Quantitative Evaluation in Terms of BER of the WBAN System at the ISM Band

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1. Introduction

In recent years, wireless body area network (WBAN) using a device that includes a radio terminal placed in or on the body has received a lot of attention [1]. It has the potential to provide various ubiquitous services for medical, health care, entertainment, and security. To analytically investigate the transmission mechanism of a wearable device for on-body wireless communications, we derive and discuss exact solutions represented by eigenfunction solutions for the scattered electromagnetic fields. We then consider the propagation characteristic of the wearable device attached to a human body by approximating the body to a dielectric circular cylinder. First, we derive the frequency-domain integral representations of the eigenfunction solutions for the scattered electric fields. We analytically obtain the transmission coefficient between the transmitting and receiving antennas in the vicinity of the dielectric cylinder. Then, we evaluate the influence of the infinite dielectric circular cylinder on the BER (Bit Error Rate) performance for the digital wireless communications using the industrial, scientific and medical (ISM) band of 900-928 MHz. Additionally, we discuss the measured results of the transmission coefficient in the vicinity of the 2/3-muscle equivalent phantom body for comparison with the calculated results.

2. Transmission Coefficient

The geometry of the problem for the dielectric circular cylinder of radius a in free space is illustrated in Fig.1. The permittivity, permeability and conductivity of the dielectric cylinder are ε, μ and σ. The permittivity and the permeability of free space are ε_0 and μ_0. A dipole antenna that is in the vicinity of the dielectric cylinder is placed parallel with the r direction of the cylindrical coordinate system. The length of the dipole antenna is l and the maximum amplitude of the current in the antenna is I_1. The center of the transmitting dipole antenna is located at $\mathrm{Q}(r_1, \phi_1, z_1)$, and the observation point is located at $\mathrm{P}(r, \phi, z)$ in the cylindrical coordinate system. When the center of the dipole antenna is located at the origin, the form of the current distribution on the antenna is found from experimental measurements to be approximately given by

$$I(r) = I_1 \sin k_0(l/2 - |r - r_1|). \quad (1)$$

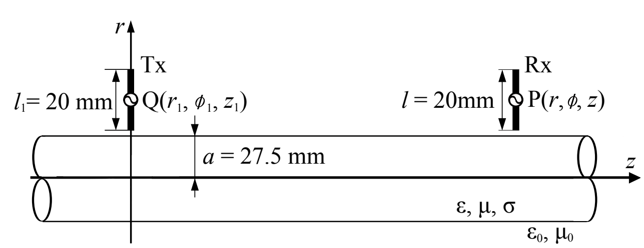


Figure 1: Transmitting and receiving dipole antennas in vicinity of infinite dielectric circular cylinder.

When the cylinder described above is illuminated by a radiation electromagnetic wave from the dipole antenna, the frequency domain scattered field observed at $P(r, \phi, z)$ can be represented by an eigenfunction solution. By separating the variables in Maxwell's equations and by imposing boundary conditions on the cylinder surface $r = a$, a series of solutions can be obtained for the r components of electric scattered field, as follows

$$E_r^s(r, \phi, z) = -\frac{\omega\mu_0 I_1}{8\pi} \int_{-\infty}^{\infty} dh \sum_{n=0}^{\infty} \frac{2-\delta_0}{\eta^2} e^{-jh(z-z_1)} \cos n(\phi - \phi_1)$$
$$\left[P_n(\lambda) \left\{ A_n \frac{n}{r} H_n^{(2)}(\eta r) + B_n \frac{jh}{k_0} \dot{H}_n^{(2)}(\eta r) \right\} + Q_n(\lambda) \left\{ C_n \frac{h^2}{{k_0}^2} \dot{H}_n^{(2)}(\eta r) - B_n \frac{jhn}{k_0 r} H_n^{(2)}(\eta r) \right\} \right]. \quad (2)$$

The function and coefficients of this equation are shown in [2]. Fig. 2 illustrates the distribution of the electric field near the cylinder. We calculated for 915 MHz, which is the center frequency of an ISM band of 902-928 MHz. The parameters of the dielectric circular cylinder are a = 27.5 mm, and the permittivity and the conductivity for the dielectric circular cylinder are close to 2/3-muscles at 915 MHz. The transmitting antenna is located at Q(40.5 mm, 0°, 0 mm), and the observation point is located at P(30.5 mm - 80.5 mm, 0°, 3 mm - 200 mm). Moreover, to examine the influence of the cylinder, the distribution when there is a cylinder is also shown. The case without a cylinder is the incident electric field, and the case with a cylinder is the total electric field, which is the sum of the incident and scattered electric fields. Fig.2(a) shows that the incident field spreads as a circle with a center at the transmitting antenna because the dipole antenna has a toroidal radiation pattern. Fig.2(b) shows that the stronger total electric field tends to spread along the cylinder, because of the efficiency of the scattered electric field.

