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FDTD Analysis of Optimum Antenna Arrangement for Surface Clutter Rejection in Landmine Detection

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1. Introduction

GPR is a well-known technique to non-destructively investigate underground anomalies. Recently, an importance of application of GPR to landmine detection has been increasing. GPR systems for landmine detection are specialized to detect anomalies near the ground surface. Generally, it works in the frequency range of several GHz. The surface-clutter generated by the surface roughness often makes it difficult to detect the target reflections in this frequency range. The reduction of the surface clutter can be achieved by combining the images obtained at different received points in an array antenna system. However, the optimum antenna arrangement has not been clarified for the application to mine detection. In this report, the small dipole-based GPR system is considered. We discuss the optimum combination of the antenna separation, antenna direction and antenna polarization to achieve the high signal-to-clutter ratio (SCR) using a FDTD analysis.

2. FDTD analysis

A FDTD analysis is effective to obtain the scattered signals from the target in the medium with 2D rough surface and 3D-distributed dielectric constant. The calculation size is a cube having the size of 80 cells in this analysis. The cell size corresponds to 1cm. The surface of the ground is assumed as 2D rough surfaces in which the 2D spatial spectrum is logarithmically decreased as the wave number. The peak-to-peak of the height of the roughness is 4cm. And the spatial distribution of the dielectric constant is gradually increasing from 4 to 7 as the depth is increased. The cylindrical target is placed at the depth of 6cm, having the diameter of 5cm, the width of 2cm and the dielectric constant of 2. A small dipole antenna having the length of 1 cell is used as a transmitter. The three kinds of electric field components are considered as transmitting polarization. We observe the three kinds of electric field components at the receiving positions, which have the Tx-Rx separation from 1cm to 15cm and the Tx-Rx direction of -x, -y, +x and +y. The transmitter and the receiver are placed at the height of 5cm. We select the transmitting pulse so that the averaged receiving signals have the frequency bandwidth from 2 to 5 GHz as shown in Fig.2.

3. Migration Result

The set of the transmitter and receivers scans the surface around square region with the length of 40cm and the step interval of 5cm. The complex value of the calculated waveform is used in the migration processing, generated with the analytical function of the FDTD waveform. We employed the diffraction stack method taking into consideration of the refraction at the two-layer boundary between air and subsurface. We calculate 3*3*4 antenna combinations for transmitter polarizations, receiver polarizations and receiver directions. In these combinations, we can theoretically obtain 6 kinds of individual images without cross-polarized arrangement. Fig.3 shows the migration images obtained in the antenna separation of 7cm after removal of a background waveform.

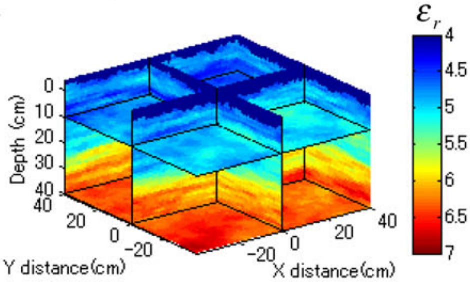

Fig.1 Assumed subsurface condition

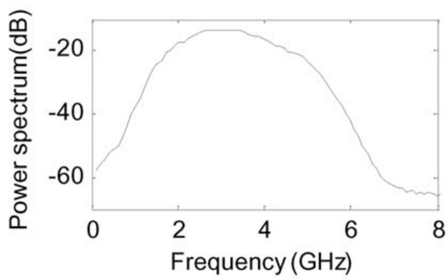

Fig.2 Averaged power spectrum of reflected signal

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When the horizontal polarizations (*Ex*) are used in both the transmitter and receiver, co-linear and parallel antenna arrangements are defined as shown in Fig. 3 (a) and (b). Clear target images are obtained with these combinations. However, the surface clutter is also as strong as the target. When the vertical polarizations (*Ez*) are used in both the transmitter and receiver, a parallel antenna arrangement is also defined as shown in Fig. 3 (c). In this case, the target image is not clear. And the surface clutter affects the deep region. When the vertical and horizontal polarizations are used in the transmitter and receiver, respectively, two co-linear and cross-polarized arrangement are defined as shown in Fig.3 (d), (e) and (f). In Fig.3 (d) and (e), we cannot theoretically obtain the symmetrical image along the z-axis. The peak of the target image appears with bias in the x-z plane. In Fig.3 (f), the target image is split in the x-z plane and is not obtained in the y-z plane.

