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EXPEDITED SITE CHARACTERIZATION GEOPHYSICS

GEOPHYSICAL METHODS AND TOOLS FOR SITE CHARACTERIZATION

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INTRODUCTION

PURPOSE AND GOAL OF THE PROJECT

Expedited Site Characterization (ESC) is a project now being conducted by Ames Laboratory for the Department of Energy (DOE), Office of Technology Development (OTD). Its purpose is to speed the adoption of innovative, state-of-the-art environmental characterization technologies within DOE. The goal of this effort is to reduce restoration costs by decreasing the time required to acquire, process, interpret, and synthesize the chemical and hydrogeologic data needed to characterize a site. Ames Laboratory will conduct field testing at a number of contaminated sites in the Midwest during FY94 and FY95. The sites include those containing volatile organic compounds (VOCs), heavy metals, and radiological species in the subsurface.

The main value of geophysics to the ESC project is the ability to locate underground sources of contaminants (e.g., leaking drums or underground storage tanks), to help map conductive or energy-reflective contaminant plumes from leaking vessels, and to help map local hydrogeologic features such as fracture zones.

ABOUT THIS REPORT

WHAT THIS REPORT COVERS

Methods and Instruments for Field Testing

This report describes nonintrusive or minimally intrusive surface geophysical methods and specific instruments that could be considered for field testing during the ESC project, including their supporting software. For each geophysical method, several competing instrument systems are commercially available for purchase or rental. Some of these were introduced in the last 12 months; because they are new, they are not supported by field case-history papers. Most, however, are proven technologies that have been in use for mining exploration and engineering applications. More recently, they have been used at environmentally impaired sites, including DOE Integrated Demonstration Sites, and have been upgraded over time through the design of better field hardware and improved software. Both new and proven instrument systems are discussed in this report, but we did not include emerging technologies being funded through other OTD programs.

ABOUT THIS REPORT *(cont'd)*

Geophysical Technologies

This report covers five classes of geophysical technologies:

- Magnetics
- Electrical/electromagnetic
- Seismic reflection
- Gamma-ray spectrometry
- Metal-specific spectrometry.

Except for radiometry, no other classes of geophysical technologies are specific for direct detection of the types of contaminants present at the selected sites.

For each of the five classes covered, the report gives a general description of the methodology, its field use, and its general applicability to the ESC Project. In addition, the report gives a sample of the most promising instruments available for each class, including the following information:

- Hardware/software attributes
- Purchase and rental costs
- Survey rate and operating costs
- Other applicable information based on case history and field evaluations.

INFORMATION SOURCES

The sources of information used to compile this report include published case histories, technique evaluation reports, and manufacturers' sales literature. Brochures and price lists from a number of manufacturers are attached. The author apologizes for any errors or omissions that might result in inaccurate or incomplete descriptions of instruments or software.

MAGNETICS

DESCRIPTION

APPLICATIONS AND LIMITATIONS

Magnetics is a rapid, reliable technique for locating buried steel drums, tanks, and other iron and steel objects in landfills. Man-made ferromagnetic items possess two types of magnetization: a component induced by the earth's field (the induced component) and a permanent component acquired during manufacture. The permanent component may be several times larger than the induced component, and, among similar objects, it often varies in both direction and intensity. For this reason, tanks can yield both positive and negative magnetic anomalies, the latter if the steel contains a strong reverse magnetization (Schutts and Nicholls, 1991).

Interference by Noise

Field tests indicate that a single 55-gallon drum (a convenient unit to quantify magnetic detection) shallower than 3 m should produce a magnetic field disturbance large enough to be detected by a magnetometer or a vertical gradiometer.[1] However, the presence of noise, both natural and man-made, produces false anomalies and obscures the anomalies sought.

Geological Noise

Geological noise is not a serious problem in the sedimentary rock environments of the midwestern U.S. but could become a problem in areas of volcanic rocks. However, the size of the signals from tanks and drums at shallow burial depths are apt to be large, 500 to 4000 nT (Schutts and Nichols, 1991), and therefore much larger than most geological noise effects.

Cultural Noise

Noise from industrial activities, such as railroads and steel buildings, is a more common and serious problem. Surface noise sources would limit the ability to detect small buried objects but can be effectively reduced. Reduction is achieved by making vertical

[1]A magnetic gradiometer consists of two identical sensors spaced roughly one meter apart and carried on a rigid staff. The output is the difference in the magnetic fields at the two locations, thus nulling all fields the locations have in common, such as the natural time-varying field.

DESCRIPTION *(cont'd)*

gradient measurements using a two-sensor gradiometer to suppress distant noise sources off to one side. However, gradient measurements also reduce the size of the anomaly sought, hence the depth at which a buried ferromagnetic object can be detected. For example, field experiments at the Stanford University test site indicate that the probability of detecting and locating drums deeper than 3 m below the surface with a gradiometer is not high. On the other hand, Geometrics, a manufacturer of tools for site characterization, claims detection at depths of up to 9 m with a single sensor over nonmagnetic soils.

Drum Count Limitation

In the absence of cultural noise, magnetics provides good lateral resolution of buried sources and an approximate estimate of source depth, but only a rough estimate of the number of drums present. The factor limiting the accuracy of the drum count is that all drums have a permanent magnetization (or remanence) with direction and intensity that varies from drum to drum. As a result, the apparent dipole moment from a collection of drums, whether stacked or dumped randomly into a burial pit, may not provide a good estimate of the number of drums present.

DATA ANALYSIS METHOD

If the magnetic data are collected as continuous profiles or as a set of closely-spaced individual readings of field and vertical gradient, Euler deconvolution is a quasi-automatic method for picking the location and estimating the depth of ferromagnetic sources. A commercial software package called GRIDEPTH (Geosoft Inc., Toronto, Canada) is available to perform Euler deconvolution.

INSTRUMENTATION AVAILABLE

ENVI-MAG ENVIRONMENTAL MAGNETOMETER/ GRADIOMETER SYSTEM

This system features one of the newest proton-precession-type magnetometers to be developed specifically for rapid ground surveys. The device measures the scalar total magnetic field and/or its vertical gradient. Because proton-precession-type magnetometers are not vector instruments like flux-gate magnetometers, this device requires no orientation. It is manufactured by Scintrex, Concord, Ontario, Canada.

Software Support

PC-compatible software is included to download data to a PC. A variety of software is available at extra cost for interpretation and contouring.

INSTRUMENTATION AVAILABLE *(cont'd)*

Cost/Rental Information

Purchase

Item	Price
Gradiometer system	$6,995
Magnetometer only	5,450
Upgrade to a simultaneous gradiometer	1,620

Rental

Item	Price
Gradiometer system	$1,000/mo*
Magnetometer only	850/mo*

*Plus base charge of approximately $180.

Survey Rate

The operator can select sampling rates from the basic 2-s charging time (0.1-nT accuracy) to the faster 0.5-s charging time (5-nT sensitivity). Other features include:

- "Walking-mag" feature for rapid reconnaissance
- Ability to plot profiles on an LCD display
- Internal storage capacity for 28,000 readings, expandable to 200,000 readings.

One person could collect over 1000 station readings per day. At current labor rates, the cost per data point would amount to roughly $1 to $2, excluding costs to establish a station grid. Full data-acquisition cost, including transportation, equipment, supervision, and daily subsistence, is likely to add 100%, bringing the total cost per data point up to $2 to $3.

PORTABLE GRADIOMETER MODEL G-856AG

Manufactured by Geometrics of Sunnyvale, CA, this instrument is the gradiometer version of the **G-856A** proton-precession magnetometer. The receiver stores up to 2850 pairs of gradiometer readings.