The transmission coefficient S_{21} can be determined from the ratio between the voltages of the receiving V_{Rx} and the transmitting V_{Tx} antennas. The voltage at the feed point of the receiving antenna V_{Rx} is written as

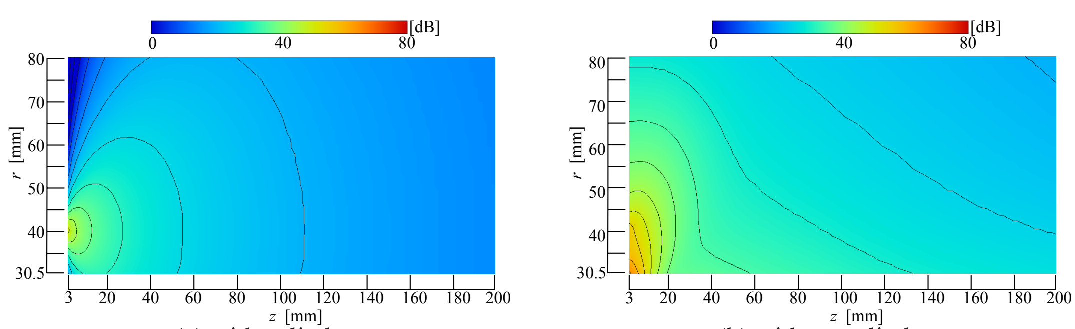
$$V_{Rx} = \iint_S \boldsymbol{w}(\boldsymbol{r}) \cdot \boldsymbol{E}^t(\boldsymbol{r})\, dS, \quad (3)$$

where S is the surface of the receiving antenna and $\boldsymbol{w}$ is the weighting function of the current distribution on the receiving antenna. Furthermore, the voltage at the feed point of the transmitting antenna V_{Tx} is derived from the current at the feed point and the input impedance of the antenna. The input impedance of the antenna in the vicinity of the dielectric cylinder is written as

$$Z_{in} = Z_{in}^{MoM} - \iint_S \boldsymbol{I}(\boldsymbol{r}) \cdot \boldsymbol{E}^s(\boldsymbol{r})\, dS, \quad (4)$$

where the Z_{in}^{MoM} is the calculated input impedance of the dipole antenna in free space using the moment method, and the $\boldsymbol{I}$ and $\boldsymbol{E}^s$ are the current and the scattered electric field on the surface of the transmitting antenna.

Fig.3 shows the measured and calculated results of the transmission coefficient. The parameters of



(a) with cylinder (b) without cylinder

Figure 2: Electric distribution near the dielectric cylinder at $\phi = 0°$.

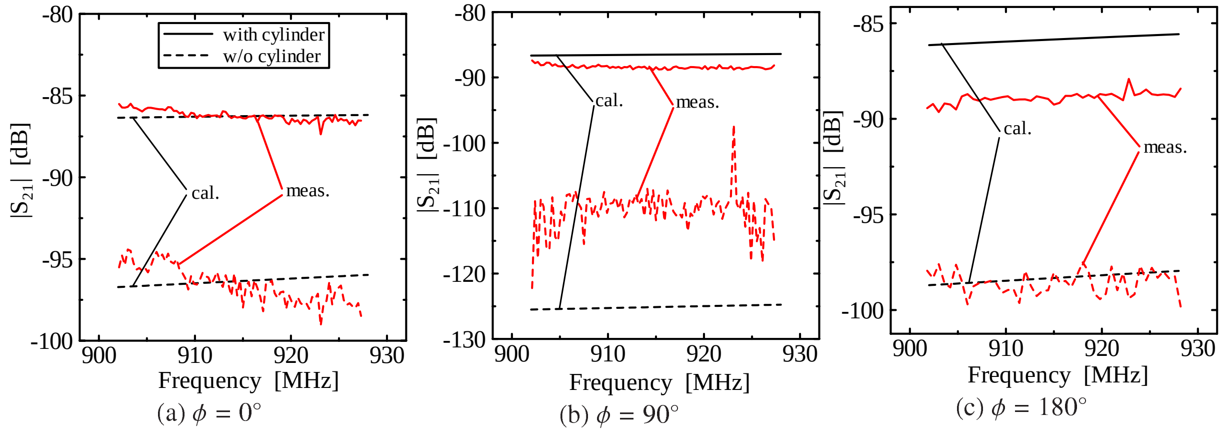


Figure 3: Calculated and measured transmission coefficient (a =27.5mm, $r_1 = r$ =40.5mm, z =200mm, $l_1 = l$ =20mm).

the dielectric circular cylinder are a = 27.5 mm, the permittivity and the conductivity for the dielectric circular cylinder are close to 2/3-muscles in the ISM band. The transmitting and receiving antenna lengths are 20 mm. The transmitting antenna is located at Q(40.5 mm, 0°, 0 mm), and the receiving antenna is located at P(40.5 mm, ϕ, 200 mm). We calculated the case for ϕ = 0, 90, 180°. The length of the phantom body is 650 mm, and the radius is 27.5 mm. The phantom body is composed of deionized water, agar, polyethylene powder, sodium chloride, TX-151, and dehydroacetic acid sodium salt [3]. The electric constants of this phantom body are almost in agreement with the characteristics of the human body. We used dipole antennas of length 20 mm, and attached a bazooka balun that is suited to 915 MHz. These antennas have almost the same structure and characteristics. It can be seen that the calculated and measured results are almost in agreement. However, Fig.3(b) shows that the measured results in the case without a cylinder do not agree with the calculated results. This is because the measurements were not exact since the noise floor level of the vector network analyzer is −115 dB. The results for the others show that the difference between the calculated and measured transmission coefficient S_{21} were less than 4 dB.

