Review on Implantable Antennas for Biomedical Applications

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***Abstract*— Modern medical systems are working on the concept of monitoring human health conditions by inserting certain implantable devices into the body. The design of these devices has been in considerable attention regards to the development of various parameters like miniaturization, person safety, biocompatibility, upgraded communication quality with exterior and interior control system. In this review paper, One of the major application areas of wireless communication technologies is in the biotelemetry domain is represented. Implantable medical devices (IMDs) are the area of the recent development in biomedical telemetry. Due to limited distance of communication which is less than 10cm and an increase in sensitivity the use of low-frequency inductive links in biotelemetry fields for implantable medical devices results in poor data rates (1-30 kbps).**

The research work focused on solving these problems and radiofrequency (RF)-linked implantable medical devices. The Medical Implant Communication System (MICS), Wireless Medical Telemetry Service (WMTS), industrial, scientific, and medical (ISM) bands are some of the frequency bands are available for smooth functioning and safety of the patients so with the advancement in technology new variations are being done to the implantable medical devices to improvise their functionality and increase their use.

***Keywords*— Implantable antenna, Implantable Medical Devices (IMDs), biocompatibility, miniaturization, patient safety, Bio-medical telemetry, patch Antenna.**

1. Introduction

In the field of implantable biomedical devices (IMDs), one of the latest developments in technology so far is wireless biomedical telemetries. Nowadays, due to complex medical conditions, implanted biomedical devices are serving as desirable solutions. These devices are installed in the patient's body with the help of surgical operations and can be utilized for various monitoring, therapeutic and diagnostic applications [1]. Bio-medical devices help people to improvise the overall health care and lifestyle which has grabbed a lot of centres of attraction among researchers. Implantable medical devices are efficient in communicating with an external gadget with the help of wireless technologies. The focal sight of the health monitoring system with a wireless implantable medical instrument is to give appropriate information from within the human body to an external Base communicating Station (BS) [2].

In the following paper, a review on the design of antennas for biomedical applications has been studied and presented. A brief gist of such implanted antenna system, an elaborative review of several antennas utilized in implantable medical applications has been presented. The various challenges faced during the designing of such antennas are discussed during studying the various techniques that can be utilised in reducing the dimensions of the antenna for safer insertion inside the human body.

The simulation software HFSS is used in addition to the measurement techniques. The biocompatibility issues and safety considerations concerned in the designing of implanted antennas for biomedical applications are also considered. Designing phase of the antenna are very well elaborated and measurement outcomes are presented.

2. CONCERNED PARAMETERS FOR IMPLANTABLE DEVICES

Patients' safety is one of the major and the most important concern for the designing of implantable devices. as the antenna would be placed in the complex body environment .so various requirements are being taken care of while the manufacturing of the implantable devices that are mainly miniaturization, patient safety, communication capability, biocompatibility, power consumption, and lifecycle of the implantable circuits. In this section, detailed information is presented regarding the concerned parameters for implantable devices.

2.1) Operation on frequency bands:

Operating in approved bands is one of the most common restrictions for a system to be deployed in biomedical applications. For data communication, high frequencies with wide bandwidth are preferred. We mostly use the MICS band (402-405 MHz) for biomedical applications [3].

2.2) Size:

Since the antenna must be placed into the human body, so size is the key requirement for its design that implies the dimension of the antenna should be small that would be provide beneficial in conserving the patient's safety. with the advancement of integrated circuits, integrated chips due to its compact size can be used for implantable antenna designing which can be implemented with help of CMOS technology [4]. since the antenna would operate at acceptable frequency bands. various methods have been there for achieving the compact size of the antenna. These are various methods such as:

1) Usage of high permittivity dielectric substrate or supersubstrate.
2) Usage of F structured antennas
3) Elongating the path of current of the radiator
4) Using various loading techniques to get the improved impedance matching
5) frequency of operation

These methods provide a considerable shift of the resonant frequency to the lower resonant frequency by reducing effective wavelength. This results in better and improvised impedance matching, gain, bandwidth, and performance at the desired resonant frequency [4]. Hence these requirements are essential for considering the overall framework of the device. For miniaturization, we use dielectric material with high permittivity, increase the path of the current on the antenna plane, and adding patch stacking and shorting pins [3].

