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Compact Dual-Band Implantable Asymmetric Multi-Slot Patch Antenna for WMTS and ISM Applications

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***Abstract*—A compact dual-band implantable multi-slot patch antenna for biotelemetry applications is proposed here. The proposed dual-band antenna operates at both WMTS frequency band of 1395-1400 MHz as well as the 5.8 GHz ISM band. The size of the dual band antenna is greatly reduced by inserting multi-slots into patch and ground plane in an asymmetric patterns. The proposed antenna occupies a compact size of 12 X 12 X 0.64 mm^3 . The antenna, which is fed by a microstrip feed line, achieves gains of -20.29 dBi and -8.52 dBi at dual-band of operation. The proposed antenna has the potential to be employed in different implantable biomedical devices for real-time monitoring of physiological data due to its small size and dual-band characteristics. Specific Absorption Rate (SAR) is also analysed to ensure human safety conditions.**

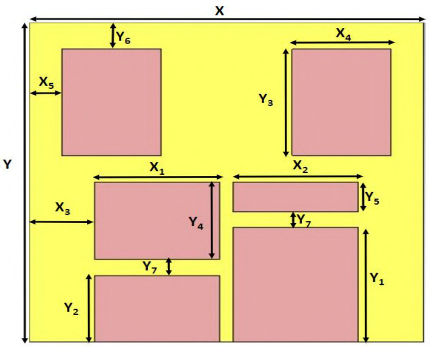
***Index Terms*—Dual band, Implantable devices, Microstrip patch antenna, Biotelemetry**

I. Introduction

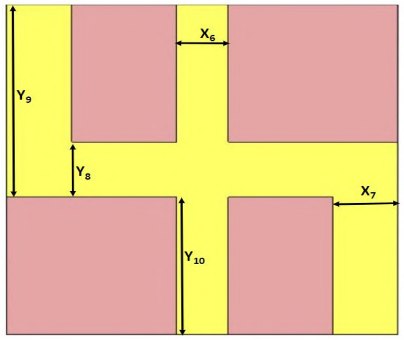
Implantable medical devices (IMDs) have developed as a key component of biomedical engineering due to their ability to continuously track and treat organ abnormalities. These devices enable the real-time transmission of physiological data from a patient to an exterior unit or a medical center located at some distance for short-range biotelemetry applications [1]. Different applications of IMDs are retinal implants, Intra-Cranial Pressure (ICP) monitors, ingestible capsule pills, defibrillators, pacemakers, gastric stimulators, glucose level monitors and so on [2]. By constantly monitoring the trajectory of various diseases, implantable devices improve healthcare quality by reducing the risk of certain diseases' complications.

Implantable antenna is considered as a vital component of an IMD and its design plays an important part. Since implantable antennas have distinct radiation properties, they must be smaller than free space antennas, and meet a number of safety requirements such as specific absorption rate, biocompatibility, miniaturization, license-free frequency bands of operation and coupling with the lossy biological tissues in human body [3].

In recent years, several types of implanted antennas for biomedical applications have been proposed. Authors in [4] & [5] suggested PIFA-shaped antennas for implantable applications. Loop antennas are suggested for biomedical applications by authors in [6] & [7]. Spiral antennas are suggested by authors in [8] & [9] for ingestible capsule applications. Microstrip patch antennas are proposed by authors in [10] & [11]. Microstrip patch designs are preferred for implanted antennas because they are versatile in terms of design and shape, enabling for simple miniaturization and incorporation into the structure of an Implanted Medical Device [12]. In this work, a compact dual-band asymmetric multi-slot microstrip patch antenna for Wireless Medical Telemetry Service (WMTS) and Industrial, Scientific and Medical (ISM) applications is presented.