The power of the target signal can be evaluated by finding the maximum amplitude in the cylindrical region of the diameter of 10cm and the depths from 5cm to 8cm. The power of the clutter can be defined as a function of depth by calculating RMS of the amplitude in a horizontal square region having the size of 40cm except for the cylindrical region. Fig.4 shows the evaluated power of the target and clutter in each antenna separation. In Fig.4 (a), the power of the target and the clutter significantly decreases according to the antenna separation due to the directivity. On the other hand, there is little change of the power in Fig. 4 (b) and (c). In Fig.4 (d), (e) and (f) the target signal and clutter are smaller than those in the co-polarization case. When the antennas are close to the target, the reflection from the target is weak due to the directivity of the transmitting antenna. When the antennas are far from the target, the reflection from the target is also weak due to the cross polarization nature. In Fig.3 (d) and (e), however, the target has strong reflection having the polarity opposite to each other when the target is between the transmitter and receiver. Thus, we can obtain a target image by combining with *Ex*(+x) and *Ex*(-x) components directed to the transmitter. This is discussed in the following section.

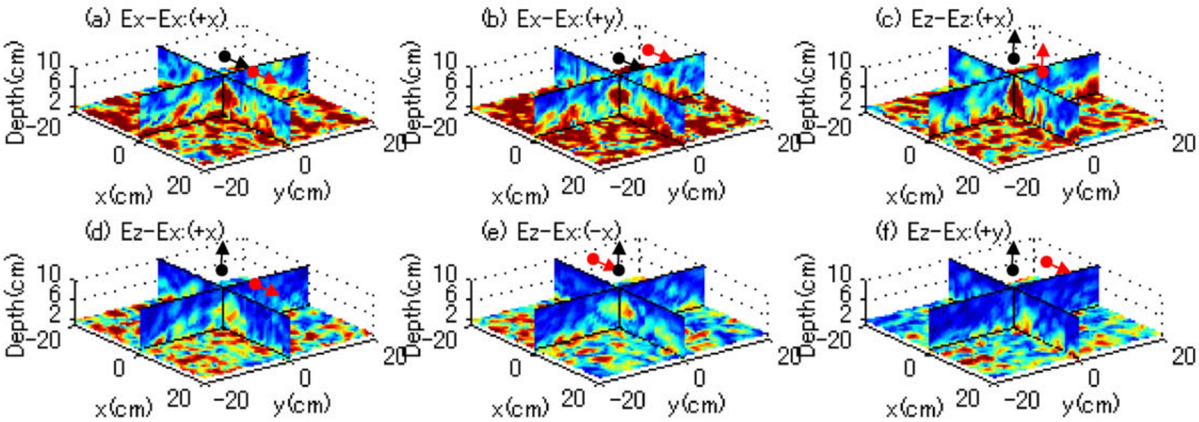

Fig.3 Individual migration images at the antenna separation of 7cm after removal of background.

