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TWO-DIMENSIONAL ACTIVE IMAGING OF CONDUCTING OBJECTS BURIED IN A DIELECTRIC HALF-SPACE

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I. INTRODUCTION Various subsurface radars have been investigated and developed by many researchers for the purpose of detecting the underground objects such as water pipes, power and communication lines, historical ruins and so on[1]. However, the reliability and the resolution of present subsurface radars are still insufficient for practical uses. Its one reason is that too much simplification is assumed for the subsurface propagation and scattering mechanism, and only a delay-time of received pulse is utilized for underground imaging, notwithstanding the propagation and the scattering mechanism are very complicated. We have theoretically and experimentally demonstrated that there exist the lateral wave and the direct wave propagations between an antenna in the air and the buried object, and the lateral wave becomes considerably large under certain circumstances[2].

The authors have proposed an exact passive imaging method of line source buried in a dielectric half-space[3]. This method does not include any approximation except that it is two dimensional. In this paper, a two dimensional active imaging method of conducting underground objects is investigated. If a secondary current on the buried object is known, the active imaging method can be applied. In this paper the secondary current is approximated by a physical optical approximation. The validity of this imaging method is confirmed by both numerical simulations and experiment.

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 lossless medium. An infinitely long conducting cylinder having arbitrary cross section is buried underground and is parallel to y-axis. An exciting current source is also parallel to y-axis.

First, the physical optics current is assumed on the buried object. It has been confirmed that this approximation gives a good result for this polarization[4]. The scattered electric field at an observation point (x_2, z_2) in air is obtained as follows:

$$E(x_1, x_2, \omega) = \frac{\omega\mu_0 P(\omega)}{2\pi^2}\int_C dl \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \frac{\xi\sin\theta + u_2\cos\theta}{(u_1+u_2)(u_1\prime + u_2\prime)}$$

$$e^{j[(u_2+u_2')z-(\xi+\xi')x-u_1z_1-u_1'z_2]}e^{j(\xi x_1+\xi' x_2)}d\xi d\xi' \qquad (1)$$

where, $P(\omega)$ is the frequency characteristics of the current source, θ is the angle between unit normal on the buried object and z-axis. k_1 and k_2 are wave numbers in air and the medium, respectively. $u_1 = \sqrt{k_1^2 - \xi^2}$, $u_2 = \sqrt{k_2^2 - \xi^2}$, $u_1' = \sqrt{k_1^2 - \xi'^2}$, $u_2' = \sqrt{k_2^2 - \xi'^2}$, and C indicates the illuminated surface of object.

Next, Fourier-transforming Eq.(1) with respect to the position of current source x_1, observation point x_2, and also the frequency ω, we obtain

$$\int_C dl \cos(\theta - \phi) p\Big(\frac{2n}{c}(\hat{s}\cdot\mathbf{r} - s)\Big) = \frac{(\gamma + n\cos\phi)^2}{2n}\sqrt{\frac{\varepsilon_0}{\mu_0}}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} e(x_1, x_2, t)\,dx_1 dx_2 \quad (2)$$

where, c is the light velocity, $n = k_2/k_1$ is a refractive index, $p(t)$ is an amplitude of current, $e(x_1, x_2, t)$ is transient scattering filed at x_2. $t = [(z_1 + z_2)\gamma + n(x_1 + x_2)\sin\phi - 2ns]/c$, $\gamma = \sqrt{1 - n^2\sin^2\phi}$. The parameter ϕ is an arbitrary angle and $\hat{s} = (\sin\phi, \cos\phi)$. It is found from Eq.(2) that the synthesis of transient scattering fields along the ground surface gives the projection of buried object weighted by pulse form. The physical meaning of Eq.(2) is illustrated in Fig.2. Therefore, we refer to the right hand side of Eq.(2) as an image function and denote it by $f(s)$ in this paper. A two-dimensional underground image $g_n(\mathbf{r})$ is synthesized by superposing the image functions for several angles ϕ as follows.

$$g_n(\mathbf{r}) = \frac{1}{n}\sum_{i=1}^{n} f_i(\mathbf{r}\cdot\hat{s}_i) \quad (3)$$

III. NUMERICAL SIMULATIONS The simulation model is shown in Fig.3. The buried objects are a circular cylinder and a flat plate. The depth of plate and cylinder is 78cm and their interval is 30cm. A mono-pulse,

$$p(t) = \begin{cases} \cos^6(\frac{\pi t}{P_d}) & ; \quad -P_d/2 \le t \le P_d/2; \\ 0 & ; \quad \text{otherwise,} \end{cases} \quad (4)$$

is chosen as the exciting current, where P_d =1nsec. The transient fields in the air are computed by using FDTD method.

