Project Title: High-Frequency Electromagnetic Impedance Measurements for Characterization, Monitoring and Verification Efforts
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RESEARCH OBJECTIVE

Non-invasive, high-resolution imaging of the shallow subsurface is needed for delineation of buried waste, detection of unexploded ordinance, verification and monitoring of containment structures, and other environmental applications. Electromagnetic (EM) measurements at frequencies between 1 and 100 MHz are important for such applications, because the induction number of many targets is small and the ability to determine the dielectric permittivity in addition to electrical conductivity of the subsurface is possible. Earlier workers were successful in developing systems for detecting anomalous areas, but no quantifiable information was accurately determined. For high-resolution imaging, accurate measurements are necessary so the field data can be mapped into the space of the subsurface parameters. We are developing a non-invasive method for accurately mapping the electrical conductivity and dielectric permittivity of the shallow subsurface using the EM impedance approach (Frangos, 2001; Lee and Becker, 2001; Song et al., 2002). Electric and magnetic sensors are being tested in a known area against theoretical predictions, thereby insuring that the data collected with the high-frequency impedance (HFI) system will support high-resolution, multi-dimensional imaging techniques.

RESEARCH PROGRESS AND IMPLICATIONS

This report summarizes work after 2 years of a 3-year project, which in turn is a renewal of the previous one (Project ID; #60328) with the same project objectives. During the previous 3-year project, a prototype 0.1 to 30 MHz system was assembled using off-the-shelf components including a magnetic dipole transmitter, electric and magnetic antennae sensors. The system was tested at sites of different electrical properties demonstrating the proof-of-concept (Lee and Becker, 2001).

This report primarily consists of progress in the improvement of sensor qualities. The success in achieving the overall objective of the HFI system depends on the accurate field measurements, especially in the electric field. Our experience indicates that the electric field is often contaminated with stray pick-up caused by wiring attached to the antenna. We have been able to identify the main part of the pick-up by making measurements twice with reversed polarizations. The estimated pick-up is used to make a correction of each measurement. The correction is valuable in improving data quality of the existing system, but it requires repeat measurements in reversed polarizations, thereby requiring additional acquisition time. Furthermore, the correction appears to be only effective in eliminating the first-order pick-up by wires. The other spurious noise caused by the interference of protruding electronic components near the center and at the base of the receiver unit remains unchecked. To make a fundamental improvement to the existing sensor, we started redesigning the sensor by miniaturizing the electronic components and replacing all wires with optical fibers. Figure 1 shows two sensors, one the old stub antenna on the left (Figure 1-a), and the other redesigned and repackaged stub antenna on the left (Figure 1-b). All electronics components have been miniaturized and packed together and positioned at the center of the stub antenna (Figure 1-b). All communication is done via optical fibers directly attached to the central electronics box. Figure 2 illustrates electric field measurements using the old and redesigned stub antennae. Figure 2-1 shows the comparison of the electric field (dots) with the antenna in one direction and the electric field (line) with the antenna in the reversed direction. These two measurements are significantly different, especially at the high frequency end. Using these two measurements, the pick-up by the wires is numerically estimated and is used to correct measurements, and the result is shown in Figure 2-2. The corrected data compare reasonably well except for those at frequencies below 0.3 MHz and around 10 MHz. Finally, the redesigned stub antenna (Figure 1-2) was used to measure electric fields. Figure 2-3 shows fields in reversed polarizations and they match very well for all frequencies. Notice that field characteristics in Figures 2-2 and 2-3 are different because these two sensors have different calibration factors, which need to be further investigated.

The other important improvement has been the replacement of the lock-in amplifier with the HP network analyzer. This allows much wider operating bandwidth for the HFI system well beyond 100 MHz with greatly improved efficiency. With the use of the network analyzer, the separate function generator is no longer necessary either.

Figure 1. Electric field stub antennae; the old one on the left (Figure 1-a), and the other redesigned and repackaged one on the right (Figure 1-b). All electronics components have been miniaturized and packed together and positioned at the center of the stub antenna. All communication is done via optical fibers directly attached to the central electronics box.

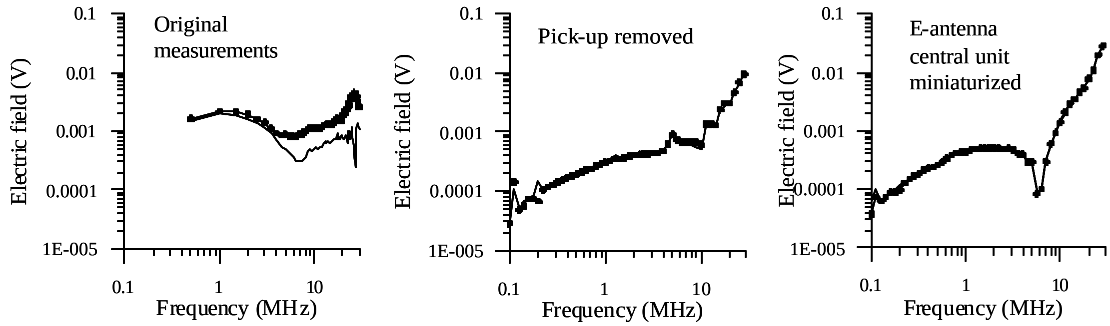

Figure 2. A comparison of electric field measurements between the old and the miniaturized stub antennae. Figure 2-1 shows electric fields measured with the old antenna in reversed polarization. After estimating the pick-up, correction is made to these measurements and the result is shown in Figure 2-2. Figure 2-3 shows the electric fields in reversed polarization using the redesigned antenna.

PLANNED ACTIVITIES

We are in the third and last year of the project. The project will be finalized by completing the following three subtasks: 1) Completion of system improvement by improving performance of the magnetic field sensor and the transmitter. Bandwidth will be expanded up to 100 MHz. EMCO magnetic loop, ARA magnetic loop, and Nanofast antanna are under consideration for this purpose. 2) A prototype HFI system will be assembled and field-tested at a site to be chosen (SRS, Idaho, or Hanford). 3) Final project report will be prepared. The report will include software for analyzing HFI field data in real time for continuously profiling the layered-structure of the resistivity and dielectric constant (moisture content).

<u>Timeline</u>

2002 ... 2003

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct

System improvement

Field demonstration

Final report

INFORMATION ACCESS

Frangos, W., 2001, High Frequency Impedance Measurements for Non-invasive Permittivity Determination, PhD Thesis, University of California, Berkeley.

Lee, K.H., and Becker, A., 2001, High frequency electromagnetic impedance measurements for characterization, monitoring and verification efforts, Interim Report, Project #60328, U.S. DOE.

Song, Y., Kim, H.J., and Lee, K.H., 2002, High-frequency EM impedance method for subsurface imaging, Geophysics, **67**, 501-510.