UWB Antenna Impedance Matching in Biomedical Implants

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***Abstract*— Ultra-wideband (UWB) technology has been considered for the physical layer in recently proposed IEEE802.15 standard (TG6) for Wireless Body Area networks. Wireless links covered by this standard will operate in UWB unlicensed band with antennas on implanted devices having small form factors. Except for those installed on-body and on external receivers, the antenna will be operating in-body, surrounded by body tissue. Body tissues have high dielectric constants and are highly dissipative. Once implanted beneath multiple layers of tissue, the device, which is expected to be consuming very low power, experience heavy losses in its transmission and reception path. Therefore, it is essential that antenna losses, both mismatch and resistive, are minimised. In this paper we will demonstrate a method to minimize antenna mismatch losses by loading the antenna with insulating material.**

I. Introduction

Development of UWB (Ultra-wideband) antennas has been previously addressed in the context of high data rate short range communications in consumer electronics for entertainment purposes. The introduction of WBAN (Wireless Body Area Network) standard IEEE802.15 will shift research focus towards UWB-based implantable devices. An Impulse Radio UWB (IR-UWB) transmitter has been developed for broadband multi-channel communication [1]. The system developed is simple and low power, ideal for biomedical implants when integrated with an efficient UWB antenna.

Implanted antenna designs have been proposed for various frequency bands [2-6]. The target of the proposed design is 3.5-4.5 GHz, which is the operating frequency of the in-house developed IR-UWB transmitter. As we shall see shortly the antenna matching may not be sustained if it is designed and optimised in the free-space. Moreover, if the antenna is optimized for particular type of tissue, it may not perform as efficient with spatial and temporal changes of tissue properties [7]. Dielectric loading has been used in implantable antenna design as a means of optimization. Antenna size reduction has been achieved owing to high permittivity of superstrates [8]. Application of this miniaturization technique is essential as the implanted devices are often compact. In addition, an implanted antenna needs to operate either inside or close proximity to dissipative media. It has been shown in [9], based on dipole behaviour, an antenna in dissipative medium, unless loaded with insulating material, needs infinite power to overcome losses in the surrounding. Results provided in [9] can be further extended to show that when the dielectric constant of the insulator is close to that of dissipative media and in the range of one order of magnitude to two orders of magnitude, maximum power transfer can be achieved across a wide frequency band or wide range of electrical properties, i.e. conductivity and permittivity of dissipative media.

In this paper we present a small antenna that has the cross-sectional dimensions of a size 000 capsule. The antenna in principle is a wide-slot antenna with a fork shaped feed [10]. However, it is loaded with Glycerine solution to achieve impedance matching across a wide range of tissue types. The antenna design and optimization has been carried out using CST Microwave Studio (MWS) electromagnetic modelling software. A proof-of-concept experiment is presented to demonstrate that the antenna behaves as predicted by theoretical investigations.

II. Antenna Configuration

The dimensions of the antenna are shown in Fig. 1. It consists of a grounded-CPW (Coplanar Waveguide), a wide slot and a fork-shaped feed printed on a TMMi substrate with the dielectric constant of 9.8 and 1.27 mm thickness. The CPW has two grounds on both sides of the substrate. These grounds are interconnected by three 0.75 mm vias, symmetrically placed 2 mm from the centre of the feed pad. The circular pad at the feed end of the CPW is indeed a broadband probe-to-CPW transition, which is needed for SMA connector feeding of prototypes. Nevertheless, a differential feed with 50 Ohms internal impedance has been used in CST MWS simulations. The grounded-CPW has the characteristic impedance of 50 Ohms.

The overall length of the antenna is 23.70 mm; exactly half of that is occupied by the slot antenna, while rest may be used for other electronics. In prototypes presented here, an SMA connector has been soldered in this location.

