On the Use of Ultra-Wideband Communications into Wireless Body Area Networks for Medical Check-up

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***Abstract*— This paper shows discussions on the use of ultra wideband (UWB) signals into wireless body area network (WBAN) especially applied into wireless medical information systems such as medical check-up. First, UWB communication technologies and related regulations in US, Europe and Japan are briefly introduced. Then, radio propagation characteristics around human body in UWB band are overviewed with a couple of measured channel characteristics. Also, a couple of discussions related to electro-magnetic compatibility (EMC) are given from the viewpoint of the compatibility with human body and medical equipments.**

Key words: Ultra wideband (UWB), Wireless body area network (WBAN), RF immunity test, medical equipments.

I. Introduction

The use of wireless communication technologies into medical information system has been paid attention since requirement to access or storage medical information ubiquitously. One important source of medical information is patient's body. Wireless body area network (WBAN) [1] is a new research area; WBAN enables wireless medical check-up by using attached body sensors to body surface and a bedside monitor or another device gathering the data [2]. To introduce such WBAN into wireless medical information systems, we need to use a suitable communication technology for WBAN through discussions on both the system performance of wireless communication (e.g., data rate, transmission range, bit error ratio) and EMC for human body, medical equipments, and other wireless systems. From the viewpoint of EMC with other wireless communication devices, the use of 2.4-GHz ISM band contains a severe barrier that a lot of wireless systems and industrial and medical equipments are operated.

Ultra wideband (UWB) communication system is a wireless communication technology in the frequency band from 3 to 10 GHz. A plenty of efforts have been dedicated to research and development of UWB communication systems since the use of UWB signals has been opened in 2002 [3]. Currently, there are a couple of standards on wireless communication technology which include UWB technology. Based on the regulation in US, UWB signal has to occupy signal bandwidth of 500 MHz or more, and its power spectral density level has to be less than -41.3 dBm/MHz in eirp. This communication system is basically operated over the frequency bands of other radio communication systems. That's why the permission level of transmission power is weak as to enable to coexist with other radio systems.

This paper shows a discussion on the use of UWB communication technology for WBAN especially applied into a medical information system. The next section provides overview of UWB current technologies and regulations. Then, Section 3 introduces characteristics of radio propagation around human body in the UWB frequency band. In Section 4, EMC issues related to the use of UWB signals around human body near medical equipments are shown. Finally, conclusions are given in Section 5.

II. UWB Technologies and Related Regulations

A. Technologies

The application of UWB technologies is categorized into several types; for example, high-speed data transmission, high-precision ranging, and low-power consumption. UWB devices towards the high-speed data transmission enjoy the channel bandwidth of UWB signal especially for data transmission. A popular standard for this category is ECMA-368 [4], which employs multi-band OFDM (MB-OFDM) technology utilizing 128-subcarrier with frequency separation of 4.125 MHz to achieve a 512-MHz bandwidth. This MB-OFDM is also adopted as physical layer of wireless USB [5]. Another category is high-precision ranging which utilizes a characteristic of precise time resolution of UWB signal. The standard for this category is IEEE802.15.4a [6], which has established to provide precision ranging with estimation error of less than 30 cm. IEEE802.15.4a employs an impulse radio systems in contrast to the MB-OFDM system. And the other category is low-power consumption. Its power consumption is reduced by turning off both RF and baseband devices during wireless communication processes are out of operation. The high-speed transmission of UWB enables to shorten the time duration of communication processes. That's why UWB provides wireless transmission in low-power consumption.

B. Regulations

Original regulation is settled in each country or area since UWB occupies wide frequency band and frequency allocation is different in each country and area. Fig. 1 shows spectral mask for UWB signals in US, Europe, and Japan. The maximum permission level is -41.3 dBm/MHz in all

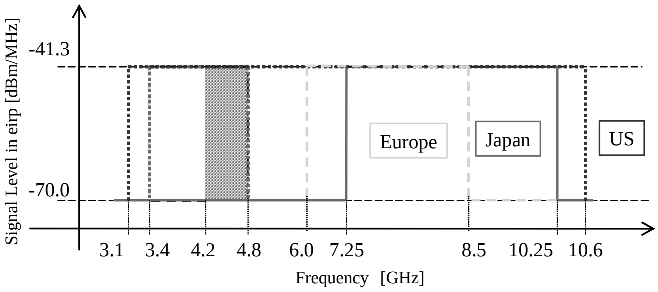
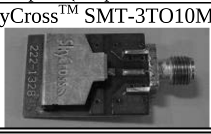


Fig. 1. UWB spectral masks which gives permissible transmission signal level in eirp for the US, Europe and Japan.

