Compact Multi-band PIFA with Meandered Radiator for Wireless Brain Implant Communications

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Abstract

Implantable devices bring promising prospects for monitoring physiological data in health care services. To build up a proper wireless data link, designing a miniaturized antenna is prime importance. The objective of this paper is designing a small meandered multi-resonant planar inverted-F antenna (PIFA) for wireless brain implants. The proposed PIFA resonates on both, the medical implant communication services (MICS) band of 402 MHz and industrial, scientific and medical (ISM) bands containing the frequency ranges of 902 MHz and 2.4 GHz. Methods of meandering and shorting the radiating element to the ground plane lead to miniaturize the antenna to the volume of 12.6×19×1.25 mm^3. A seven-layer human head model is utilized for optimizing and characterizing the proposed PIFA numerically. Overall, we attain a compact multi-band implantable PIFA with –42.3 dBi gain at 402 MHz, –24.2 dBi gain at 902 MHz, and –21.6 dBi gain at 2.4 GHz.

1 Introduction

Over the past few decades, advancements in wireless communication techniques and medical technologies have led to a great deal of research on biomedical telemetry systems. These systems enable wireless communications between implantable medical devices (IMDs) and wearable and off-body nodes for healthcare and medicine. A major and crucial component of the biotelemetry systems is implantable antenna integrated into IMDs for continuous remote monitoring of human physiological signals. In the implantable antenna design, several challenges should be considered including miniaturization, proper radiation efficiency, appropriate impedance matching, wide bandwidth, biocompatibility and resonating frequencies. Defined frequency bands for implantable antennas involve MICS resonating at the range of 402–405 MHz to transmit data for diagnosis and subsequent therapy functions, whereas to provide IMDs communications and wireless power transfer the ISM bands are introduced operating at the range of 433.1–434.8 MHz, 868–868.6 MHz, 902.8–928.0 MHz, and 2.4–2.48 GHz [1]-[5]. In this context, a multi-resonant implantable antenna can be a compelling approach for establishing implant wireless communications with more versatile functions. Dimension of implantable antenna is the other important criteria in antenna design, in view of implant size reduction and patients comforting. To meet designing requirements for implantable antennas, PIFA structure has been found a promising candidate. Furthermore, various improved multi-resonant PIFAs have been studied for different biomedical telemetry applications, including square, circular, meandered, and spiral PIFA, planar dipole, and loop antennas [2]-[5]. Nevertheless, designing a small antenna with wide bandwidth and maximal radiation efficiency when implanted in human body, is still a topic ongoing research.

In our previous approach [3], we introduced a compact dual-band implantable PIFA for wireless biomedical telemetry systems where we used the slotted radiator to reduce the PIFA size and provide dual-resonant at the ISM band operating at the ranges of 902 MHz and 2.4 GHz. Due to the narrow bandwidth of PIFAs and its sensitivity to the properties changes in lossy human tissue, we utilized a superstrate layer for covering the radiating patch. According to the simulation results the embedded PIFA in the seven-layer head model with the volume of 11×19×1.25 mm^3 could attain the frequency range from 800 MHz to 1 GHz (22%) with the maximum gain of –26.71 dBi and 0.2% radiation efficiency at 902 MHz; and achieve the bandwidth from 2.2 GHz to 2.65 GHz (18.6%) with the gain of –17.5 dBi and 0.31% radiation efficiency at 2.4 GHz. To advance upon our previous work, we proposed a multi-band meandered PIFA resonating at both MICS (402 MHz) and ISM bands (902 MHz and 2.4 GHz) with appropriate radiation performance.

2 Antenna Design Principles

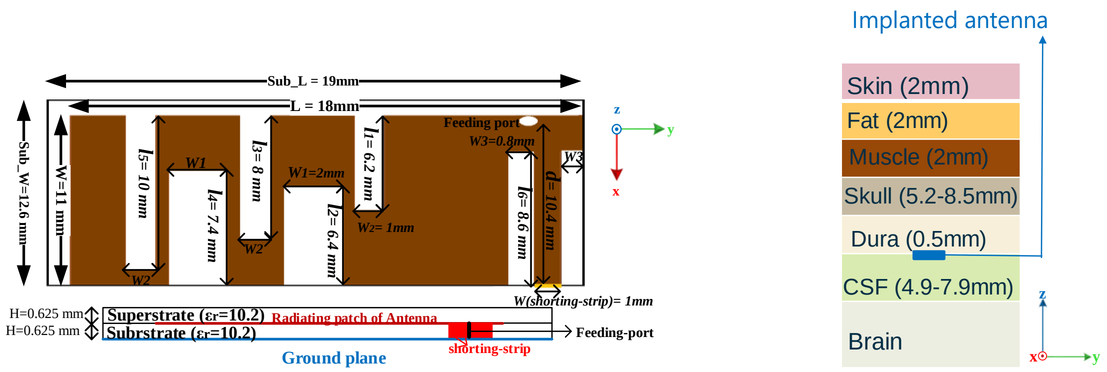
Fig. 1 (a) demonstrates the proposed miniaturized multi-resonant PIFA with meandering slots. The antenna is fed via a 50 Ω coaxial cable connected to an embedded pin in the radiator with 0.6 mm radius and in the vertical y-z coordinate, a shorting strip links the radiating element to the ground plane [5]. In the first step, we calculated the geometry of the radiator for operating at the ISM band of 902 MHz by the given formula

