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Low Frequency Characteristics of Electric Wire Antenna onboard Scientific Spacecrafts

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1. Introduction

Plasma waves are important targets in scientific spacecraft missions. The electric and magnetic field detected by the sensors aboard a spacecraft is converted into an electrical signal and sent to the earth as digital data via A/D conversion. Therefore it is very important to calibrate the sensors accurately for exact observation. However the effective length of a wire antenna, which is ordinary used to observe electric field intensity, is not easy to estimated its characteristics especially at low frequencies. An effective length h_{eff} is a parameter which convert the electric field intensity E into the antenna output voltage V;

$$V = h_{eff} \cdot E \tag{1}$$

For example, GEOTAIL spacecraft's wire antennas, whose total length L is 100 m, observes both of the waves and the static fields. When we make analysis the wave data, the effective length is assumed to $L/2$, however in the static field analysis, it is assumed to L. Considering the fact that a wire antenna seems to has two different effective lengths, the effective length should be changed depending on the frequency of the electric field.

In this paper, we measured the frequency dependency of the effective length of wire antenna by method of "Rheometry Experiment", and investigated the result of it by method of theoretical analysis using equivalent circuits and computer simulations.

2. Rheometry Experiment

Rheometry experiment is a experimantal method which measure the output voltage of a model antenna in the water which has quasi-static electric field generated artificially (fig. 1). In this method, we can estimate the effective length of the model antenna directly, when we know the intensity of the quasi-static electric field.

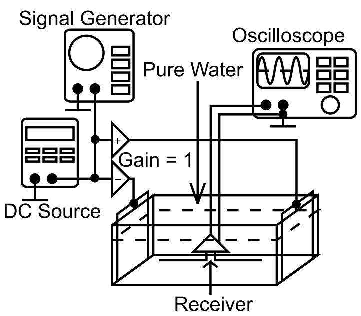

Figure 1: Overview of the rheometry experiment.

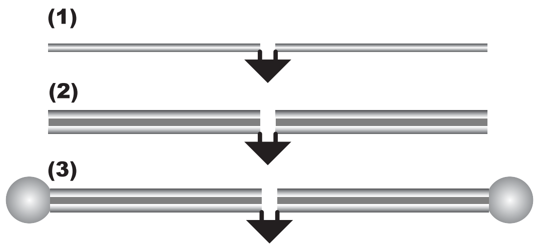

Figure 2: The antennas used to the experiment.

ISBN: 978-4-88552-223-9 C3055©IEICE

We made 3 types of model antennas for this experiment (fig. 2), and observed the difference of the effective length characteristics among them, at the frequency from 10 Hz to 100 kHz. Each of them has a pair of 15 cm wires, and the third one has a pair of spherical probe which is 13 mm in diameter at the tips of the wires.

3. Electrical Equivalent Circuits

In this section, we make analysis by means of electric equivalent circuit of the experiment circumstances. The elements of electric circuit appears around the model antenna are shown in fig. 3 and fig. 4. The insulator can be assumed to a capacitor C_I placed between the water and the antenna wire, which is connected to the ground impedance of the wire R_I series through the water. The ground impedance exists also at the both wire tips (or at the probes), we describe it R_M (or R_P for probes). The quasi-static electric field can be assumed to a "distributed power supplier", and it can be described to a lot of parallel power suppliers approximately. The output voltage of each power supplier is 0 at the center of antenna and be stronger proportionally to the distance from the antenna center. The parameters R_I, C_I, R_M (R_P) can be calculated via theories of electric circuit.

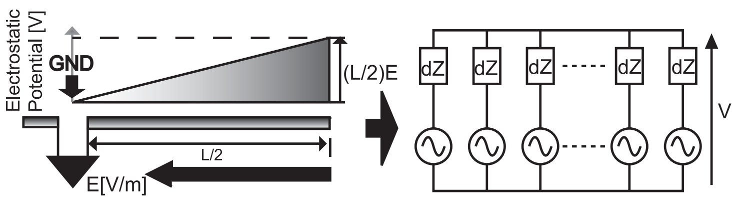

Figure 3: The equivalent circuit of model antenna in the experiment.