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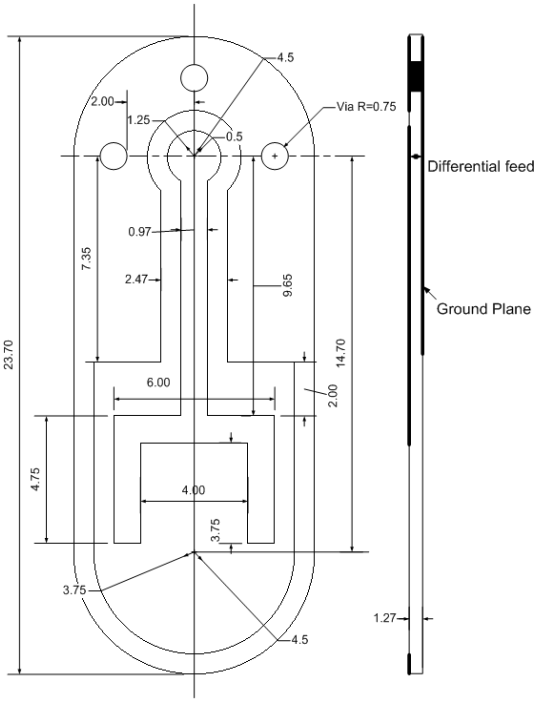

Fig. 1 Antenna configuration; dimensions of the patch and substrate

Overall slot width is 7.5 mm, whereas the substrate width is 9 mm. The antenna substrate can be easily slipped inside a size 000 capsule. The classical fork-shaped feed of the wide slot antenna is 6 mm wide and 4.75 mm long, optimised by simulations discussed in the section to follow. The dimensions of the feed and the gap between the feed and slot edge can be adjusted to change input impedance [10].

III. Simulated Results

The antenna matching has been achieved inside a cylinder of tissue simulating material, while the slot-half of the antenna is loaded with Glycerine, as shown in Fig. 2. According to the tissue properties given in [11] the dielectric constant of Glycerine, 50, is close to many of tissue types. The table I outlines the tissue properties used in our simulations. The values are given for 2.4 GHz and we use them as approximations at 4 GHz.

According to Table I approximate values taken from [11] has close to 50 dielectric constants except for breast tissue and bladder. The dielectric properties of tissue are susceptible to changes due to variations in temperature, frequency and other physiological conditions. We can therefore assume a range of 40-60 for dielectric constant for any tissue. The antenna is indeed impedance matched in the expected frequency band (3.5-4.5 GHz) within this range of dielectric constants of the dissipative media, as shown in Fig. 3 with the exemption of Bladder and Breast tissue. This is due to their low dielectric constants. Note that conductivity of Bladder and Breast tissue is also lower resulting in lower propagation losses, making matching requirements of Breast or Bladder implanted antennas less critical.

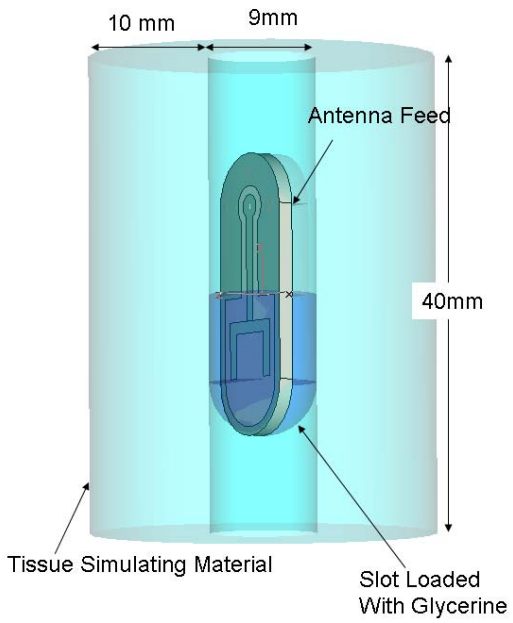

Fig. 2 CST Simulation setup for insulated slot antenna

TABLE I

APPROXIMATED BODY TISSUE PROPERTIES FOR 4GHZ

Tissue Type	ε_2	σ_2 (S/m)
Aorta/ Liver	43	1.47
Bladder	18	0.69
Blood	58	2.58
Breast	5	0.14
Kidney/Muscle	53	1.77
Small intestine	54	3.21
Stomach	62	2.25

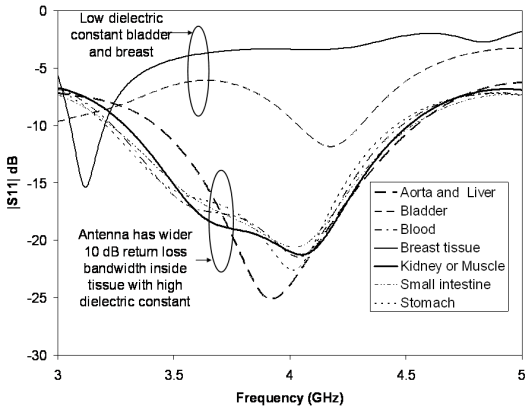

Fig. 3 Theoretical S11 values from CST MWS

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IV. THE EXPERIMENT

An experiment has been designed to demonstrate the matching performance of the proposed UWB antenna. Samples of Pork Midloin Chops from a supermarket have been selected as tissue. The properties of these samples are unknown, but assumed to be similar to those of human tissue. On two different chops, insertions were carved out with a sharp knife and they were shaped with a size000 capsule. The insertion thus created has a depth of approximately 11 mm and diameter of 9 mm. S11 was measured using E5071B vector network analyser. Following three scenarios have been considered:

