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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Smart Body Area Network (SmartBAN).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document has the scope to evaluate ultra-low power, Ultra-WideBand technology (UWB) for a swallowable, pill-camera, wireless medical device operating in the 3,1 GHz to 10,6 GHz frequency band within the context of Smart Body Area Networks (SmartBAN).

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

Not applicable.

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADC	Analog-to-Digital Converter
BAN	Body Area Network
BER	Bit Error Rate
BPF	Band Pass Filter
BPSK	Binary Phase Shift Keying
CMOS	Complementary Metal Oxide Semiconductor
CT	Computed Tomography
FDTD	Finite-Difference Time-Domain
FPGA	Field Programmable Gate Array
FSK	Frequency Shift Keying
IR	Impulse Radio
MICS	Medical Implant Communication Service
MIMO	Multiple-Input Multiple Output

ML	Maximum Likelihood
MPPM	Multi Position Pulse Modulation
MRC	Maximum Ratio Combining
MRI	Magnetic Resonance Imaging
OFDM	Orthogonal Frequency Division Multiplexing
RF	Radio Frequency
RMS	Root Mean Square
RMSE	Root Mean Square Error
RSSI	Received Signal Strength Indicator
SNR	Signal-to-Noise power Ratio
TOA	Time Of Arrival
UWB	Ultra WideBand
WCE	Wireless Capsule Endoscope

4 Introduction and Background

BANs attracted a lot of attention as a future technology for wireless networks. Typical applications of wireless BANs include healthcare, medical treatment and medical monitoring Generally, wireless BANs are classified into two groups: wearable BANs and implant BANs. Wearable BANs are mainly used to monitor a person's healthy condition in daily life, whereas Wireless Capsule Endoscopy (WCE) has been one of the most important applications in implant BANs. WCE involves swallowing a small capsule by a patient, which contains a colour camera, light source, battery and transmits images to the outside receiver in order to assist in diagnosing gastrointestinal conditions such as obscure malabsorption, gastrointestinal bleeding, chronic diarrhoea and abdominal pain. The present document focuses on implant BAN applications. Such a medical application requires a reliable wireless communication channel and extremely low power consumption for increasing device longevity.

To realize the implant communications, the 400 MHz band and 2,4 GHz band are usually chosen. For example, a commercially available implant communication chip for cardiac pacemaker employs the 400 MHz band for data transmission and the 2,4 GHz band for waking-up and control. It has been reported that all of WCE techniques employ 400 MHz, 2,4 GHz or dozens of MHz band with narrow-band modulation schemes, such as Frequency Shift Keying (FSK) or Binary Phase Shift Keying (BPSK). The data rate is limited to several hundred kbps. However, in view of the implant communication application, for instance, WCE requires a higher data rate for a real-time image and video transmission.

In order to satisfy the above requirements, the present document pays attention to Ultra-Wideband (UWB) transmission. As UWB transmission schemes, UWB-Impulse Radio (UWB-IR), direct sequence-UWB (DS-UWB), and multiband-Orthogonal Frequency Division Multiplexing (multiband-OFDM) have been considered so far. Of all UWB schemes, UWB-IR is a technique that iteratively transmits extremely short pulses on the nanosecond time duration per bit. Therefore, it has merit in respect of low power consumption. Furthermore, coherent detection, namely correlation detection, claims to be one of the most suitable solutions for the UWB-IR communication system. Although the coherent detection needs to generate a template signal in the receiver side, the reliability of the coherent detection is generally superior to that of a non-coherent detection.

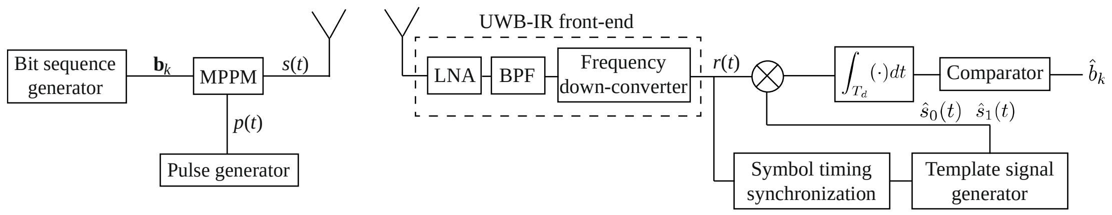
In implant BANs, the UWB-IR signals suffer from large attenuation, which may lead to undesired performance degradation. Therefore, it is important to investigate the transmission performance of the implant BANs. The present document aims to analyse the basic characteristics of the UWB-IR communication system by a liquid phantom experiment and then, evaluate the realistic performance of the implant UWB-IR system in a living animal experiment. In addition, Multiple-Input Multiple-Output (MIMO) technology is then considered for further improving the implant UWB communications. For this purpose, an example of implant side diversity antenna is developed, and the fundamental performance of the developed implant antenna is experimentally evaluated. Based on the measurement results, the communication performance improvement is discussed.

