DESIGN OF A CIRCULARLY LOADED HEXAGONAL LABYRINTH IMPLANTABLE ANTENNA FOR BIO TELEMETRY APPLICATIONSD

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Abstract

The health care industry is continuously revolutionizing and advancing towards developing more efficient system suitable for human body. Today implantable devices have become a more interesting topic in health care services which primarily started with the pacemakers. Since then it is continuously evolving due to its non-invasive nature, instant monitoring and diagnosis, and periodic simulation. In this work, a novel Hexagonal Labyrinth implantable antenna has been proposed for medical applications to be operated in medical band. The biocompatible polyamide substrate (Er = 4.3 and ta0.004) with 0.05mm thickness has been used as both substrate and superstrate. The proposed antenna is featured with very good miniaturization with the dimensions of 6x 6x0.1 mm3 by employing circular maze shaped structure in radiator. The performance of the proposed antenna was evaluated by placing in a realistic human model using HFSS. The simulated results for the gain and reflection coefficient exhibited reasonable agreement. The safety of the antenna was verified according to the IEEE SAR regulation. The analysis of the link budget revealed that the antenna can perform reliable wireless communication.

Introduction

The evolution in our world is running very fast because of the rapid development of scientific research methods and tools. The base for such evolution is the human needs in different life styles including health and entertainment etc. There is no doubt in that the health has the priority over most other needs because it relates directly to human life. It attracts a lot of research funding and has a very active market. Consequently, researchers in both academic and industrial sectors are very interested in designing and developing health tools and medical devices to be more reliable, safer and more comfortable. Communication to provide essential bio information. Such information is important for therapeutic and diagnostic purposes. Wireless communication requires efficient antennas to establish links. Many considerations should be taken into account when the antenna is designed since it is intended to be implanted inside the human body. Some of these considerations are the size to be as small as possible, the shape to be conformal to the medical device, the radiation pattern to be suitable for the related application and more importantly the transmitted power to be within the specific absorption rate (SAR) safety limit.

Figure 1 Several wireless implantable medical devices are used in human body

Implants are supplied generally by primary batteries. Deep brain neuro stimulators and pacemakers for example are supplied by non-rechargeable batteries with a scheduled lifetime of 5 to 7 years based on the function of the device. After the lifetime end of battery, the implantable device should be changed surgically with an expensive cost and potential infection hazard to the patient. The occurrence of infection related to such surgical change of pacemakers ranges from 1%-19%.

Moreover, some implantable devices that function in direct interaction with blood cannot use batteries such as pH and glucose monitoring sensors due to the

Potential hazard of injuring in case leakage occurs [8]. From the total volume of device, a battery occupies more than 50% of volume. Another solution to use such batteries leads to considerable reduction in the implant size. Additionally, it leads to long life usability of the implant and is cost effective.

Table 1 Comparison various Energy sources used in implantable devices

Power source	Power density	Pros	Cons
Primary batteries	0.09 $\mu W/mm^2/year$	Reliable	Limited life span
Piezoelectric	< 0.2 1, $\mu W/mm^2$	Internal energy	Depending on moving Parts
Glucose bio-fuel cell utilizing glucose from blood (5 mM)	2.8 $\mu W/mm^2$	Internal energy	It's limited by the glucose enzyme density
Thermoelectric, T=5°C	0.61 $\mu W/mm^2$	Internal energy	Low efficiency
Electromagnetic power transfer	10 to 1000 $\mu W/mm^2$	High power density and Controllable	Limited by safety Regulations

Requirements, Standards and Challenges of Implantable Antennas

Due the electromagnetic properties of the human body, implantable systems face more challenges and difficulties in designing antennas than conventional wireless communication systems. Unlike free space, human body tissues are lossy and have relative permittivity. Therefore, the antenna requires the compliance with many conditions, standards and requirements such as: size, radiation performance, frequency of operation and SAR.

Radiation Performance

Due to the high path loss, the implanted antenna should have gain as high as possible in the desired direction to guarantee communication between the antenna and the external devices. In the case of capsule endoscopy antennas, Omni- directional radiation is required in order to cover all direction during fluctuation of the capsule endoscopy device. However, implanted antenna radiation has to comply with SA Requirements and emitted power regulations.

Specific Absorption Rate (SAR)

The one of the main effects of the human body on the implanted antennas is the high attenuation of the radiated power. This power attenuation in the lossy surrounding media generates heat in the human body tissues which could be hazardous to health. Therefore, for safety reason, in-body radiation is restricted to certain level. Thus, the Specific Absorption Rate (SAR) has been introduced to measure the Electromagnetic (EM) Energy absorbed by biological tissues mass when exposed to radiating devices. SAR can be defined using the following equation:

$$SAR = \frac{P_L}{\rho} = \frac{\sigma\,|E|^2}{\rho}$$

Where E (V/m) is the electric field and (kg/m3) is the mass density.

SAR can be defined in many terms such as (Mass averaged SAR) for each point SAR, a cube with a defined mass (1 g or 10 g) is found. Then, the power loss density is integrated over this cube and then the integrated power loss is divided by the cube mass.

The FCC and ERC define that the maximum limits for SAR averaged over l g and 10 g of tissue mass by 1.6 and 2 W/kg respectively. The maximum EIRP, according to European Telecommunications Standards Institute (ETSI), is -10 dBW (100mW) where EIRP is the Effective Isotropic Radiated Power. Therefore, the antenna radiation has to comply with SAR requirements and emitted power regulations (EIRP).