1. Antenna in free-space
2. Antenna inside the empty insertion
3. Antenna inside the insertion filled with Glycerine solution

The experiment setup is shown in Fig. 4. Measurements were repeated for two different insertions on two different samples of Pork Chops. Measured S11 values are shown in Fig. 5.

It is obvious that antenna is not matched in the band of 3.5-4.5 GHz band in free space. There is a matched band at higher frequencies due to the small size of the slot antenna. Once the antenna has been lowered into empty insertion its S11 characteristics have changed due to the presence of air-tissue interface in the near field. Still clearly there is no 10 dB return loss matching in the expected frequency band or at any other frequency within the measured range. When the insulation medium fills the insertion, antenna has good matching from 3-5 GHz, as expected from simulations. There is about 3 dB difference in S11 between two insertions, due to the experimental tolerances and potential differences of dielectric properties between the two samples.

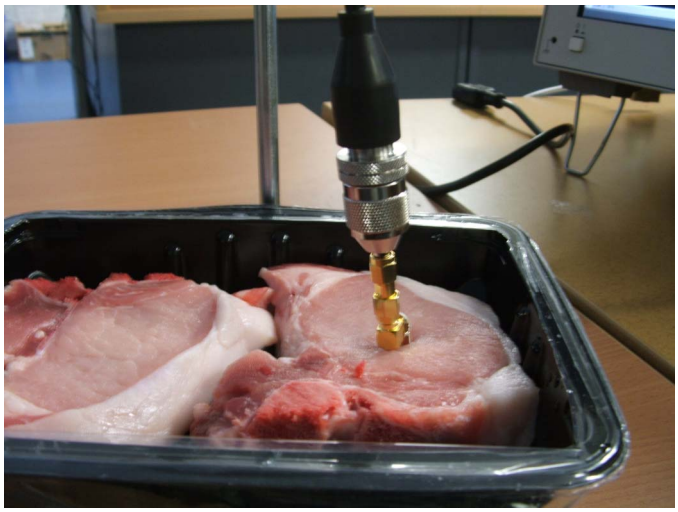

Fig. 4 Experiment setup using antenna prototype and pork Midloin chops

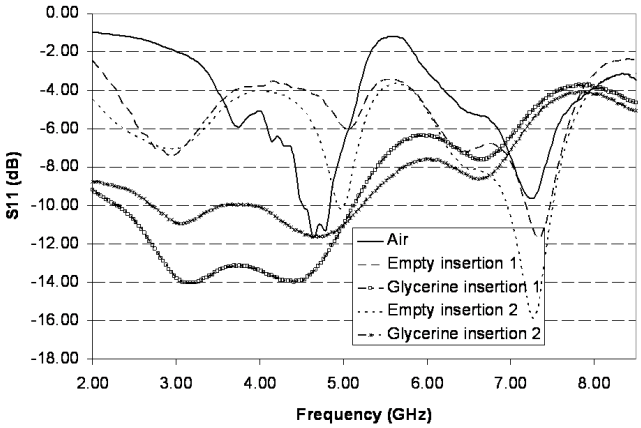

Fig. 5 Measured S11 values for loaded and unloaded slot antenna prototypes

V. CONCLUSION

An antenna is matched in the UWB frequency band of 3.5-4.5 GHz following the principles of insulator loading. For the dielectric constants of tissue material, Glycerine was selected as the insulator. Simulations as well as the proof of concept experiment demonstrate that the loading can shift the frequencies to the desired band and achieve greater than 10 dB return loss. The method is feasible in small implantable antenna design for low power UWB medical systems. With proper packaging methods an antenna, radio module and sensor nodes can be completely integrated into one module. This module is expected to have high radiation efficiency within a wide range of human and animal tissue types when the proposed antenna design method is followed.

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