2.3) Specific Absorption Rate:

As the human structure has been electrically lossy with various skin as well as muscle tissues of varied permittivity and conductivity. These implanted devices have to be set off in the lossy media of frequency dispersive material parameters. The electrical field emission from the implantable device and along with the magnetic field is responsible for the moving charges near to tissues to experience the Lorentz force in addition to the increasing temperature of the tissues which may affect the overall properties of the tissues or may cause damage if has higher heat radiation. Implantable antennas face more struggles while designing, because of the electromagnetic properties of human bodies. These challenges include limiting the Specific Absorption Rate (SAR) and having gained as high as possible [3].

Specific absorption rate determines the rate at which the amount of radiation emitted from the device is absorbed by the body tissue. The IEEE C95.1-1999 standard specifies the standard for the measurement of SAR value over 1g of tissue should be less than 1.6W/Kg. The IEEE C95.1- 2005 standard sets standard for SAR over 10g of tissue to be less than 2W/Kg.

SA (specific Absorption) =SAR $\times$ T_p

Tp is the pulse duration [2].

If the value of SAR would be more than the specified standards then radiations emitted would affect the muscle tissues thereby, affecting the properties of the tissues where the antenna is being inserted in. Hence, SA is required for comparing the transmitting device with the international safety standards.

2.4) Biocompatibility

Implantable antennas should always be biocompatible for long-term operations to ensure safety. We can achieve this by using biocompatible components straight in the fabrication of the antenna or by enveloping the implantable element using a thinnest layer of the biocompatible material [3]. For maintaining the lifecycle of the device biocompatible antennas comes into the highlight. for ensuring the implantable device to be biocompatible. there are two methods for implementing them that are – by designing the antenna directly on these biocompatible materials or by providing a layer of biocompatible material coating to the device [3]. Various biocompatible materials are being used for this which are ceramic, Teflon, etc **[4].** This would enhance the overall performance of the device by not compromising the patients' safety.

2.5) Power Considerations

Operating the implantable antenna ceaselessly will result in consequential energy consumption and reduction of the antenna's life. To overcome it, we use various approaches like the inductive loop approach, to recharge the battery [4].

2.6) Return Loss

Return loss can be defined as the power loss in the signal coming back or reflected from the input through an interruption in an optical fiber or transmission line.

The antenna return loss determines the antenna power to be transmitted and reflected. It has an inverse relation with the power to be transmitted. The frequency where the return loss value is at the lowest value is considered as the resonant frequency of the antenna. In other words, it should be less than 10db at the desired resonant frequency so that most significant power is being transferred to the device (around 90%) and at minimum power is being reflected (around 10%) to have an efficient performance of the device. The frequency range for which the return loss value should have range within -10dB points is generally treated as the antenna's bandwidth [4].

2.7) Focalized temperature limit

When the device is deployed into the body then, tissues surrounding the implantable device would absorb some power that could increase the temperature of body tissue around that region. Hence, tissues surrounding the implantable device should not increase by 1-2^{o}C as it may damage the tissue or may lead to a change in the tissue properties within that region [4].

3. SIMULATION METHODS FOR ANTENNA TESTING

Various software is employed for the design and simulation of antennas for medical uses. The frequently used are the High-Frequency Structure Simulator (HFSS), the market oriented tool employed for antenna designing, and for the designing of complex radio frequency electronic circuit elements; CST Microwave Suite, a special tool for the 3D simulation of Electromagnetic components that allows the fast and accurate analysis of high frequency (HF) devices; Finite-Difference Time-Domain (FDTD) or Yee's method, a numerical examination method that is implementing the modeling computational software; employed for the analysis and design of 3 dimensional and of planar microwave circuits; FEKO software deployed in a computational electromagnetics software. Field calculations involving bodies of various shape [5]. The various electrical properties of human tissues relative permittivity (ε_r), conductivity (σ), and dielectric loss tangent (tan δ) are frequency-dependent [6]. Hence, to make the simulation more effective, various skin layer models are being used thereby, making measurements much easier. When these measured results using various phantoms have been compared with these simulated results of the same type, it would be useful information of accurate antenna design.

