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A STUDY ON THE VALIDITY OF CREATING EQUIVALENT CIRCUITS IN ELECTRIC FIELD COMMUNICATION USING AQUEDUCT

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Abstract. *For rapid leak detection, we proposed an electric field communication using water pipe and evaluated the validity of numerical calculations of equivalent circuits using electromagnetic field analysis simulation software (Sim4life). In this study, input signals (10 Vpp, 600 MHz) were input to a water pipe model reproduced in Sim4life, and by comparing the electric field distribution between the model with water and the model without water, it was observed that the electric field communication was distributed using water as a path, and it was confirmed that water field communication using aqueduct was possible in Sim4life. In addition, the capacitance was derived from the S-parameter information obtained from the experiment using the parallel plate model and the parallel plate model reproduced in Sim4life. Comparison of the capacitance values showed a value near 14.8 (pF), which is the theoretical value, confirming the validity of the numerical calculation of the equivalent circuit using Sim4life.*
Keywords: Electric field communication, Aqueduct, Disaster management

1. **Introduction.** In the event of disasters, water leakage occurs due to breaks in water pipes, which take a great deal of time to restore, hindering rapid restoration. To solve this problem, we are studying electric field communication using water in water pipes as a communication channel to transmit information on leaks to the water department through a wireless LAN [1,2]. The equivalent circuit of an aqueduct has been developed by Nippon Denki Co., Ltd. to represent a network of pipes that transport fluids as an electric network according to the characteristics of the fluid [7]. The purpose of this system is to analyze the flow rate in a water network by relating the loss to the current and voltage that can be placed in an electric circuit, and it does not clarify the electrical properties and transmission characteristics of the water network when it is used as a transmission line. The objective is to create an electrical equivalent circuit by clarifying the effects of the shape of the main water pipe, water volume, flow velocity, and foreign matter on the transmission characteristics of the water supply, and no previous studies have been conducted in this regard. Electric field communication in the vicinity of the human body [6] exists as a communication method using dielectric polarization. In addition, research has been conducted on the equivalent circuitization of the human body as a transmission line [5].

In addition, to achieve this, it will be essential to create an equivalent circuit of the water network to detect leaks. In this study, before creating the equivalent circuit of a water pipe, the capacitance values due to parallel plates were derived by experiment and simulation, and the validity of the numerical calculations of the electromagnetic field diffraction simulation software (Sim4life) was evaluated. In addition, the distribution of

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the electric field in the water pipe was clarified using the water pipe model reproduced in Sim4life, and the validity of creating an equivalent circuit using Sim4life was confirmed. The remainder of this paper is organized as follows. Section 2 describes each experimental method in detail. Section 3 describes the experimental results and Section 4 discusses and concludes the paper.

2. Methodologies.

2.1. Verification of electric field distribution. To check the electric field distribution in a water pipe in Sim4life, simulations were performed with and without water in the pipe, and with no water pipe present [4]. Specifically, the transmitting and receiving terminals were placed at a distance of 1 m, and the electric field distribution was observed when a (10 Vpp, 600 MHz) signal was output from the transmitting terminal.

The side views of each water pipe model are shown below in Figure 1, Figure 2, and Figure 3.

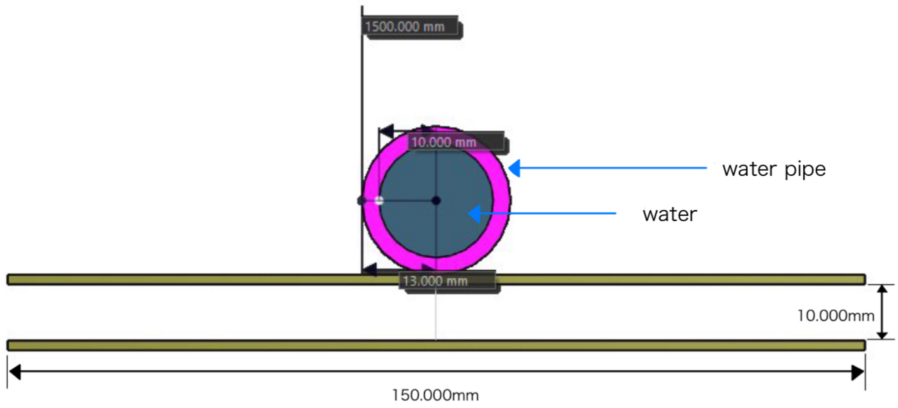

FIGURE 1. Water pipe with water (Side view)