INSTRUMENTATION AVAILABLE *(cont'd)*

Gradiometer sensitivity is 0.10 nT/m when a 0.9-m (3-foot) separation between sensors is used. The gradiometer may be configured in any direction, but a vertical gradiometer is the preferred orientation.

Software Support

A free software package provides automatic diurnal correction, averaging, filtering, profiling, contouring, and modeling of total field or gradient data.

Cost/Rental Information

Purchase

The purchase prices is $4950 for the magnetometer plus $1620 for the gradiometer option.

Rental

The standard rental rate is 0.5% of purchase price per day plus 1% of price for mobilization.

Survey Rate

This instrument does not have the "walking mag" feature of the Scintrex ENVI-MAG. Consequently, the operator must stop longer at each station to take readings, and therefore the survey rate is slightly lower than that for the Scintrex ENVI-MAG.

Case History Information

Schutt and Nichols (1991) give a good case history for the G-856A at an industrial site in South Carolina, where the instrument was used with electromagnetic surveying devices to map over 4572 m (15,000 feet) of pipe and over 100 tanks ranging in size from 1.04 to 378 m^3 (275 to 100,000 gallons).

CESIUM MAGNETOMETER (MODEL G-822L)

To our knowledge Geometrics, Sunnyvale, CA, is the only company still manufacturing a cesium magnetometer for ground searches. This device is the commercial equivalent of a detection system developed as part of the company's military ordnance detection project. It provides a sensitivity of 0.1 nT with a heading error of ± 1 nT.

INSTRUMENTATION AVAILABLE *(cont'd)*

Software Support

The console has a 5-digit display and an RS-232 output link so that individual readings may be transferred to a small PC that can be carried by the operator. Geometrics provides software to handle the data-logging process, including profiling and contouring the corrected data.

Cost/Rental Information

Purchase

The purchase price is $14,500 for the magnetometer plus $3285 for the portable data-acquisition system, which includes the MAGLOC processing software package.

Rental

The system can be rented for $89/day plus a $178 mobilization fee. Shipping and insurance are extra.

Survey Rate

The relatively small, lightweight, battery-powered unit is designed for rapid surveying. Geometrics reports on a test survey where the G-822L with its RS-232 interface took 2660 readings over an area of 1600 m^2 in 30 minutes. Readings were taken at intervals of 0.15 m along lines 4 m apart. The survey rate reduced the survey time by 75% compared to a previous survey with the Geometrics G-856AX proton-precession Memory-Mag®, but because the two surveys were not run in identical fashion, it would be hard to make a fair comparison.

Application to the ESC

For standard ground surveys, this type of magnetometer or gradiometer probably has some speed and sensitivity advantages over proton-precession types, but these qualities have to be weighed against a much higher equipment cost.

SURFACE-TOWED ORDNANCE LOCATOR SYSTEM (STOLS)

In a recent development, Geo-Centers, Inc., Newton, MA, has developed the STOLS with funding from the Naval Research Laboratory and some assistance from Sandia National Laboratories and the Army

INSTRUMENTATION AVAILABLE *(cont'd)*

Environmental Center. The system employs an array of seven cesium magnetometers. It is mounted on an off-road vehicle and comes complete with computer-controlled data-acquisition, data-processing, and global-positioning systems. Moving at a speed of 5.6 to 8.0 km/h, the vehicle can map 0.10 to 0.14 km^2/day (25 to to 35 acres/day), according to sales information. The cost per 0.004 km^2 (1 acre) for this system is approximately $2230, assuming an average rate of 0.05 km^2/day (12.5 acres/day). STOLS was tested by Sandia at the Mixed Waste Landfill Integrated Demonstration in 1993.

Because the vehicle-driven system is applicable to large open areas, Geo-Centers is presently attempting to commercialize a hand-held/man-portable version of the system (Beers, 1993).

RAPID GEOPHYSICAL SURVEYOR

The Rapid Geophysical Surveyor (RGS) is an automated magnetic gradiometer system developed by INEL in 1992 under the Buried Waste Integrated Demonstration Program. The RGS is now being commercialized by Sage Earth Sciences Company, Idaho Falls, Idaho. The System consists of a flux-gate vertical gradiometer mounted on a one-wheeled vehicle that can be hand-pushed. Positioning information is recorded via wheel rotation. In demonstrations, the RGS collected magnetic data at a maximum rate of 25,000 points per hour, or 30 to 300 times faster than a conventional hand-held gradiometer (DOE, 1993).

REFERENCES

Beers, R.H., 1993, "Cleaning up with STOLS," *The Military Engineer*, Sept.–Oct., pp. 68–69.

DOE-ID, 1993, Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference: ID-121213.

EG&G Geometrics Sales Brochure, no date.

Schutts, L.D., and D.G. Nichols, 1991, "Surface Geophysical Definition of Groundwater Contamination and Buried Waste: Case Studies of Electrical Conductivity and Magnetic Applications," in *Proceedings of the 5th National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods*, May 13–16, 1991, Las Vegas, NV (Dublin, OH, Water Well Journal Publishing Co., 1991), pp. 889–903.

ELECTRICAL/ELECTROMAGNETIC METHODS

DESCRIPTION

APPLICATIONS

The E/EM methods and instruments discussed in this section are used for a variety of reasons:

1. To map the electrical conductivity of the ground and detect anomalous conductors,
2. To detect magnetic objects, or
3. To detect voltage variations on the surface related to fluid flow and chemical conditions near the surface.

A combination of methods—magnetic and E/EM—would be needed to differentiate between conductivity anomalies caused by metallic storage containers and the adjacent or subjacent zones of leaking contaminants.

E/EM methods have been used in many environmental site characterization applications:

- Mapping variations in soil conductivity
- Mapping depths to bedrock or groundwater
- Detecting buried man-made conductive and magnetic objects
- Mapping conductive contaminant plumes such as acid mine drainage
- Detecting fiberglass tanks filled with corrosive liquids with high conductivity
- Mapping resistive contaminant plumes such as leaking organic fluids
- Mapping geologic contacts and discontinuities such as buried fluvial channels.

Unique to the self-potential method are three other applications:

- Detection of chemical corrosion of buried drums
- Detection of leaking dams and ponds
- Detection of liquid and gaseous hydrocarbon flows.

DESCRIPTION *(cont'd)*

For all E/EM techniques, the questions of survey rate, equipment and operating costs, depth of investigation, reliability and interpretability of results are extremely important to expedited site characterization.

CONVENTIONAL CLASSIFICATION OF E/EM METHODS

Inductive Methods

Inductive methods require minimal contact with the ground. Eddy currents are induced by creating a time-varying electromagnetic field by using a loop antenna or a grounded electric dipole, the former being the standard for site characterization work. The earth response is measured by means of a second loop antenna connected to an amplifier/receiver.

Inductive methods tend to be more rapid than conductive methods and safer to apply where soils are contaminated. One disadvantage of inductive methods is that inductive-coupling noise sources arise from human activities in most industrial sites, e.g., grounded steel fences, underground utilities, railroad tracks, buildings.

Inductive methods fall into two categories: those that obtain data at one or more narrow-band frequencies (the frequency-domain or FEM instruments) and those that obtain broadband information by detecting eddy-current decay in the earth after the rapid termination of a current pulse in a transmitter loop (the time-domain or TEM instruments). The more rapidly one is able to measure current decay in the earth after current "shut-off" in the transmitter loop, the greater will be the resolution of shallow conductivity effects.

