THE TRANSIENT FIELDS OF A DIPOLE ANTENNA LOCATED NEAR THE INTERFACE OF LOSSY HALF-SPACE

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I. INTRODUCTION Recently, vigorous investigations have been made for the development of underground radar system, which detects and locates underground objects such as water pipes, electric communication lines, etc. However, the present system is still insufficient for practical uses, partly because there are many problems to be solved such as EM-wave transmission into the underground from an antenna in the air, scattering from objects buried in the ground and so on. Especially, it is very important to investigate the characteristics of an antenna located near the ground surface and to investigate the EM-field in the underground. This paper presents the theoretical and experimental studies of the fields excited by a dipole antenna near the interface of a lossy half-space in time domain and frequency domain. The Sommerfeld integrals involved in the formulation are transformed into the tractable forms which contain numerically fast convergent integration. An experiment is carried out by using a water tank modeling the ground in order to confirm the validity of the theory. It is shown that the measured data agree very well with the theoretical results.

II. ANALYSIS The geometry of the problem is illustrated in Fig.1. The space is partitioned into two halves, one of which is filled with air and the other with a homogeneous lossy medium. The horizontal dipole antennas are located in the air and the lossy medium, respectively. The dipole in the lossy medium is a model of a cylindrical conducting underground object with finite length. Both antennas are assumed to be parallel to the x-axis, and whose height and depth are z_1 and z_2. The driving points of both antennas are located in the y-z plane. The two antennas are shifted along the y-axis by y_2. It is well known that the electromagnetic fields are expressed by the Sommerfeld integrals[1],[2], and that the numerical calculation of the Sommerfeld integral is very difficult when the source point and the observation point approach to the interface, simultaneously.

First, we have derived an efficient method to calculate the Sommerfeld integral as follows. For example, the x-component of the scattered electric field due to an infinitesimal dipole in the air is expressed as

$$E_{Sx}^{(1,1)} = -\frac{\omega\mu_0}{4\pi}\int_0^{\infty}\frac{dh}{h_1}e^{-jh_1(z+z_1)}\left[a_1\frac{J_1(\lambda r)}{r} - \frac{h_1^2}{k_1^2}b_1\frac{\partial J_1(\lambda r)}{\partial r}\right] \quad (1)$$

where

$$a_1 = \frac{h_1 - h_2}{h_1 + h_2},\ b_1 = \frac{n^2 h_1 - h_2}{n^2 h_1 + h_2},\ h_1 = \sqrt{k_1^2 - \lambda^2},\ h_2 = \sqrt{k_2^2 - \lambda^2},\ n^2 = \epsilon_r - j\frac{\sigma}{\epsilon_0\omega} \quad (2)$$

Extracting from the integrand in eq.(1) the terms which are slow-convergent, but analytically integrable into closed form[2], we obtain the alternate fast convergent expression,

$$E_{Sx}^{(1,1)} = e_1 + e_2 + e_3 + \frac{\omega\mu_0}{4\pi}\int_0^\infty \{ [\frac{\lambda}{h_1}(a_1 + b_u + b_v)e^{-jh_1(z+z_1)} - j(b_u - b_v)e^{-\lambda(z+z_1)}] \frac{J_1(\lambda r)}{\lambda r} - [\frac{h_1^2}{k_1^2}(b_1 - b_u) + b_v] \frac{\partial J_1(\lambda r)}{\partial r} \frac{e^{-jh_1(z+z_1)}}{h_1} \} d\lambda \quad (3)$$

where

$$e_1 = \frac{j\omega\mu_0}{4\pi} b_u \frac{e^{-jk_1 R}}{R} \{1 - \frac{j}{k_1 R} - \frac{1}{k_1^2 R^2} + (-1 + \frac{3j}{k_1 R} + \frac{3}{k_1^2 R^2}) \sin\theta \}$$

$$e_2 = \frac{\omega\mu_0}{j4\pi} b_v \frac{e^{-jk_1 R}}{R}, \; e_3 = -\frac{j\omega\mu_0}{4\pi}(b_u - b_v)\frac{R - (z + z_1)}{r^2} \quad (4)$$

$$R = \sqrt{r^2 + (z + z_0)^2}, \; \sin\theta = \frac{r}{R}, \; b_u = \frac{n^2 - 1}{n^2 + 1}, \; b_v = \frac{b_u n^2}{n^2 + 1}$$

The remaining integral in (3) is carried out by the numerical integration. Convergency of this integration is the order of $\lambda^{-7/2}$.