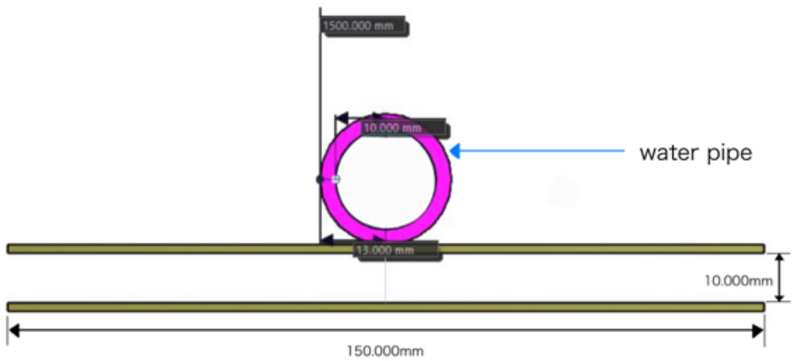

FIGURE 2. Water pipe without water (Side view)

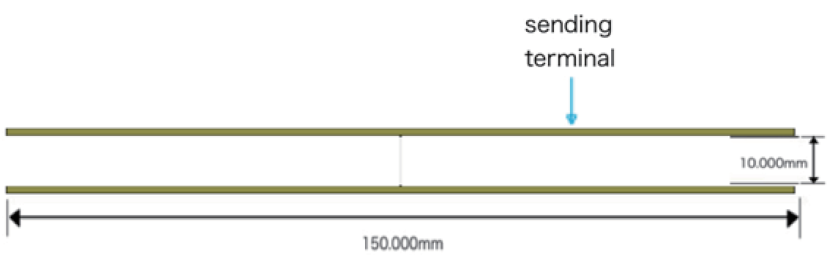

FIGURE 3. Model without water pipe (Side view)

The input signals output from the edge source of the transmitting terminal (Figure 4) are shown in Figure 5.

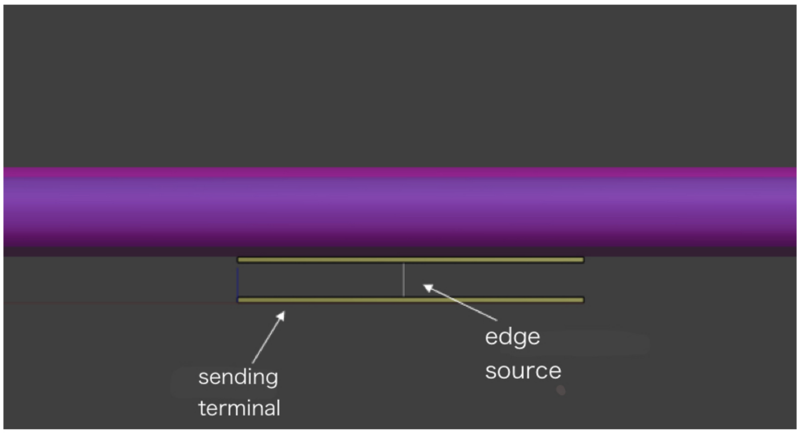

FIGURE 4. Sending terminal

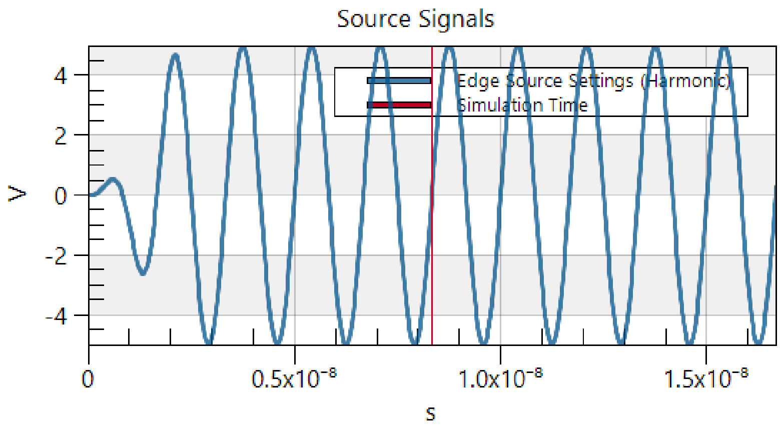

FIGURE 5. Input signal

The following is a detailed description of the preferences [4].