FEM Instruments

FEM instruments, such as simple metal or ordnance detectors, are used primarily to search for shallow conductors and magnetic objects. These instruments have tremendous application when rapid profiling and simple, lightweight instrumentation are the prime requirements. FEM systems consist of a pair of small ferrite-core loops. Their circuitry is tuned to one or several operating frequencies, and they yield measurements in terms of the in-phase and/or quadrature amplitudes or phase difference between current in the transmitter loop and voltage detected. A precise geometrical relation between the loops must be maintained to get meaningful readings.

DESCRIPTION *(cont'd)*

TEM Instruments

TEM instruments are used primarily when it is necessary to obtain a more complete 3-D mapping of the subsurface conductivity distribution, but when speed of operation is not a prime requirement. For TEM readings, the control of loop orientation need not be as strict as for FEM readings.

Transmitter-Detector Configurations

TEM and FEM employ a variety of transmitter-detector configurations; the three most common configurations are:

- Coaxial, coplanar, horizontal transmitter and detector loops (the central-loop mode)
- Coplanar horizontal loops a fixed offset distance apart (the Slingram mode)
- A long grounded electric dipole or large loop transmitter far outside the area of interest and fixed in position (the Turam mode).

Except for Turam, which is normally employed for its greater depth of investigation, all configurations require that the transmitter and detector move in tandem to each new measuring position.

The depth of investigation depends on frequency and loop separation, larger depths requiring lower frequencies and larger loop separations but at the loss of near-surface resolution. A wide-enough bandwidth is therefore necessary to achieve a balance between resolution and adequate depth of investigation.

Reference

MacLean (1992) evaluated 19 commercially available inductive EM ground systems in terms of their applicability for waste site characterization, and his report gives an excellent overview of the technology. Only a sampling of the more promising techniques for expedited site characterization is discussed in the following sections.

MacLean, H.D., 1992, *Commercially Available Broadband Electromagnetic Systems for U.S. Department of Energy Waste-Site Characterization*, Chem-Nuclear Geotech, Inc., U.S. DOE, Grand Junction Projects Office, Grand Junction, CO, GJPO-GP-2, 29 pp. plus a 49-page appendix.

DESCRIPTION *(cont'd)*

Conductive Methods

Conductive methods require the insertion of time-varying currents directly into the ground by means of a pair of electrodes and the measurement of the resulting voltages across other pairs of electrodes. The electrodes are laid out in one of several standard arrays to simplify data acquisition, and the electrode array is moved over the area of interest. Such methods include dc resistivity, induced polarization, and spectral resistivity. Because depth of investigation for induced polarization/resistivity depends on inter-electrode separation and ground conductivities, these techniques have good sensitivity in shallow conditions when used with tightly-spaced electrode arrays. Their disadvantages are:

- They cannot be used easily in paved areas.
- They sometimes require much moving of wires, cables, or electrodes.
- Decontamination procedures may have to be followed in areas of contaminated soil.

Conductive methods include:

- Simple resistivity in which ground resistivity, expressed in terms of an apparent resistivity (ρ_a), is measured at a single frequency close to dc
- Induced polarization in which a frequency-varying ρ_a is measured over a limited range of frequencies from nearly dc to several Hz
- Spectral resistivity in which ρ_a is measured over a broad bandwidth of up to 1 kHz.

As a rough rule of thumb, depth of investigation for in-line electrode arrays is less than about 0.15 times the distance between current electrodes. Thus, to achieve a nominal depth of investigation of 30 m, current electrodes have to be separated by more than 200 m.

TIME-DOMAIN ELECTRO-MAGNETICS

INSTRUMENTATION AVAILABLE

PROTEM II System

This system has been used for geotechnical work for several years. It is one of a series of PROTEM systems manufactured by Geonics Ltd., Mississauga, Ontario, Canada, employing this company's lightweight PROTEM 57 receiver. The system's major feature is its relative light weight and low cost.

TIME-DOMAIN ELECTRO-MAGNETICS *(cont'd)*

The system consists of the PROTEM 57 receiver and the TEM47 transmitter. The transmitter delivers 2 A into a 40-m single-turn loop and has a turn-off time of 2.5 µs. The eddy current decay is measured at 20 logarithmically spaced gates covering the time range of 6 µs to 80 µs after current turn-off and at 20 additional time gates (or data channels as they are often called) from 80 µs to 8 ms. Under these conditions, the depth of investigation ranges from a few meters (5 according to the manufacturer's spec sheets) to over 100 m below the surface.

The 5-m, eight-turn transmitter loop Geonics provides is preferable for most site characterization applications because it is easier to use in tight, constricted areas. However, because of its higher inductance, this loop has a longer turn-off time and is therefore less able to provide the very early time information needed to resolve near-surface conditions.

Software Support

TEMIX Plus from Interpex, Golden, CO, accepts PROTEM data. It computes both foward and inverse 1-D models and produces a 1-D layered model plot (up to five layers) along each profile. This code requires a 386 PC or later with a math coprocessor. Geonics provides standard PC display software that allows the user to plot profiles of the data channels. These "stacked" profiles are useful for detecting individual conductive features, such as edges of pits or buried tanks.

Cost/Rental Information

Purchase

The basic PROTEM II System costs $36,510.

Rental

Rental of the system directly from Geonics or from one of its distributors is possible at a cost of around 0.5 % of the purchase price per week, plus shipping.

Survey Rate

Typical of TEM soundings, data acquisition tends to be cumbersome and slow because it is necessary to move transmitter and receiver loops for each station reading and because each reading requires several minutes for stacking and averaging up to 1000 decay curves. The survey rate could be doubled by using multiple detector coils, e.g., one on each side

TIME-DOMAIN ELECTRO-MAGNETICS *(cont'd)*

of the transmitter coil. Costs are roughly $400 to $500 per profile with a three-man crew. Daily production was 200 stations with a separation of 2 m. A data logger is built into the PROTEM 57 receiver.

Using a 1-m-diameter air-core detector loop, one can also measure the horizontal components of the decay field in addition to the vertical component. This procedure would increase survey time, but if used selectively, could help resolve the depth and location of individual conductors.

Case History Information

Mac Lean, H.D., 1993, *Time Domain Electromagnetic Survey of Three Waste Burial Pits at INEL Radioactive Waste Management Complex,* Preliminary Report: TTP AL 911201-G2, Chem-Nuclear Geotech, Inc., U.S. DOE, Grand Junction Projects Office, GJPO-GP-5, 23 pp. plus appendices.

Applicability to the ESC Project

One of the drawbacks of this system is that important information in the uppermost 5 m cannot be resolved. A second drawback, common to all time-domain electromagnetic systems, is that they are relatively complex, and field surveys are best done by a trained crew. For this reason, we recommend that a qualified geophysical service contractor be hired to provide both equipment and crew.

General References

Hoekstra, P., R. Lahti, J. Hild, C.R. Bates, and D. Phillips, 1992, "Case Histories of Shallow Time-Domain Electromagnetics in Environmental Site Assessment," *Groundwater Monitoring Research,* Fall, pp. 110–117.

NT-20 TEM System

The NT-20 TEM system, manufactured by Zonge Engineering and Research Organization, Tucson, AZ, consists of the NanoTEM TEM transmitter which drives a loop on the ground. Decay fields are detected by means of a smaller coaxial horizontal loop, and the signal voltages are input to the digital, broadband GDP-16/3 receiver. Normally, over 100 decay signals are stacked and averaged to reduce noise. The actual number of data stacks needed may be determined by monitoring error-bar information displayed on the console.

TIME-DOMAIN ELECTRO-MAGNETICS *(cont'd)*

A feature of this new transmitter is that it is engineered to drive loops 5, 10, 20, 50, and 100 m in diameter. Because dipole moment increases linearly with loop area, the larger the loop area, the greater the depth of investigation. For the shallow exploration typical of most site characterizations or in tight areas where a large area loop cannot be deployed, the 5-m loop could be used. Not only does the smaller and lighter loop speed up the survey, but the lower loop inductance permits a faster turn-off of the energy stored in the loop. For this reason, the decay field can be measured sooner, 0.7 μs after current turn-off, so that the measurements are sensitive to conditions in the first meter.

