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Design and Analysis of Optimum Performance Pacemaker Telemetry Antenna

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Abstract

The demand for health technology is increasing especially in the telemetry applications. These applications generally use implanted antennas to be utilized for data transfer from patients to other reader devices. This procedure can make the health care more efficient since it provides fast diagnosis and treatment to the patient. Therefore, in order to effectively implement an implanted antenna inside the human body, thorough numerical analysis and simulations are required prior to the fabrication of antenna. In this work, an implanted antenna has been proposed to be designed at 402.5MHz within the biomedical frequency band of 402- 405MHz. By introducing a compact loop antenna for telemetry applications in a Pacemaker, a number of advantages can be achieved for health care such as efficient data information and quick diagnosis. Moreover, in this work an investigation of compact loop antenna with casing in Pacemaker has been carried out by placing the antenna inside the phantom of human body model.

Keywords: pacemaker, telemetry antenna, compact loop antenna and return loss

1. Introduction

The requirements of efficient antenna development are rapidly increasing especially in the telecommunication technology, defense system and mobile communications applications [1]. The capabilities of antenna performance for health care, radio communications and monitoring have become major concern for designing high performance antennas.

Telemetry antennas have been identified as highly attractive solution for many applications such as healthcare, entertainment, identification system, sports, smart home, space and military applications. The telemetry antenna offers number of advantages, flexibility and can directly communicate with other devices.

In telemetry antenna design, the interference should be minimized in order to reduce any consequences to patient and other electronic devices worn/placed on the body. One of the examples of implanted antennas is the use of telemetry antenna with pacemaker [2]. Pacemaker are used to treat arrhythmias that are problems with the rate of heartbeat in a way that it maintains an adequate heart rate by delivering electrical stimuli to the chambers of the heart rate [3, 4]. With the advent of numerous wearable devices, the possibility of interference by high frequency external electric field with pacemaker has become a matter of concern [5].

Based on the demand, telemetry antenna has to be designed compact in order to fulfill the requirement of small in size and light weight antenna to be placed inside a pacemaker. The ideal telemetry antenna should be designed with high efficiency maintaining the antenna performance even with small and compact size. Other than that, the Implanted Medical Devices such as pacemaker has also a crucial limitation which is that the signal might interfere to other nearby electronic devices especially those attached to the body. This interference can corrupt the signals on both devices and hence can cause malfunctioning.

The use of antenna technology on the human body with significant innovative features allows possible solutions for multi-purpose applications such as tracking systems, mobile communications systems, defense systems and healthcare applications [6-9]. The increasing growth in use of Body Area Networks (BANs), Wireless Personal Area Networks (WPANs), and

medical sensors has eved an interest in wearable antennas in order to improve the quality of life [10-13].

Nowadays, the technology for medical treatment and diagnosis has been developed as an important additional functions of implanted medial devices such as pacemaker and defibrillators which need to transfer information [2,14].
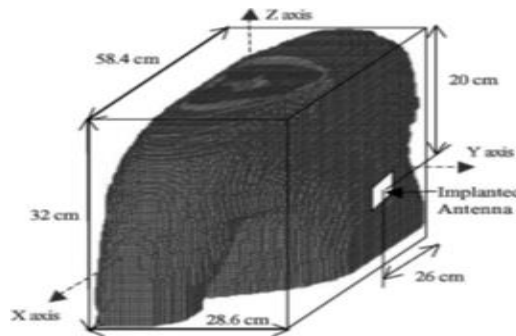

Figure 1. Three-dimensional FDTD human body used for the implanted antenna design in a human chest [2]

Figure 1 shows the geometry of a standard human body model. In order to realize the size of the human body box and to represent human body, the given dimensions have been used to place the proposed telemetry antenna. The resonant characteristic of the designed antenna have been simulated by using phantom box (consisting of the skin tissues). Therefore, in this work a telemetry antenna is developed to achieve compact size, lighter weight and low interference with other devices. Moreover the effect of the presence of human body and the active implanted medical devices on the antenna performance is studied which helps in the characterization of the implantable antenna design.