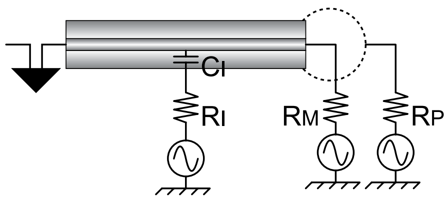

Figure 4: The electric circuit elements.

Fig. 5 shows the result of the analysis plotted with the experimental result. Both of the results of experiment and analysis show that, the effective length fluctuates depending on the frequency and the structure of the antenna, and it is close to L at low frequencies, and be close to $L/2$ when the frequency becomes higher. This result can be explained considering the impedance of the insulator. The insulator works as capacitance between the water and the wire, so that its impedance is quite large at very low frequency and becomes small when the frequency becomes high.

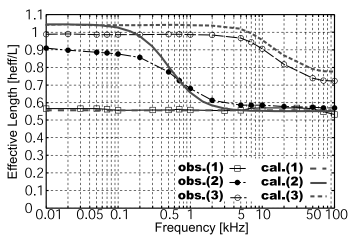

Figure 5: Frequency dependency of the effective length of each antenna observed by the rheometry experiment.

4. Computer Simulation

4.1 Case 1: The Antenna with No Insulator

The result of the experiment and the analysis are almost coincident each other, however they are slightly different for 5 - 10 %. In this section, we made computer simulations for detail investigation. At first, we tried on the case of the wire without insulators, the simplest case.

Fig. 6 and Fig. 7 show the simulated electro static potential around the wires. According to the distribution of electric static potential, each wire picks up the electric potential at the center of it. We swept the frequency from 10 Hz to 100 kHz, the potential the wire picks up is same at any frequencies.

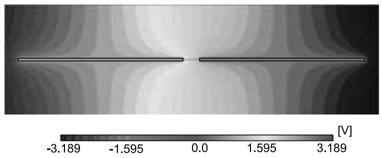

Figure 6: The simulation result of electro static potential around the wire without insulator at 10 Hz - 100 kHz.

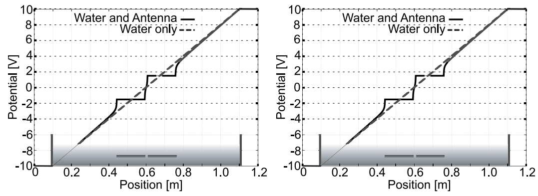

Figure 7: The electro static potential along the wires without insulator at 10 Hz and 10 kHz.

4.2 Case 2: The Antenna with Insulator on the Side of Wires

For the case of the wires with insulator at the side of them, the electric static potential is different depending on the frequency (Fig. 8).

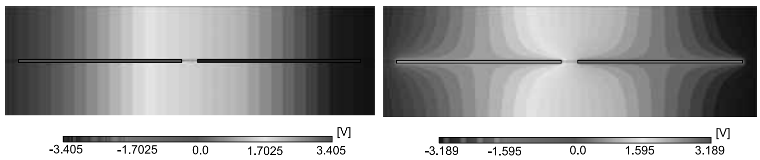

Figure 8: The simulation result of electro static potential around the wire without insulator at 10 Hz and 10 kHz.

When the frequency is 10 Hz, the antenna picks up the potential at the tips of them, and when 10 kHz, it picks up at the center of the wires. Fig. 9 shows the magnified figure of fig. 8 at the right tip of the wire, and fig. 10 shows the potential along the insulated wires at 10 Hz and 10 kHz.

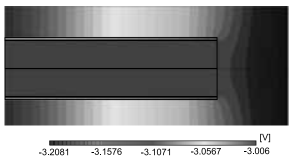

Figure 9: The electric potential around the tip of the wire.

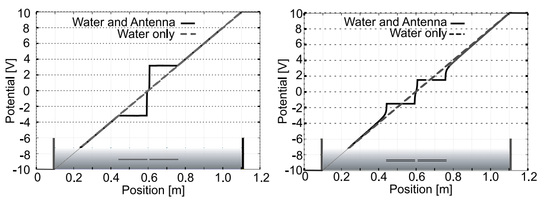

Figure 10: The electro static potential along the insulated wires at 10 Hz and 10 kHz.

