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Physical Modeling of Small Shallow Conductive 3-D Targets with High-Frequency Electromagnetics

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PHYSICAL MODELING OF SMALL SHALLOW CONDUCTIVE 3D-TARGETS WITH HIGH-FREQUENCY ELECTROMAGNETICS

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INTRODUCTION

The goal of this study is to show that physical modeling can provide important support for three-dimensional (3D) interpretation of electromagnetic geophysical data for environmental problems. This is specially true when high-frequency electromagnetic methods are used, which are difficult to model with existing 3D forward modeling programs. Existing electromagnetic geophysical systems usually operate in the frequency range of a few Hertz to several hundred Hertz. For environmental problems, such as characterization of waste sites, systems with higher frequencies are desirable. This is because at lower frequencies, the depth of investigation is too deep for environmental characterizations. This leads to subsurface images, which don't have enough resolution to map small shallow objects.

Electromagnetic 3D modeling programs which solve the full wave equation are still not widely available, even though 3D modeling has improved remarkably during the last few years (Oristaglio and Spies, 1995). Since such a program was not available for this study, we used a specialized 3D program EM1DSH (Zhou, 1989). With this program, we can model layered-earth cases, taking dielectric effects into account over the whole frequency range of interest. Stewart et al. (1994) published ellipticity curves for similar system configurations and frequency ranges that indicate that dielectric effects can not be neglected for model calculations using frequencies above several 100 kHz. EM1DSH can also model thin conductive sheets in a two-layer earth but neglecting dielectric effects. Therefore, we are only able to model and compare our field data with 3D forward modeling results for the lower frequencies. One way of bridging the gap between the interpretation needs and limitations of existing 3D forward modeling programs is to conduct physical modeling experiments.

HIGH-FREQUENCY ELECTROMAGNETIC ELLIPTICITY SYSTEM

Two high-frequency electromagnetic imaging systems (Sternberg and Poulton, 1994, Sternberg and Poulton, 1996) that overcome the depth restrictions of ground penetrating radar and the resolution limitations of existing electromagnetic methods have been developed at LASI for the frequency ranges of 1 kHz to 1 MHz and 32 kHz to 32 MHz, respectively. Currently 11 frequencies are transmitted sequentially in binary steps over the frequency ranges. The loop-loop systems record the electromagnetic ellipticity, which is calculated based on three arbitrary orthogonal components of the magnetic field (Thomas, 1996). The higher frequency ranges are necessary to provide high resolution over the range of depths that are of interest in environmental geophysics surveys. The interpretation of data collected by the system is performed by neural networks for frequencies below 1 MHz. Our goal is to find a combination of computer and physical modeling to develop training data above 1 MHz.

PHYSICAL MODELING EXPERIMENTS

The first experiment described was conducted in the physical modeling facility (Thomas, 1996) at the Avra Valley Geophysical Test Site near Tucson, Arizona. The physical modeling facility is a 3 m deep modeling tank, 23 m long, and 6 m wide, with a volume of 360 m^3. A wood framework surrounds the tank and supports two decks which run the length of the tank. The decks straddle the center of the tank with 3 m separating them. A wooden trolley runs down the center of the tank on wood tracks. Targets are suspended from the trolley and moved into any position in the tank. Since the antennas remain in fixed position over the tank and the target moves, there are no background variations in these profiles which can obscure the target response. Care was taken during design and construction of the trolley to ensure that it contained no metal components below the water line. This facility is used to examine responses of small 3D-targets in a homogeneous host environment as a function of target size, position, depth, and conductivity. We collected ellipticity profiles showing anomalies for barrels, steel pipes and aluminum sheets in different orientations and at various depths.

In the second experiment we buried a 20 m long 45.7 cm diameter PVC pipe in soil. The PVC pipe is filled with water and allows us to move 3D-targets such as small sheets or steel pipes through the PVC pipe while keeping the antennas in a fixed position, comparable to the physical modeling tank. The PVC pipe has screws through the walls of the pipe which are spaced around and along the pipe to allow currents to flow between the target in the water and the surrounding soil.

In a third experiment we extend the concept of the physical modeling experiments to 3D-targets buried in soil. This experiment allows us to test the system and interpretation in heterogeneous material, to compare the responses with the results from experiments one and two, and gives us an idea of the applicability of the physical modeling in the tank or PVC-pipe. We buried several barrels and aluminum sheets in different orientations and at different depths.