Software Support

The Interpex TEMIX Plus code accepts data from the GDP-16 receiver and calculates a 1-D inversion for each station on a profile. These 1-D inversions are pieced together to create 2-D sections and 3-D displays. This approach is adequate where the earth approximates a stratified condition. However, in most locales, 1-D inversions lead to a "fuzzy" image of true resistivity conditions. Typically, the best these inversions can do is to resolve three layers.

Complete software for TEM data processing, 1-D data inversion, and plotting of contoured resistivity cross-sections may also be obtained directly from the manufacturer. At the present time, graphical displays of the subsurface conductivity (or its numerical inverse resistivity) are constructed from individual 1-D inversions at separated stations along profile lines.

Cost/Rental Information

The complete system package, including software, costs approximately $54,000. The system can be rented on a daily rate basis, with a 10-day minimum rental period. There is a one-day rental-preparation charge and round-trip shipping at cost.

Survey Rates

A two-person crew is required to handle this relatively complex system. Survey rate information has not been provided by the manufacturer, but based on experience, a well-trained crew should be able to collect about 60 soundings per day over relatively level and open ground using a 20-m square-loop transmitter antenna. Under these conditions, the minimum operating cost would be approximately $30 per sounding ($1800 per day), including equipment rental costs.

TIME-DOMAIN ELECTRO-MAGNETICS *(cont'd)*

Case History Information

Because the NanoTEM is new, there are no published case history accounts of the system.

Applicability to the ESC Project

Although its cost is slightly higher than that of the Geonics PROTEM System, the NT-20 has a faster turn-off time, and this makes it more applicable to shallow investigations.

Geonics EM61

Commercially available since January 1993, the Geonics EM61 is a buried-metal detector designed for rapid detection of metallic targets such as drums and underground storage tanks. It consists of a pair of coaxial, horizontal air-cored coils (1 m × 1 m) on a frame to which wheels can be attached for towing. One of the coils, which serves as the transmitter, generates bipolar EM pulses at the rate of 150 per second (75 Hz). Both coils detect the secondary fields during the off-times between pulses. A time delay is built into the receiver so that the early time response from the earth is not measured; only the later time decay currents from more conductive metallic targets are integrated. A two-coil detection system gives a gradient measurement, which reduces the noise from fences and other nonrelevant noise sources.

Software Support

Up to 10,000 records may be stored in the receiver memory, but an OmniData 600 or 700 Series data logger is now supplied with the EM61, so that up to 20,000 records, or 5 hours of field data, may be stored. The data are then downloaded into a PC for plotting. Geonics uses the GEOSOFT mapping software to produce contour maps in units of signal strength expressed in mV.

Cost/Rental Information

Purchase

The complete EM61 system, including trailer and an OmniData 600 data logger, sells for approximatly $12,000.

Rental

The rental cost is $425 per week, for periods of one to three weeks. A minimum rental of one week is required, and rates decrease for periods longer than three weeks.

TIME-DOMAIN ELECTRO-MAGNETICS *(cont'd)*

Survey Rate

Despite its size and weight (about 80 kg with trailer accesories), the EM61 can be operated by a single person. The survey rate and operating cost should be comparable to that for a magnetic gradiometer.

Case History Information

Because this is a new instrument, there are no case histories for it as yet. In company sales literature, Geonics shows comparative survey results obtained with the EM61 and a magnetic gradiometer over the Columbia Test Site, University of Waterloo, where drums, pipes, and sheet metal have been buried in a nonmagnetic soil. All objects, including a single drum at a depth of 2 m, were detected and well resolved spatially. There were no false signals. Geonics states that the EM61 can also be operated in a mode that screens out signals from pieces of scrap metal buried at very shallow depths. The depth and size of the buried object are inferred from data on anomaly height versus width.

Applicability to the ESC Project

The EM61 competes with magnetics and the EM31 (discussed next) for the detection of ferrous materials and with GPR for the detection of nonferrous conductive metals. Although the EM61 cannot distinguish between ferrous and nonferrous objects, it seems to be able to resolve both very well. Its main advantages over magnetics are:

- Its response is not impaired by strengths and directions of remanent magnetization.
- It does not give the confusing dipolar anomalies characteristic of magnetics.

Its ability to detect a single 55-gallon drum, in terms of depth, is about the same as for a magnetometer and somewhat better than for the EM31. Its main advantages over GPR are:

- It responds to nonferrous conductors at greater depths than possible with GPR.
- Its display is simpler.

References

Geonics, Ltd., no date, *Buried Metal Detection with the EM61*, company brochure.

FREQUENCY-DOMAIN ELECTROMAGNETICS

INSTRUMENTATION AVAILABLE

EM31 Soil Conductivity Meter

This is a one-person, single-frequency instrument consisting of two coplanar loops 3.7 m apart built into a rigid boom and operating at 18 kHz. Manufactured by Geonics, Ltd. of Mississauga, Ontario, Canada, the EM31 is designed on the principle that, at low induction numbers (defined as the ratio of loop separation to skin depth), the quadrature signal is directly proportional to the average conductivity of the near surface, usually to a depths of less than 6 m. In high-conductivity areas, such as soils contaminated by salts due to irrigation and evaporation, this condition is not likely to be true, and corrections have to be made for nonlinearity.

Operated from a shoulder sling, the EM31 can be used only in the vertical dipole mode. Laid on the ground, it may be rotated into the horizontal dipole mode as well. This mode has less depth of exploration, and so may have some advantage in particular situations.

The EM31 has a switch-selectable feature that converts it to an in-phase-only reading device. In this mode, it is sensitive to the presence of steel drums and other man-made items with a high magnetic permeability. Geonics reports that a single 55-gallon drum can be detected at a depth of 2 m below the surface.

Software Support

The EM31 provides data directly calibrated in units of conductivity (mS/m), and these data require no further processing in applications where a rapid mapping of near-surface conductivity suffices. To speed up data acquisition, individual readings may be stored sequentially on an auxiliary data logger and then downloaded to a PC at the end of the session. Software for the EM31 is discussed in the next section on the Geonics EM34-3. A graphics package is needed to plot data as profiles and as iso-conductivity contour maps.

Cost/Rental Information

Purchase

Purchase Price: $12,985.

FREQUENCY-DOMAIN ELECTROMAGNETICS *(cont'd)*

Rental

$450 per week for one to three weeks. A one-week minimum is required. Shipping is extra. Rates decline for periods longer than three weeks.

Survey Rates

This is an extremely rapid geophysical-measurement technique because there is no instrument setup required and the readings are instantaneous. With the instrument carried on a shoulder sling, readings may be taken almost as fast as the operator can walk between stations. To speed up operations, a second person can serve as note taker/data recorder, although it is possible to utilize an electronic data logger. Over 200 stations per day are possible. In one case history, a two-person crew surveyed a 24,282-m^2 (6-acre) tract in 6 hours. Again using the $1800 per day operating cost for a two-person crew, the cost amounts to only $300 per acre.

Case History Information

Goldstein et al. (1990) used the EM31 and the EM34-3 (see next section) together to help map a conductive plume. Used by itself, the EM31 would not have detected the plume.

Applicability to the ESC Project

A fast and reliable instrument, virtually unchanged since it was introduced 15 years ago, the EM31 is probably the most often used EM system for environmental site studies. In a few documented cases, it appears to have been the only EM technique run over a site.