(a) Top view



(b) Bottom view

Fig. 1: Proposed antenna layout with parameter marking

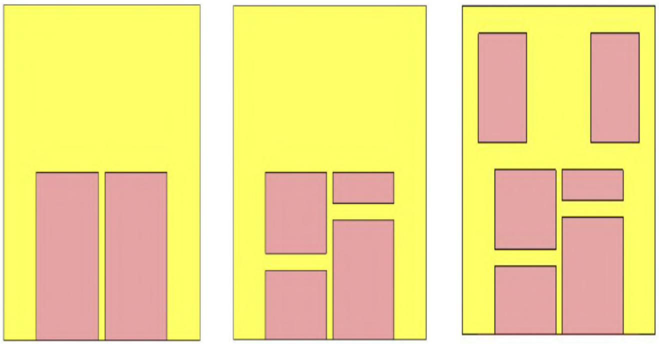
TABLE I: Design parameters (in mm)

X, Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	Y_1
12	3.8	3.8	2	3	1	1.6	2	4.3
Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}
2.5	4	2.9	1.1	1	0.6	2	7	5

The frequency band between 1395-1400 MHz is designated as WMTS band by Federal Communications Commission (FCC) [13]. WMTS is a short-distance data communication service that uses radiated electromagnetic signals to transmit physiological indicators and other patient medical information. Authors in [14] - [15] proposed implantable antennas resonating in WMTS band and authors in [16] & [17] proposed implantable antennas resonating in the Industrial, Scientific, and Medical (ISM) band of 5.8 GHz. The proposed antenna is resonating in WMTS band as well as ISM band of 5.8 GHz.

II. ANTENNA DESIGN

In this section, a compact dual-band implantable antenna has been introduced. The proposed implantable antenna layout is depicted in Fig.1. The dielectric substrate used in the design is Rogers RT6010LM with a permittivity of 10.7 and loss tangent of 0.0023. The antenna has the dimensions of 12 mm x 12 mm x 0.64 mm corresponding to a volume of 92.16 mm^3. Table I lists all the design parameters of the proposed antenna. The antenna is fed by a 50 Ω microstrip feed line. The antenna has an impedance same as the feed in desired frequencies. The antenna thereby matches the impedance without the need for a separate matching network.



(a) Ant 1 (b) Ant 2 (c) Ant 3

Fig. 2: Evolution of patch side of antenna by keeping same ground

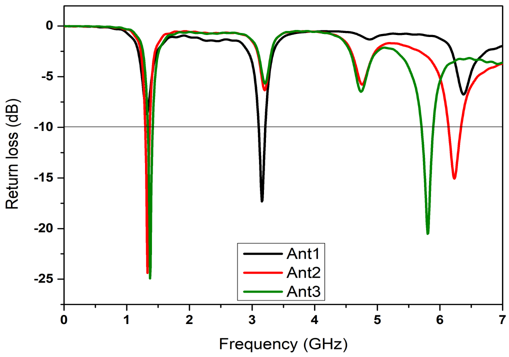


Fig. 3: Comparison plots of return loss for Ant 1, 2 & 3

TABLE II: Dielectric properties of human body

Tissue	Permittivity		Conductivity (s/m)	
	1.4 GHz	5.8 GHz	1.4 GHz	5.8 GHz
Skin	40	37	1.04	3.9
Fat	5.3	5.2	0.07	0.2
Muscle	53	50	1.2	5.2

The evolution of the patch side of the proposed antenna by keeping the ground side constant is shown in Fig.2. In the first design (Ant 1), two slots are placed on both sides of the feed line of dimension 6 mm x 0.4 mm. With these two slots antenna is resonating is in the desired band of 1.4 GHz. In the second design (Ant 2), two more slots are made along the feed line. In the final design (Ant 3), the slots are made in the top section of the feed line as shown to get better return loss results at 5.8 GHz. The Return loss comparison plots of these three designs are shown in Fig. 3 and found that in the third design, the antenna is resonating in the WMTS band of 1395-1400 MHz band as well as the ISM band of 5.8 GHz. In this way, asymmetric multi-slots are embedded on the patch and ground plane which achieves a dual band of operation. Since an implanted antenna is embedded within the hu- man body, the implantable environment is replicated in the simulated phantom model by a three-layer of skin, fat, and muscle tissue model with dimensions of 30 mm x 30 mm x 28 mm using CST Studio Suite as depicted in Fig.4. The frequency-dependent dielectric properties of human tissues that are depicted in table II [18] are taken into consideration for the design and construction of the antenna. The proposed antenna is placed in fat tissue 4 mm underneath the skin tissue. A biocompatible layer of alumina with a thickness of 0.02 mm is wrapped around the implant antenna to prevent direct contact with the human tissues.