$$\left(L + W + H - W_{(Shorting-strip)}\right) = \frac{c_0}{4f\sqrt{\varepsilon_r}}, \tag{1}$$

where C_0 is the light speed, ε_r denotes the substrate relative permittivity, L and W define the length and width of the radiating patch, $W_{(shorting\text{-}strip)}$ and h determine the shorting strip width and the thickness of substrate, respectively [3],[5]. Based on this formula, high permittivity dielectric substrate and superstrate (Rogers RO3210; ε_r=10.2, tanδ=0.003) helps to minimize the PIFA size. Moreover, the superstrate decreases the surrounding tissue loss and improves the attainable gain [2], [3]. In the next step, we inserted several cutting slots into the radiator for further antenna size reduction and broadening its bandwidth. After that, to resonate PIFA at MICS band, it was required to enhance the effective physical length of the patch. To this end, we meandered the cutting slots to increase the current path. In the last step, by considering one more meandered cutting slot close to the antenna feeding port, we generated the third resonance point at 2.4 GHz. However, in this designing we created one more unused resonance between 902 MHz and 2.4 GHz that is not tuned to any specific frequency band. As a result, compact meandered PIFA is a promising approach for achieving a multi-band antenna for biotelemetry systems [5].

3 Simulation Results and Discussions

We utilized a seven-layer model of human head to analyze the silicone-coated antenna at the depth of 13.25 mm placed between the cerebrospinal fluid (CSF) and dura region, as shown in Fig. 1 (b). All the simulation and modeling were conducted in the ANSYS HFSS v15 simulator. To assess the designed PIFA and tune the desired resonant frequencies, we investigated all key



(a) **(b)**

Fig. 1: (a).The proposed meandered multi-band implantable PIFA configuration, (b). The located PIFA in the seven-layer human head model.

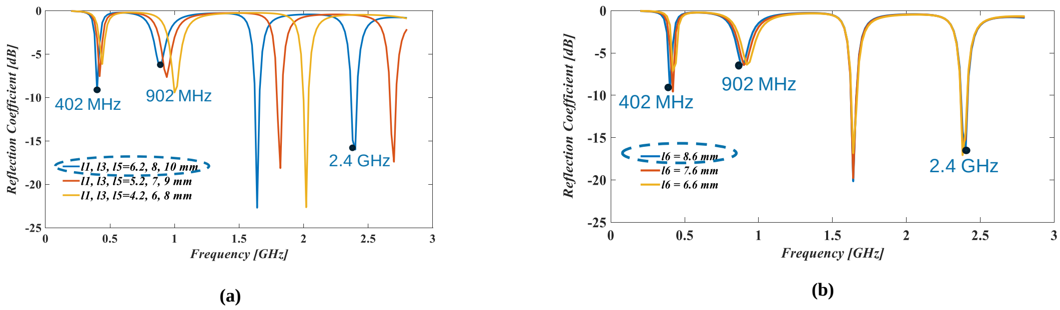


Fig. 2: (a). Effect of shortening the cutting slots length (l_1, l_3, l_5), (b). Effect of increasing the shorting strip length (l_6).

parameters including the effective lengths of the cutting slots and shorting strip, as well as, the embedded location of the feeding port. As is observed in Fig. 2 (a), shortening the cutting slots length (l_1, l_3, l_5) give rise to the higher resonant frequency bands. Conversely, as shown in Fig. 2 (b), obtaining lower frequency bandwidths arise from longer shorting strip (l_6). Simultaneously, the shorter distance between feeding pin and shorting point (d) we considered, the more suitable reflection coefficient magnitude we achieved. Consequently, we were able to design and tune a triple-band PIFA. Its resonances were primarily controlled with only three geometry parameters. Fig. 1 (a) depicts the designed antenna geometries. Fig. 3 demonstrates the comparison between the improved impedance matching of the triple-resonant PIFA and the dual-band antenna from our previous approach. The added MICS resonance frequency band in our proposed PIFA at 402 MHz could achieve the reflection coefficient magnitude of –8.7 dB, the other operating frequencies at the ISM band involve 902 MHz and 2.4 GHz with $|S11|^2$ equals to –5.9 dB and –5.5 dB, respectively. The broad impedance bandwidths cover frequency ranges of 290 MHz to 500 MHz (52.2%), 695 MHz to 1.1 GHz (45%) and 2.2 GHz to 2.8 GHz (25%). Moreover, Fig. 4 illustrates the proper directivity of the triple-band PIFA in the outward direction of the human