We have compared the responses of several different targets used in the physical modeling experiments. As an example, the following figures show the responses of four different thin aluminum sheets in different media at 250 kHz (figure 1) and 4 MHz (figure 2). The data for the profiles over the sheets in soil were collected with a constant 4 m transmitter-receiver inline array moving perpendicular to the long side and over the center of the sheet. The model tank profile over the sheet is collected with both antennas in fixed position 4 m apart and the coordinates are converted to match the profiles over the sheets in soil. One target is a sheet 17 m long and 0.3 m wide buried 1 m deep in soil. The sheets used for the other profiles have dimensions of 5.55 m by 0.3 m and are 1 m deep in soil or in the water-filled PVC-pipe. In the modeling tank we used a 1.83 m by 0.31 m sheet at a depth of 1.03 m. The sampling interval varies for different profiles from 0.5 m to 2 m.

DISCUSSION AND CONCLUSIONS

Note the similarities in the shapes of the anomalies, independent of the background ellipticity. The peaks appear slightly shifted, which could be attributed to the relatively coarse sample interval for some of the profiles over soil. A very interesting aspect is that the size of the anomalies for the three sheets in soil are very similar for 4 MHz (figure 2), which is a frequency that is highly affected by dielectric effects. But for 250 kHz (figure 1) the size of the anomaly in the profile over the 17 m long sheet is about four times as strong as the other three. The

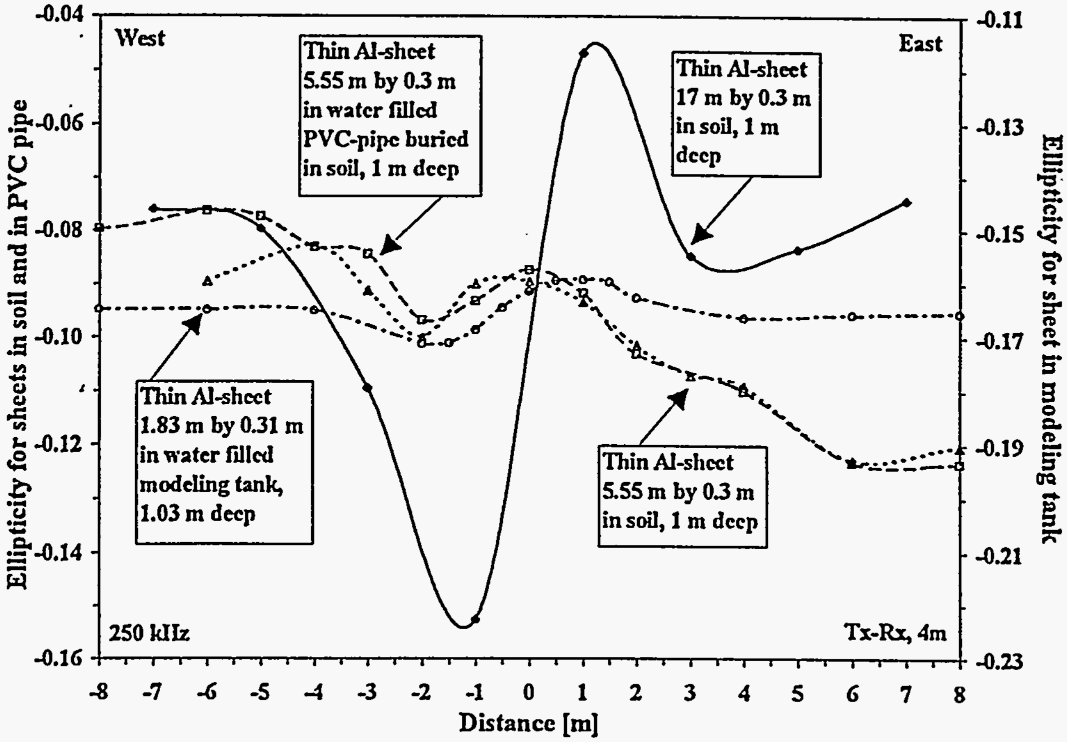

Figure 1: Ellipticity profiles over four thin aluminum sheets with different dimensions as described in text. Sheets are centered at 0 m. Data are collected at 250 kHz with an antenna separation of 4 m and the transmitter west of the receiver. Profiles are run from west to east.

