Multi-band Implantable Microstrip Antenna on Large Ground Plane and TiO2 Substrate

Multi-band Implantable Microstrip Antenna on Large Ground Plane and TiO_2 Substrate

Lida Kouhalvandi[1*], Ladislau Matekovits[2* # ◇], Ildiko Peter[3+]

[*] *Department of Electronics and Telecommunications, Politecnico di Torino, Turin, Italy*

[#] *Department of Measurements and Optical Electronics, Politehnica University Timisoara, Timisoara, Romania*

[◇] *Istituto di Elettronica e di Ingegneria dell'Informazione e delle Telecomunicazioni, National Research Council, Turin, Italy*

[+] *Faculty of Engineering and Information Technology,*
University of Medicine, Pharmacy, Science and Technology "George Emil Palade", Târgu-Mureş, Romania

lida.kouhalvandi@ieee.org[1], ladislau.matekovits@polito.it[2], ildiko.peter@umfst.ro[3+]

***Abstract*—Biomedical implanted devices are typically used for interacting with organs and/or for investigating various physiological signals. Hence, enhanced performance devices for clinical uses have got the attention of researchers. In this study, a multi-band implanted microstrip antenna suitable for transmitting/receiving biomedical signals in the Industrial, Scientific and Medical (ISM) frequency bands is presented. The antenna is built on a bio-compatible substrate, as titanium dioxide (TiO_2) with relative permittivity of 95. The ground plane is thought to be a bio-metallic implant located within a bone. The proposed antenna is compact in size, 14 $\times$ 18 $\times$ 1.6 mm^3, and works in both 2.45 GHz and 5.8 GHz centered frequency bands. It is designed and optimized considering the actual biological tissues as bone, muscle, fat, and skin surroundings. The simulation results referring to a planar stratification prove that the multi-band single microstrip antenna is working properly within the human body and it can be used for medical communication services.**

***Index Terms*—Biomedical, implanted antenna, Industrial, Scientific, and Medical (ISM) band, titanium dioxide (TiO_2).**

I. Introduction

In the last decade, designing human wearable devices and apparatuses for medical applications have got the attention of engineers [1]. By the help of implanted devices, capable to transmit biological signals to the medical doctors, remote surveillance/diagnosis became reality. Among the others, such survey contributes to the general well-being of the patient, since they can stay at their home instead of occupying places in hospitals. At the same time, the reduced hospitalization time decreases the cost supported by the healthcare systems. Figure 1 presents a general concept of the remote healthcare using implanted device.

In the biomedical applications, there are many critical aspects: for example one of them is related to assemble the bio-potential signals that include very small amplitudes and to accurately deal with minimal $1/f$ noise interference.

The main aspects related to the radiofrequency propagation in any type of medical implants are: $i)$ transfer power to the implanted devices, and $ii)$ transmit or receive included data to/from devices. Typically, the rate of data transmission is low, even if some applications require higher data-rate: 1 Mbps and 20 Mbps for cochlear implants and visual prostheses, respectively [2]. The actual rate of data transmission can be varied for example due to the generated heat in human's tissues; the same holds for the amount of absorbed power [3].

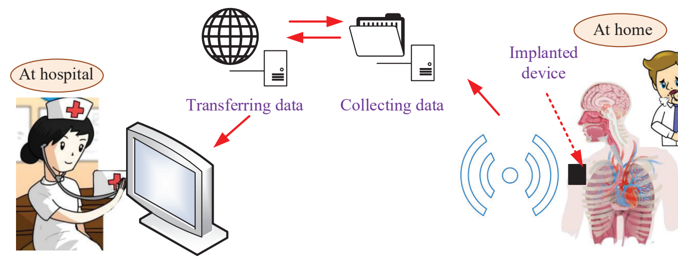

Fig. 1. A general concept of a patient-physician relationship approach.

Implanted devices are playing important roles in biomedical applications [4]. For example, they can be used for neural interfaces where a communication bridge between the central nervous system and brain functions is created for providing treatments. In simple words, these devices forward the bio-signal data to the devices that are placed outside the body for monitoring and investigating the achieved information. They can be operated in three frequency bands: medical device radio (MedRad), medical implantable communication service (MICS), and/or industrial, scientific and medical (ISM) bands [5].