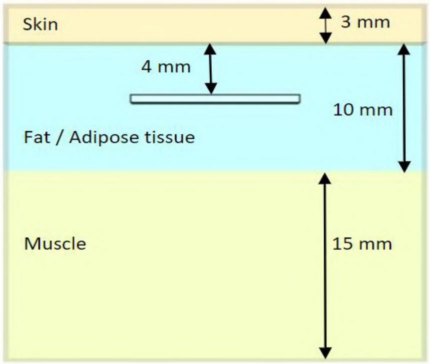


Fig. 4: Typical structure of three tissue phantom model

III. RESULTS AND DISCUSSION

The simulated return loss for the proposed dual band antenna is shown in Fig. 5. It can be seen that the proposed antenna is resonating in the desired frequency bands. The maximum obtained gains are -20.29 dBi and -8.52 dBi in WMTS and 5.8 GHz bands respectively. The maximum gain over frequency plot is shown in Fig, 6. The antenna spans the -10 dB bandwidths of 55 MHz and 180 MHz over WMTS and 5.8 GHz bands respectively. Radiation patterns at WMTS band and 5.8 GHz ISM band are shown in Fig. 7.

In addition, the consideration of electromagnetic field exposure is important because of the implanted environment in the human body. Specific Absorption Rate (SAR) values

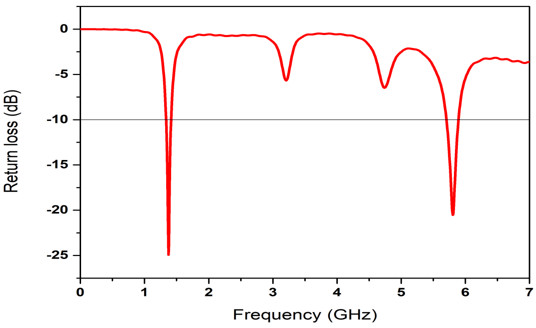


Fig. 5: Return loss Vs Frequency

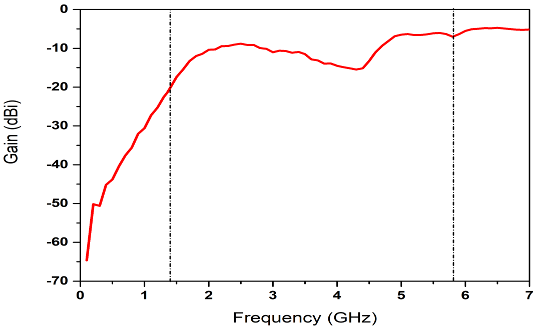


Fig. 6: Gain vs Frequency

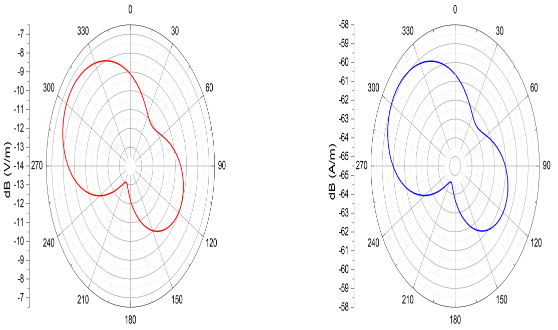
for human safety are regulated by the IEEE C95.1-1999 standards, which specify that the SAR averaged over any 1 g of tissue shall be less than 1.6 W/kg. Assuming that the antenna's provided input power is 1 W, the greatest SAR value that can be obtained is 221 W/kg and 433 W/kg at 1.4 GHz and 5.8 GHz respectively. To comply with the IEEE SAR regulation, the maximum supplied power should be limited to 4 mW and 7.5 mW at WMTS and 5.8 GHz band respectively. The typical input power for implantable devices is in μW [19].

IV. EXPERIMENTAL VALIDATION

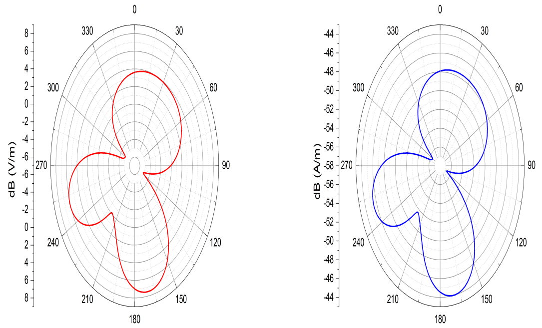
The antenna is fabricated and its return loss is measured by using Microwave Network Analyzer in frequency between 0.5 GHz to 7 GHz. The fabricated antenna is depicted in Fig.8. The antenna is tested with a single-layer fat phantom prepared as shown in Fig. 9. Table III shows the components required for the preparation of a single-layer fat phantom [20]. The return loss results comparison between the single-layer simulated antenna and fabricated antenna in single-layer fat phantom is shown in Fig. 11. It can be seen that despite a little shift in operating frequencies, the measured value of return loss is in accordance with simulation results.