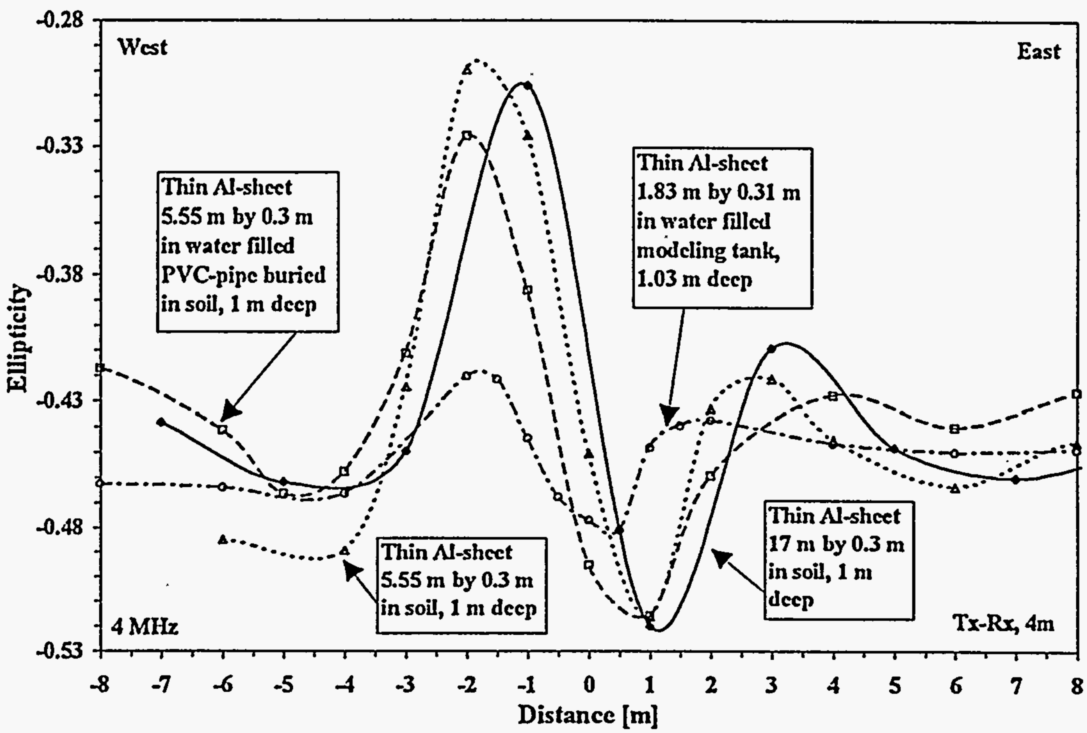

Figure 2: Ellipticity profiles over four thin aluminum sheets with different dimensions as described in text. Sheets are centered at 0 m. Data are collected at 4 MHz with an antenna separation of 4 m and the transmitter west of the receiver. Profiles are run from west to east.

other two profiles over soil are very similar in both figures, which indicates that a water filled PVC pipe can give comparable results to the same target buried in soil, but provide more flexibility for the physical modeling. The background matches so well because the PVC pipe was buried at the same location after the sheet-in-soil experiment took place. The results from the water-filled tank have a uniform background response (figure 1) which makes it easier to extract the target signature and to compare to computer models. The modeling tank seems to give comparable results for frequencies below 1 MHz, since the background ellipticity shift can be explained by different background resistivities (30 Ωm for the water in the tank and about 60 Ωm for the soil). We also observed significant effects on anomaly amplitudes as a function of sheet length for frequencies below 1 MHz. For frequencies above 1 MHz displacement currents become an important factor. The shape of the anomaly for the sheet in water is similar to those of sheets in soil but of lower overall amplitude. Sheet length does not appear to alter the amplitudes at high frequencies.

Physical modeling is an important tool in the interpretation of buried shallow 3D targets. We use physical modeling to support 3D forward modeling, especially for the high frequencies of our systems. For the lower frequencies we are able to match EM1DSH forward models with field data profiles. We are planing on using the collection of anomalies over different targets to train neural networks to detect and classify similar anomalies in field data.

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