Project ID: **60328**

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 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 imaging the electrical conductivity and dielectric permittivity of the shallow subsurface using the plane wave impedance approach. 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

Following the initial sensor verification done last year for the frequency range of up to a few MHz, the project moved on to a wider portion of the radio spectrum up to 30 MHz during FY99. Unlike at lower frequencies, this step required development of a transmitter system in order to have signal at specified frequencies. Additionally, we have refined the behavior of the toroid sensor. A report was published (Frangos and Becker, 1998) concerning the magnetic fields of AM radio broadcast stations as measured at the Richmond Field Station.

Transmitter System: We acquired a function generator good to 30 MHz and an amplifier with a bandwidth of 250 kHz through 110 MHz. We also built and tested an electric transmitter antenna capable of acting as an electrically short dipole through at least 30 MHz. A magnetic (loop) antenna has also been built but is not yet satisfactorily characterized. Additionally, we purchased two more lock-in amplifiers (the basic measurement instrument) and set up a digital data acquisition system that operates under control of a notebook computer through a GPIB interface.

Field Measurements: Measurements were made at the Richmond Field Station (RFS), University of California at Berkeley. The observed electric field components of the transmitter antenna operated in vertical mode compare well with calculated values, except for some discrepancies at the higher frequencies. These are due to deviations in the assumed transmitter current, and to stray pickup on the coax leads between the sensors and the instruments. The resulting impedance (E_x/H_y), however, evens out some of the irregularities due to errors in estimation of the source current. Indeed, this very independence of the transmitter characteristics is the reason for using impedance measurements in the first place. The measured impedance shows good agreement with calculated

values through 10 MHz. Determining the electric and magnetic fields independently, however, is important because it is the only way one may identify probable sources of errors in the eventual impedance measurement. So, we are presently attempting to reduce the observational errors as much as possible.

Toroid Electric Field Sensor: Improvements in the shielding and extraneous pickup problems with the prototype toroid have lead to an improved response spectrum shown in Figure 1.

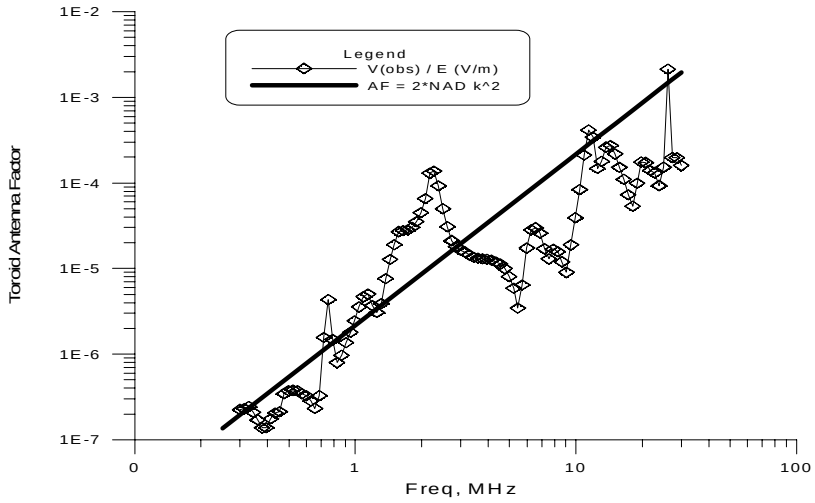

Figure 1: Measured (diamonds) and calculated (solid line) response spectra for the toroid antenna

Theoretical Developments: **1)** A reconsideration of the toroid electric field sensor response function using analytic forms rather than the discrete approximation previously employed (Lee, 1997) indicates that the antenna factor is twice the previous value. **2)** A functional comparison between the stub and toroid sensors has been made. The longest dimension of each sensor is 5 cm and the toroid is presumed to have an air core. The toroid has a weaker sensitivity at all but the highest frequencies and a higher source-impedance in the higher portion of the spectrum. **3)** An inversion scheme for layered earth (1-D) has been developed. For a given number of layers, parameters to be inverted are the electrical resistivity, permittivity (dielectric constant), and the layer thickness. Currently we have been successful in dealing with a three-layered earth.

PLANNED ACTIVITIES

Future research will focus on cleaning up the signal measured by the stub dipoles and loop antenna through optical isolation and better signal conditioning. We will also investigate the phase calibration and stability of the system. We shall consider enhancing the toroid response amplitude through the use of a high-frequency ferrite core. An overall evaluation of the feasibility of the high-frequency impedance methods will be made as part of the final project report to DOE and end users.

INFORMATION ACCESS

Frangos, W. and Becker, A., 1998, Magnetic fields of AM band radio broadcast signals at the Richmond Field Station, Lawrence Berkeley National Lab Report LBNL-42654.

Lee, K.H., 1997, High-frequency electric field measurement using a toroidal antenna, Lawrence Berkeley National Lab Report LBNL-39894, UC-2040.