Jurnal
Teknologi

Full Paper

Propagation Characterization of Implantable Antenna at UWB Frequency – A Review

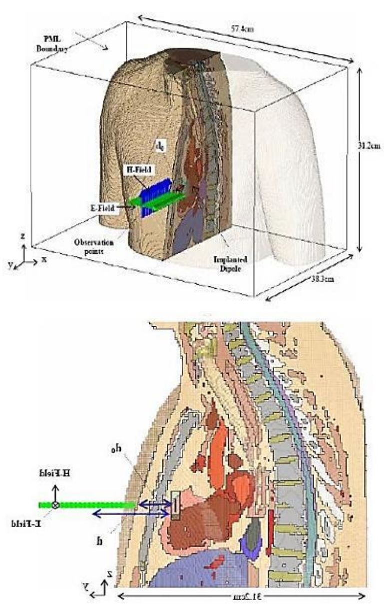
Maisarah Abu, Najmiah Radiah Mohamad, Adib Othman, Nor Azlan Mohd Aris, Indra Devi S., Nurul Hafiza Izahar*

Department of Telecommunication Engineering, Center for Telecommunication Research and Innovation (CeTRI), Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia.

Article history
Received
19 June 2015
Received in revised form
26 June 2015
Accepted
10 July 2015

*Corresponding author
hafiza.izahar@yahoo.com

Graphical abstract



Abstract

A technology of wireless body area network (WBAN) was invented in order to enhance the quality of healthcare management as well as to determine faster disease prevention. However, to obtain the real-time data of images and videos from inside the human body, an implantable device is required. Currently, the Medical Implant Communication System (MICS) is used, but, this system has limited data rate which is a narrow-band of 402 – 405 MHz. Thus, this study on Ultra Wideband (UWB) for implanted device is conducted as UWB offers a wide transmission bandwidth as well as high data rate. Knowledge of radio wave propagation behaviour inside human body is needed to perform the implantation. Past researches related to this topic are limited and those conducted focused only on the human torso. This paper aims to provide a better understanding on the characteristics of radio wave propagation inside the human body by using an implantable device at UWB frequency. It is also hoped that this study could be used as reference for future research on this subject.

Keywords: Radio propagation characteristics, signal behaviour, implant antenna

Abstrak

Teknologi rangkaian kawasan badan tanpa wayar (WBAN) telah dicipta bagi meningkatkan kualiti pengurusan penjagaan kesihatan dan juga sebagai langkah yang lebih cepat untuk mencegah penyakit. Walau bagaimanapun, bagi mendapatkan data masa sebenar imej dan video dari dalam badan manusia, alat implan diperlukan. Pada masa ini, Sistem Komunikasi Implan Perubatan (MICS) telah digunakan, namun, sistem ini mempunyai kadar data yang terhad melalui frekuensi jalur lebarnya yang sempit iaitu 402-405 MHz. Dengan itu, kajian ke atas Ultra Wideband (UWB) untuk peranti yang diimplan dijalankan kerana UWB menawarkan jalur lebar penghantaran yang luas serta memberikan kadar data yang tinggi. Oleh itu, untuk menjalankan kajian tersebut, pengetahun mengenai tingkah laku perambatan gelombang radio dalam badan manusia adalah diperlukan. Hanya beberapa kajian telah dilakukan mengenai topik ini di mana mereka telah memberikan tumpuan hanya pada bahagian dada manusia. Melalui kertas kajian ini, ia adalah untuk memastikan pemahaman tentang ciri-ciri perambatan gelombang radio di dalam badan manusia yang disebarkan dari alat implan pada frekuensi UWB untuk rujukan masa hadapan.

Kata kunci: Ciri perambatan gelombang radio, tingkah laku signal, antena implan

1.0 INTRODUCTION

Nowadays, the number of people with chronic disease is constantly increasing worldwide. Various technologies have been developed wirelessly for the purpose of improving quality of life, providing efficient healthcare management, as well as for disease prevention. This wireless technology known as body area network (BAN) has been developed for medical applications, e.g. to monitor numerous physiology signals for example electrocardiogram, body temperature, blood pressure, and endoscopic video [1][2]. These medical applications are available in a variety of scenarios; on-body, outer body, and in-body applications. Yet, to attain the data of images and videos from inside the human body, the scenario of in-body application is utilized through Medical Implant Communication System (MCIS). This system comes with various potentials such as tracking system, drug delivery to specified organs and non-intrusive way of entering the body.