The above procedure is performed for other fields and the antenna of finite length as shown in Fig.1. The input impedances and the current distributions of the two antennas are calculated by using the sinusoidal Galerkin's method[3]. The transient fields are obtained by transforming the results in frequency domain to the time domain. In this paper, the numerical Fourier transformation is used. The theoretical results are shown in Figs.4-8 together with the experimental results.

III. EXPERIMENTS In order to confirm the validity of the analysis, the experiment is carried out with the city water. The experimental setup is illustrated in Fig.2. The unit the dimensions in Fig.2 is mm. Fig.3 shows the measured frequency characteristics of the relative permittivity ε_r and the conductivity σ of the water. In the experiment, all the components of the scattering matrix are measured at 801 points frequencies ranging from 45MHz to 5GHz by using the network analyzer YHP-8510B.

Examples of the measured data are shown in Figs.4-7. In these figures, the solid lines indicate the measured data and the broken lines are the theoretical results. The height of the antenna from the water surface is z_1=5cm. Fig.4 shows the frequency characteristics of s_{11} at the driving point of the antenna in the air whose length is $2l_1$=60cm. Fig.5 and 6 show the s_{12} and s_{22} when two 6cm-antennas are located in the air and in the water with depth, z_2=-20cm. Fig.7 shows the H-plane(y-z plane) pattern of the x-component of the electric field at a frequency of 645MHz. Thus, all the experimental data agree very well with the theoretical results.

Fig.8 shows the transient response of the driving point voltage V_d^1 of the 60cm-antenna in the air for the following driving pulse.

$$V_1(t) = \cos^6\{\pi(\frac{t}{P_d} - \frac{1}{2})\}, \; 0 < t < P_d \quad (5)$$

The pulse width P_d is 1[nsec]. The experimental result was calculated by the numerical transformation of the data of Fig.4.

IV. CONCLUSIONS The scattering matrix, the transient responses and the near field patterns of a horizontal dipole antenna above a lossy half-space have been investigated theoretically and experimentally. In evaluation of Sommerfeld integrals a fast convergent formulation has been obtained by extracting the slowly convergent parts from the integrands and by obtaining the closed forms for them. Comparison between the measured results and the theoretical results has shown the validity of the present analysis.

REFERENCES

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[2]A.Mohsen, "On the evaluation of Sommerfeld integrals," IEE Proc., vol.129, Part H, no.4, pp.177-182, August 1982.

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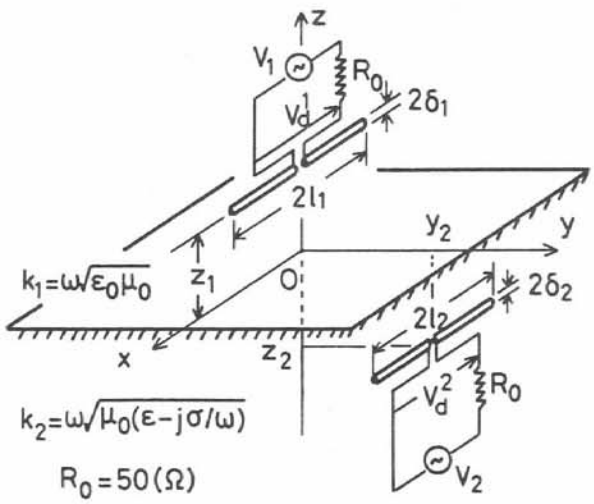