4. MEASUREMENT METHODS FOR ANTENNA

For the effective study of the design in a real-world environment, implantable antennas can be analyzed and checked within different human body conditions. There are mainly two different types of measurements that are being deployed for the implantable medical devices, which are in vitro measurements and in vivo measurements [5]. There is a connection between in vitro and in vivo data which must be utilized during the enhancement for the reducing dimensions of design time and optimizing the overall results obtained.

4.1) In Vitro Measurement

This is a type of measurement, where the implantable device is immersed into a human body like a liquid/solid. This phantom liquid/solid is generally a container containing a liquid or gel-like material that has similar electrical properties to the human tissue for which the device is being tested [5]. Usually for the preparation of these samples distilled water will provide a basis for the base ingredient [7]. The various properties like permittivity, conductivity is controlled by the ingredients used in phantom preparation, such as salt enhances the conductivity as well as the relative permittivity of the phantom whereas sugar enhances the permittivity without affecting the conductivity [8]. For testing purposes, the phantom prepared is solidified or for multilayer, formation is done by using agar hence this helps in analyzing various other ingredients for handling the viscosity of the phantom [6].

To avoid air bubbles formulation the phantom mixture is stirred and poured slowly into the container [9]. After the preparation of the phantom, the testing is done through a network analyser when the implant is placed in the phantom, measuring the parameter like reflection coefficient of the antenna. The results are measured, then compared to the simulated ones for acceptance. The placement of the antenna inside the sample is very practical and convenient in use.

Various phantoms have been provided for deployment, that is a liquid like material very similar to the dielectric properties of human body tissue very much same to body medium, Polyacrylamide scalp phantom and saline, dental model, a tissue-emulating material consisting of ultra-pure water, sugar, and salt, a heterogeneous sample of a male child from a virtual family and pork skin phantom [5].

Fig 1. Provides the in vitro testing of the implantable antenna used in referenced paper [7]. Table 1 provides the table for various phantoms stated in the referenced research papers.

Table 1. Simulation tools and measurement types were being deployed during testing [5].

Simulation Tool	**In Vitro Measurements**	**In Vivo Measurements**
HFSS	Equivalent body	NO
FEKO	Pork skin phantom	NO
2.5 field simulator	Liquid mimicking tissue	NO
HFSS	Polyacrylamide, scalp phantom, saline,	NO
NA	Liquid mimicking tissue	NO
IE3D	Dental model	Human body model
IE3D	Testing rig	Animal
NA	Water, sugar, and salt	NO
HFSS	NO	NO

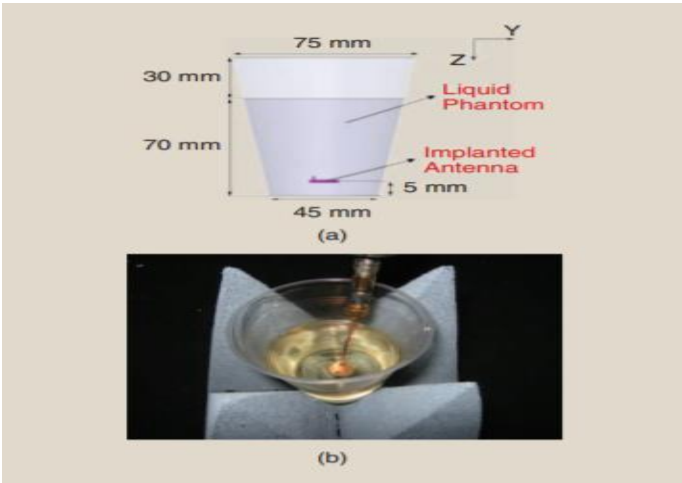

Fig. 1. In vitro testing of the implantable antenna depicting (a)numerical model and (b) experimental setup [7].