TABLE III: Preparation of single layer fat phantom layer

Ingredients	Fat (125 mL)
Distilled water	2.9 % (3.625 mL)
NaCl	0.1 % (0.125 g)
Vegetable oil	30 % (37.5 mL)
Flour	67 % (83.75 g)

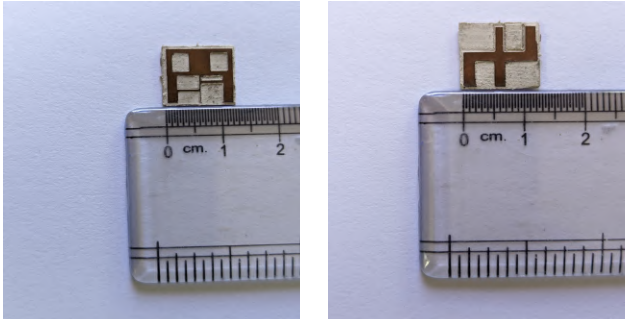


(a) E-Field at 1.4 GHz (b) H-Field at 1.4 GHz



(c) E-Field at 5.8 GHz (d) H-Field at 5.8 GHz

Fig. 7: Simulated Radiation pattern at dual-band of operation



(a) Top view (b) Bottom view

(c) Antenna connected to SMA

Fig. 8: Fabricated antenna

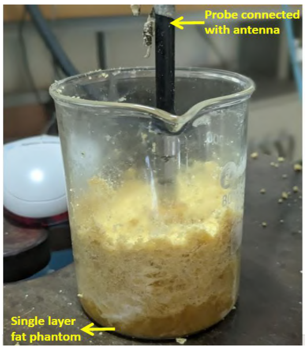


Fig. 9: Antenna in single layer fat phantom

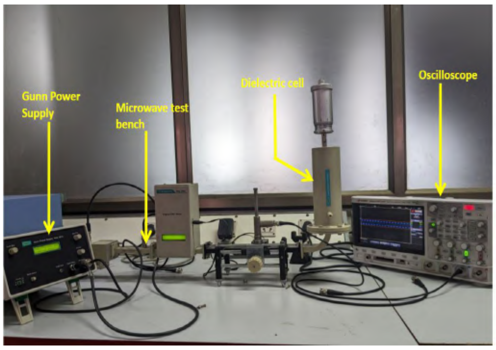


Fig. 10: Experimental setup to calculate dielectric constant of phantom prepared

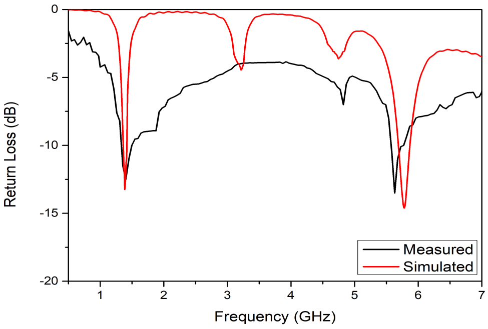


Fig. 11: Measured return loss Vs Frequency

TABLE IV: Comparison of proposed dual-band antenna with reported ones

Ref.	Substrate	Dimensions	Frequency (GHz)
[4]	Rogers RO 3210	16x14x1.27	0.4, 0.91
[5]	Taconic TLY-5	9x13x0.8	1.5
[10]	Polyamide	24x22x0.07	2.48
[16]	FR-4	44x41x1.6	5.8
[21]	TMM 13i	7.7x6.9x1.52	2.45, 4.8
This work	Rogers 6010LM	12x12x0.64	1.4, 5.8

V. CONCLUSION

In this work, a compact microstrip patch dual-band antenna is designed. The antenna is resonating in the WMTS band of 1.4 GHz as well as 5.8 GHz. The results obtained by the antenna makes it a suitable candidate for implantable biotelemetric applications.

VI. ACKNOWLEDGEMENT

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