For most site characterization efforts, the EM31 should not be the only EM technique used. There are better anomaly detectors, and it provides limited information on subsurface conductivity. Its greatest value is in mapping variations in shallow conductivity, and thus it can be extremely useful for mapping changes in shallow bedrock geology and landfill boundaries (McQuown et al., 1991). It requires little training unless used with an auxiliary data logger, for which some instruction is needed.

FREQUENCY-DOMAIN ELECTROMAGNETICS *(cont'd)*

The readings are mainly sensitive to soil moisture and thus to soil type, seasonal meteorological effects, and local drainages, as well as to nearby metal objects. While the EM31 can be used to detect buried ferromagnetic objects, its sensitivity to them is not as good as a magnetometer. On the other hand, the EM31 response is independent of remanent magnetization effects, which may be highly variable and which would therefore complicate the interpretation of standard magnetic surveys. The EM31 is also less likely to be affected by man-made steel structures on the surface than a single magnetic detector.

Reference

McQuown, M.S., S.R. Becker, and P.T. Miller, 1991, "Subsurface Characterization of a Landfill Using Integrated Geophysical Techniques," in *Proceedings of the 5th National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods*, May 13–16, 1991, Las Vegas, NV (Dublin, OH; Water Well Journal Publishing Co., 1991), pp. 933–946.

EM34-3 Soil Conductivity Meter

The EM34-3 system is a ground-conductivity instrument consisting of a pair of coils that are moved in tandem along a survey line at fixed separations of 10, 20, and/or 40 m. The coils may be operated in two modes: the vertical-dipole mode (with the coils held horizontally and coplanar) and the horizontal-dipole mode (with the coils standing on edge and coplanar). This system is manufactured by Geonics, Ltd. of Mississauga, Ontario, Canada, and is often used in conjunction with the EM31. Like the EM31, it provides direct conductivity readings, but by utilizing all three coil separations and the two-coil configuration modes, one can obtain a sufficient number of data points for a rough 1-D inversion.

Software Support

Interpex provides software specific to the EM31 and EM34-3 for PCs (386 or later, MS-DOS 3.1 or later with a math coprocessor). Not only does this EMIX 34plus software jointly invert all EM31 and EM34-3 data for all separations and coil configurations, but it also accepts data from the auxiliary data logger.

Cost/Rental Information

Purchase

Purchase price: $18,900

FREQUENCY-DOMAIN ELECTROMAGNETICS *(cont'd)*

Rental
$740 per week for one to three weeks. A minimum rental of one week is required. Shipping is extra. Rates decline for longer periods.

Survey Rate

An experienced two-person crew would be able to make roughly 200 station readings per day. However, because the reference cable must be changed for each of the three possible coil separations, it is convenient to run complete surveys, one coil separation at a time. Consequently, the survey area must be retraced three times in order to obtain the most complete depth coverage possible. Assuming high-resolution coverage is desired with station and line separations of 5 m, it would require two days of effort for 4047 m^2 (1 acre) for all three coil separations. With 144 stations per acre, the cost of data acquisition amounts to roughly $25 per station for all three separations.

Case History Information

Goldstein et al. (1990) describe a situation in which the EM34-3 was used to map a shallow plume of conductive water leaking from unlined ponds.

Applicability to the ESC Project

The EM34-3 represents an alternative method to TEM for obtaining the shallow conductivity distribution. Because two and preferably all three coil separations are needed per station, the technique may not be more rapid than TEM. It does not have the vertical resolution of TEM, and the readings require correction in areas of high conductivity.

References

MacLean, H.D., 1992, *Commercially Available Broadband Electromagnetic Systems for U.S. Department of Energy Waste-Site Characterization*, Chem-Nuclear Geotech, Inc., U.S. DOE, Grand Junction Projects Office, Grand Junction, CO, GJPO-GP-2, 29 pp. plus a 49-page appendix.

SELF-POTENTIAL MEASUREMENTS

Self-potential anomalies are generated by the flows of fluid, heat, and ions in the earth, and so the technique has been used for detection of oxidizing metal drums or pipelines and seepage from ponds and dams. This technique maps the static electric potential over the surface relative to a base station by utilizing a pair of nonpolarizing electrodes connected via reels and wire to a digital voltmeter. The reader is referred to the review and tutorial paper on the subject of self-potential measurements and equipment by Corwin (1990).

INSTRUMENTATION AVAILABLE

Practitioners of self-potential methods normally make their own copper-copper sulfate electrodes and buy wire, reels, a digging tool, and a digital voltmeter from commercial sources. The voltmeter should have a high input impedance (10 MΩ) and a low-pass filter to reject 60-Hz noise.

Supporting Software

Corrected readings are plotted in both profile and contour form by available data-display software. Detailed interpretations are often made by comparing data to simple curves generated for point and line sources and sinks of heat, fluid flow, or ionic flow due to chemical reactions. The program SPXCPL permits a 2-D analytical solution, but has required a more powerful machine than a PC due to memory needs and execution time. To our knowledge, no one offers a complete self-potential software package, but there are special programs available, such as the new 2-D code PTSP (Yasukawa, 1993), which calculates the surface self-potential from the distribution of subsurface fluid velocities. The fluid velocities are first calculated from pressure and temperature sources and sinks.

Cost/Rental Information

The total cost for a complete set of instrumentation should be less than $2000.

Survey Rate

A self-potential survey can be conducted by measuring the potential difference between the ends of a fixed-length wire whose trailing end is "leap-frogged" over the leading end for successive readings. A two-person crew is needed. Self-potential may also be measured by moving a single electrode, the base electrode remaining fixed. In this mode of operation, the one-person crew must carry reel with sufficient wire. In either mode, an experienced crew can obtain over 100 station readings

SELF-POTENTIAL MEASUREMENTS *(cont'd)*

per day. This equates to a survey cost on the order of $1000 per line km, assuming station separations are varied from 10 m down to 1 m in areas where detailing is required.

Case History Information

Most published case histories pertain to minerals or geothermal exploration. For engineering problems, self-potential has been used mainly to map the locations of leakage from dams and ponds.

Corwin (1990) provides an extensive bibliography on this topic. The self-potential anomalies from pond leaks are typically very small negatives (about –1 to –5 mV) corresponding to downward flow. The small amplitudes are of the order of the noise background and therefore are difficult to detect unless a measurement accuracy of ± 0.3 mV or better can be achieved (Zonge, no date).

Self-potential can also detect corroding steel objects, such as drums, buried in the ground to depths of 1.5 to 2 times their diameters. Goldstein (1967) performed a careful field experiment and confirmed that the sharp negative anomaly of –80 mV (in a noise envelope of 5 to 10 mV) centered over the drum can be explained by steel corrosion. Drums buried for longer times, thus having more rust, and drums buried in a more resistive environment are likely to produce larger self-potential anomalies than clean drums in wet conductive soils.

Applicability to the ESC Project

Although an single steel drum buried at depths of up to 2 m may be detected by means of self-potential measurements, a very tight survey grid is needed, i.e., stations no more than 2 to 3 m apart. Magnetic and electromagnetic methods, which do not require the planting of electrodes, would be both faster and safer than the self-potential method. Therefore, we believe that the main value of the self-potential method to

ESC lies in its ability to detect leaks from containment ponds and dams. However, because these electrokinetic voltages have such small amplitudes relative to natural and measurement noise, such measurements must be made with a great deal of care and by experienced operators.

SELF-POTENTIAL MEASUREMENTS *(cont'd)*

References

Corwin, R.F., 1990, "The Self-Potential Method for Environmental and Engineeering Applications," in *Geotechnical and Environmental Geophysics*, S. H. Ward, ed. (Soc. Expl. Geophys., Tulsa, OK), pp. 127–145.