Fig.1 Geometry of the problem

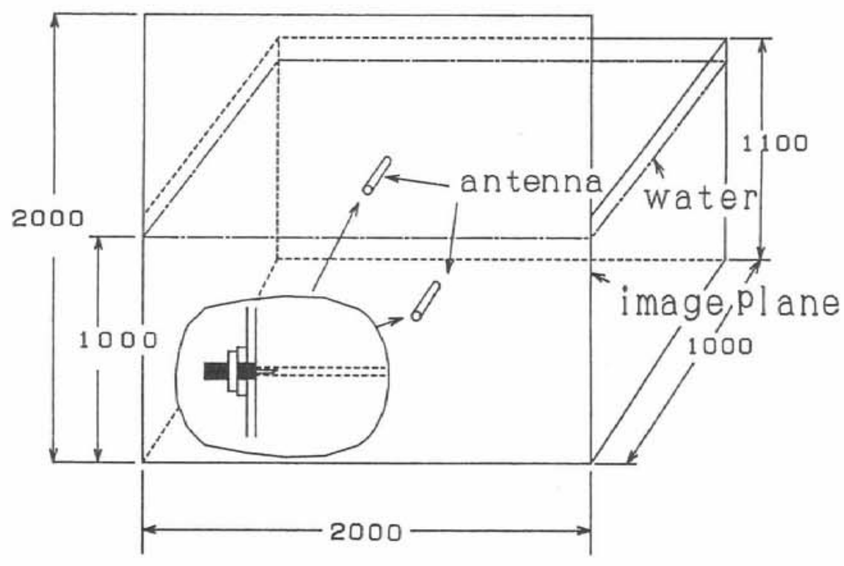

Fig.2 Experimental setup.

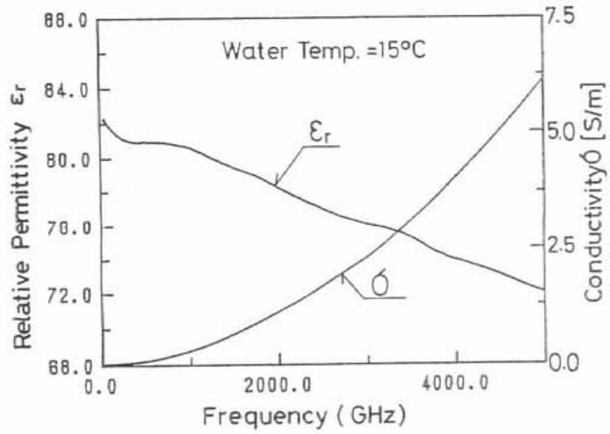

Fig.3 Measured relative permittivity and conductivity of the city water.

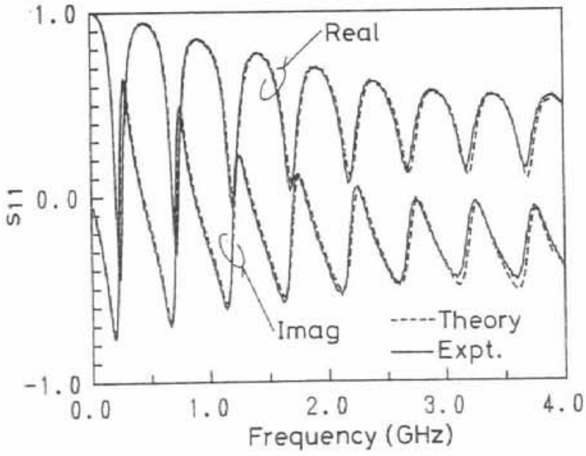

Fig.4 Frequency Characteristics of s_{11}. ($2l_1=2l_2=60$cm, $z_1=5$cm)

