Miniaturized Slot PIFA Antenna for Tripleband Implantable Biomedical Applications

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***Abstract* — This paper presents the design of a triple-band implantable miniaturised slot PIFA antenna for Medical Implant Communication Service (MICS) band at 433MHz, Wireless Medical Telemetry Service (WMTS) band at 1430 MHz and Industrial, Scientific, and Medical (ISM) band at 2.4GHz. Simulations based on homogeneous and inhomogeneous phantoms are employed to design the proposed small antenna suitable for implanting in the arm or under the chest. The measured results are obtained by immersing a prototype of the proposed antenna in a phantom. The antenna occupies a volume less than 1cm^3 and its size reduction is about 50% compared to the standard E-shaped patch antenna reported in the literature.**

***Index Terms* — PIFA, biomedical applications, implantable antennas.**

I. Introduction

In recent years, several works have appeared on the characterization and design of implantable antennas [1-3]. The implanted antenna must fulfill miniaturization and have good radiation performance when it is implanted inside the human body [4-5]. Also for optimum performance, it is necessary to design the implanted antenna in the environment in which it is expected to operate. Hence, implantable antennas have been characterised inside both tissue equivalent liquids and mimicking gels [2] or in animal models [6]. In this paper, an implantable miniaturised slot PIFA antenna is proposed for operation in 433MHz MICS band, 1430MHz WMTS band and 2.4GHz ISM band. Also we will demonstrate the effectiveness of employing shorting post which is placed between the patch and the ground plane so that the antenna is compact in size and resonates over the three chosen bands useful for biomedical implant communications. The antenna characteristics are measured inside a phantom and the measured results agree reasonably well with the simulated results on numerical multilayered phantoms.

II. Design of Slot PIFA

Implantable antenna plays a key role in establishing a reliable medical implanted wireless communication link between human body and the outside environment. In general, E-shaped antennas are well established for communication in air [7]. They can provide wide bandwidths than conventional patch antennas for mobile communication applications. However, their physical size becomes significantly large making them not suitable for implantable communications. To overcome this limitation, we propose to modify the E-shaped configuration so that there is an asymmetry with respect to the position of the slot as shown in Fig1. Further size reduction has been obtained by employing a properly positioned shorting post so that the antenna resonates at the frequencies of interest when implanted inside phantoms. The locations of the shorting posts depend on the resonant modes [9] and they can modify the impedance of the antenna by introducing inductive effects on input impedance [10].

By fixing the antenna size and adjusting the relative positions of the feed and shorting post, we can make the slot PIFA resonate at all the three chosen frequency bands. Thus, the proposed antenna can be tuned to either multiple bands or a single frequency band. Our investigations have revealed that, when the distance between shorting post from the feeding point is $>\lambda/8$, the resonance occurs in a single, but lower, frequency. When the shorting post is positioned at a distance of $< \lambda/12$ from the feeding point, three different resonant frequencies appear as tabulated in Table 1. This feature of the proposed antenna can be useful for applications where two or three different carrier frequencies are employed for implantable communications.

To determine the antenna's input impedance match, we obtain the appropriate feeding position by performing numerical experiments using numerical human tissue mimicking phantoms with FEKO™ [11]. The finally designed slot PIFA has a volume of about 0.9cm^3 when placed inside a numerical phantom and can operate over 433 MHZ MICS band as well as covering 1430MHz WMTS and 2.4GHz ISM bands simultaneously. The overall size of the proposed antenna is 19 x 30 x 1.6 mm, which is quite appropriate for implantable wireless system.

III. Simulations inside Numerical Phantom

For simulations, we have used block and cylindrical shaped numerical human tissue mimicking phantoms which employ multiple layers [1] to model the human body effects as shown in Figure 2(a)–(b). Comparison of the results on reflection coefficient obtained in both cylindrical and layered block phantoms, show that the antenna can resonate over the desired operating frequency bands and the agreement on resonant frequencies is close. The layered rectangular block numerical phantom mimics the implantation under body chest as shown in Fig. 2(a) in which the antenna is positioned at 2mm from the top of the skin surface. It is placed in the fat under the skin to be parallel to boundary. For simulations, we used the dielectric properties of skin, fat and muscle as tabulated in Table 2 [11]. Moreover, cylindrical shaped multi layered numerical phantom was used for mimicking the antenna implantation inside the human arm [1]. In the cylindrical phantom, the average thicknesses of each layer is chosen to be 28mm for muscle, 4mm for fat and 2mm for skin respectively, as shown in Fig 2(b). Fig 3 shows the calculated surface current distribution with FEKO on the proposed slot PIFA. The plot in Fig. 3(a), shows that the path of current flow is in the same direction in both the arms which may be primarily responsible for exciting the fundamental resonant frequency that covers the MICS band. In Fig 3(b), the current paths are opposite in each arm however, the current in one arm is stronger than the other exciting higher order mode, in this case, corresponds to the resonant frequency at WMTS band.

