IEICE Communications Express, Vol.12, No.12, 640–642

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LETTER

A study on the effect of water on the received power characteristics of water level gauge antennas installed in underpass

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Abstract In this paper, we investigate the change in received power at the access point when the sensor terminal is submerged in water by electromagnetic field simulation, aiming to realize an underpass flooding monitoring system using IoT wireless access technology and obtaining design guidelines for such a system. In particular, since the relative permittivity and electrical conductivity of muddy water are unknown, simulations were performed by changing these parameters. As a result, it was confirmed that the received power decreased by approximately 5 dB when the bottom of the antenna was submerged and by approximately 20 dB when the antenna feed point was submerged.

Keywords: half-wavelength dipole antenna, IoT, M2M, finite element method (FEM), water level gauges, underpass

Classification: Sensing

1. Introduction

In recent years, the damage caused by torrential rain has become a problem all over Japan due to the effects of global warming. In particular, accidents involving underpasses being flooded and vehicles being submerged have been observed nationwide.

Therefore, a system is being considered that installs water gauges in underpasses, transmits data via IoT wireless access, and manages data centrally [1]. However, this system will have restrictions on the location of the antenna depending on the installation cost and the shape of the structure, and in some cases, the sensor terminal may be submerged under water. In such a special radio propagation environment, the effect of water on the terminal is not clear, and it is necessary to clarify this effect in order to realize highly reliable wireless communication [2].

This study aims to quantitatively clarify the performance of the sensor terminals by simulating electromagnetic fields that consider the rising water level in the underpass. In particular, we examine the change in received power at the access point when the antenna is submerged in water as the water level rises. Since the relative permittivity and electrical conductivity of muddy water are unknown, the simulation was performed by changing these parameters.

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DOI: 10.23919/comex.2023XBL0026
Received March 1, 2023
Accepted September 5, 2023
Publicized October 17, 2023
Copyedited December 1, 2023

2. Simulation model

Figure 1(a) shows the configuration of the transmission system in this study. In this system, rising water levels are detected by sensor terminals in the underpass, and the data is centrally managed at access points located tens to hundreds of meters away. The access points centrally manage data transmitted from multiple underpasses. In this study, we used a 920 MHz half-wavelength dipole antenna as the transmitting antenna. This frequency band has a relatively long wavelength, which increases the communication distance and diffractiveness. Therefore, it is suitable for use in non-line-of-sight propagation paths like this system.

Figure 1(b) shows the 2D axisymmetric model used in the simulation. We used the finite element method (FEM) to simulate electromagnetic fields in this model. The model can be analyzed three-dimensionally by rotating it around the leftmost axis of the figure. This method significantly reduces memory requirements and computation time [3].

In this study, a point half a wavelength (16.25 cm) away from the bottom edge of the antenna was set as the 0 m

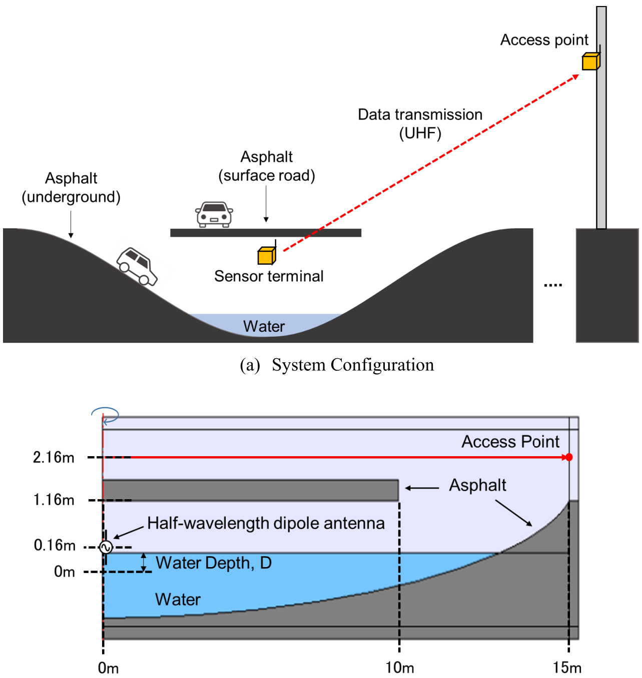


Fig. 1 Simulation model

point. A disk-shaped asphalt roof was placed 1 m above the antenna feeder. The water depth D was increased by 3 cm, and we measured the received power at the access points located horizontally from 2 m above the antenna feeder. The distance from the antenna to the right edge of the model is 15 m. The radius and height of the asphalt are 10 m and 0.5 m, respectively. In order to avoid short-circuiting of the antenna feed, a 1 mm air coating was created on the surface of the antenna.

3. Simulation conditions

Table I shows material property values in this simulation [5]. When an underpass is flooded, the water is assumed to be a soil suspension. However, the exact relative permittivity of soil suspension is not known. In General, it is known that the relative permittivity of soil is higher in wet soils than in dry soils. Therefore, the relative permittivity is expected to increase as the ratio of water to soil increases. Given the above, since the relative permittivity of pure water is generally known to be 80, we varied the relative permittivity of the soil suspension between 10 and 80 in Simulation 1 (Table I (a)).

The electrical conductivity of a typical soil suspension is between 0.68 and 445 [mS/m], so in Simulation 2 (Table I (b)) the conductivity was varied between 0.1 [mS/m] and 1000 [mS/m]. It is known that the higher the concentration of the electrolyte in the soil suspension, the higher the electrical conductivity. It has also reported that crops are damaged when the electrical conductivity exceeds 100 mS/m [4]. In this case, the relative permittivity was fixed at 80.