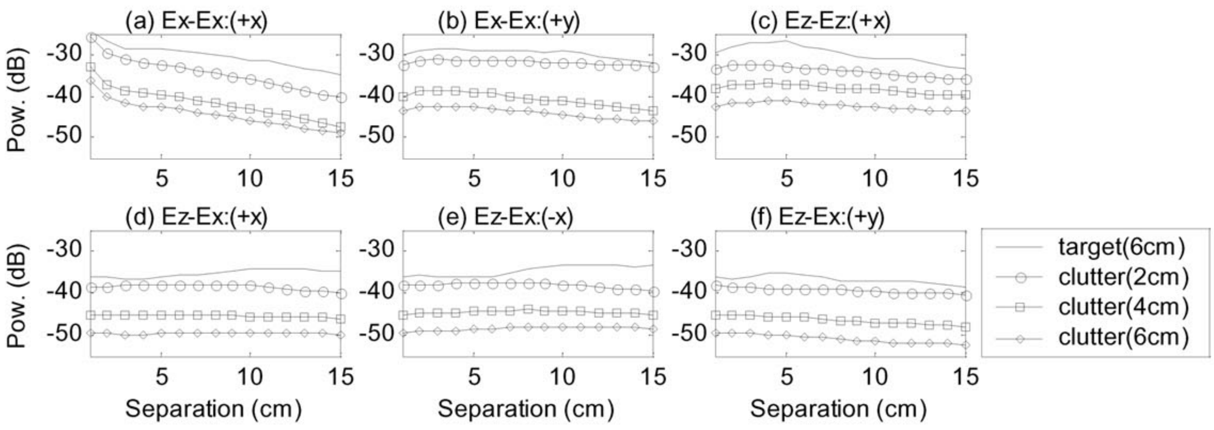

Fig.4 Evaluated power of the target and clutter in each antenna separation. The solid line shows the power of the target placed at the 6cm. The clutter is calculated as the function of depth.

4. SCR ratio combined with circular array

The final image is obtained by coherently adding the migration images obtained in 4 kinds of receiver positions to reduce the surface clutter. In the conventional GPR, a linear array with a horizontal parallel combination is used. In this analysis, however, we can combine a circular array in a certain antenna separation. To evaluate the ability of reduction of the surface clutter, we define the ratio of the target signal to the clutter level (SCR) in each depth. Fig.5 shows the difference of the SCR between a linear array and a circular array combination. The SCR shown in broken lines is calculated by combining with the linear array having the antenna separation of 4, 6, 8 and 10cm in the *Ex-Ex* combination. The SCR shown in solid line is calculated by combining with a circular array in a certain antenna separation. In Fig.5 (a) the SCR in the circular array is greater than that in the linear array. The circular array combination is effective to clutter reduction. Thus, we discuss about optimization of SCR for the circular array combination of the *Ex-Ex*, *Ez-Ez* and *Ez-Er* arrangement.

The *Ez-Er* arrangement is obtained with *Ez-Ex*(+x), *Ez-Ex*(-x), *Ez-Ey*(+y) and *Ez-Ey*(-y) combinations which have the receiver polarity directed to the transmitter. In Fig.5 the *Ex-Ex* combination has the highest SCR in a deep region (z=6cm). On the other hand, the *Ez-Er* combination has the highest SCR in a shallow depth (z=2cm). Thus, the *Ez-Er* combination is suitable to reduce the surface clutter because the *Ez-Er* combination has low sensitivity to downward direction near the target. Fig.6 shows the migration image combined with the circular array for the antenna separation of 7 and 13 cm. The amplitude of the image is normalized with the amplitude of the target in each figure. In the *Ex-Ex* combinations, the amplitude of surface clutter is almost same as the amplitude of the target. Thus, it is difficult to distinguish the target from the clutter using the amplitude information. The surface clutter in the *Ez-Ez* combinations is smaller than that in the *Ex-Ex* combinations. Especially for the antenna separation of 7 cm, the surface clutter is smaller than that in the other combinations. However, the vertical resolution of the target decreases. Thus, the most superior image is obtained around the antenna separation of 13 cm in the *Ez-Er* combinations.

Fig. 7 and 8 show the SCR and migration image, respectively, when the target depth is 3cm. In this case, only the target amplitude is increased because the target is placed at the shallower depth.