The characterization of in-body propagation channel is necessary in designing a wireless implant device with selection, frequency, bandwidth and power [1]. Ultra Wideband (UWB) is a radio technology that may well support multiple medical applications comprising medical radar, microwave imaging, microwave tomography, microwave hyperthermia, and wireless communications with medical implants [3][4]. These happen due to UWB's distinctive characteristics which enables it to carry signals through many obstacles. It usually reflects signals at a more limited bandwidth and a higher power [5]. UWB has various features that include low-power and high data rate technology that offers insusceptibility to multipath interference. It is robust to jamming owing to its low probability of detection.

Nevertheless, the current technology of implant devices was stated to have a standard frequency of 402 – 405 MHz allotted by the Federal Communication Commission (FCC) [2][6][7]. This frequency range is said to have appropriate propagation characteristics in human tissues. Yet, it comes with several disadvantages in which the requisition of power hungry components for example voltage-controlled oscillator (VCO), phase-locked loop (PLL) and analog-to-digital converter (ADC) making it an inefficient factor for implant devices. Unlike UWB that comprise features such as simple structure, high data rate, low-power consumption and low cost which had given this device a valuable aspect [1][5][6],[8]-[12], It is perfectly compatible with the specifications of an implant device.

Additionally, UWB is commonly used for on-body or outer-body medical applications. It is rarely used for an in-body implantable medication device. This situation is due to the different frequency-dependent material properties of the human tissues that need to be considered in the calculations [13][14].

2.0 UWB IMPLANTABLE ANTENNA

Implantable antenna for medical technology is increasingly used nowadays as this kind of medication analysis enables easier penetration into the human bodies and provides data that indicates health condition of a person as shown in Figure 1.

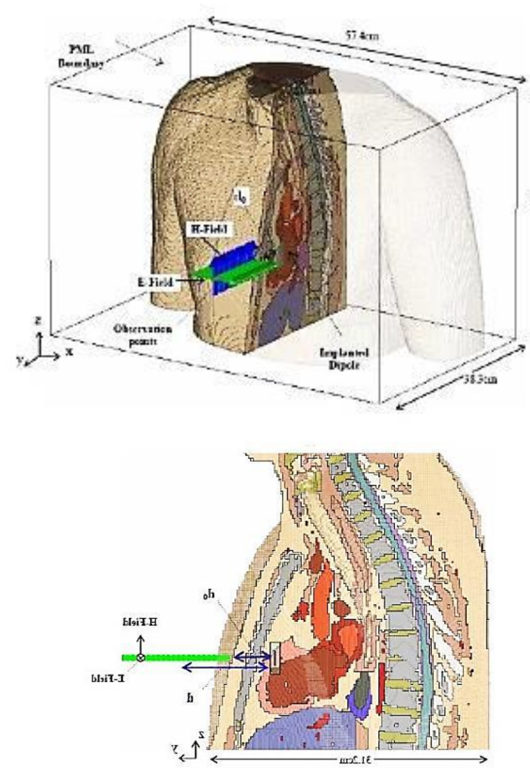


Figure 1 Layout of human chest with implanted antenna [11]

MICS band of 402-405 MHz are used currently due to its features such as ultra-low power, unlicensed, mobile radio service for transmitting data of the diagnosis from the implant (transmitter) to the external monitor (receiver). However, in [15][16] it is found that UWB frequency range offers an exceedingly wide transmission bandwidth that helps in giving more accurate real-time data.

In [8], [9], [11] and [17], the design of implantable UWB antenna was executed. Different shapes and designs with the same purpose of generating and implanting UWB antenna were explained by each author. There are three main difficulties faced in designing an UWB antenna for implant device; (1) restricted to small dimensions, (2) required to be biocompatible, (3) demands for electrical insulation from the human body.

Authors in [8] and [11] proposed for an elliptical antenna each designed with a disc dipole antenna and a slot antenna in both ground planes respectively. The elliptic disc dipole with major axis of 16 mm and minor axis of 14 mm was entrenched into a lossless dielectric case with a dimension of 24 mm x 40 mm x 4 mm using biocompatible silicon case material. This is to avoid direct current flow from the disc dipole to the conductive body tissue. As for the elliptical slot antenna, the two ground planes and the elliptic antenna were utilized using RO4003 substrate with $\varepsilon_r =$ 3.38 and thickness of 0.51 mm.

As posited by [9], the antenna was designed using three different antennas featuring different geometric parameters, overall sizes and shapes in which later they were compared to observe their performances. The first and second antennas were designed using the same substrate of Rh-5 with relative permittivity of 1 while the third antenna utilized an AlO_2O_3 ceramic substrate with thickness of 1 mm. These three antennas were designed to be independent planar monopole antennas with impedance matching of 50Ω microstrip transmission line. The dimension of these antennas can be referred to [9].