TABLE I
SPECIFICATIONS ON MEASUREEMNT EQUIPMENTS

Parameters	Values
VNA	Agilent EB8363B
Frequency range	3 - 11 GHz
The number of points	3201
Sweep time	Auto
Calibration	Full-2-port (Tx power = 0 dBm)
Antenna	SkyCross™ SMT-3TO10M-A 

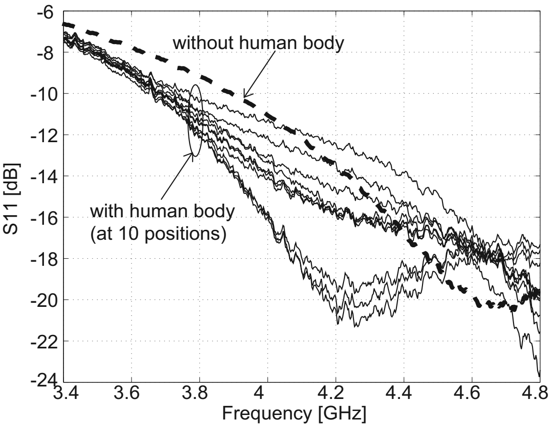


Fig. 2. The S11 characteristic of the Skycross antenna with and without human body.

regulations. This level is originally from FCC 47 CFR Part 15, which gives permissible radiation level from electrical devices such as personal computers. In US regulation, the spectral mask is flat over the frequencies from 3.1 to 10.6 GHz. In European and Japanese regulations, there are two frequency bands where the permission level is set to -41.3 dBm/MHz. In the European regulation, the frequency bands are 3.1 to 4.8 GHz and 6.25 to 9.25 GHz. On the other hand, Japanese regulation allows to use the frequency bands of both 3.4 to 4.8 GHz and 7.25 to 10.25 GHz in the transmission power level of -41.3 dBm/MHz. However, both European and Japanese regulations have a strict constraint on the use of the lower frequency bands. All UWB devices operated in the lower bands must have a mechanism to detect signals from wireless radio communication systems using the same frequency band and avoid any interference affected to detected radio communication systems. This mechanism is called detect-and-avoid (DAA). However, in the frequency band from 4.2 to 4.8 GHz, the implementation of DAA is exempted by the end of 2010 in both European and Japanese regulations.

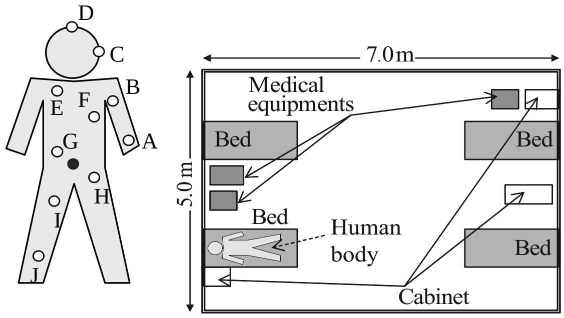


Fig. 3. Positions of the body-worn antennas to measure channel transfer functions. Layout of the measurement site, which is a hospital room, is also shown.

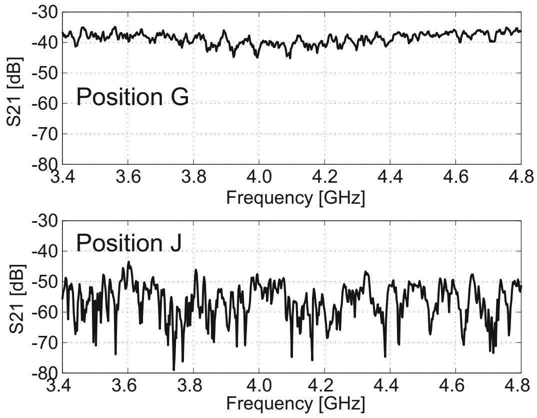
The current Japanese regulation has some restrictions on the use of UWB systems into WBAN. The first one is that the use of UWB devices is restricted into indoor use. The second one is related to the data rate of the UWB system; the minimum data rate of UWB devices is 50 Mbps. And, the third on is that at least one of the devices in a wireless network has to be connected to the commercial AC electrical power socket.