Goldstein, N.E., 1967, *The Detection of Buried Artifacts by Means of Spontaneous Electrical Potential Measurements*, SRI International, Menlo Park, CA, Tech. Note OAD-TN-4923-27, 21 pp.

Yasukawa, K., 1993, *A Coupled Self-Potential, Fluid, and Heat Flow Model for Subsurface Flow Systems*, M.S. thesis, University of California, Berkeley.

Zonge, no date, "Mapping Leaks in a Waste-Containment Pond with SP: Electric Geophysics Seminar Notes," Zonge Engineering & Research Organization, Tucson, AZ.

RESISITIVITY/ INDUCED POLARIZATION

In the galvanic electrical methods, current is injected into the ground through a pair of current electrodes using batteries (a motor-generator is used in the most powerful systems), and the resulting electric field voltage is measured across a pair of "potential" electrodes. The reader is referred to the excellent tutorial and review paper by Ward (1990) for details on theory, methods of interpretation, and application to environmental problems.

A variety of in-line electrode configurations or arrays (Wenner, Schlumberger, dipole-dipole, to name a few) are used. The choice depends on the specific application and resolution desired. Depth of exploration is increased by increasing electrode separations while, at the same time, increasing current flow into the earth and suppressing unwanted naturally-occurring voltages from telluric currents and self-potentials.

In cases where detailed vertical electric soundings (VES) are required, the Schlumberger array provides very good depth discrimination in relation to the time and effort required to move wires and electrodes. The problem, and one common to all electrode arrays, is that lateral near-surface conductivity inhomogeneities occurring near an electrode cause large effects attributable to variations in the vertical distribution of conductivity directly below the center of the array. To overcome this problem, various authors have suggested five electrode arrays to spatially average out these lateral effects (Barker, 1981).

RESISTIVITY/ INDUCED POLARIZATION *(cont'd)*

For the standard resistivity technique, a battery-powered transmitter delivers into the ground a current as a series of long-period, square-wave pulses of tens of milliamperes to one ampere at a single frequency around 1 Hz. The resulting voltage across the potential electrodes is obtained by synchronously averaging the voltages for many repetitions of the applied current.

For the induced polarization or spectral resistivity techniques, the transmitter generates a broadband signal either in the time domain or at discrete frequencies up to about 1 kHz. The induced-polarization effect is related to the fact that the amplitude and phase of the observed voltage changes with frequency when conduction changes from ionic to metallic (electrode polarization) and when ionic conduction is impeded by electrically-charged clays lining and blocking paths in partially and saturated rocks (membrane polarization).

Simpler systems designed for shallow investigations have a transmitter and receiver together in a single field unit. They measure resistivity only, usually one dipole at a time. The more powerful systems utilize a separate transmitter and receiver. These systems are able to read multiple dipoles and compute and store self-potential, resistivity, and induced-polarization parameters in memory.

It is usually hard to make induced-polarization/spectral-resistivity measurements in the field at frequencies above, say, 200 Hz. Capacitive and inductive coupling effects occur between closely spaced wires on the ground and between electrodes and earth. These effects increase with increasing frequency and cannot be removed from the data.

Another noise problem arises from frequency-dependent EM signals thrown off by conductors such as fences and pipelines. The dipole-dipole array is best for rejecting this type of noise.

Modern induced-polarization/resistivity receivers automatically remove self-potential offsets from the induced-polarization/resistivity measurements.

INSTRUMENTATION AVAILABLE

Excellent instruments for galvanic induced polarization/resisitivity are available from a number of manufacturers and suppliers. Examples of available instrumentation and prices are listed below. The examples are limited to a sampling of systems designed for shallow groundwater and engineering investigations.

RESISTIVITY/ INDUCED POLARIZATION *(cont'd)*

1. Androtex **TDR-6** multichannel resistivity, induced-polarization, self-potential receiver.

2. Phoenix Geophysics manufactures a variety of induced-polarization/resistivity transmitters and receivers. Applicable to shallow site characterization are the two-channel **RV-2** (resistivity only) or **V-2** (induced polarization/resistivity) receiver and one of Phoenix's battery-operated transmitters.

3. Zonge GGT-3 transmitter, XMT-16 transmitter controller, and GDP-16 multi-purpose receiver.

4. Bison Instruments Earth Resistivity Meter **Model 2350B** is an 11-Hz transmitter and receiver for shallow-depth investigations. It sells for $3600, plus $690 for electrodes, wires, and reels. The more powerful **Model 2390** system is adequate for almost all resistivity and frequency domain IP (0.1 to 5.0 Hz) work, and it sells for $10,000, plus $1500 for electrodes, wires, and reels.

5. Scintrex manufactures several resistivity systems. The company's basic unit, on the market for many years, is the **Model IPR-10A** digital, time-domain induced-polarization/resistivity receiver, which can be used with the **IPC-9** 200W battery-powered transmitter. The costs of these instruments are $8450 and $14,000, respectively, excluding accessories.

   At the top of the Scintrex line is the **Model IPR-12** induced-polarization/resistivity receiver, which can measure eight dipoles simultaneously. It processes the data and stores the resistivities and IP parameters in memory. The cost is approximately $24,000.

6. Scintrex is the North American distributor for the Campus resistivity equipment manufactured in England. The most advanced is the fully automated **MRT/Geopulse System,** which utilizes 20, and up to 32, preplanted electrodes connected via a special single multicore cable to a switching module and a lap-top PC to control switching for rapid coverage of an area. The manufacturer includes a set of special programs that run the system in the field. The results can be viewed, edited, and stored to disc for later processing. The power supply produces square wave pulses at three frequencies (2.1, 4.2, 8.4 Hz) to give an induced-polarization measurement.

RESISTIVITY/ INDUCED POLARIZATION *(cont'd)*

The cost of the Geopulse System varies, depending on whether one wants a simple conventional system or a deep-sounding (~200-m) fully automated system. Costs also depend on the type and length of cable system selected. For the purposes of ESC, one might select the Shallow Electrical Imaging System (automated) at $21,175 with perhaps two or three different Imager Profiling Cables that cost in the range of $1500 to $2500 each and come with electrode takeouts at 1-, 2-, 5-, and 10-m intervals for different depths of investigation. The Imager Profiling Cables are configured for the Electrical Imaging survey technique, which uses a multiple a-spacing Wenner profiling array.

Software Support

Both Interpex, Ltd., and Geosoft offer software tools for the processing and plotting of resistivity and induced-polarization soundings. One should check the compatibility between the software and the receiver used to store the data in the field. Interpex offers codes that compute foward and inverse 2-D models of resistivity and induced polarization.

Equipment Costs

Examples of instrument and accessory costs are given above.

Survey Rate

We found no data on survey rates, but published cost figures for groundwater and environmental surveys are roughly $3,100 and $5,200 per line kilometer ($5,000 and $8,400 per line mile), respectively, based on industry data for 1991 (Riley, 1993). The report did not specify array type, electrode separations, or instruments used. We assume that the higher average cost for the environmental surveys is due to the smaller electrode separations (i.e., higher density of data collected). Field operating costs might be lower by a factor of nearly one-half using an automated Geopulse System.

Case History Information

There are a few reported case histories on the use of galvanic techniques for mapping both conductive aqueous plumes and hydrocarbon spills (Ross et al., 1990; Zonge, no date). Case history data indicate that where hydrocarbon fluids wet the surfaces of mineral grains, one observes coincident low conductivity (0.001 S/m) and low induced-polarization effects.