Lastly in [17], the authors designed an RFID (radio-frequency identification) antenna featuring planar inverted-F antenna (PIFA) characteristics. This antenna was designed in a stacked design in which the radiating element was covered with a biocompatible superstrate with dielectric constant of 10.2 and having a thickness of1.25 mm. Similar to [9], this antenna was also designed to match the antenna input impedance with the highly capacitive impedance of the chip of 50Ω which is exclusive of a loss of generality.

3.0 PROPAGATION CHARACTERIZATION

Since human body is made up of various organs consisting of different types of tissues, the electrical characteristics of the entire body show vast heterogeneity and anisotropy, for instance the conductivity, power absorption, path loss and relative permittivity.

3.1 Path Loss and Power Absorption

Path loss, which is sometimes known as path attenuation, is a reduction in power density of electromagnetic waves as it propagates through space. It is also a measure of the average attenuation of a signal that propagates from a transmitter to a receiver [1][14]. It can be presented as:

$$PL_{dB} = -|S_{21}(f)|_{dB} \qquad (1)$$

Around the average value, there will be a variation called scattering that is caused by the difference of material dielectric properties in terms of conductivity and permittivity along the propagation path. This path loss (PL) definition in terms of scattering parameter is repeatedly utilized for the body area network (BAN) applications as it is easily computable. On the contrary, for practical in-body implant applications, it cannot be directly measured in vivo, thus it is carried out thru ex vivo with simulations and measurement [12].

A technique of finite difference time domain (FDTD) was used to numerically calculate the scattering parameter, at each considered frequency with the ratio between power level on the receiving end and the output power level at the transmitter which is defined as:

$$PL_{dB} = \frac{P_{in}}{P_{rec}} = -10\log(d/d_o) = -|S_{21}|_{dB} \qquad (2)$$

In order to model a path loss between the transmitting and the receiving antenna as a function of distance. The semi-empirical formula that is based on Frii formula is as shown in [2][10][18] and as stated in dB was represented as follows:

$$PL_{dB} = PL_{o,dB} + 10n\log(d/d_o) \qquad (3)$$

As shown in [1],[10],[19],[20], path loss model was expressed as the following:

$$PL_{dB}(d) = PL_{o,dB} + a(d/d_o)^n + \mathcal{N}(0,\sigma) \qquad (4)$$

where d is the depth of the implant from skin surface, unit in millimeters, a is fitting constant, d_o is the reference depth that will remain constant, n is the path loss exponent that is commonly subjected to the environment where the radio signal is propagating through. Whereas, the $\mathcal{N}$ is the random variable (RV) that is distributed by Gaussian in which it approximately shows the scattering in decibels.

Power absorption which is described as energy photon, where in this case, is an electromagnetic energy that is taken up by matter generally the electrons of an atom and converted to internal energy of the absorber such as thermal energy. In [18], it measures the power absorption in terms of specific absorption rate (SAR) for muscle tissue that surrounds the implant device. A maximum of 2 W/kg for 10 g tissue of basic restriction as defined in International Commission on Non-Ionizing Radiation Protection (ICNIRP) was used to safeguard the public from electromagnetic fields. SAR can be referred to as the rate of energy that is absorbed by the body when it is open to a radio frequency (RF) electromagnetic field. Authors in [18] stated that the maximum permitted radiated power in the MICS band is 25 μW.

3.2 Influence On Propagation Characteristics

There are many influences that are able to effect the results of propagation characteristics including antenna separation for different tissues, antenna misalignment, antenna rotation, line of sight as well as size and shape of subject [18][20][21].

For human tissues, it is indicated that there are differences in human tissue properties in terms of permittivity and conductivity. These two, highly affect the results of path loss and power absorption. In comparison the results of PL in [18] specifies that PL increased with the increased conductivity and decreased permittivity. As for SAR, the nearer the implant device to the skin surface in which the antenna depth is decreased, the SAR attained was higher in comparison to the other locations of the antenna within the human body. This is most likely effected from the proximity of the interface muscle-air.

For antenna misalignment, the antenna was shifted as shown in [18]. From the results of the comparison of path loss against distance at different layers of tissues, the separation of 160.5 mm was selected. The antenna was shifted vertically in a vertical displacement from the original -100 mm to +100 mm. The curves of PL versus vertical displacement seemed to be almost symmetrical between the original and sifted one due to the antenna's shape that is not symmetrically formed. The highest PL can be detected at the esophagus due to its high conductivity and low permittivity. As the separation gets higher, this shifting antenna results in a big difference of 10 dB to 12 dB indicating that the increase in misalignment is caused by an increase of the PL.