Recently, implanted antennas get the view of medical applications that are typically used in data communications from the human body to the external base stations. They can be used either for diagnosing or treating the sickness using magnetic resonance imaging, biomedical telemetry, wireless capsule endoscopy, microwave hyperthermia, or microwave coagulation therapy [6], [7], just to mention some. The design of implanted antennas is a challenging task; when implanted into the body, the performances of the antenna are worsening (with respect to the free space case) due to the effects of dielectric properties of the biological tissues. Depending on the deepness of the antenna location, the multi-layer environment will give rise to multiple reflections. Surface waves can also be generated, and losses are significant. Hence, consideration of implanted antennas in terms of efficiency and resonant frequency becomes essential [8] to be applicable for biomedical usages.

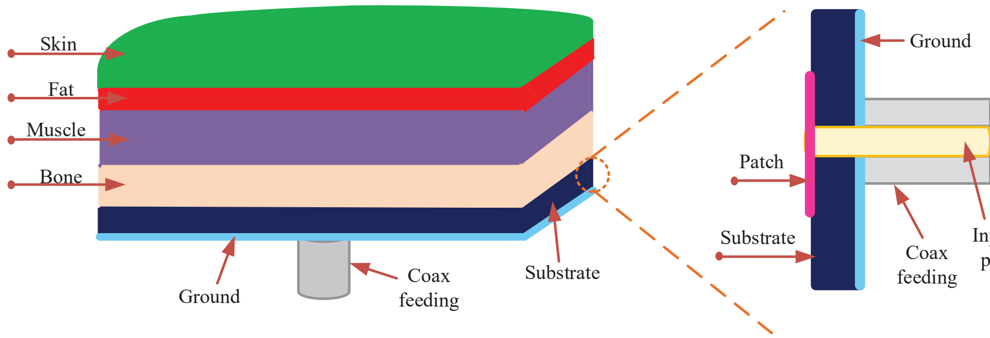

Fig. 2. General perspective of the biological tissues mounted to the microstrip antenna with beside view of the antenna.

This paper presents a multi-band microstrip single antenna that can be used for biomedical applications at the ISM band frequencies, i.e., 2.45 GHz and 5.8 GHz. This work is focused on developing a real and practical implementation of patch antenna covered by biological tissues of bone, muscle, fat, and skin. The antenna is supposed to be immersed inside the bone. The design, referring to a planar configuration, is validated using commercial numerical tool, here Microwave Studio (Dassault Systèmes), where the antenna is fed by a coaxial cable.

The paper is organized as follows: Section II provides a procedure of developing the implanted antenna. Section III describes the simulation results of the designed multi-band microstrip antenna, and the last section is devoted to conclusions.

II. Antenna Development

For the implanted devices equipped with antennas, it is of critical responsibility to radiate properly when the actual biological tissues are present. Hence, to be employed as a fully implantable antenna, the dielectric properties of tissues (i.e., bone, muscle, fat, and skin) have accurately been considered.

In this section, firstly, the accurate dispersion of different tissues of human body is described and then the multi-band single microstrip antenna is designed embedded in the considered tissues. The designed antenna is targeted to operate in the ISM frequencies, covering both 2.45 GHz and 5.8 GHz bands.

A. Dielectric properties of biological tissues

Under skin of each human body, there are at least three other layers as fat, muscle, and bone, respectively, as shown