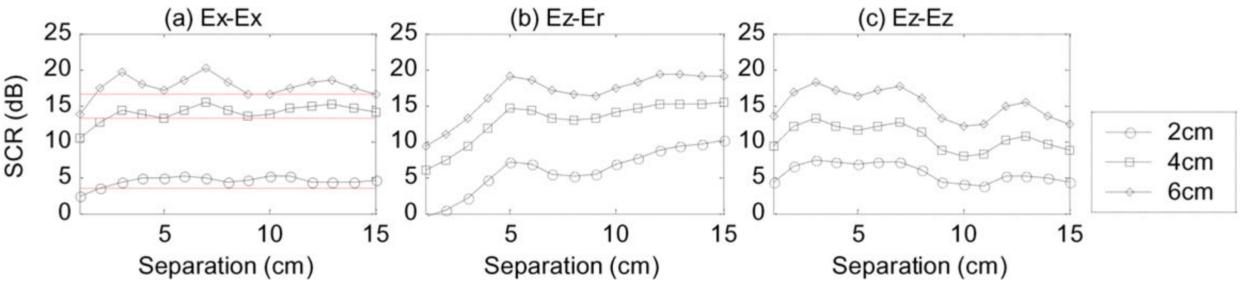

Fig.5 SCR combined with circular array(solid line) and linear array(broken line) arrangement. The *Ez-Er* is combined with *Ez-Ex*(+x, -x) and *Ez-Ey*(+y, -y) which has the polarity oriented to the transmitter.

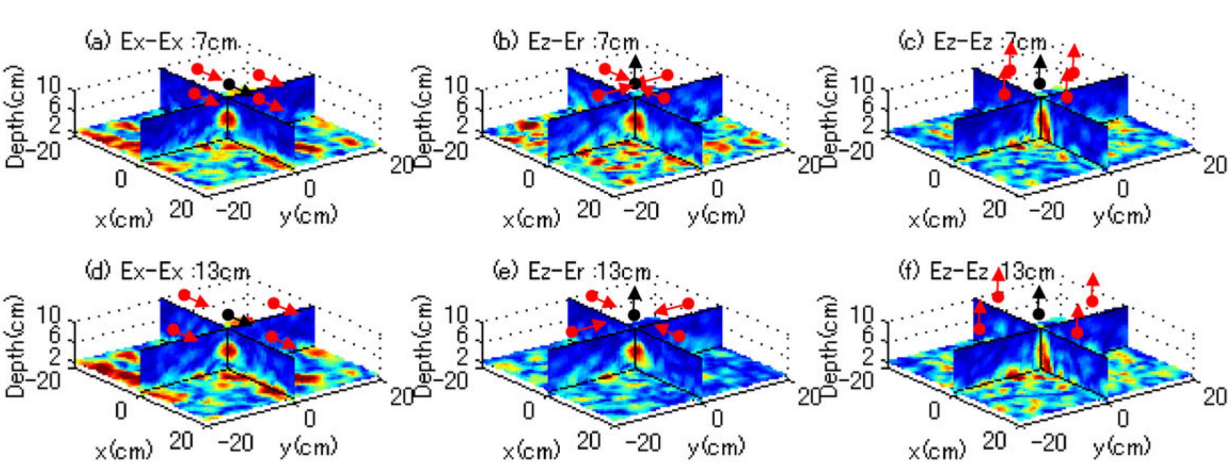

Fig. 6 Migration image combined with circular array in antenna separation of 7 and 13 cm. The amplitude is normalized with the amplitude of the target in each figure.

Especially, the *Ez-Ez* combination has significantly high SCR in every antenna separation. The *Ez-Ez* combination has the sensitivity around the horizontal plane due to its directivity. Therefore, the *Ez-Ez* combinations are more superior to the other combinations in the shallow target case.

5. SCR ratio combined with tilted dipole array

We can realize both characteristics in the *Ez-Ez* and *Ez-Er* combinations by tilting the receiving dipole in the z-r plane. Fig. 9 shows the synthesized SCR in the clutter depth of 2cm using tilted receiving dipole in antenna separation of 7 and 13 cm. All the receiving dipoles are tilted to the same angle. The tilted angle at 0 and 90 degree means the r-direction and z-direction, respectively. For the antenna separation of 7cm and 13cm, we can select the optimum tilted angle around 45 and 20 degree, respectively, in order to realize relatively large SCR for the surface clutter. Especially for the separation of 13cm, 6 dB improvement is achieved against the conventional system.

6. Conclusion

We discussed the optimum antenna combination in the small-dipole-array GPR in order to achieve the high SCR for surface clutter using a FDTD analysis. 6 dB improvement in SCR for the target depth of 3 and 6 cm is achieved in comparison with a conventional linear array combination when we use the *Ez* dipole for a transmitter and the circularly arrayed dipoles which are tilted to 20 degree from Rx-Tx direction for receivers.