The image function is calculated by integrating the scattering fields along the ground surface over a region of $-1.5m < x < 1.5m$ at a height of $z_1 = z_2$ =6cm. The Fig.4 shows the two-dimensional image of buried objects obtained by superposing 21 image functions. It is seen that the upper contours of plate and cylinder are well reconstructed. However the lower contours are not reconstructed because the current on the shadow region is very small.

IV. EXPERIMENT To confirm the validity of this method, an experiment is carried out. The experiment setup is illustrated in Fig.5. A plastic tank is filled with a moist sand. The buried object is an aluminum cylinder whose radius is 15cm. The measurement is carried out by using two 3cm monopole antennas. The measurement points are also shown in Fig.5.

The transient receiving voltage of one dipole antenna is obtained by Fourier-transforming the transmitting parameter measured in frequency domain. The exciting voltage is the same form as Eq.(4) whose amplitude is 1[V]. Fig.6 shows an example of the received voltage. The ripples in early time are due to the direct wave between two antennas and reflected wave from ground surface. Small ripples observed at 6.5nsec are the scattering field from the buried cylinder.

The two-dimensional imaging result is shown in Fig.7. The upper part of buried cylinder is precisely reconstructed. The horizontal line in the figure is due to the early-time response which could not completely be removed as a noise in signal processing.

V. CONCLUSIONS A new two-dimensional quasi-exact active imaging method has been proposed. It has been found from the numerical simulation that the upper contour of buried object is well reconstructed. However the lower side could not be reconstructed because the secondary current is too small in this region. The effectiveness of this method is also studied experimentally using two monopole antennas. It has been shown that the precise position of buried object can be reconstructed.

REFERENCES

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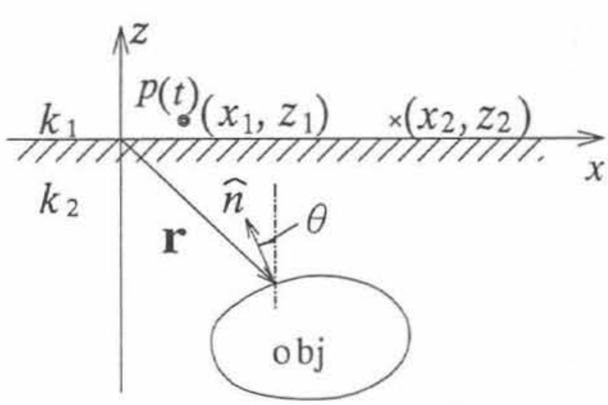

Fig.1 Geometry of the problem.

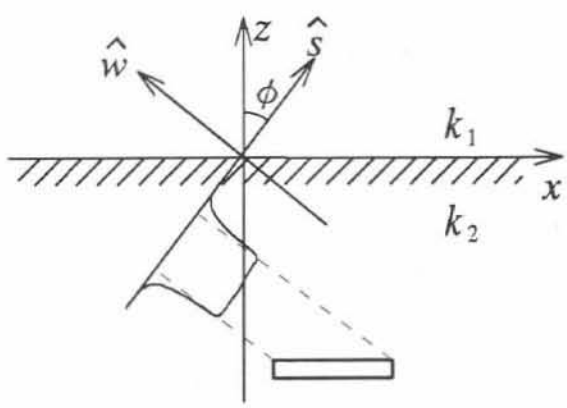

Fig.2 Physical meaning of image function.

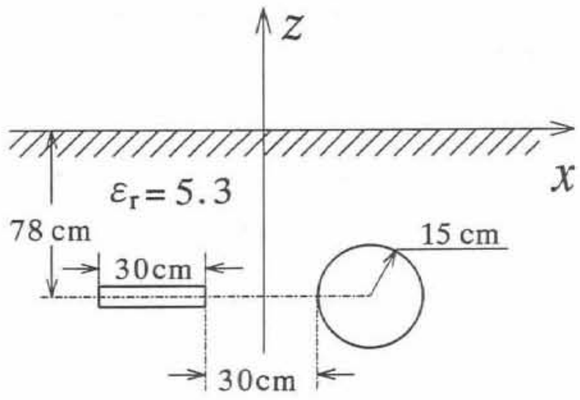

Fig.3 Buried objects in the ground.

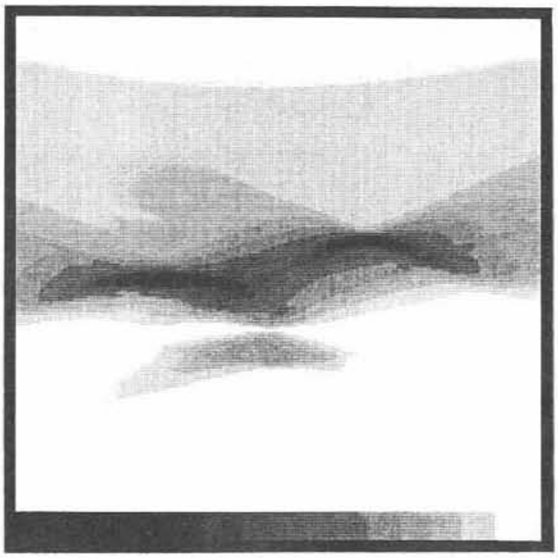

Fig.4 Reconstructed image of buried objects.