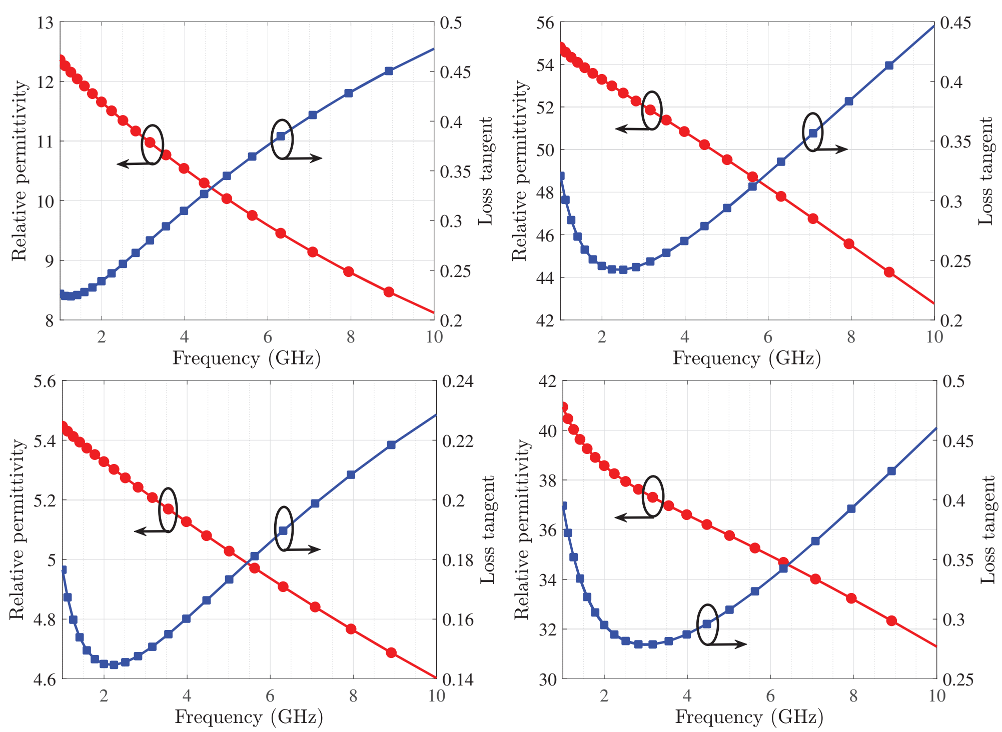

Fig. 3. Relative permittivity and loss tangent of bone cortical tissue (top, left), muscle (top, right), fat (bottom, left) and of dry skin (bottom, right) tissues. Note the different scales.

in Fig. 2. Dielectric properties of each layer such as relative permittivity (ε_r) and loss tangent ($\tan\alpha$) values are different and they must be accurately taken into considerations during the design process. However, these values are altered by various factors as weight and patient age.

Precisely, the values can be obtained, for example, from [9] for the interested frequency range. In particular, the values of ε_r and $\tan\alpha$ are collected for dry skin, fat, muscle, and cortical bone layers. Figure 3 present the dispersion of these tissues in the frequency range from 1 to 10 GHz. It can be observed that all considered tissues have a quite different values of the considered tissue characteristics for the two central frequencies of interest.

B. Single microstrip antenna for ISM band frequency

This section deals with the design of a single multiband microstrip antenna that can work properly in the presence of biological tissues. The antenna is employed below the defined biological layers. It uses as ground plane a large extesion bone implant, such as hip, covered by a biocompatible substrate, here titanium dioxide (TiO_2) with ε_r= 95 and of thickness of 1.6 mm.

This substrate is selected due to its nanotechnology capability in different health care areas. It is white and poorly soluble bio-compatible material. For the designed antenna, the feeding occurs through a coaxial cable. Matching has been optimized by changing the location of the feed and the configuration of antenna has been optimized using the random iteration optimization.

III. Simulation Results

After determining and mounting the biological layers all together, the patch antenna built on TiO_2 substrate is designed and simulated in the Microwave Studio. Figure 4 shows the designed multi-band microstrp antenna with sizes that is suitable for the ISM band frequencies.

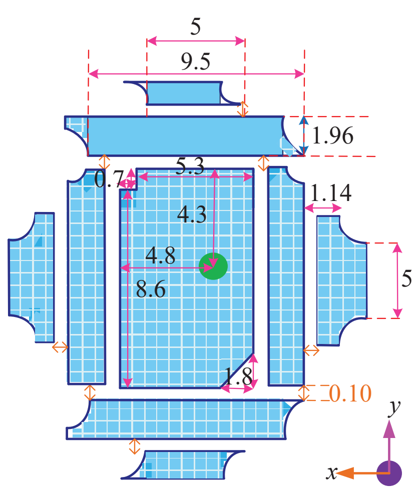

Fig. 4. Designed microstrip single antenna suitable for ISM band frequencies (width and length are in mm; drawing not in scale).