4.2) *In Vitro Measurements*

This is the type of measurement, where the impact of the living tissues on antenna performance is determined by deploying a phantom that resembling the human tissue properties or by inserting the antenna into the animal body. Animal-tissue samples provide a convenient method for mimicking the frequency-dependent properties of the tissues. Thus, providing a great advantage for multi-band implantable antennas [10].

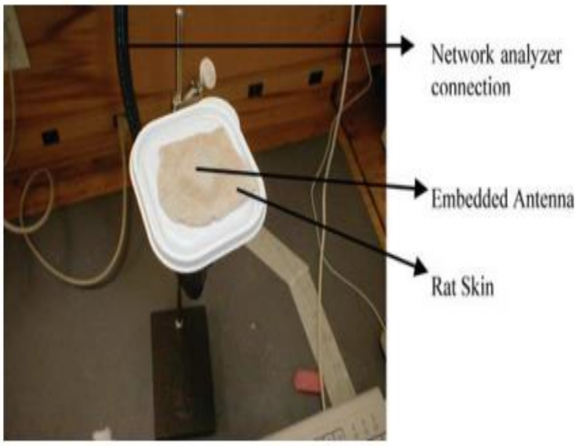

Fig 2. Patch antenna inserted in the animal tissue sample [3].

An in-vivo testing environment is required to be formed before experimentally testing the antenna as the implantation of the antenna within the body tissues would be challenging [3]. To deal with this situation legal requirements regarding the choice and number of animals, pre-surgical preparation, anesthesia, surgical procedure, measurements, and post-surgical treatment are taken care of [3].

Fig 3. Implantable patch antenna surgically implanted in rat tissue [4].

5. FREQUENCY BANDS

Band of frequencies play one of the significant roles for a device to be deployed in biomedical applications. for smooth operation, the frequency bands must be within the approved bands. There are many operating frequency bands for this purpose that are ISM (Industrial Scientific and Medical band), MICS, WMTS,4GHZ,868MHZ, and 1MHZ Also, higher operating frequencies lead to shorter wavelengths thereby, reducing the overall dimensions of the antennas size [11]. High frequencies along with wider bandwidths provide a basis for communication, but they lead to higher tissue attenuation than at lower frequencies [12]. Wireless Medical Telemetry Service (WMTS) bands are operated at 1427–1432 MHz and industrial, scientific, and medical (ISM) bands are operated at 433-434 MHz and 2.4–2.4835 GHz. The Medical Implant Communication System (MICS) is used for short-range communication of2 m due to its lower power. it provides high-data-rate communication of 401–406 MHz (the core band is 402–405 MHz). This communication network has been accepted worldwide for data transmission so, as for supporting the curative or medicinal functions correlated with medical implantable devices [13]. This frequency band is studied to design mobile and safer communication systems for supporting lives.

6. FUTURE SCOPE

For improving patient's life and enhancing the quality of healthcare the growing technology of implantable medical antennas have high potential and a great role to play. Both patients and caregivers will be served with many benefits using Radio Frequency technology for biomedical implant [14]. To keep in check various medical and technical concerns the deployment of highly-permittive dielectric (substrate/superstrate) materials are usually done for implantable patch antennas because they assist in antenna miniaturization by shortening the overall significant wavelength resulting in lowering the resonance frequencies [5]. We can also get further a more suitable miniature size for the implantable antenna by elongation of the current-flow path on the surfaces of patch. as it reduces resonance frequency so several techniques like patch-stacking, parasitic patch, defective ground structure, dual feed, path geometry modification, feeding techniques are being further explored to boost the performance of the antenna to look out for various challenges like radiation efficiency, miniaturization, biocompatibility, physical requirements, gain, and safety [15].

7. CONCLUSIONS

In this paper, an overview of implantable devices in the wireless technology field has been introduced. Different frequency bands at which the operation of an antenna is possible, are studied. parameters that concern the design of such devices have been presented and various requirements related to it have been explained with the help of techniques to achieve the compact size. various simulating environments have been studied for testing of the antenna and how these parameters would be measured in the realistic environment. For preserving patient's safety-testing methods, design environments and biocompatible materials have been discussed and how they influence the overall performance of the implantable devices. In the end, the future scopes have been successfully discussed to improvise the performance of the device.

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