RESISTIVITY/ INDUCED POLARIZATION *(cont'd)*

Most of the resistivity case history information comes from work done in Eastern Europe and China, where modern TEM and FEM equipment is scarce or nonexistent.

Applicability to the ESC Project

Because conventional galvanic techniques require direct electrical coupling of the electrodes to the ground, they are not amenable to sites paved over with asphalt or concrete and sites with natural or man-made rubble at the surface that would impede the planting of electrodes to a depth where electrical contact can be made with moist soil. However, prototype systems utilizing quadrupoles electrostatically coupled to the ground have been tested in France (Tabbagh et al., 1993), but these have not yet been commercialized. The electrostatic system yields information similar to that from grounded electrode systems as long as it is operated at a frequency low enough to avoid its behaving like an inductive EM system.

Galvanic techniques have good sensitivity to resistive zones, and induced polarization/spectral resistivity techniques seem to be sensitive to the wetting phase on mineral surfaces. For these reasons, the combination of standard resisitivity and induced polarization may be the best approach to finding hydrocarbon spills and leaks. This point has been demonstrated in laboratory experiments using sandstones and clays. Broadband laboratory measurements spanning six decades of frequency were made on rocks saturated with brine versus those saturated with hydrocarbons (gasoline, hexane, benzene) (Börner et al., 1993). The results indicate a large decrease in both the in-phase and quadrature components of resistivity. Although the laboratory results are encouraging, more work in this area must certainly be done to determine how well organic liquids may be detected under field conditions.

In summary, galvanic methods are not an immediate first choice for ESC, but must be considered on a site-by-site basis. If galvanic techniques are used, induced polarization should be done in addition to standard resistivity.

References

Barker, R.D., 1981, "The Offset System of Electrical Resistivity Sounding and Its Use with a Multicore Cable," *Geophys. Prospecting* **29**, 128–143.

Börner, F., M. Gruhne, and J. Schön, 1993, "Contamination Indications Derived from Electrical Properties in the Low Frequency Ranges," *Geophys. Prospecting* **41**, 83–98.

RESISTIVITY/ INDUCED POLARIZATION *(cont'd)*

Ross, H. P., 1990, "Dipole-Dipole Electrical Resistivity Surveys at Waste Disposal Sites," in *Geotechnical and Environmental Geophysics,"* S.H.Ward, ed. (Soc. Expl. Geophys., Tulsa, OK), **2**, 145–152.

Tabbagh, A., A Hesse, and R. Grard, 1993, "Determination of Electrical Properties at Shallow Depth with an Electrostatic Quadrupole: Field Trials on Archeological Sites," *Geophys. Prospecting* **41** (5), 579–598.

Ward, S.H., 1990, "Resistivity and Induced Polarization Methods," in *Geotechnical and Environmental Geophysics*, S.H. Ward, ed. (Soc. Explor. Geophys., Tulsa, OK), **1**, 147–189.

Zonge, no date, "Mapping a Toxic Waste Plume with IP," *Electrical Geophysics Seminar Notes*, Zonge Engineering & Research Organization, Tucson.

GROUND PENETRATING RADAR (GPR)

Small, portable GPR units, which have been in use for several years, produce "echograms" or wiggle time traces showing subsurface reflectors. The systems consist of transmitter-receiver antennas towed or carried between sounding points. Transmitters emit short pulses of very-high-frequency electromagnetic energy (usually in the range of 10 to 1000 MHz). At these frequencies, and as long as the ground conductivity is not high (say less than about 10 mS/m), part of the energy propagates into the earth like a pure wave and is reflected back to surface by layers of high electric permittivity (clays and the phreatic zone) or by buried metallic objects. To avoid recording the horizontally propagating waves in the air and in the earth, a delay of nanoseconds occurs before the output of the receiver antenna is digitally sampled, stored, and averaged with many other repetitive waveforms. Stored data are downloaded into a PC for processing and display.

The radar technique has been used for high-resolution imaging to depths of as much as 40 m in high-resistivity areas such as clean, relatively dry sands, granites, and limestones (conductivities < 0.1 mS/m). The range decreases with the presence of pore water and clays. Figure 1 shows one-way radar-probing distances in various types of rocks. Davis and Annan (1989) provide an excellent overview of GPR. According to these authors, experience indicates that a center frequency of around 100 MHz gives the best compromise for getting energy into the ground, depth of penetration, adequate resolution, and system portability.

GROUND PENETRATING RADAR (GPR) *(cont'd)*

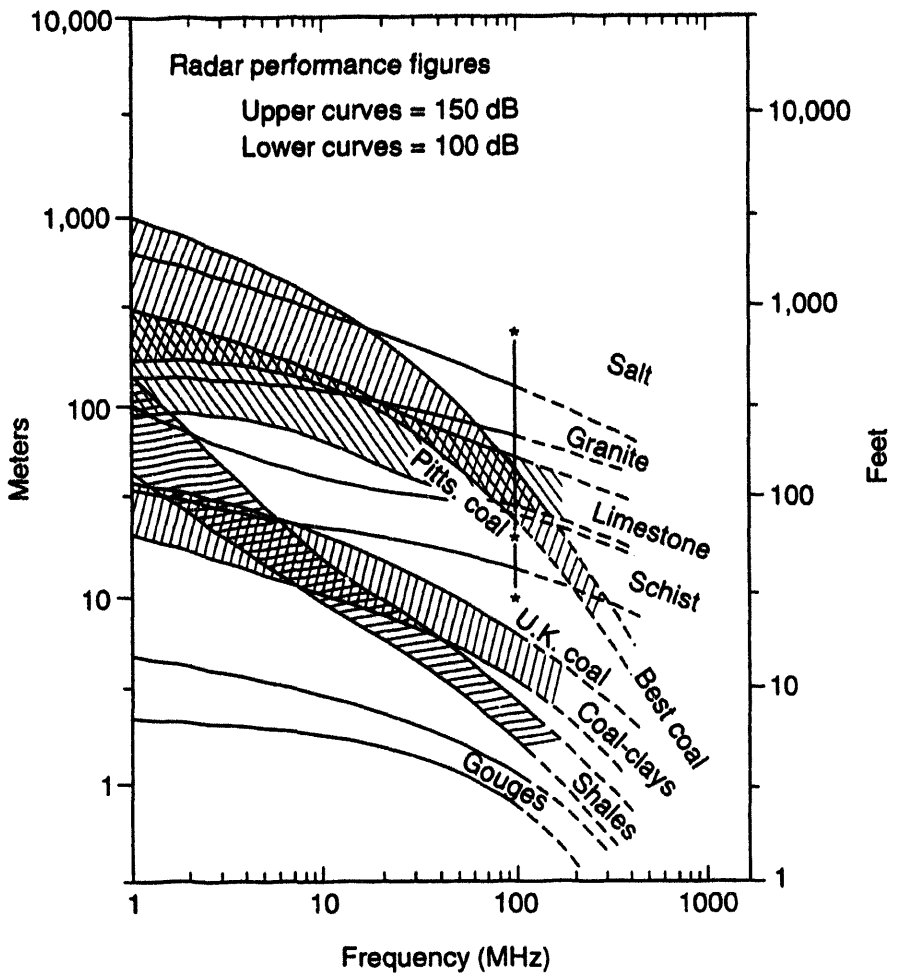

Figure 1. Radar-probing distances through some typical "rocks." The radar-probing distance is defined as the distance a radar signal travels before being attenuated by 100 to 150 dB (from Keller, 1982).