3. BER Performance

Fig. 4 shows the flowchart of the BER simulation. We use the conventional binary phase-shift keying (BPSK) for the modulation. We chose the frequency of the carrier wave as 915 MHz, which is the center frequency of the ISM band. In general, the signal-to-noise ratio (SNR) is a ratio of the electric power between the received signal and the noise, and it is called the output SNR in this report. On the other hand, we obtain the SNR by using the transmitted signal instead of the received signal, and it is called the input SNR in this report. The input SNR can be evaluated including not only a wave distortion but also the antenna gain and a propagation channel's influence. The BER performances are shown in Fig.5. The BER performances for the case without the cylinder are also shown in Fig.5. In this simulation, the bit rate is 5 Mbps. It is observed that BER for the case with the cylinder is better than that without the cylinder in any of the cases shown in these figures. In addition, the BER performances from the measured and calculated results are almost in agreement. However, in the case without the cylinder at ϕ = 90°, the BER performances are not in agreement. This is because the measured transmission coefficient S_{21} did not agree with the calculated result. In the calculated results, the difference of E_b/N_0 between the case with the cylinder and the case without the cylinder is 10.2dB, 38.5dB, 12.6dB for ϕ = 0, 90, 180° at a BER = 10^{-2}. In the measured results, the difference of E_b/N_0 between the case with the cylinder and the case without the cylinder is 10.3dB, 22.5dB, 9.0dB for ϕ = 0, 90, 180° at a BER = 10^{-2}. In particular, the improvement on the BER from the existence of the cylinder is greatest at ϕ = 90°, because the receiving antenna is perpendicular to the transmitting antenna, and the received voltage

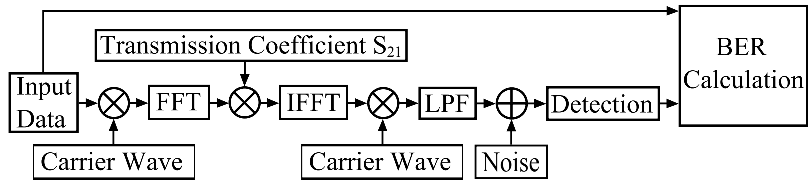


Figure 4: Flowchart of BER simulation.

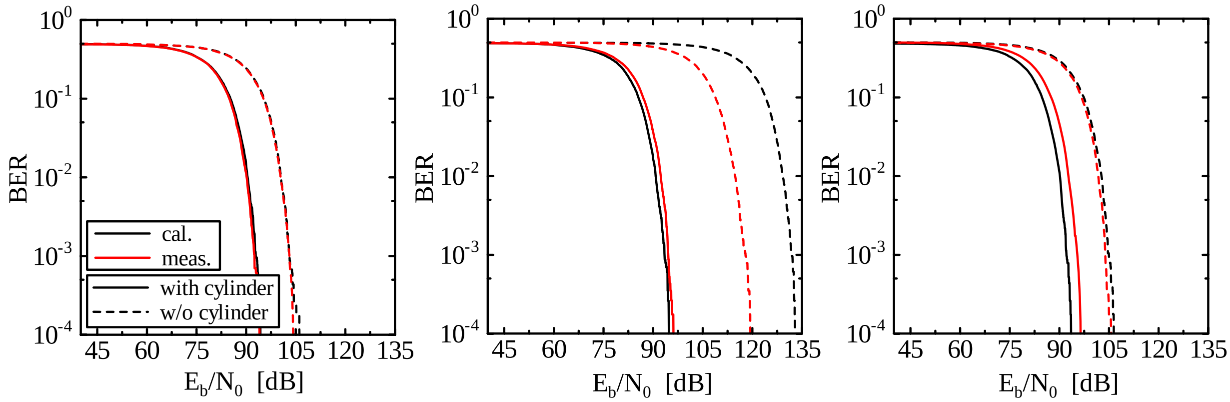


Figure 5: BER performances.

level is low at $\phi = 90°$. When the cylinder exists, the creeping wave that propagates on the surface of the cylinder causes the received level to increase, and the BER to become small. Finally, we confirmed that the BER performance is improved by the cylinder, in both cases, for the measured and calculated results.

4. Conclusions

In this report, in order to identify the transmission mechanism of the wearable device for on-body wireless communications, we have derived transmission coefficients analytically, and have evaluated digital communication at the ISM band of 902-928 MHz in terms of the BER. To emulate the propagation characteristics of a wearable device attached to a human body, we approximated the body to a dielectric circular cylinder. In addition, we discussed the measured results of the transmission coefficient in the vicinity of the dielectric circular cylinder. As a result, it has been shown that the existence of the dielectric circular cylinder improved the BER performance of digital communications in the case of the measured and the calculated results.

References

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