IV. Measurement Results

The dielectric properties of any tissue mimicking experimental phantom must be similar to the realistic human body for obtaining reliable measurements to verify the performance of the implanted antenna. In the literature, pork leg [8] and skin gel [1] were proposed as tissue mimicking phantoms for multiband operation. However, skin gel can only be used for one special single band and the relative permittivity and conductivities of pork leg is higher than the normal human tissue [8]. Therefore, to measure the performances of the antenna inside a human body, we have used a mixture of lean pork and beef. This mixture shows a good agreement with the desired dielectric properties at frequencies above 1 GHz, however, it is not suitable for making measurements at MICS band. Hence, we employed another experimental phantom using the pork skin with fat. The size of our phantom was 350 x 350 x 15 mm which has provided reasonable measured results over all the three bands. The dielectric properties of the pork skin phantom are measured from 0.1 to 3 GHz by using dielectric assessment probe kit from SPEAG and Agilent E5071C network analyser.

The proposed slot PIFA antenna fed by a coaxial probe is composed of a single metallic layer and is printed on one side of a FR4 substrate. The substrate thickness is 1.6 mm, and its dielectric constant is 4.7 and loss tangent of 0.0038. A dielectric superstrate having the same dielectric and thickness as that of the substrate is used to cover the antenna.

TABLE I
MULTI BAND PIFA

Tissue	Band 1.	Band 2.	Band 3.
Centre Frq.	433 MHz	1433 MHz	2400 MHz
Bandwidth	16 MHZ	100 MHz	200 MHz
Efficiency calculated	.06%	2.63%	1.12%
Gain calculated	-32 dBm	-11.5 dBm	-13 dBm

TABLE II
DIELECTRIC PROPERTIES OF HUMAN BODY

Tissue	Permittivity			Conductivity s/m		
	433MHz	1433MHz	2.4GHz	433MHz	1433MHz	2.4GHz
Muscle	57.12	54	52.7	0.80	1.15	1.73
Skin	46.78	39.5	38	0.69	1.047	1.46
Fat	5.58	5.39	5.28	0.04	0.065	0.10

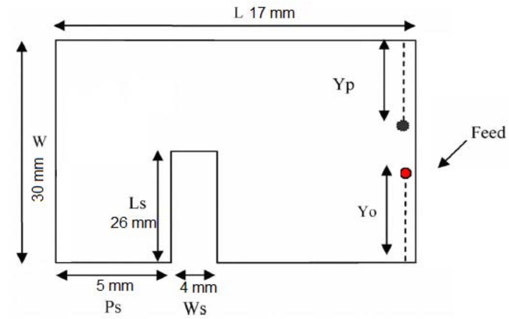
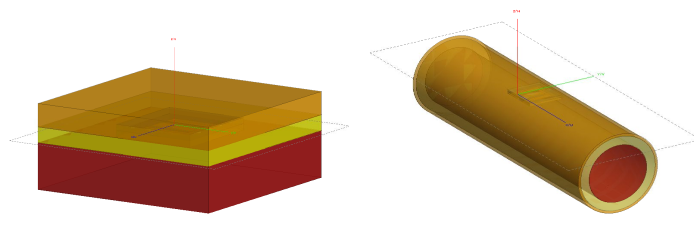
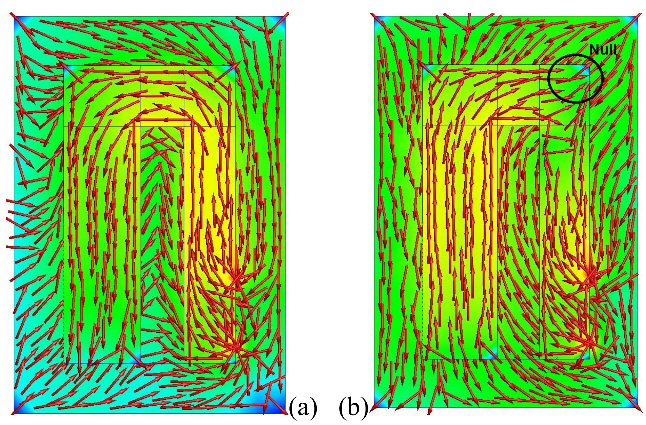


Fig. 1. Geometry of slot PIFA antenna.



(a) Layered Block model. (b) Layered cylindrical model.

Fig. 2. Simulation models of human body phantoms.



(a) (b)

Fig. 3. Surface current distribution of the proposed antenna at (a) MICS band and (b) WMTS band.