The presented antenna consists of a main center patch resonating at the higher frequency band, i.e., 5.8 GHz, surrounded by passive resonators that have the role of inserting additional resonances. Since they are longer, their resonant frequency will be lower. The arrangement is such that the two above mentioned IMS bands are covered. The considered ground plane has an extension of 18 mm and 16 mm, along x and y directions, respectively.

Figure 5 presents the behaviour of the S_{11} parameter. The multiple resonances are due to the different lengths of the parasitic elements around the main patch. Two of such resonances correspond to the two ISM bands, namely to those centered in 2.45 GHZ and 5.8 GHz.

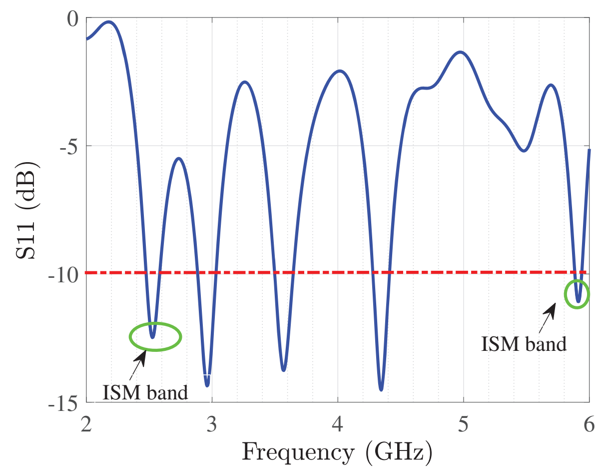

Fig. 5. Input scattering parameter S_{11} of the designed antenna. The two resonances corresponds to the two ISM bands.

The radiation pattern in the E- and H planes at the two central frequencies are reported in Fig. 6. The non symmetric patterns are due to the non symmetric central shape and loading elements, and different extension of the ground plane in the x and y directions, respectively. However, when used on a cylindrical/conical ground plane the effect of the finite ground plane will be reduced. Investigations in this direction are undergoing.

For the sake of completeness, Tab. I presents a (not exhaustive) comparison of different planar antennas with various substrate materials that are used for the medical applications.

TABLE I
Comparison between materials and antenna types at ISM Band Frequency

Ref.	**Materials**	**Dimension (mm^3)**	**Design Type**
[10]	Rogers 4003	15×15×0.78	Planar Inverted-F Antenna
[11]	Alumina ceramic	18×24×0.65	Inverted L-shaped slot, inverted U-shaped slot
[12]	Rogers 3210	15×15×1.92	L- Shaped fed spiral
[13]	Alumina ceramic	30×30×1.6	Dual - spiral
This work	TiO_2	14×18×1.6	Microstrip antenna

However, it is to be mentioned that not all substrates are bio-compatible, so in case of in-body use of these configurations requires special attentions. Rogers RO4003C™ materials are

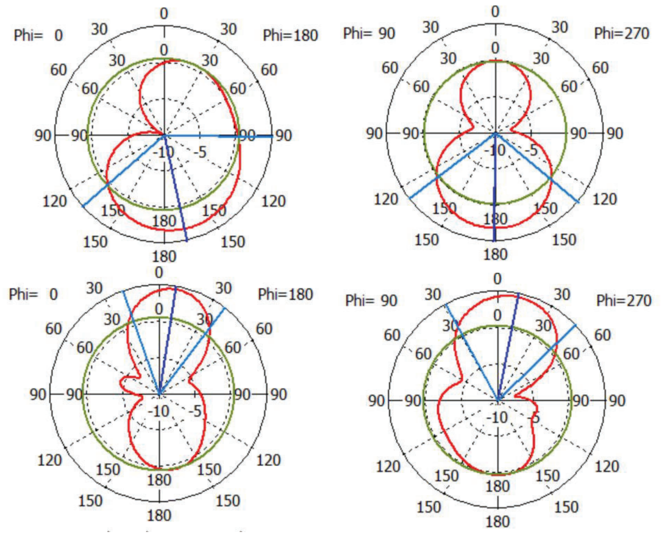

Fig. 6. Radiation pattern of the considered antenna in the E- (left) and H- (right) planes at 2.45 GHz (top) and 5.8 GHz (bottom).

proprietary woven glass reinforced hydrocarbon/ceramics with the electrical performance of PTFE/woven glass and the manufacturability of epoxy/ glass [14]. Rogers RO3210™ laminates are ceramic-filled laminates reinforced with woven fiberglass [15].