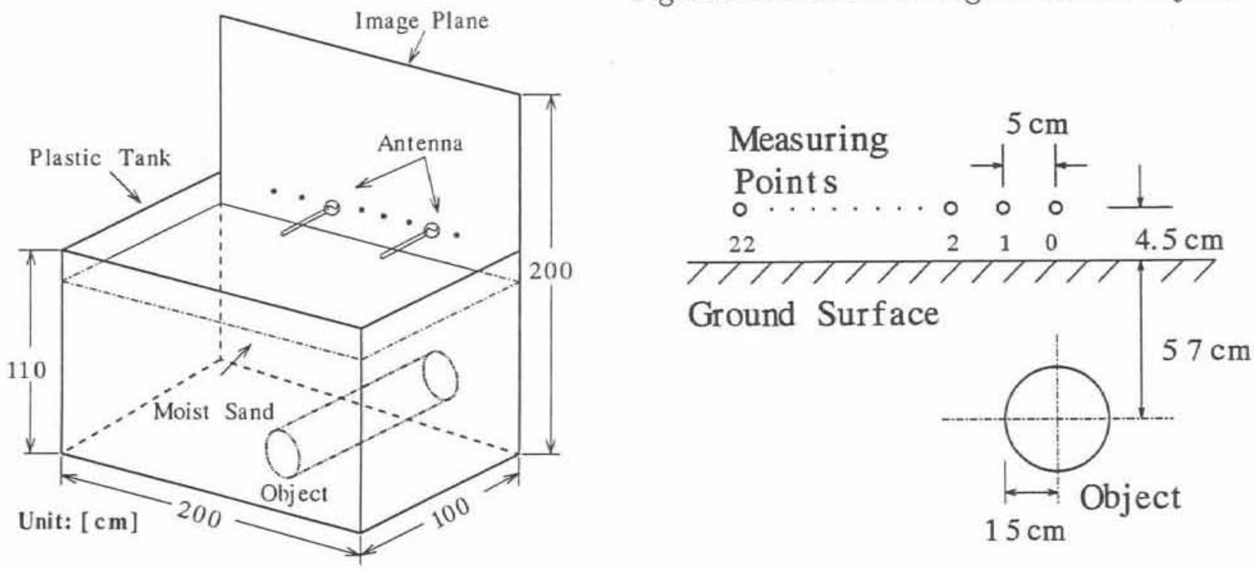

Fig.5 Experiment setup.

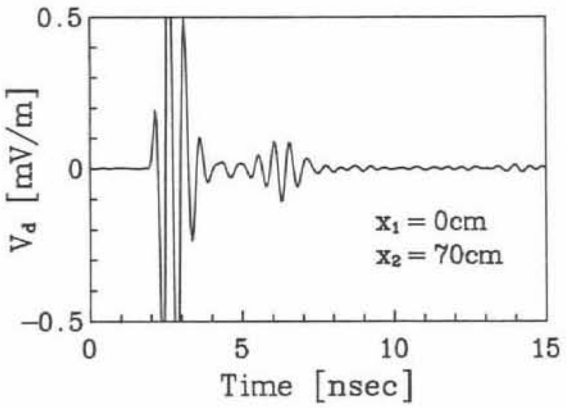

Fig.6 Transient receiving voltage.

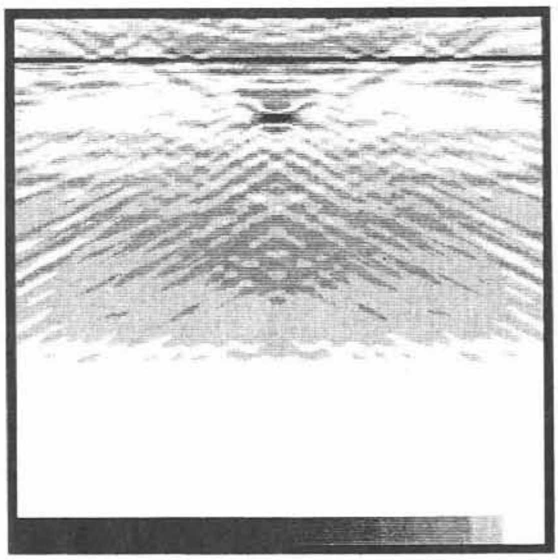

Fig.7 Reconstructed image of buried cylinder.