III. CHARACTERISTICS OF RADIO PROPAGATION AROUND HUMAN BODY IN UWB SIGNALS

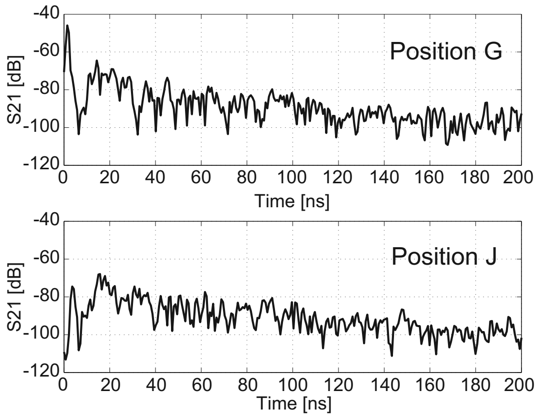
This section gives an overview of radio propagation characteristics around human body in UWB frequency band. Measurement results of channel transfer functions between antennas attached to body surface are shown. Path loss model derived from the measured results is also given.

A. *Measurement setup*

Channel transfer functions between two body-worn antennas are measured by using a vector network analyzer over the frequency range from 3 to 11 GHz. Specifications on the measurement equipments are listed in Table I. Skycross antenna [7] is used as each body-worn antenna, and its separation between the human body and the antenna is kept in 15 mm. The characteristics of S11 of the antenna are plotted in Fig. 2. Fig. 3 shows the positions where the body-worn



(a) Measured S21 at position of G and J in the frequency domain



(b) Measured S21 at position of G and J in the Time domain

Fig. 4 Measurement results of S21 at position of G and J shown in time and frequency domain.

antennas are attached. One antenna connected to Port 1 and marked by '●' is fixed into the waist. And, the other antenna connected to Port 2 and marked by '○' is placed in 10 positions. These positions are typical ones where body-worn sensors are attached to measure vital signs for medical checkup. Each position is denoted by an alphabet from A to J. Distances between the fixed and the other antennas are also listed in Table II. In the position A, we set two conditions on the measurement; in A-1 and A-2, the body-worn antenna is toward the front of the body and the side of the body, respectively. Layout of the measurement site is also shown in Fig. 3. This room is surrounded by metallic walls. In each position, we take 10 snapshots of S21. The height and weight of the human is 163 cm and 65 kg, respectively. These are typical figures for a Japanese male.

B. Measurement results

Some of measurement results on S21 in both the frequency and time domain are shown in Fig. 4. All the snapshots are superimposed on each plot. Its path loss and mean excess delay of the measurement results are calculated. The path loss is obtained by averaging path gain over the measured frequency band, as shown in the following equation.

$$PL(d(p)) = -20 \cdot \log_{10}\left\{\frac{1}{10}\frac{1}{N_f}\sum_{j=1}^{10}\sum_{n=1}^{N_f}\left|H_j^p(n)\right|\right\} \qquad (1)$$

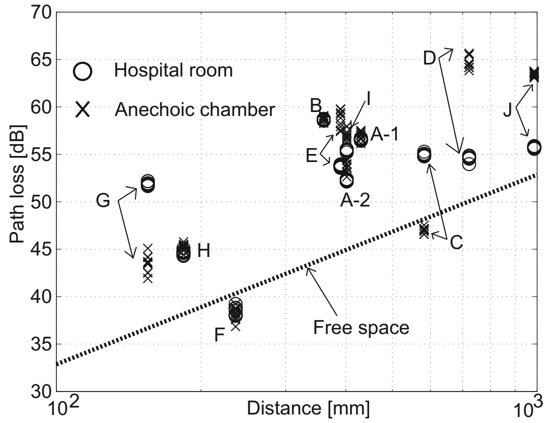


Fig. 5 Measured Path loss corresponding to the distance between the body-worn antennas.

where $PL(d(p))$ is the path loss at the position of p, at which the distance between Tx and Rx is a function of the position p, thus the distance is denoted by $d(p)$. N_f is the number of frequency samples of the VNA. $H_j^p(n)$ is the measured S21 for the position p, j th snapshot, and n th frequency sample.

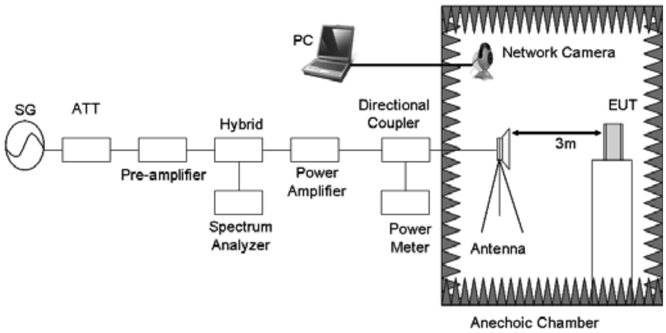
The path loss for each position is shown in Fig. 5. In this figure, values on the path loss in free space (without human body) and measured path loss in an anechoic chamber are also shown. The largest path loss is measured at J (ankle) in the hospital room and D (top of the head) in the anechoic chamber. The reason for this observation is that even in the case of anechoic chamber, reflections from the floor are available; reflection from the ceiling is not available. By comparing with the path loss in free space, additional path loss due to the existence of the human body is around 10 dB. The measured path loss within distance of less than 1000 mm is less than 70 dB.