Frequency of Operation

Medical electronic devices can be classified into two categories depending on the protocol and standards that these devices use. The first category is Wireless Medical Telemetry Services (WMTS) for wearable devices. The second category is Medical Implant Communications Service (MICS) which was allocated by the European Telecommunications Standards Institute (ETSI) for implantable devices. The frequency band allocation for MICS is 402 MHz to 405 MHz .The

Industrial, Scientific, and Medical (ISM) bands (433.1-434.8 MHz, 868-868.6 MHz, 902.8- 928 MHz, and 2400-2500 MHz) are also suggested for implantable medical device biotelemetry in some countries, especially for subcutaneous application.

State of The Art Implantable Antennas Design and Challenges

A large number of implanted antennas have been presented the literature. However, they can be classified into two categories; the first one is subcutaneous implanted antennas or antennas to be placed in a fixed area of the body, and the second category is implantable antennas that move through the body such as capsule endoscopy systems. In this section, antennas are reviewed in term of bandwidth, gain and size. In addition, capsules antennas minimum gain and radiation patter=n directionality are reviewed and compared.

Antennas Size

In the literature, different techniques have been used thoroughly to reduce implantable antenna size. Designing antennas to operate at high frequency bands ,such as 5.8 GHz or higher, is one of the techniques to presents applicable size antennas to be implanted inside human body.

Human Body Modeling

The human body is, complex, having a large number of systems with different electromagnetic characteristics for every part of the body. The human body's permittivity vary from 70 to 0 overlapping tissues. During implanted antenna design process, human body modeling carries out two times:

Numerical Phantoms

Numerical body phantom can be a single component with single electromagnetic characteristics (homogeneous) or multilayer, multi-component represents the variety of the human body's electromagnetic characteristics (inhomogeneous).

Physical Phantoms

In order to experimentally investigate the interaction between the human body tissue and the electromagnetic fields, phantoms are used to simulate the biological tissues of human body. For this purpose, phantoms have been used extensively in medical and engineering research. Examples of using phantoms include the effects of electromagnetic radiation on health, X-ray, magnetic resonance imaging (MRI) scan and implantable system design.

Antenna Performance Parameters

A brief overview of the parameters used to evaluate antenna performance is given below. The definitions in quotations are taken from IEEE Standard Definitions of Terms for Antennas, IEEE Std 145-1983.

Antenna directivity: The directivity of an antenna is given by the ratio of the maximum radiation intensity (power per unit solid angle) to the average radiation intensity (averaged over a sphere). The directivity of any source; other than isotropic, is always greater than unity.

Domain Description

Antenna

Antennas are a very important component of communication systems. By definition, an antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space. Antennas demonstrate a property known as *reciprocity*, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band of the radio system to which it is connected, otherwise the reception and the transmission will be impaired. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a *radiation pattern.*

Antenna Glossary

Before we talk about specific antennas, there are a few common terms that must be defined and explained:

Input Impedance

For an efficient transfer of energy, the impedance of the radio, of the antenna and of the transmission cable connecting them must be the same. Return loss

The relationship between SWR and return loss is the following:

$$\text{Return Loss (in dB)} = 20\log_{10}\frac{SWR}{SWR-1}$$

Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz forwhich the antenna will exhibit an SWR less than 2:1.

The bandwidth can also be described in terms of percentage of the center frequency of the band.

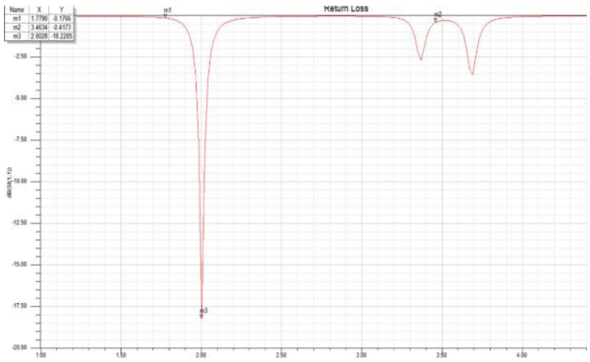
$$BW = 100 \times \frac{F_H - F_L}{F_C}$$

where Fri is the highest frequency in the band, FL is the lowest frequency in the band, and Fc is the center frequency in the band. In this way, bandwidth is constant relative to frequency. Directivity and Gain

High Frequency Structure Simulator (HFSS)

HFSS is a high-performance full-wave Electro Magnetic (EM) field simulator for arbitrary 3 D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Package Modeling — BGA, QFP, Flip-Chip

- PCB Board Modeling —Power/ Ground planes, Mesh Grid Grounds,
- Backplanes Silicon/ GaAs - Spiral Inductors, Transformers



Radiation Pattern

Figure 1 SAR rate

Table 2 Performance parameter

Parameter	Existing 1	Proposed 1	Proposed 2
Gain	-26.5	-4.4	-4.6
Volume	2.11	1.8	2.11

Conclusion

A miniaturized dual-band CP antenna was designed and experimentally validated for WCE applications. The optimum performance and miniaturization of the antenna were achieved via the introduction of slots in the radiating patch. The surface current distribution was visualized to confirm the circular polarization of the antenna. The impedance BW and AR BW of the antenna covered the desired frequency bands. The performance of the proposed antenna was evaluated by placing in a realistic human model using HFSS. The simulated results for the gain and reflection coefficient exhibited reasonable agreement. The safety of the antenna was verified according to the IEEE SAR regulation. The analysis of the link budget revealed that the antenna can perform reliable wireless communication.

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