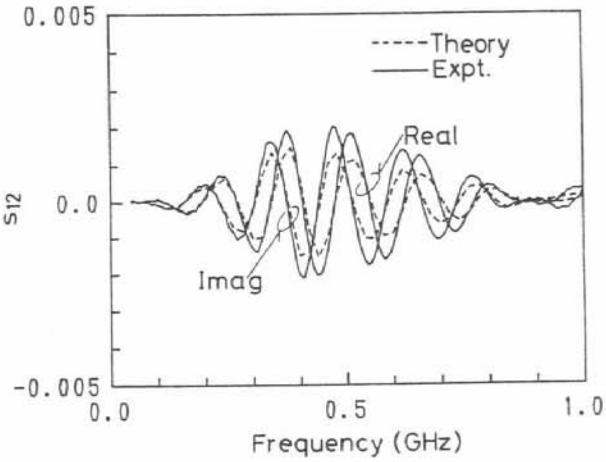

Fig.5 Frequency characteristics of s_{12}. ($2l_1=2l_2=6$cm, $z_1=5$cm, $z_2=-20$cm, $y_2=0$)

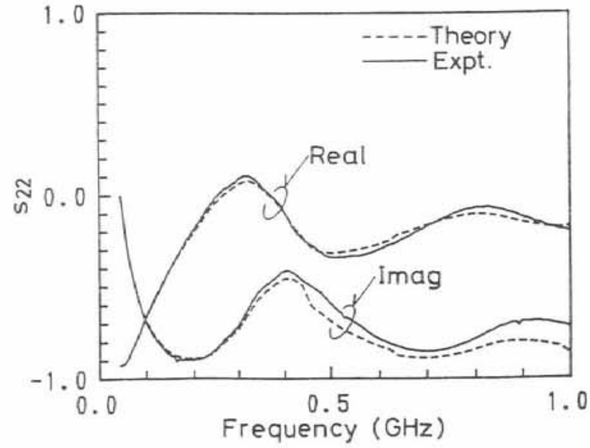

Fig.6 Frequency characteristics of s_{22}. ($2l_1=2l_2=6$cm, $z_1=5$cm, $z_2=-20$cm, $y_2=0$)

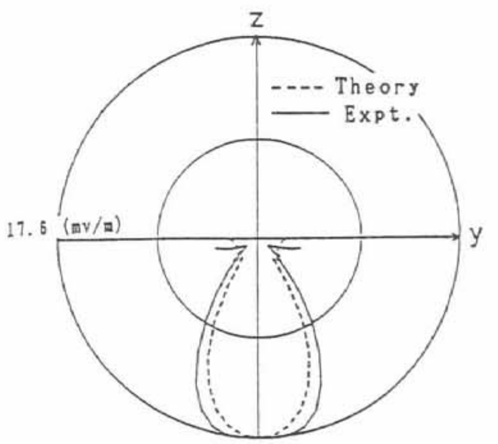

Fig.7 H-plane(y-z plane) near field pattern of E_x at a frequency of 645MHz. ($2l_1=6$cm, $z_1=5$cm)

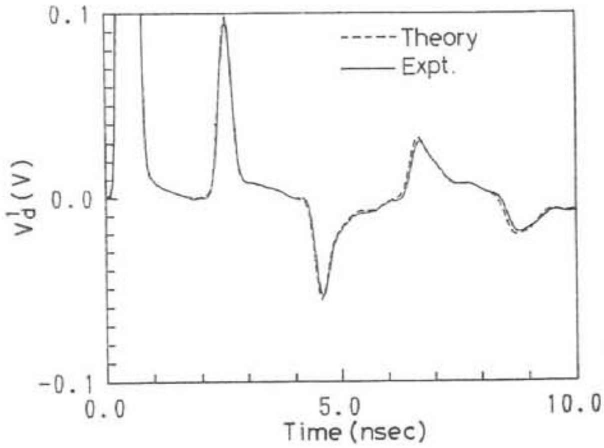

Fig.8 Transient responses of the transmitting antenna calculated from the data of Fig.4.