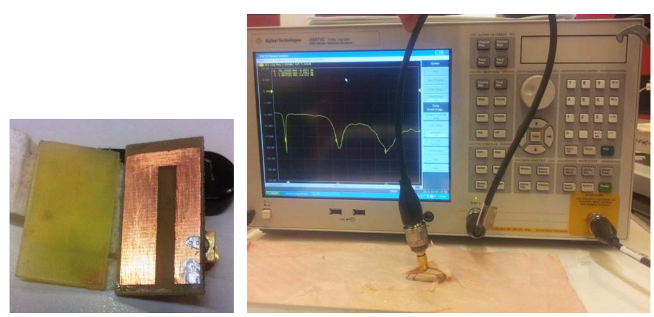


Fig. 4. Slot PIFA antenna on FR4 and Measurement set up.

Figure 4 shows measurement setup and the prototype of Slot PIFA antenna on FR4 substrate. We assume that the antenna and its cover will be coated with a biocompatible coating [1], [13], whose dielectric constant is close to that of the surrounding media, so that it does not affect the antenna performance.

The simulated results on reflection coefficient for the proposed antenna when immersed inside both homogeneous and multi-layered numerical phantoms are compared with the measured results when the antenna is immersed in the pork skin phantom and are shown in Figs. 5 and 6 respectively. The numerical phantoms are designed using frequency dependent dielectric properties to represent human tissues closely at the required frequency bands. From Fig. 5, one can observe that the antenna has a reflection coefficient of -17dB at 433MHz and has an impedance bandwidth of 16MHz which is adequate for implanted biomedical applications. In these figures, the measured data obtained using pork skin phantom compares reasonably well with results obtained using block shaped homogeneous numerical phantom. The comparison of results shown in Fig. 6 also demonstrates a good agreement between measured data with simulations on three-layered numerical phantoms. The shifts in center frequencies are attributable to fabrication tolerances, as well as due to possible reflections within multiple layers of the numerical phantoms.

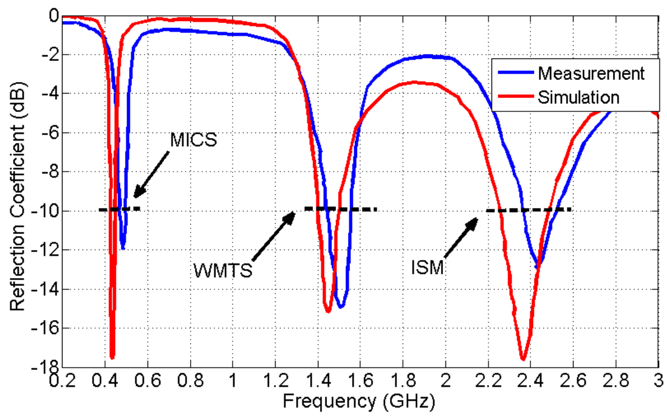


Fig. 5. Reflection coefficient: Measured in pork skin vs. simulation using block homogeneous tissue phantom.

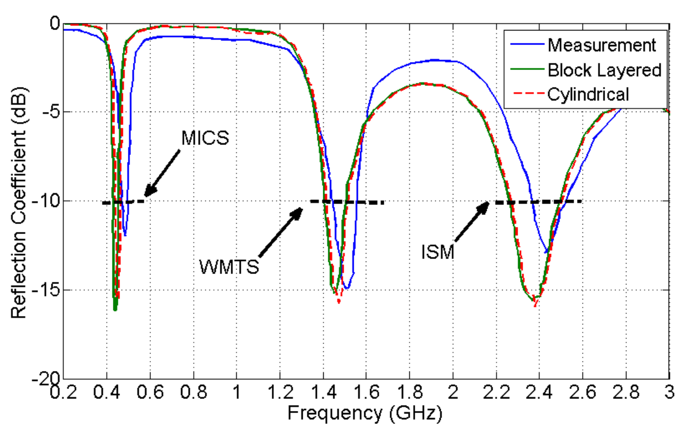


Fig. 6. Reflection coefficient: Measured in pork skin vs. Simulation in layered block and cylindrical tissue phantoms.

V. CONCLUSIONS

This paper proposes a miniaturized slot PIFA antenna of size 19 × 30 mm using a shorting post for implantable biomedical applications. The antenna can cover three bands viz., ISM band (2.4 GHz), WMTS band (1427–1432 MHz) and MICS band (433–434 MHz). The antenna can also be made to resonate at other frequencies by varying the position of the shorting post without changing the antenna dimensions. The simulated performance of the proposed implantable antenna was carried out using FEKO [12] employing multi layered block and cylindrical tissue mimicking numerical phantoms. The measured performance was obtained using a pork skin experimental phantom. The proposed implantable antenna exhibits low reflection coefficient, wide band impedance matching and has small size.

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