IV. Conclusion

In this paper, a multi-band microstrip single antenna is designed and simulated that can be used for biomedical applications. The designed antenna is working in the two ISM frequency band centered in 2.45 GHz and 5.8 GHz. The dispersive dielectric properties of layers as bone cortical, muscle, fat, and dry skin are considered. Then these actual layers are mounted together and the the microstrip antenna that is located inside of the bone is simulated. The presented antenna can be used for the biomedical systems.

Acknowledgement

This work was partially supported by a grant of the Romanian Ministry of Education and Research, CNCS - UEFISCDI, project number PN-III-P4-ID-PCE-2020-0404, within PNCDI III.

References

[1] Z. Zhou, "A front-end amplifier with current compensation feedback input impedance booster for neural signal applications," *IEEE Access*, vol. 8, pp. 178 055–178 062, 2020.

[2] M. M. Ahmadi and S. Ghandi, "A class-e power amplifier with wideband FSK modulation for inductive power and data transmission to medical implants," *IEEE Sensors Journal*, vol. 18, no. 17, pp. 7242–7252, 2018.

[3] S. Hansen, C. Bredendiek, G. Briese, and N. Pohl, "A compact harmonic radar system with active tags at 61/122 GHz ISM band in siGe BiCMOS for precise localization," *IEEE Transactions on Microwave Theory and Techniques*, vol. 69, no. 1, pp. 906–915, 2021.

[4] L. Matekovits, J. Huang, I. Peter, and K. P. Esselle, "Mutual coupling reduction between implanted microstrip antennas on a cylindrical biometallic ground plane," *IEEE Access*, vol. 5, pp. 8804–8811, 2017.

[5] G. Kaur, A. Kaur, G. K. Toor, B. S. Dhaliwal, and S. S. Pattnaik, "Antennas for biomedical applications," *Biomedical Engineering Letters*, vol. 5, no. 3, pp. 203–212, Sep 2015. [Online]. Available: https://doi.org/10.1007/s13534-015-0193-z

[6] M. Särestöniemi, C. Pomalaza-Ráez, C. Kissi, and J. Iinatti, "Simulation and measurement data-based study on fat as propagation medium in wban abdominal implant communication systems," *IEEE Access*, vol. 9, pp. 46 240–46 259, 2021.

[7] Y. Mohtashami, N. Behdad, and S. C. Hagness, "Ex vivo performance of a flexible microwave ablation antenna," *IEEE Transactions on Biomedical Engineering*, vol. 68, no. 5, pp. 1680–1689, 2021.

[8] M. Yousaf, I. B. Mabrouk, M. Zada, A. Akram, Y. Amin, M. Nedil, and H. Yoo, "An ultra-miniaturized antenna with ultra-wide bandwidth characteristics for medical implant systems," *IEEE Access*, vol. 9, pp. 40 086–40 097, 2021.

[9] "Calculation of the dielectric properties of body tissues," http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.php, accessed: 2021-04-30.

[10] M.-R. Tofighi, "Characterization of biomedical antennas for microwave heating, radiometry, and implant communication applications," in *WAMICON 2011 Conference Proceedings*, 2011, pp. 1–6.

[11] S. Ashok Kumar and T. Shanmuganantham, "Design of implantable CPW fed monopole H-slot antenna for 2.45GHz ISM band applications," *AEU - International Journal of Electronics and Communications*, vol. 68, no. 7, pp. 661–666, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S143484111400051X

[12] M. Palandoken, "Compact bioimplantable MICS and ISM band antenna design for wireless biotelemetry applications," *Radioengineering*, vol. 26, pp. 917–923, 2017.

[13] M. Nachiappan and T. Azhagarsamy, "Design and development of dual-spiral antenna for implantable biomedical applications." *Biomedical Research (India)*, vol. 28, pp. 5237–5240, 01 2017.

[14] https://rogerscorp.com/advanced-connectivity-solutions/ro4000-series-laminates/ro4003c-laminates, Accessed: 2021-05-09.

[15] https://rogerscorp.com/advanced-connectivity-solutions/ro3000-series-laminates/ro3210-laminates, Accessed: 2021-05-09.