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Enhancements to and Characterization of the Very Early Time Electromagnetic (VETEM) Prototype Instrument and Applications to Shallow Subsurface Imaging at Sites in the DOE Complex

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Research Objective

The objective of this project is to enhance the state-of-the-art of electromagnetic imaging of the shallow (0 to 5 m) subsurface in electrically conductive media where ground penetrating radar (GPR) provides insufficient penetration and time domain electromagnetic (TEM) systems provide insufficient resolution. This objective is being pursued by instrumentation enhancements to the existing very early time electromagnetic (VETEM) system coupled with physical and numerical modeling. Success in this endeavor will improve the speed and accuracy of waste pit and trench location and characterization, and could have additional applications to shallow DNAPL and LNAPL spill and cleanup monitoring, clay cap integrity assessment, and landfill stabilization monitoring. This could result in significant savings in time and money during characterization, remediation, and decommissioning of facilities.

Research Progress and Implications

This report summarizes accomplishments after 8 months of a three-year project. We have focused mainly on instrumentation and numerical modeling during this time.

Examination of data recorded with the VETEM system, as it existed in 1995, showed very encouraging response to relatively shallow buried conducting targets, but also showed a need for improved response to shallow dielectric (non-conducting) objects and also for greater depth of investigation for conducting objects. The need for numerical and physical modeling to optimize system design and to enable better interpretation of data was also clear.

To address the need for better response to shallow buried dielectric objects, we have designed, built, and laboratory tested a new transmitter that puts out several times more current (> 5 A as compared to ~ 1 A for the existing transmitter) with a much shorter risetime (~ 3 ns as compared to ~ 20 ns fall time for the existing transmitter). This transmitter is ready for field tests, but we anticipate that we may require new antennas (both magnetic loop and electric dipole) to achieve the best results from this transmitter.

The need for deeper penetration was addressed by the design and construction of another transmitter that can drive up to 30 A into a new larger loop antenna. The current rises almost linearly at a rate of about 6 A per microsecond and has a fall time of about 120 ns. The 30 A transmitter has been mated to a new magnetic loop antenna with 10 times the area of the original antennas. A similar larger receiving antenna has been constructed. This new transmitter/antenna combination is ready for field tests.

We now have three distinctly different transmitters and two sets of loop antennas with a factor of 10 difference in area between the two sets. Both sets are single-turn to minimize inductance.

Another factor in depth of penetration is the separation between the transmitting and receiving antennas. The original antenna cart limited this separation to a 2 m maximum. We have designed and built a new cart that will permit separations of more than 4 m. In addition, the new cart is stiffer than the old one to reduce any potential of errors caused by changes in relative antenna alignment.

Construction of non-metallic materials has been retained. The new cart will be ready for the July, 1998 field tests.

In order to transport the new antenna cart, a trailer large enough to carry it is necessary. This trailer has been obtained and is currently being equipped to transport VETEM and other geophysical equipment, and for use as a mobile remote site in-the-field data processing facility. It will be ready for the July, 1998 field tests.

To improve signal-to-noise performance and to allow better potential for technology transfer, a commercial digitizer/signal averager has been selected and ordered. It is not clear whether delivery will be in time for anticipated field tests in July, 1998. This unit will replace one built by the USGS that uses high speed memory chips that are no longer readily available. The USGS system remains as a back-up.

In order to take full advantage of the new transmitters and antennas, a new receiver will be required with programmable bandwidth, and greater dynamic range. A laboratory prototype has been built and is being evaluated, but a field worthy version will not be available in time for the July, 1998 field tests. We will use the existing receiver.

An outdoor buried object geophysical test range suitable for VETEM, GPR, and EM system calibration and physical modeling is planned for the Denver Federal Center. A proposal has been submitted to the General Services Administration for approval.

Numerical modeling of the effects of buried dielectric and conducting objects has been done using a scattering formulation and method of moments solution requiring the evaluation of large numbers of Sommerfeld integrals. In order to make such an approach practical at high frequencies, fast evaluation of Sommerfeld integrals is essential. The very fast leading-order approximation method has been generalized in this work to allow lossy (conductive) as well as lossless cases. The results were applied to calculate primary, reflected, and scattered fields from a buried dielectric cuboid and a conducting plate.

The results of the numerical modeling show that the scattered field from the conducting plate is greater in amplitude and distinctively different in shape than the scattered field from the dielectric cuboid. The numerical modeling also demonstrated the orders of magnitude difference in amplitude between primary and scattered fields. This is also observed in field data and demonstrates the need for a receiver with extremely wide dynamic range, as we had anticipated

Planned Activities

The next major activity will be field tests at the Idaho National Environmental and Engineering Laboratory (INEEL) currently scheduled for the second and third week of July, 1998. It is an objective to rerun many of the same lines that were run as part of the Electromagnetics Integrated Demonstration (EMID) in 1995 at the Cold Test Pit to help us assess the relative performance of the new antennas and transmitters over the same targets. We anticipate running at new sites as well. Assessments of these results will help guide our activities during the second and third years of this work. We anticipate that the emphasis will gradually shift to numerical modeling, data processing, interpretation, and visualization during the final two years, although improvements to the instrumentation will continue.

Other Access To Information

Reports and papers produced as part of the present work are:

- Cui, T.J., and W.C. Chew, Efficient evaluation of Sommerfeld integrals for TM wave scattering by buried objects, J. Electromagnetic Wave Appl., Vol. 12, pp.607-657, 1998.
- Cui, T.J., and W.C. Chew, Efficient method for the near-field detection of buried dielectric and conducting objects, Research Report, Electromagnetic Laboratory, University of Illinois at Urbana-Champaign, 1998.
- Cui, T.J., and W.C. Chew, Fast evaluation of Sommerfeld integrals for EM wave scattering and radiation by three-dimensional buried objects, Technical Report, Electromagnetic Laboratory, University of Illinois at Urbana-Champaign, 1998.
- Wright, D.L., Cui, T.J., and Chew, W.C., Progress on the very early time electromagnetic (VETEM) system, Proc. of the Seventh International Conference on Ground-Penetrating Radar (GPR'98), May 27-30, 1998, Lawrence, Kansas, (in press).

Additional information may be found in the References contained in the above papers and reports.