4.3 Case 3: The Antenna with Spherical Probes at the Both Tips of the Wires

In this section we investigate the effective length of the wire antenna with spherical probes at the tips of the wire. The size of each probe is 1 cm in diameter. Fig. 12 and fig. **??** show the simulated potential around the probes at 10 Hz and 100 kHz.

At 10 Hz, The antenna picks up the potential at the center of the probe, and at 100 kHz, at the position a little closer to the center of the wire. Fig. 12 shows the potential along the wires.

4.4 Simulated Effective Length for the Case 1 - 3

According the simulation result, we can calculate the effective length using the electric field intensity which is simulated for the case of water only and the potential difference between the gap of wires. The

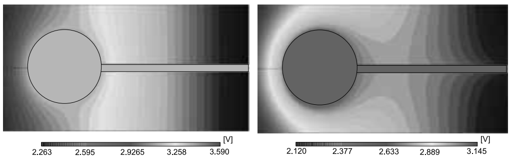

Figure 11: The electric potential around the probe at 10 Hz and 100 kHz

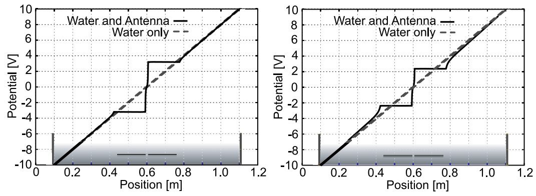

Figure 12: The electro static potential along the wires with probe at 10 Hz and 100 kHz.

result is show in fig. 13. The result of the experiment, the analysis and the simulation are coincident at all frequencies.

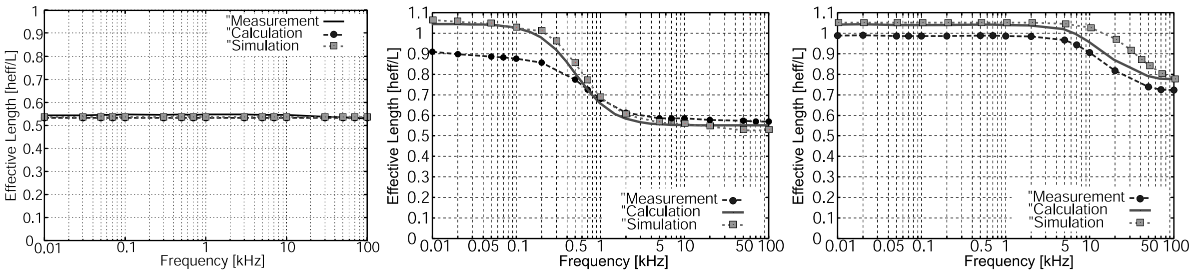

Figure 13: The simulated frequency dependency of the effective length of the wire for case 1 - 3.

5. Conclusion

In this paper, we investigated the effective length of wire antenna by means of the experiment, the equivalent circuit analysis and the computer simulation. The result shows that the frequency dependence of the effective length of a wire antenna depends on the structure of it, and especially, for the case of the antenna using insulated wires, the the effective length is almost L at very low frequency and it becomes $L/2$ when the frequency becomes high, and this characteristics is coincident with that of actual wire antenna aboard scientific spacecrafts. This phenomena can be explained considering the impedance of the insulator which surrounding the side of the wires.

References

[1] T. Imachi, S. Yagitani, R. Higashi, I. Nagano, "Rheometry Experiment for a Wire Antenna Aboard Spacecraft at Low Frequencies", IEICE Trans. (B), Vol. J89-B, No. 4, pp.552–559, 2006.

[2] T. Imachi, S. Yagitani, I. Nagano, M. Tsutsui, H. Matsumoto, "Evaluation of the effective length of electric field observation antenna on board GEOTAIL satellite", IEICE Trans. (B), Vol. J85-B, No. 1, pp.97–104, 2002.