TABLE 1. Preferences (Water)

Material	Water
Effective mass	994.035 [kg/m^3]
Electrical characteristic (600 MHz)	
Electrical conductivity	0.08275 [S/m]
Relative permittivity	84.562

TABLE 2. Preferences (Air)

Material	Air
Effective mass	1.164 [kg/m^3]
Electrical characteristic (600 MHz)	
Electrical conductivity	0 [S/m]
Relative permittivity	1

TABLE 3. Preferences (Sending/receiving terminals)

Material	Sending/receiving terminal
	Copper (PEC)

TABLE 4. Preferences (Water pipe)

Material	Water pipe
Effective mass	1400 [kg/m^3]
Electrical conductivity	0 [S/m]
Relative permittivity	4

Set up a simulation model environment corresponding to the frequency of the signal output from the transmitting terminal (600 MHz).

Figures 6 and 7 below show the scope of the simulation.

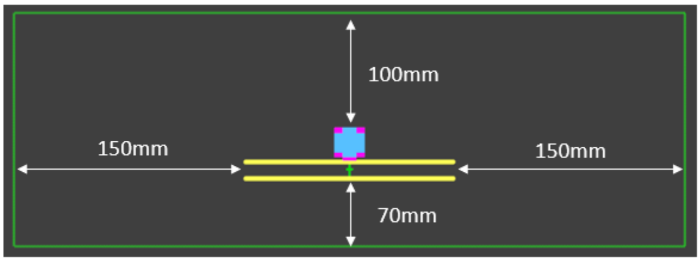

FIGURE 6. Simulation range (Side view)

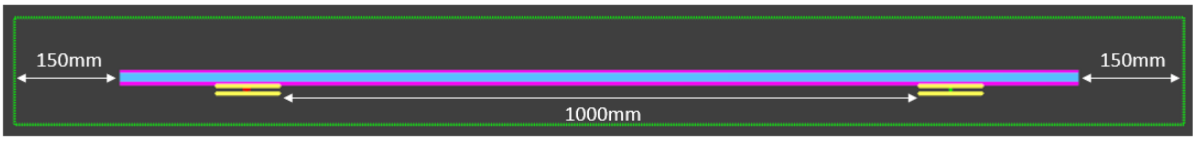

FIGURE 7. Simulation range (Front view)

2.2. **Derivation of capacitance values.** To evaluate the validity of the numerical simulations with Sim4life, a comparison was made between experiments and simulations using a parallel plate model. A pseudo-parallel plate was fabricated by sandwiching a 9 (mm) piece of Styrofoam between two 150 (mm) × 100 (mm) copper plates. A model similar to this parallel plate was reproduced in Sim4life, the S-parameters were measured under the same conditions, and the capacitance of the parallel plate was derived from the reflection coefficient and phase values obtained from the S-parameters. The process of deriving capacitance and theoretical values is shown below. For the parallel-plate model, the theoretical value of capacitance is electrode area $S = 100 \times 10^{-3} \times 150 \times 10^{-3}$ (m^2), electrode spacing $d = 9 \times 10^{-3}$ (m), permittivity $\varepsilon = 8.855 \times 10^{-12}$. The theoretical value of capacitance is [3]

$$C = \varepsilon \frac{S}{d} = 8.855 \times 10^{-12} \times \frac{100 \times 10^{-3} \times 150 \times 10^{-3}}{9 \times 10^{-3}} = 14.8 \text{ (pF)} \quad (1)$$

The following are equations for deriving capacitance. ω is the respective frequency.

$$\Gamma = \frac{Z_0 - Z_L}{Z_L + Z_0} \quad (2)$$

$$Z = Z_0 \frac{1+\Gamma}{1-\Gamma} \quad \Gamma = 10^{\frac{S11(\text{dB})}{20}} \cdot e^{j\phi} \quad (3)$$

$$X_C = \frac{1}{\omega C}, \quad C = \frac{1}{\omega X_C} \tag{4}$$

Figure 8 below shows the experiment.