In terms of antenna rotation, it is likely to have the same effects as the influence of line of sight. In [18], [20] and [21], the authors tabulated the results in the form of graph and table to show the effects of the location of the transmitter and receiver that is whether it faces each other or vice versa. This line of sight as well as its relationship to the subject's size and shape is as indicated in [21]. In line of sight cases, the subject specification does not have effect on the propagation path similar to the non-line of sight cases. This is caused by the fact that the wave reaches the receiver largely through reflections from the surrounding environment making the received signal to be non-subject-specific. However, when it is in a non-line of sight position, in which the rotation is 90º, it generated the highest value of PL due to the position of the transmitter which is totally perpendicular to the receiving end and not pointing directly to it.

4.0 RECENT RESEARCH

By offering exceptionally broad transmission bandwidth that leads to high data rate as well as low complexity makes UWB communication an interesting and high-demand technology in both research community and industry. It has high potentials in numerous medical applications including implant devices. Thus, in order to understand the implant system, several researchers have studied on its characterization propagation from inside the human body. Hence, UWB communication system is an interesting topic that has recently gained more attention instead of the MICS band that is being currently used in medical implant systems. Only several studies have been found on this UWB characterization propagation in [4],[10] and[11]

Authors in [4] and [10] studied on UWB characterization propagation from inside the human body using an adult male's chest as test area. Both electric and magnetic field probes were set in a rectangular cube space with dimensions of 140 mm x 160 mm x 80 mm as well as resolutions of 20 mm x 10 mm x 20 mm. These probes were inserted in various tissues including blood, lung, heart, fat, bones, muscles and others. Considering the probes as isotropic radiating antennas, they operated at a frequency range of 100 – 1000 MHz for spectral bandwidth of -15 dB in [4], whereas [10] using both range of 0.1 – 1 GHz and 1 – 6 GHz as interest frequency. The characterizations that were investigated include power density, spectral analysis and delay spread in both [4] and [10].

As studied in [4], it has been revealed that significant power loss befell at the superficial area near to the skin which was taken from the calculated radiograph of power density at different xy-planes. This may be caused by impedance mismatching between free-space and the multilayer body tissues. In spectral analysis of the UWB signal, the frequency range of 100 – 250 MHz displayed a better penetration depth within the body as attenuation increased with frequency. In order to evaluate different multipath channels for wireless system, delay spread was examined. In [4], it was indicated that the delay spread increased with penetration depth where the maximum delay spread was 1 ns.

Unlikely in [10], which compared two wide bandwidth of frequency 0.1 – 1 GHz and 1 – 6 GHz it was evident that, 0.1 – 1 GHz, had nearly the same power density at both horizontal polarized (HP) and vertically polarized (VP) at depths of $60mm$ to the surface, but at a depth of 120 mm the power density with HP was higher than VP. Thus, it proved that UWB signal with HP was able to penetrate deeper inside the human tissues. However, for 1 – 6 GHz, the power density was lower with higher power loss. As for delay spread, RMS delay spread was more with HP rather than VP at 1 – 6 GHz signal. It could reach a maximum of 1.7 ns delay spread at 160 mm depth. Similarly, at 0.1 – 1 GHz, it indicated the same pattern of delay spread yet with different maximum value of 1.2 ns at a depth of 100 mm.

Next in [11], the authors used an embedded elliptical disc dipole antenna to be implanted into the human torso with a resolution of 2 mm x 2 mm x 2 mm. The antenna operated at a frequency range of 1 – 6 GHz where it was placed inside the chest close to the heart at a depth of 45 mm from the surface. This paper brings to evidence that the energy density was reduced with the antenna distance that was caused by body tissue loss plus free space loss.

5.0 CONCLUSION

The issue of implantable medical device is a rising issue that has attracted the attention of many researchers in making this device more accurate and user friendly especially to the elderly. This is due to the fact that it is applicable for home monitoring especially for certain patients. A traditional implant device is not only inefficient in terms of having limited range, utilizing inductive links and low data rates. It is also not user-friendly for home monitoring. Recently, the use of UWB frequency range was explored to inspect the compatibility of this frequency and the implant towards human body as it is said that UWB is a good candidate for BAN applications. UWB has distinctive characteristics like low-power consumption, high data rates and a simple structure making it an appealing technology on top of others. Still, due to the disparity of frequency-dependent material properties of the human body tissues that needed to be considered in the calculation has deterred the production of the UWB implantable device. Thus, based on the results from several studies, it can be concluded that the UWB implant device ought to be manufactured due to its additional advantages in comparison to the current technology.

Acknowledgement

The authors genuinely express their token of appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for funding this research work under the grant of 06-01-14-SF0111L00019 and PJP/2013/FKEKK(48C)/ S01277.

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