IV. EMC BETWEEN UWB EMISSION AND HUMAN BODY AND MEDICAL EQUIPMENTS

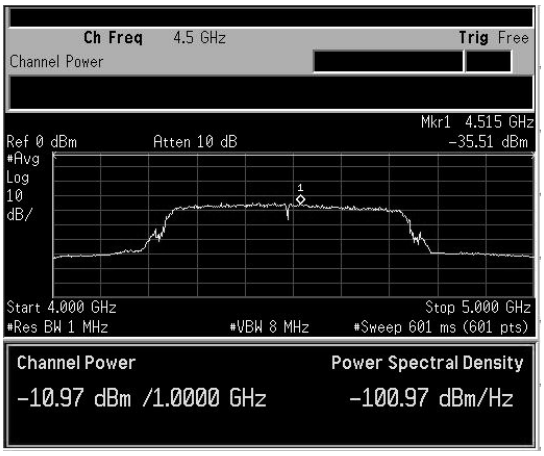
This section provides discussions on EMC issues between UWB devices between human body and medical equipments under usage scenario where UWB is applied into WBAN.

A. Human body

The exposure guidelines employ specific absorption rate (SAR). The SAR limit stated in the international guideline (ICNIRP: International Commission on Non-Ionizing Radiation Protection) is 2 W/kg averaged over ten grams of tissue. In Japanese radio regulation, this guideline is only for wireless devices that radiate RF signal in more than 20 mW. This safe level is applied into mobile phone, which is the most popular body-worn device. The level is regulated as 2W/kg in SAR averaged over 6 minutes in general environment. However, the maximum radiation level from a UWB device is much lower than 20 mW. The maximum available frequency bandwidth is 7.5 GHz in the US regulation. In this case, the permissible transmission power in eirp is -41.3 dBm/MHz + $10\log_{10}$(7500 MHz) = -2.54 dBm = 0.56 mW. That's why the use of UWB devices around human body should be allowed.



(a) Schematic diagram of radiated immunity test system



(b) Spectral waveform of the amplified UWB signal (ATT=20 dB)

Fig. 6 Test setup of ad hoc RF immunity test using UWB signal for medical equipments.

B. Medical equipments

IEC60601-1-2 has standardized RF immunity level for medical equipments (its test procedure is based on IEC61000-4-3). However, the upper frequency is limited to 2.5GHz, which is lower than the frequency band for UWB emission. Therefore, we conducted an ad hoc RF immunity test using UWB radiation onto a couple of medical equipments. As medical equipments under the test, we prepare a syringe pump, infusion pump, transmitter of wireless telemetry system, and bedside monitor as a receiver of the wireless telemetry system. A schematic diagram of this test setup is shown in Fig. 6(a). A spectrum of UWB signal to be used in RF immunity test is also shown in Fig. 6(b). This signal is based on MB-OFDM, which has center frequency of 4.488 GHz and signal bandwidth of 512 MHz. The UWB signal is amplified up to 46.5 dBm by using a power amplifier. The test results show that any malfunctions were not found on the syringe pump, infusion pump, and transmitter of wireless telemetry system. On the bedside monitor as the receiver of the medical telemetry system, we observed spiky noise in the displayed waveform when the amplified UWB signal is radiated to a specific side of the equipment in its horizontal polarization. Although such EM interference on the waveform was observed, this is caused by highly amplified UWB signal which is 50 dB larger than the permissible transmission power of UWB emission.

V. CONCLUSION

This paper shows discussions on the use of ultra wideband (UWB) signals into wireless body area network (WBAN) for medical applications such as medical check-up. The UWB communication systems have been developed, and wireless USB is based on a UWB technology. The UWB signal occupies more than 500 MHz bandwidth in a part of the frequency band in the range from 3 to 10 GHz. A radio propagation characteristic around human body in UWB band was also shown. The result showed that the average additional loss due to the human body is around 10 dB, and maximum loss at the distance of 1000 mm is less than 70 dB. Also, a couple of discussions on EMC issues were shown from the viewpoint of compatibility with human boy and medical equipments. On the interference with medical equipments, we conducted an ad hoc RF immunity tests. Note that the results obtained by the tests are not enough to conclude that the use of UWB emission is safe for all medical equipments.

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