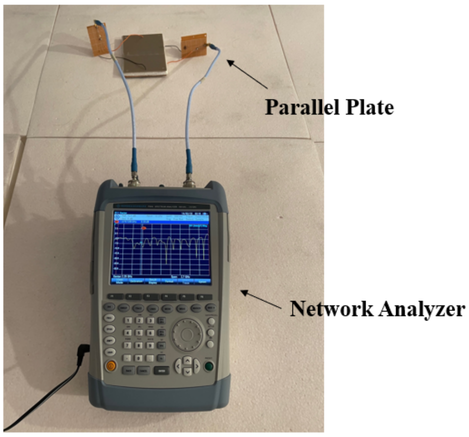

FIGURE 8. Experiment

Figure 9 below shows a front view of the parallel plate, and Figure 10 shows a side view. The distance between parallel plates is 9 mm, the size of each plate is 100 mm × 150 mm, and the thickness is 1.6 mm.

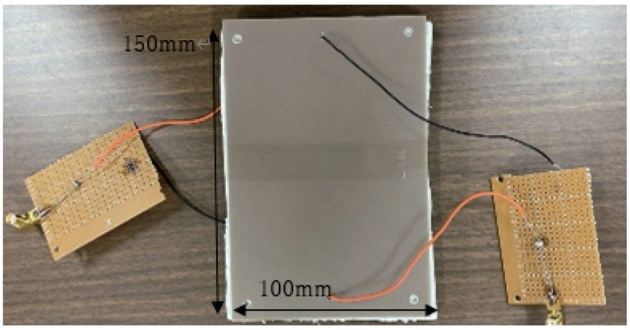

FIGURE 9. Parallel plate (Front view)

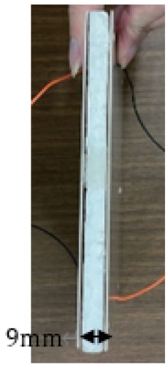

FIGURE 10. Parallel plate (Side view)

Figures 11 and 12 show the simulation model and simulation range.

3. Results.

3.1. Verification of electric field distribution.

The results of the simulations performed in Subsection 2.1 are shown in Figures 14, 15, and 16. The electric field values of the electric field distribution are also shown in Figure 13 [4].

From Subsection 3.1, it can be confirmed that the electric field distribution was not strongly distributed in the model with no water in the water pipe and no water pipe. However, in the model with water in the water pipe, it was confirmed that the electric field was strongly distributed using the water in the pipe as a pathway.

3.2. Derivation of capacitance values.

The experimental S-parameter results obtained in Subsection 2.2 are shown in Figures 17 and 18. Figures 19 and 20 show the results of S-parameters obtained by simulation.

The capacitance values derived from these results are shown in Figure 21.

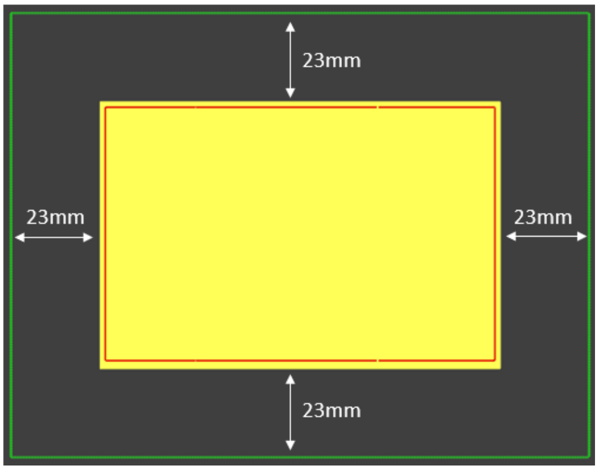

Figure 11. Simulation model (Front view)