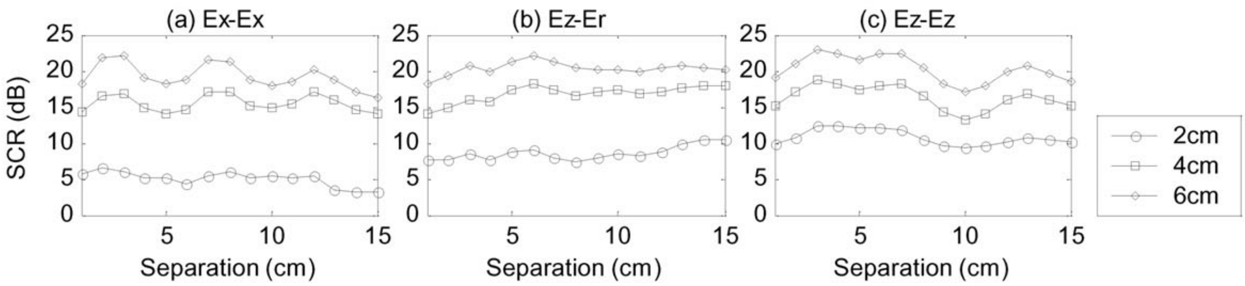

Fig.7 SCR combined with circular array arrangement for the shallow target (z=3cm).

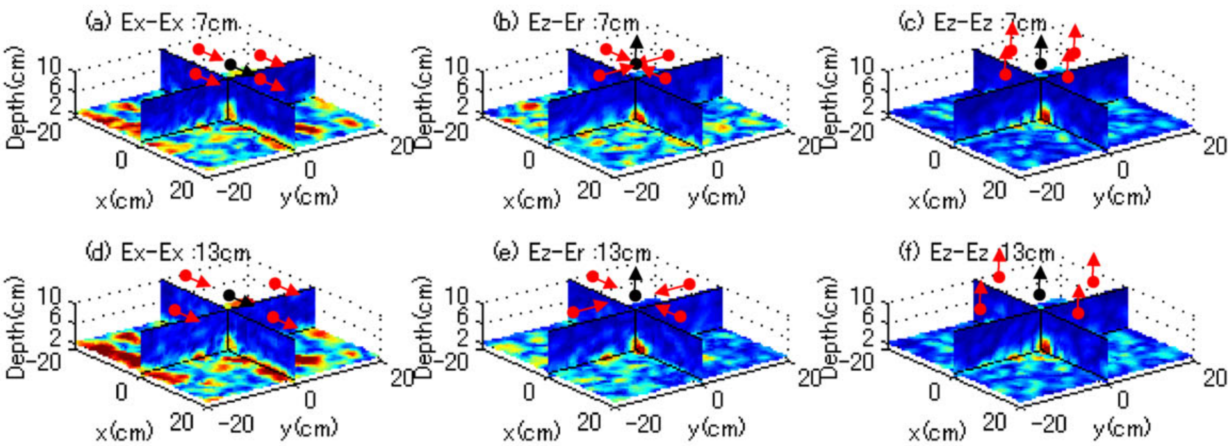

Fig. 8 Migration image combined with circular array for the shallow target (z=3cm).

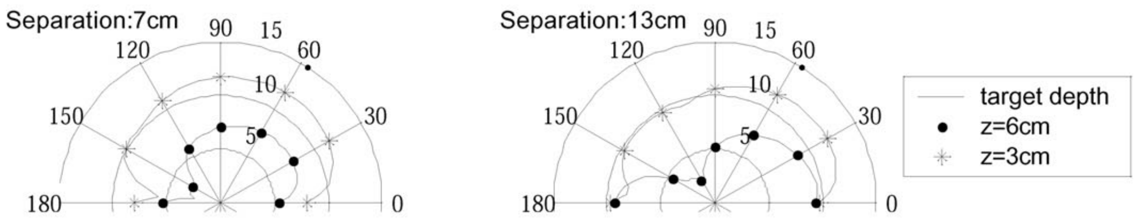

Fig.9 Synthesized SCR for surface clutter (2cm) using Ez transmitting dipole and tilted receiving dipoles. The tilted angle at 0deg. and 90deg. mean the r-direction and z-direction, respectively.