In the present document, the location estimation of an implantable device in UWB communications is also discussed. In medical treatments with implantable devices, it is important to estimate their locations accurately. So far, several kinds of localization methods have been proposed, such as magnetic field-based, Radio Frequency (RF) wave-based, and acoustic-based technologies. The present document pays attention to the Received Signal Strength Indicator (RSSI)-based localization because RSSI can be measured by a fundamental function in modern wireless communication systems without any additional special devices. High distance resolution of UWB (Ultra Wideband) communication signals is expected to achieve, as compared with a typical 400 MHz MICS band. In addition, this paper introduces an example of implant device localization systems based on UWB communications, and then discuss the achievable location estimation accuracy in a real environment.

5 Implant UWB Communication System

5.1 Transmitter structure

The structure of the transmitter is shown in Figure 1(a). As a UWB-IR pulse, the first order Gaussian monocycle pulse is employed, and this transmitter uses a Multi-Pulse Position Modulation (MPPM) scheme, which can control the trade-off relationship between the data rate and the reliability of the transmission. Figure 2 shows an example of MPPM signals when the number of chip slots L is set to 4, in which two UWB-IR pulses are assigned to each transmitted symbol. It is possible to control the data rate by changing the number of chip slots L. It is noted that the IR-type transmitter does not need a carrier signal and amplifiers. It employs a clock generator and some CMOS gates to produce pulses and a Band Pass Filter (BPF) for spectrum forming. Since CMOS gates consume low power and the passive BPF does not consume power, the total power consumption in the transmitter can be expected at a quite low level.



(a) Transmitter (b) Receiver

Figure 1: Implant UWB-IR system structure

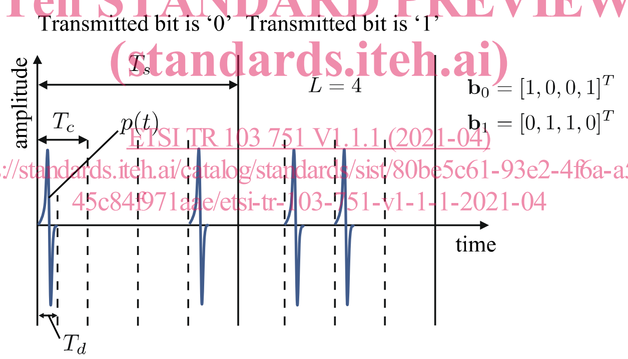


Figure 2: An example of UWB-IR modulated signals

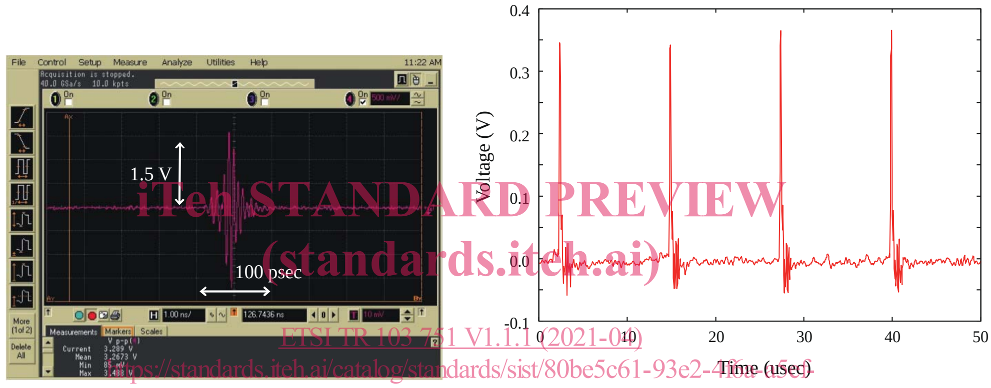
5.2 Receiver structure

Figure 1(b) shows the structure of the receiver. From pre-measurement of the implant channel characteristics, it is found that the power delay profile can be well represented as a two-path model with a very small mean time interval in the order of nanoseconds. This means that the multipaths are almost indistinguishable in the received signal and the multipath fading effect is not dominative. Therefore a detection system without any channel estimation is suitable for the implant communications, so the correlation detection is herein considered as the receive detection scheme. In the correlation detection, since the binary MPPM chooses one from two location assignments, two kinds of energies for the corresponding pulse locations from the received signal are calculated. It is noted that the receiver requires no threshold for the detection. In Figure 1(b), the symbol timing synchronization is realized with pilot signals sent from the transmitter.

6 Fundamental Performance Evaluation

6.1 Setup

This clause demonstrates the fundamental performance of the implant UWB-IR communication system. For this purpose, the fundamental characteristics are experimentally measured in a liquid phantom environment simulating a human body. In this experiment, the helical antenna as an on-body receive antenna is used on the liquid phantom surface with a spacing of 1 cm. The in-body transmit antenna is a one-wavelength loop antenna. A type of glue is coated to the antenna and feeding part for preventing a direct contact of the antenna to the liquid. The transmit antenna was inserted in the liquid phantom. The liquid phantom was produced to simulate muscle-like dielectric properties. It is confirmed that the dielectric properties of the vessel and found that its loss is almost ignorable. The transmit and receive antennas are connected to a network analyser with coaxial cables. The two coaxial cables were arranged at a right angle each other for removing possible direct coupling between them. Figure 3 shows examples of shapes of the transmitted and received UWB signals. The S_{21} performance is measured, namely the path loss characteristic, as a function of the distance from the implant transmit antenna to the phantom surface at the frequency band of 4 GHz. The measured path loss characteristics are shown in Figure 4. It is found that at a depth of 70 mm from the body surface, the path loss is around 80 dB. Such a path loss level may be acceptable in present transceiver design technology.