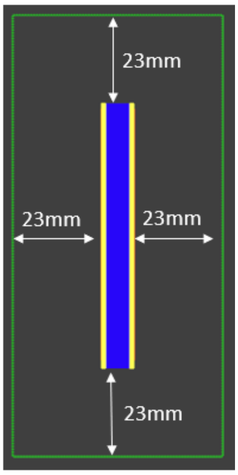

Figure 12. Simulation model (Side view)

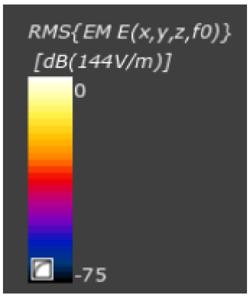

Figure 13. Electric field distribution (Value)

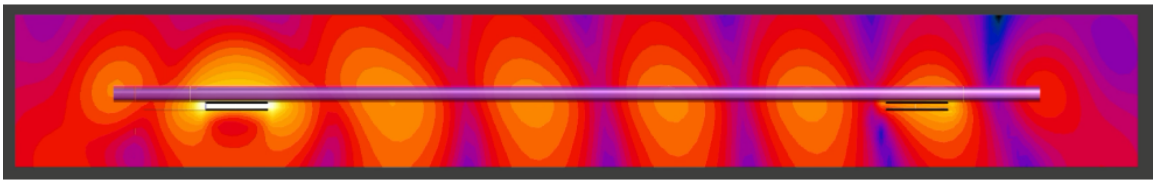

Figure 14. Electric field distribution (With water)

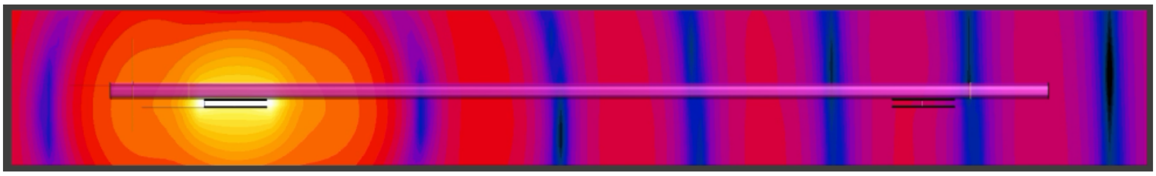

Figure 15. Electric field distribution (Without water)

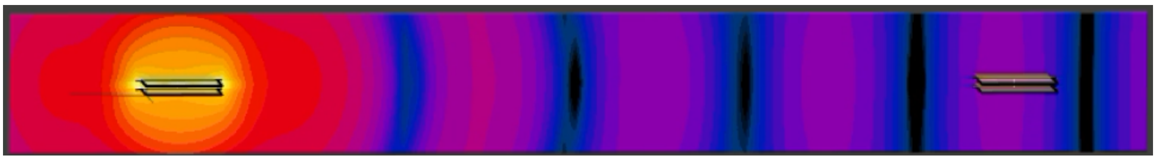

Figure 16. Electric field distribution (Without water pipe)

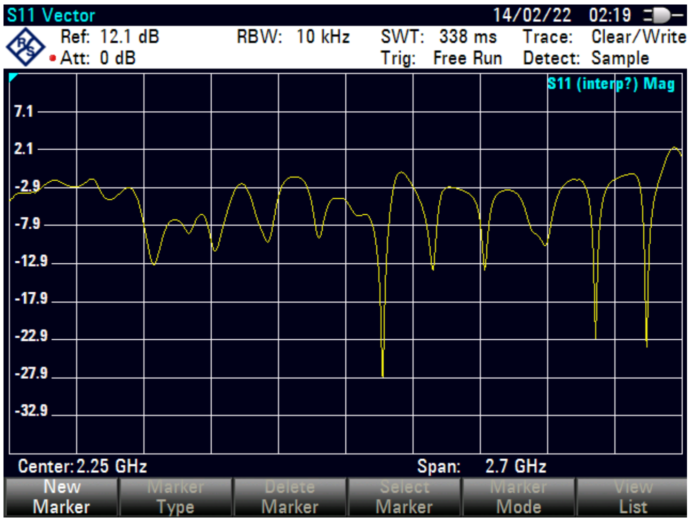

FIGURE 17. Reflection coefficient (Experimental)

