Environmental Management Science Program

Project ID Number 60328

High Frequency Electromagnetic Impedance Measurements for Characterization, Monitoring and Verification Efforts

Ki Ha Lee
Lawrence Berkeley National Laboratory
MS 90-1116
1 Cyclotron Road
Berkeley, California 94720
Phone: 510-486-7468
E-mail: KHLee@lbl.gov

Alex Becker
University of California
Berkeley, California 94720
Phone: 510-643-9182
E-mail: alexb@violet.berkeley.edu

Louise Pellerin
Lawrence Berkeley National Laboratory
MS 90-1116
1 Cyclotron Road
Berkeley, California 94720
Phone: 510-486-5026
E-mail: lpellerin@lbl.gov

June 1, 1998

60328

High Frequency Electromagnetic Impedance Measurements for Characterization, Monitoring and Verification Efforts

Ki Ha Lee, Lawrence Berkeley National Laboratory

Alex Becker, University of California
Louise Pellerin, Lawrence Berkeley National Laboratory

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 due, 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, known as the magnetotelluric (MT) method at low frequencies. 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

The summary of the work to date is divided into three sections: equipment procurement, instrumentation, and theoretical developments. For most earth materials, the frequency range from 1 to 100 MHz encompasses a very difficult transition zone between the wave propagation of displacement currents and the diffusive behavior of conduction currents. Test equipment, such as signal generators and amplifiers, does not cover the entire range except at great expense. Hence we have divided the range of investigation into three sub-ranges: 1-10 MHz, 10-30 MHz, and 30-100 MHz. Results to date are in the lowest frequency range of 1-10 MHz. Even though conduction currents dominate in this range, as in traditional electromagnetic exploration methods, little work has been done by the geophysical community above 500 kHz.

Equipment Procurement: Test equipment for our frequency sub-ranges can be very expensive and specialized, hence we are borrowing equipment whenever possible. The magnetic field sensors and a vector signal analyzer, providing 2 channels of data acquisition in addition to a reference signal, purchased as a part of the VETEM project, were borrowed from the DOE Grand Junction Project Office. We are borrowing power amplifiers from Lawrence Livermore National Lab. As a part of the EMSP funding we have acquired two lock-in amplifiers and a PC computer with GPIB software, for data acquisition. We currently have the capability to generate a transmitter signal and amplify and measure two output signals in the 1-10 MHz range.

Instrumentation: The magnetic field sensors, two EMCO Model 6507 loop antennae designed to function accurately to 30 MHz, were tested in the 1-10 MHz range, and we concluded that measurements to 10 MHz (and probably 30 MHz) can be made reliably with commercially available sensors.

Three electrical field sensors - a toroid, stub, and capacitively coupled antennae were tested. A small toroid was fabricated, but because of the size and relatively low frequency (1-10 MHz) a strong signal was needed to excite the sensor. Initial tests in a 60-100 volts/m source field correspond roughly with predicted responses. A larger toroid, with greater sensitivity, will be used for future testing. A modification to the initial design canceled the emf caused by an axial magnetic field component. Electronics needed for minimal amplification are being added to the toroid and the cable length is being shortened to minimized secondary responses.

Two ARA stub dipole antennae, designed to be used outside the influence of the earth, were acquired. Preliminary results of measured responses did not agree with the predicted response. After taking into account the radiation pattern of an imperfect conductor (the earth) and the reciprocity principle, we have been able to match the theoretical and the field response. A prototype capacitive antennae was deployed and when teamed with the EMCO magnetic field measurements, results match well with that determined from other data.

Theoretical Developments: The one-dimensional numerical investigating of approaches to compensate for the non-vertical propagation of the fields and effective parameterization of the data is complete. Measurements of the electric field at two locations simultaneously are necessary to estimate the horizontal component of the wavenumber due to non-vertical propagation. Traditional parameterization of MT data, expressed as apparent resistivity and phase, did not appear to be suitable at high frequency due to multiple reflections in any resistive layers. Data inversion seems to be a more accurate method with which to present the data.

Planned Activities

Work will continue on the analysis of the antennae through higher frequencies, and the development of the three-dimensional (3D) HFI analysis package through the rest of the FY98. A finite difference code, a finite element code and a high frequency thin sheet solution are being tested for use in the 3D analysis. The specifications for the HFI system are being written as the sensors are being tested.