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 0.1 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, Tseng et al., 2003). Electric and magnetic sensors are being tested and calibrated on sea water and 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 under Project ID #73776, which in turn was 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 progresses in the improvement of sensor qualities and survey frequency band. 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-ups caused by the wiring attached to the antenna. To make a fundamental improvement to the existing sensors, we have redesigned the sensors by miniaturizing the electronics components and replacing all external wires with much compact optical fibers. The magnetic dipole transmitter was also renovated to eliminate an external power supply (power generator) and a big power amplifier. These components and related wires all cause unwanted EM scatterings. The frequency band of the system has also been expanded to 100 Mhz from the original 30 MHz. After the system revision, the stray pick-ups from the electric antenna have been minimized as illustrated in Figure 1 in which two electric field measurements have been made: one with regular

orientation and the other measured with antenna reversed in polarization. If there are no stray pick-ups from the antenna, the measured electric field amplitude should be exactly the same and phase should differ by 180 degrees. The function generator and lock-in amplifiers in the original system were replaced by a network analyzer. Now data collection is conducted in a manner of frequency sweeping and the efficiency for data collection has been increased by ten folds. Since the full waveforms of the electric and the magnetic fields are used for deriving the subsurface impedance, calibration is required to obtain the antenna factors for both electric and magnetic sensors. For the reasons of homogeneity and a known seawater conductivity of 4 S/m and a dielectric constant of 80, the calibration has been conducted in a pier in the San Francisco Bay. As shown in Figure 2, all antennas were mounted on a float made of Styrofoam and pieces of wood.

After the problem of electric pick-ups was solved, severe signal instability in the electric measurements was observed. This may be due to electronics component failure or a proximity to industrial areas near by. We had to fabricate another set of electronics for the electric sensor, with a high-pass filter incorporated to suppress noise below 100 kHz. Figure 3 demonstrated the repeatability of the ratio of electric field and magnetic field measurements (impedance, but not calibrated) over a period of one week at the Richmond Field Station, which belonged to the University of California, Berkeley. The calibration procedure is still underway repeatedly at the Richmond Field Station to obtain the correct antenna factors for all frequency that we are interested in. However, the processes are more complicated than originally anticipated. A new procedure to obtain the correct calibration for the system is under investigation. After a series of calibrations taken lately, as displayed in Figure 4, the measured impedance data matches reasonably well with a 1-D model calculation. The layered model was concluded from three resistivity soundings and a TDR (time domain reflectometer) measurement at the same location as the impedance measurement at the Richmond Field Station.

For more efficient data acquisition in the field, we have also fabricated a cart made of non-metallic material so that the antennas can be mounted on it. This is similar to the float that has been used on seawater for calibration. The whole system can be moved on land altogether without worrying about the change in separations and heights of the antennas.

Figure 1. Electric field measured with opposite polarization at the same spot. Theoretically, in the absence of stray pick-ups, the amplitude should be the same and the phase is 180 degrees different from the other polarization. Measured data is not calibrated so that the lows in electric field at about 8, 30, 60, and 90 MHz reflect the moment of the transmitter, which is not impedance-matched with the built-in amplifier.

Figure 2. Antenna calibration on seawater in a pier in the San Francisco Bay. All antennas are mounted on a float made of styrofoams and wood. At the far end of the float is the horizontal magnetic transmitter; the two antennas at the other end are the electric and the magnetic sensors, respectively. The water was about 4.5 m deep.

Figure 3. Repeatability of the impedance measurements over a period of one week. Data were taken at the Richmond Field Station with a transmitter-receiver separation of 6 m at 1 m height.

Figure 4. Comparison of impedance between theoretical 1-D layered earth (red lines) and calibrated field data (green dots) at Richmond Field Station. Transmitter-receiver separation was 6m, at a height of 1m.

PLANNED ACTIVITIES

We plan to finalize the project by completing the following three subtasks: 1) A more accurate calibration procedures for the electric sensor will be established. 2) The prototype HFI system will be field-tested at a site to be chosen. 3) Final project report will be prepared in the form of conference or journal paper.

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.
- Tseng, H.-W., Lee, K. H., and Becker, A., 2003, A high frequency electromagnetic impedance imaging system: Proceedings, Symposium on the Application of Geophysics to Engineering and Environmental Problems, 534-540.