2. Proposed Antenna Design

In order to investigate the effect of pacemaker inside human body and also to other devices, the pacemaker has been represented as telemetry antenna to be embedded in the pacemaker. The telemetry antenna is designed to resonate at 402.5 MHz which is same as pacemaker operation frequency. Then, the pacemaker is placed inside the phantom box mimicking the implantable device inside a human body.

2.1. Telemetry Antenna Design

In this section, telemetry antenna to be implanted in has been designed using FR-4 as the dielectric substrate. Commercially available CST computer model has been used to design a Telemetry antenna constructed on a 3.2 mm thick dielectric substrate with patch element dimensions of Ls=76 mm and Ws=44 mm. In order to investigate the possibility of realizing telemetry antenna in pacemaker, a compact loop antenna has been introduced on a rectangular substrate as shown in Figure 2.

Figure 2 shows a telemetry antenna for pacemaker by employing compact loop element. The compact loop antenna has been simulated, by placing inside a phantom representing human chest, and modified to be used at 402 - 405 MHz for short range biomedical devices as explained in [15]. A compact loop antenna has been simulated with dual dielectric (substrate and superstrate) because telemetry antennas placed in pacemaker are usually positioned between skin and mussel tissues in the chest [16]. In this work, in order to see the possibility of interference of telemetry antenna in pacemaker, antenna has been placed with casing of pacemaker made of aluminum and plastic.
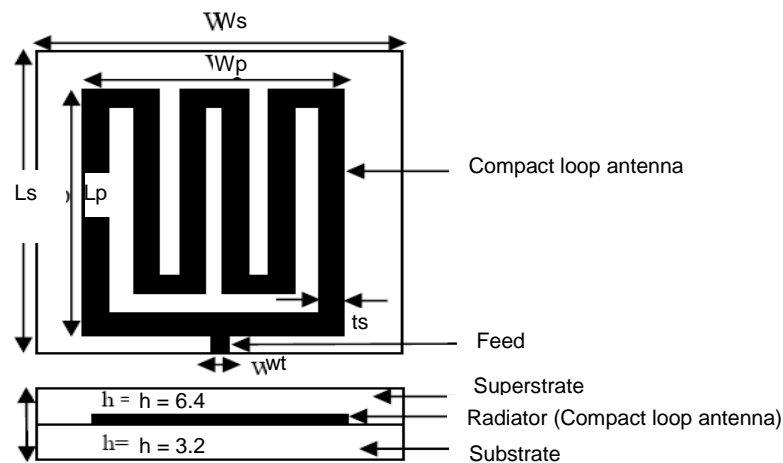
Figure 2. Detail configuration of the compact loop antenna for telemetry applications (*Ls*=76mm, *Ws*=44mm, *Lp*=70mm, *Wp*=40, *ts*=3.63, *wt*=1mm)

In this work, the proposed antenna is examined with human body tissues in order to observe the effect of human body on the antenna performance. Therefore, the compact loop antenna has been designed with substrate and superstrate layers. The superstrate is capable of protecting neighboring tissues surrounding the proposed antenna. The superstrate layer acts as buffer between the metal radiator and human tissues by reducing Radio Frequency (RF) power at the locations of lossy human tissues. Moreover, by employing the superstrate layer, the antenna can be assuredly matched to 50 Ω through decreasing effects of the high conductive biological tissues [2]. Transmission line and compact loop element have been used to achieve smaller dimension as compared to a conventional microstrip patch antenna.