In both cases, the transmit power is assumed to be 20 mW and the access point antenna is assumed to be isotropic.

4. Simulation results

Figure 2(a) shows the change in received power at the access point when the relative permittivity of water is varied between 10 and 80 (Simulation1). Figure 2(b) shows the change in the received power at the access point when the electrical conductivity of water is varied between 0.1 and 1000 [mS/m] (Simulation2). The vertical and horizontal axes indicate the depth D and the received power, respectively.

Figure 2(a) shows that the received power for each permittivity decreased from 0.16 m, where the bottom of the antenna began to be submerged in water. In this case, the received power decreased by about 5 dB to 10 dB from the 0.16 m point to the 0.24 m point. Furthermore, a rapid decrease in received power was confirmed from the 0.24 m point, which is the antenna feeding point. At this point, a decrease of about 20 dB was observed for a relative permittivity of 80, and a decrease of about 40 dB was observed for a relative permittivity of 10. In addition, it was confirmed that the received power increased as the relative permittivity increased. This can be attributed to an increase in the component of radio waves reflected at the water surface due to an increase in the relative permittivity of water.

In Fig. 2(b), as in Fig. 2(a), a decrease in received power was observed when the bottom of the antenna and the feeding point were submerged. The received power was significantly decreased up to the 0.24 m point as the conductivity increased. However, no difference of more than ±5 dB was observed for each conductivity up to 0.24 m, where the antenna feed point was submerged. In particular, the received power at the four conductivities except 1 [S/m] was almost the same. In contrast, at 0.33 m, where the top of the antenna is completely submerged, there is a significant difference in the received power. In this case, the received power decreases as the electrical conductivity increases.

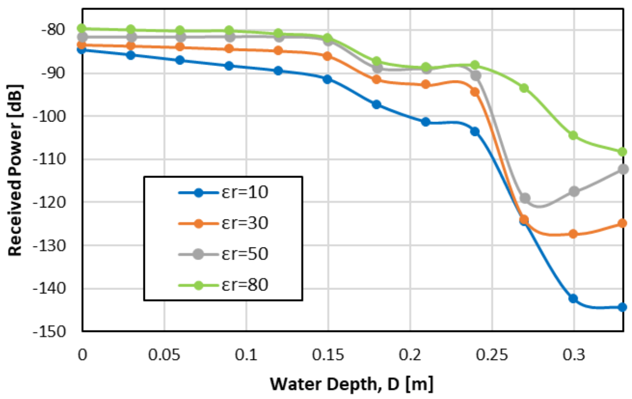
Table I Material property values

(a) Material Property Values (Simulation1)

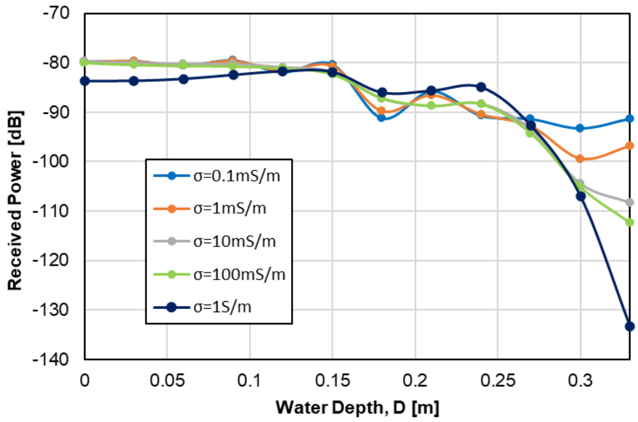
	Soil suspension	Asphalt [5]
Relative permittivity (εr)	10, 30, 50, 80	2.7
Relative permeability (μr)	1	1
Conductivity (σ) [mS/m]	10	1

(b) Material Property Values (Simulation2)

	Soil suspension	Asphalt
Relative permittivity (εr)	80	2.7
Relative permeability (μr)	1	1
Conductivity (σ) [mS/m]	0.1, 1, 10, 100, 1000	1



(a) Received Power (Simulation1)



(b) Received Power (Simulation2)

Fig. 2 Simulation results

In Fig. 2(a), a difference of up to 10 dB in received power was observed up to the point at which the antenna feed point was submerged in water (0.24 m). It was also observed that the received power consistently increased as the relative permittivity increased from 0 m to 0.33 m depth. These results indicate that the influence of the change in relative permittivity is more significant than that of the change in electrical conductivity in the soil suspension of this model.

5. Conclusion

In this paper, we investigated the change of received power at the access point when the sensor terminal is submerged by electromagnetic simulation, aiming to realize an underpass flooding monitoring system using an IoT wireless access system.

As a result, when the bottom of the antenna was submerged, the received power decreased by approximately 5 dB. In addition, a decrease in receiving power of approximately 20 dB to 40 dB was observed at the point where the feeding point was submerged. When the relative permittivity was changed, the received power increased as the relative permittivity increased. In contrast, no significant difference in received power was observed when the electrical conductivity was changed. This phenomenon was more pronounced when the conductivity was between 0.1 and 100 [mS/m]. From the above, it was found that the material property values of the soil suspension were more influenced by the relative permittivity than by the electrical conductivity.

These results quantitatively show the range where propagation loss may increase and provide a guideline for wireless system design. These results are expected to be useful in determining the area size, access point transmit power, receiver sensitivity, antenna gain, and link margins in system design.

If there is an effect of reflected waves from the side wall, it is necessary to perform rigorous calculations using a 3D model. For future studies, we will conduct simulations with various parameter and establish a general-purpose propagation path model and formulate it to reflect the results in system design.

Acknowledgments

Part of this research was conducted in collaboration with Kansai Plastic Industry Co.

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