the medical frequency's WTMS band (1.4 GHz).

Another crucial as well as essential parameter that should be considered for the implantable antennas is SAR to keep the safety of patients [13]. The amount or rate of power absorption by the human body is measured by the SAR. IEEE regulations provide that when over 1 g of human tissue is measured, the SAR value may vary within 1.6 W/kg [14]. For the proposed antenna, the total SAR [W/kg] is reported as 1.54625 which is in the safety range and maximum SAR (1 g) [W/kg] as 539.18.

4. COMPARATIVE STUDY WITH RECENT LITERATURE

Table 2 shows the comparison of our proposed antenna with some of the recent works for antenna design. From this table, the designed antenna has a geometrically smaller size than [15, 20, 21]. The VSWR is found better than the works [20, 21] which reveals the impedance match property of our antenna as satisfactory. Another parameter called gain is attained as higher value than [15–19]. Here, the gain for implantable antenna should be negative as the dissipative power characteristics of human tissues. So, our designed antenna's gain is better than that of [20, 21]. Other parameters such as BW and SAR are also satisfactory for the implants compare to other mentioned works. Hence, our proposed implantable antenna at 1.4 GHz WMTS band is bio-compatible and appropriate for biotelemetric applications.

5. CONCLUSION

The design and validation of a simple geometrical size implantable antenna is carried out at 1.4 GHz WTMS band for biotelemetric applications. This proposed antenna produces better bandwidth, provides high gain of -31 dB and reflection coefficient of about -20 dB with safe limit of specific absorption rate (SAR). At the resonating frequency of 1.4 GHz, this antenna provides good radiation and gain characteristics. The voltage standing wave ratio remains satisfactory with the value of 1.25 which ensures the proper impedance match. The essential parameters like gain and radiation pattern for the fabricated antenna have been measured experimentally in an anechoic chamber. Also, the designed antenna has been validated with tissue mimic liquid-phantom to ensure the appropriateness for the implantation inside human body.

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