2.2. Telemetry Antenna Inside Phantom Box

In order to investigate the effect of the human body, model of human body has been created by using phantom box. The proposed antenna has been placed in phantom box. The electrical characteristic of the phantom box (εr =46.7, σ =0.69 S/m at 402.5MHz) have been used which are available in CST Microwave Studio (MWS). The proposed antenna placed inside the phantom box is shown in Figure 3. The effect by the presence of phantom box on the return loss performance of antenna is provided in the next section.
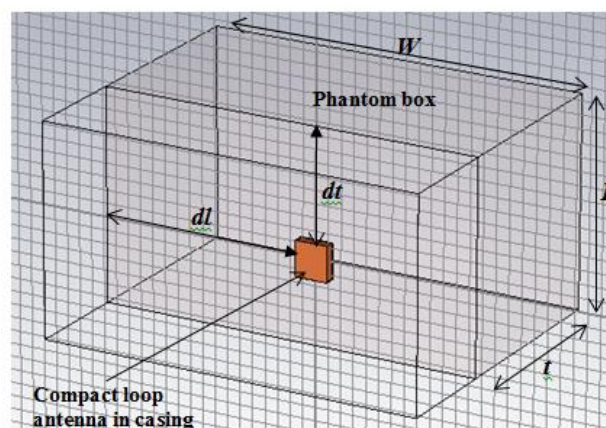

Figure 3. The telemetry antenna with proposed phantom box
(*W* = 584mm, *t*= 286mm, *L*= 320mm, *dt* = 200mm, *dl* = 260mm)

As shown in Figure 3, the proposed compact loop antenna has been embedded in the phantom box 200mm from the top of phantom box, 260mm from the left end and 4mm from the front of phantom box. Based on the human body which consists of different layers of skin, fat and muscle tissues the phantom box can also be created with single layer [2]. The thickness of the skin tissues is 4 mm which is the same as the gap between the compact loop antenna and front of phantom.

3. Results and Analysis

Due to the proposed design configuration, the surface currents travel long distance inside the loop. Therefore the electrical dimensions of the patch element elongates and provides an opportunity to design a patch at the same resonant frequency of 402.5 MHz with compact physical dimensions. In order to elaborate this phenomenon surface current distributions and electric field intensity have been generated using CST MWS simulations as shown in Figure 4.
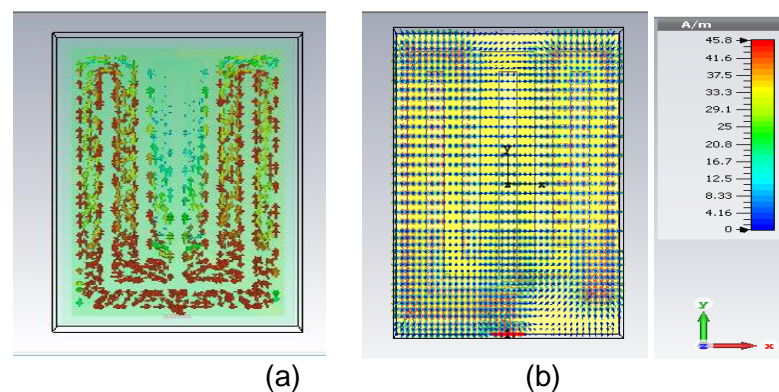

(a)   (b)

Figure 4. (a) Surface current distribution on a compact loop antenna (b) Electric field intensity on the antenna surface

Figure 4 shows the surface current distribution for compact loop antenna. It is shown that the maximum surface current occurs in the center of the loop antenna when the electric field is excited in the Y-direction. By introducing compact loop antenna, it is shown that the surface current density (J) and electric field intensity (E), the dimension of the antenna can be reduced. The increase in the surface current density (J) on the conducting material causes an increase in the electric field intensity (E) which is given by Maxwell Equation 1.

$$\nabla \times \tilde{H} = \tilde{J} + Jw\tilde{E} \tag{1}$$

Where (H) is magnetic field intensity and (J) is current density through the surface reflectarray element. The current density (J) can be correlated to electric field intensity (E) and conductivity, (σ) of conductor material which is given in Equation 2.

$$J = \sigma E. \tag{2}$$

The simulated results of the proposed compact loop antenna with and without different types of casing (aluminum and plastic) are shown in Figure 5. As depicted in Figure 5, the resonant frequency of the proposed antenna is initially 402.5MHz which can be applied in biomedical applications. The introduction of two types of casing affected the resonant frequency with a little bit distortion at the resonance. However the resonant frequency is still in the range of applicable telemetry applications and the trend of return loss curve is also acceptable.