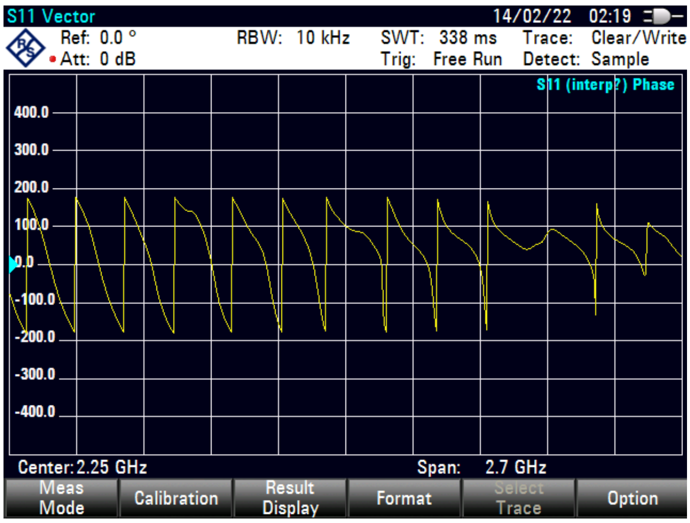

FIGURE 18. Topology (Experimental)

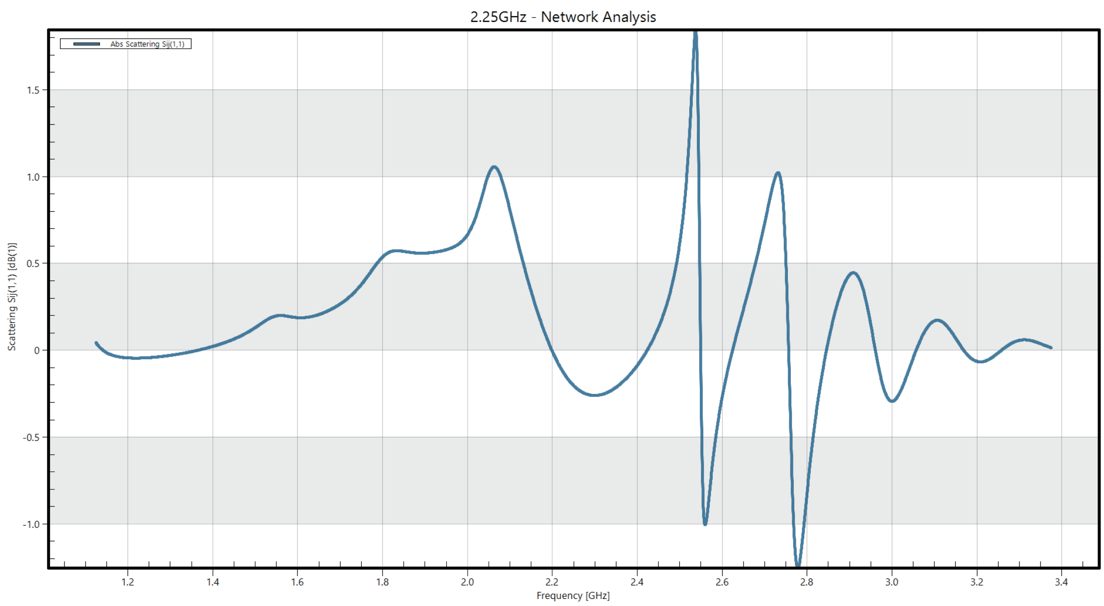

FIGURE 19. Reflection coefficient (Simulation)