(a) trasnmitted signal (b) received signal

Figure 3: Examples of shapes of transmitted and received signals

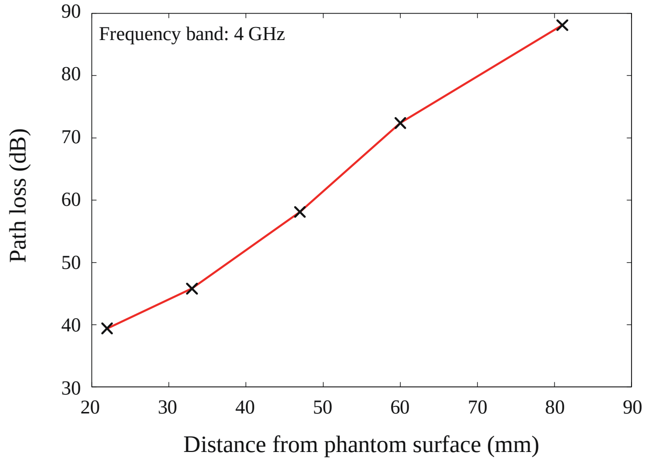


Figure 4: Path loss characteristics of liquid phantom

6.2 Results and Discussions

The BER performance of the UWB-IR transceivers is calculated based on the path loss measurement results in the liquid phantom experiment. It is assumed that the transmitter and the receiver were connected with an attenuator in order to accurately control the path loss according to the distance between transceivers, and then the BER is calculated from the comparison between the transmitted bit sequence and the received bit sequence. As for the symbol timing and sampling clock synchronization, it is almost perfectly performed with a proper length of pilot signals in the experiment. Moreover, the optimal detection time is also determined before conducting the experiment.

Figure 5 illustrates the average BER performances by the experiment and the theoretical analysis against the distance between transceivers. Good agreements are observed between the results of the experiment and the theory. Furthermore, as seen from Figure 5, the BER performance is improved as the data rate decreases (namely, L increases). Note that the BER performance of 10^{-2} is accomplished at the distance of around 70 mm when L = 16 (namely, the data rate is 1 Mbps). The achievement of the BER performance of around 10^{-2} to 10^{-3} means that it is possible to obtain an error-free BER (< 10^{-10}) if an adequate forward error correction code is adopted. This error-free BER satisfies the requirement for almost all implant BAN applications. Therefore, the developed UWB-IR communication system can establish a reliable communication link at the maximum distance of 70 mm in the biological-equivalent liquid phantom.

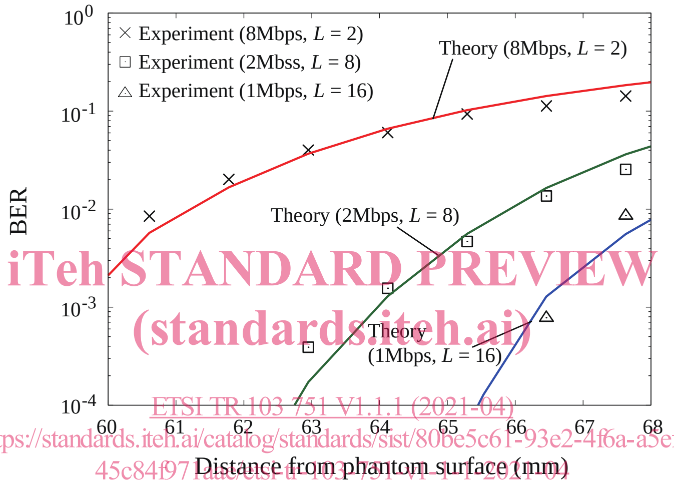


Figure 5: BER performance evaluation in liquid phantom experiment

7 Evaluation with Living Animal Experiment

7.1 Setup

Figure 6 shows an overview of the living body experiment with the developed UWB-IR system. In the living body experiment, a living animal (pig) is used instead of a human body because it is difficult to conduct an experiment with a living human body in our environment. The transmit antenna is implanted into the pig, and the receive antenna is put on the pig-body's surface. The transceivers and each antenna are connected with coaxial cables. For the received data capture, a laptop computer is connected to the receiver. The insertion points of the transmit antenna and the positions of the transmit antennas are shown in Figure 6, which indicates the transmit antenna positions when the insertion point is in the centre of the abdomen and the thorax (chest). In the experiment, the transmit antenna is covered with a vinyl material for insulation. The receive antenna is just above the transmit antenna on the body surface.