The change in resonant frequency can be negated by designing the loop antenna at a lower frequency. However it can be observed from results that the metallic casing (aluminum) has also significantly affected the return loss of the antenna bringing it below -10dB. The reason

for this change is the effect of dielectric properties of phantom on the antenna assembly which causes a variation on the effective permittivity and conductive [17]. The return loss demonstrated by antenna with aluminum casing placed in phantom is not acceptable and hence it can be concluded that plastic casing is more suitable for compact telemetry antenna.
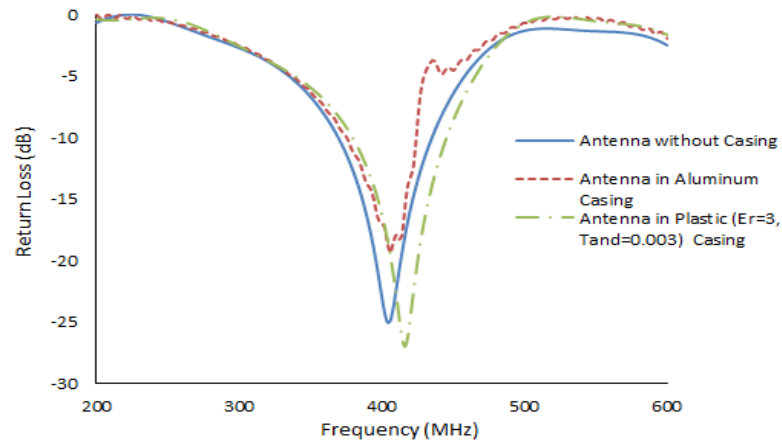

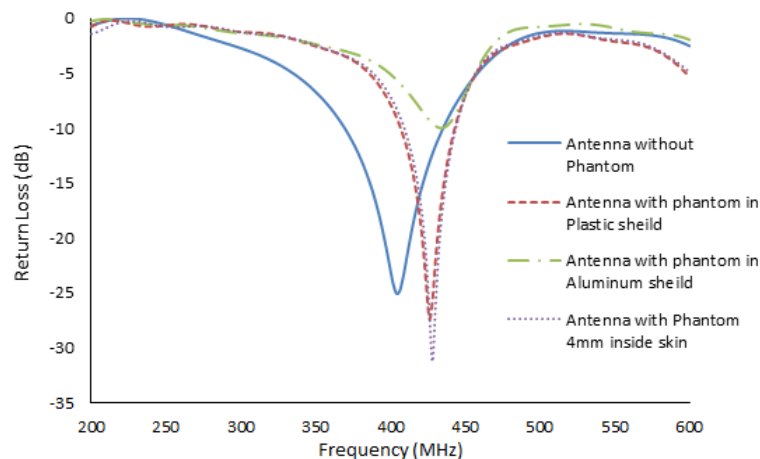Figure 5. The telemetry compact loop antenna with casing and without casing

Figure 6. The telemetry compact loop antenna with casing and without casing
(in Phantom Box)

4. Conclusion

The result obtained from the preliminary studies presented that by introducing a compact loop design, the dimension of the antenna can be minimized. Moreover, the proposed compact loop antenna can be used for telemetry application especially in biomedical applications. The compact loop antenna with minimized dimension can be further investigated for realization of pacemaker inside the human body model for Electromagnetic Interference (EMI). Measurement will be carried out in order to analyze the reliability of the simulated results from the commercially available CST computer model. Further investigation are required to observe the EMI effect between pacemaker to human body model and other external electronic devices such as wearable antennas.

Acknowledgements

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