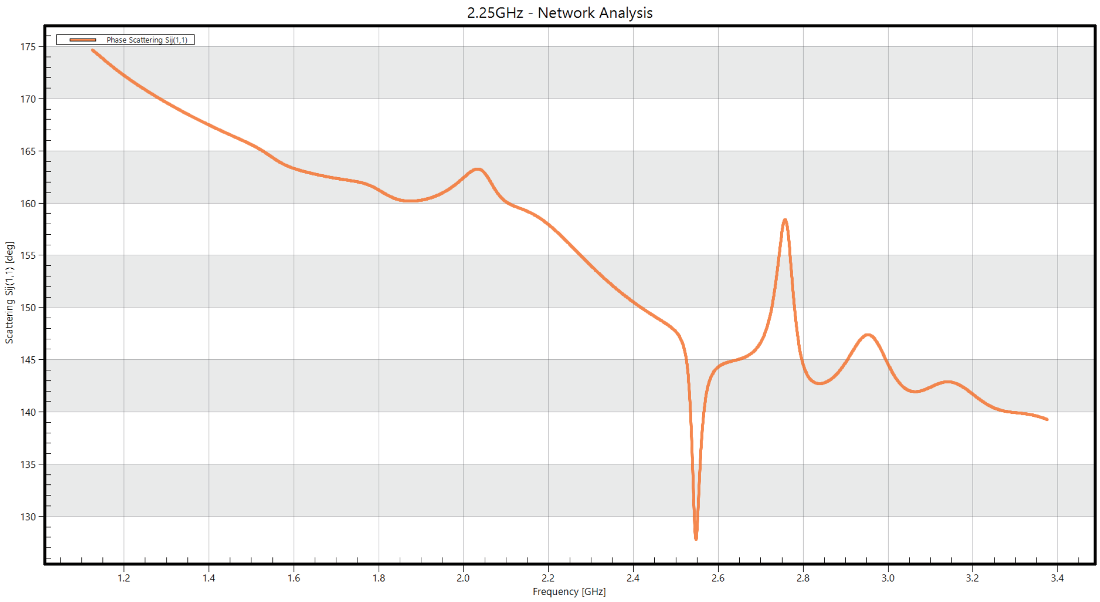

FIGURE 20. Topology (Simulation)

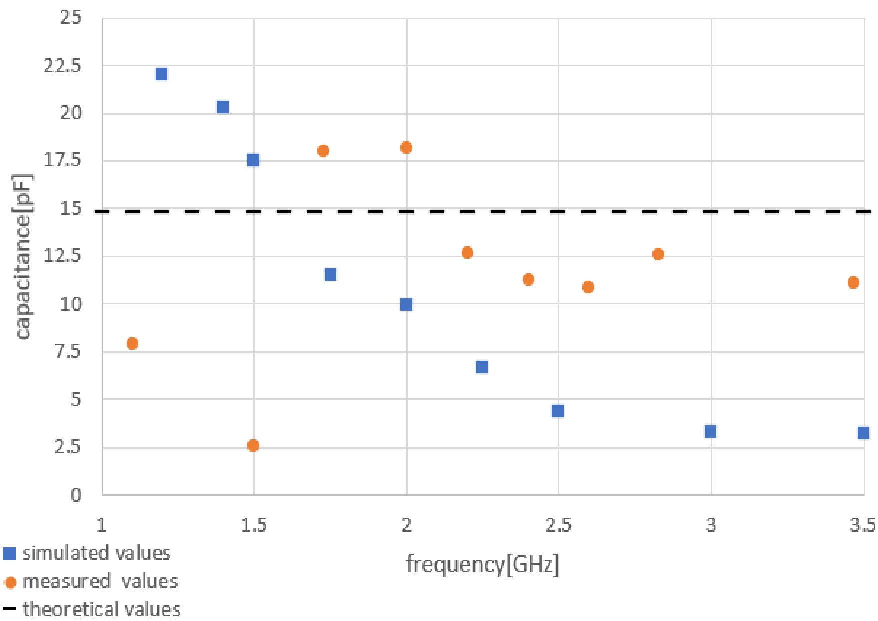

FIGURE 21. Capacitance (Measured values, simulated values)

From Subsection 3.2, it can be confirmed that the respective capacitance values derived from the experimental values using parallel plates (reflection coefficient and phase) and the simulated values using the parallel plate model (reflection coefficient and phase) are close. It can also be confirmed that the derived capacitance values are near the theoretical value of 14.8 (pF) shown in Equation (1).

4. **Conclusion.** From Subsection 3.1, we were able to confirm that electric field communication using water in a water pipe is possible within the simulation software Sim4life. From Subsection 3.2, the validity of the numerical calculation using the Sim4life simulation software can be confirmed, and the validity of the equivalent circuitization of the water pipe model using Sim4life is confirmed. Future plans include working on an equivalent circuit for water pipes using the MATCH function of Sim4life, which has been validated.

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