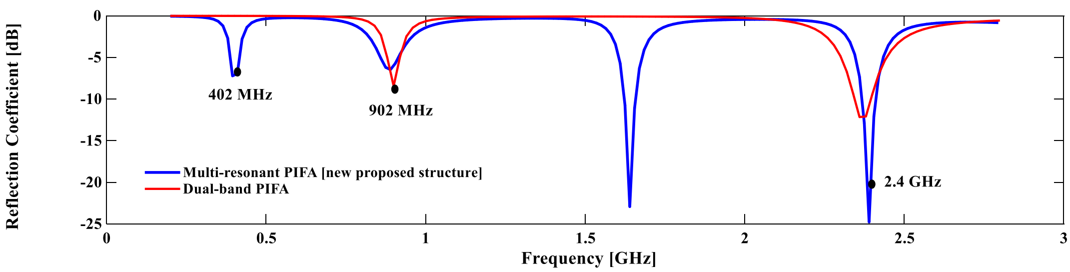


Fig. 3: Reflection coefficient of the proposed multi-band PIFA compared with our previous dual-band antenna.

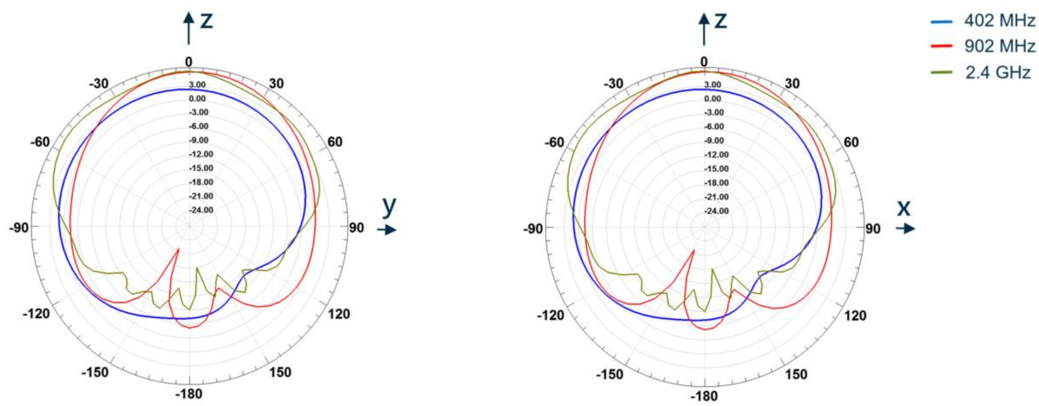


Fig. 4: Antenna directivity.

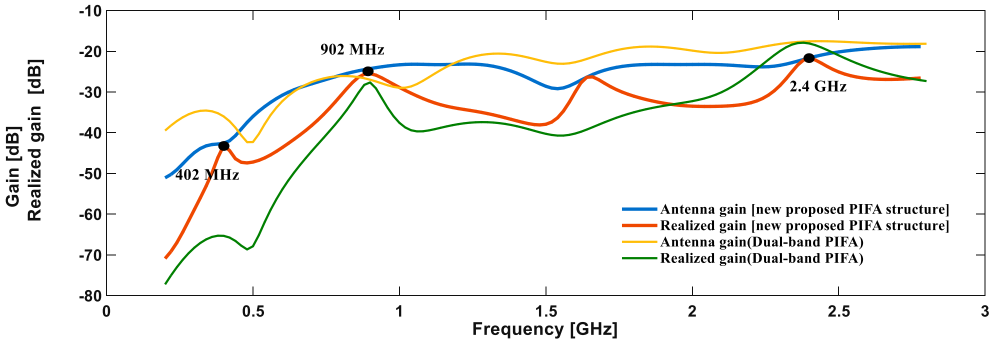


Fig. 5: Gain and realized gain of the introduced PIFA versus frequency compared with our previous dual-band PIFA.

head tissues, where PIFA with the linear polarization with E field in yz-plane achieved the peak directivity of 2.7 dBi, 6.1 dBi and 6.1 dBi on z-axis at 402 MHz, 902 MHz, and 2.4 GHz, respectively. Fig. 5 displays the gain and realized gain comparison of our proposed triple-band antenna and our previous dual-band PIFA. The maximum gain of the proposed PIFA at 402 MHz, 902 MHz, and 2.4 GHz is –42.3 dBi with the 0.003% radiation efficiency, –24.2 dBi with the 0.1% efficiency, and –21.6 dBi with the 0.1% efficiency, respectively. Similarly, as seen in Fig. 5, the realized gain obtained close values to the gain involving –43.3 dBi, –25.5 dBi, and –21.8 dBi at 402 MHz, 902 MHz, and 2.4 GHz, respectively [5].

In conclusion, we were able to propose a self-matched PIFA with a proper miniature volume for IMDs resonating at both MICS (402 MHz) and ISM bands (902 MHz and 2.4 GHz). Hence, this is a promising approach to versatile multi-band biotelemetry systems. Utilizing this structure, we are able to achieve the goals of energizing the deep implants using far-field wireless power transmission and providing data through IMD. As a future work, we plan to implement and test the proposed PIFA.

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