INSTRUMENTATION AVAILABLE

PulseEKKO IV

The pulseEKKO IV system manufactured by Sensors and Software Inc., Mississauga, Canada is a PC-based radar designed primarily for geologic mapping applications to depths of 100 m. It may be operated at center frequencies from 12.5 to 200 MHz by using interchangeable antennas. Up to 2048 individual waveforms may be recorded and averaged ("stacked") at a time to reduce thermal noise in the electronics. The low-frequency antennas would provide better depth of investigation, but lower resolution. Transmitter and receiver coils are

GROUND PENETRATING RADAR (GPR) *(cont'd)*

independent units carried from station to station. Because the coils are independent, it is possible to make variable-offset surveys.

Supporting Software

The instrument is supported by a range of processing, display, and interpretation software that runs on an MS-DOS PC. The current standard pulseEKKO software, called EKKO_BASE, produces a time-dependent wiggle-trace display. If the velocity of the EM wave in the medium is known or can be estimated, the time variable can be converted to a depth variable. Data may be exported in SEG-Y format for processing using seismic reflection codes. The manufacturer also has advanced processing packages, such as EKKO COLOR at extra cost.

Cost/Rental Information

Purchase
Sales are handled in the U.S. by Bison Instruments, Minneapolis, MN. This company quotes a price range of $30,000–50,000 for a unit, inversely proportional to frequency. For a 100-MHz antenna, the price is approximately $32,000.

Rental
Rental cost for the basic unit is $4800/month or $200/day plus $350 for mobilization. The renter also pays shipping charges and for optional items such as additional antennas and software.

Survey Rate

Surveys are conducted along pre-surveyed traverse lines. Soundings are taken at station intervals of 0.25 m at 100 MHz with a common offset between transmitter and receiver. Intervals would be larger at lower frequencies. The survey rate is generally much slower than for magnetics, perhaps 0.5 km/hr for operators on foot and 1 to 2 km/hr for antennas towed behind vehicles.

Depending on the application and the degree of 3-D coverage desired, each area surveyed could have any number of closely-spaced parallel traverse lines as well as cross-lines.

Case History Information

None available.

GROUND PENETRATING RADAR (GPR) *(cont'd)*

Applicability to the ESC Project

While GPR produces images similar to those from reflection seismology, the technique has limitations. First, depth of investigation is limited by wet, clay-rich soils. Thick clay layers and the saturated zone both form hard reflectors below which very little energy propagates. Near-surface heterogeneities produce clutter in the image that detracts from the usefulness of the high-frequency antennas. One of the main values of GPR is that it is able to image areas that have been disturbed by human activities, e.g., boundaries of burial pits.

PulseEKKO 1000

The pulseEKKO 1000 is a smaller, higher-frequency counterpart of the pulseEKKO IV system. It utilizes antennas operating at 225, 450, and 900 MHz and has a commensurately faster sampling rate and shorter time window than the "IV," thus making it more suitable for high-resolution detection of shallow artifacts. It is a completely digital unit with 16-bit data resolution, programmable stacking, internal memory.

Supporting Software

EKKO_RUN plus a complete line of processing programs are available.

Cost/Rental Information

Purchase

Bison Instruments, Minneapolis, MN, one of the sales agents in the U.S.A., quotes a price of approximately $18,000.

Rental

Rentals are handled directly through Sensors and Software, which maintains a rental pool in Buffalo, NY. The rental cost is approximately the same as for the pulseEKKO IV discussed above.

Survey Rate

With its small size and weight, shorter data-acquisition time, and user friendly features, the "1000" has been designed for rapid operation without the need to employ experienced geophysicists except to plan and interpret. The two small antennas are clamped together and may be pushed or towed over the ground. A one- or two-person crew should be able to cover an average-sized site, 8094 to 24,282 m^2 (2 to 6 acres), in a day or so. Station separations are as small as 10 cm apart.

GROUND PENETRATING RADAR (GPR) *(cont'd)*

Case History Information

A man-made DNAPL (PCE) spill into a uniform sand pooled in a layer and was imaged as a "bright spot" reflector (Greenhouse et al., 1993). The strong, coherent reflection is due to the fact that the EM reflection coefficient for a layer containing organic fluids can be relatively large. Although the test was done with a USGS 500-MHz pulsed GPR, the results may be applicable to the "1000," which has similar characteristics. In an actual situation, the low levels of contaminant, depth of contaminant, and natural EM clutter all conspire to make direct detection of a DNAPL spill highly problematic.

References

Greeenhouse et al., 1993, "Geophysics and Solvents: The Borden Experiment," *The Leading Edge*, April 1993, pp. 261–267.

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SIR System (10 and 10A)

The SIR System manufactured by Geophysical Survey Systems, Inc. (GSSI), North Salem, New Hampshire, is a relatively new pulsed system that can be obtained with a variety of antennas from 80 to 1000 MHz. One, two, or four antenna pairs (data are recorded on independent channels) may be used at a time, four antennas providing the widest swath of information. Both high- and low-frequency, real-time digital filters are available to suppress noise effects.

GSSI also offers a Model 38 color radar display unit, and a GS-608P graphic thermal plotter/printer (16 gray scales) for real-time output in the field.

Supporting Software

The MF-10 mainframe (part of the system) includes a digital-tape cartridge tape drive for mass storage of data, digital settings, alphanumerics, and time/date data. Using a serial link, the data can be transferred to an independent PC. GSSI provides proprietary, menu-driven software (RADAN) to facilitate 16-bit processing.

GROUND PENETRATING RADAR (GPR) *(cont'd)*

Survey Rate

The antenna(s) are either towed by an operator, who carries the power supply and recording electronics in the MF-10 mainframe (10.5 kg) in a backpack, or by a vehicle. Because the sounding points are so close together, a vehicle does not increase survey speed as much as provide a better means for towing multiple antennas and for giving the operators a platform for carrying a real-time color display. Because of the small size of the target, a drum search might cover only 4047 m^2 (1 acre) per day.

Cost/Rental Information

The SIR-10 costs upwards from $43,800.

Case History Information

The GSSI system with 80- and 300-MHz antennas was tested over Sandia's mixed-waste landfill test site. Both data sets revealed pit boundaries (Hasbrouck, 1993).

Applicability to the ESC Project

The system is applicable for detecting buried drums, underground storage tanks, and landfill boundaries. There is also evidence that rocks and soils saturated with certain organic contaminants have high reflection coefficients at radar frequencies, thus causing a loss of deeper reflections below the top of the contaminated zone.

GPR systems are relatively complex, and a trained crew should be hired to carry out surveys. Also, while GPR should be considered for ESC, it should be used selectively on a site-by-site basis and always in conjunction with other electrical/EM techniques. GPR provides poor results in water-saturated, clay-rich material and much better results in dry, sandy, and gravelly soils developed over a bedrock of sandstone, granite, and limestones.

GROUND PENETRATING RADAR (GPR) *(cont'd)*

References

Davis, J.L., and A.P. Annan, 1989, "Gound-Penetrating Radar for High-Resolution Mapping of Soil and Rock Stratigraphy," *Geophys. Prospecting* 37, 531–551.

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SEISMIC REFLECTION

DESCRIPTION

APPLICATIONS

The use of high-resolution, shallow seismic reflection for characterizing the hydrogeology and stratigraphic conditions in the upper 100 m is increasing. Applications include:

- Mapping of the bedrock surface
- Determining the depth to the water table
- Determining the location of specific sand/shale units
- Detecting possible faults
- Detecting large voids or cavities.

The seismic-reflection method may detect large individual buried objects under ideal conditions. For example, a 300-Hz wave has a wavelength of 5 m in unconsolidated, saturated material, and thus man-made objects with dimensions of about one meter (a 1/4 wavelength) on a side might be detectable from the surface.

In this section, we deal mainly with seismic reflection, even though seismic refraction surveys are still being carried out for many simple engineering applications such as depth to bedrock. For refraction, the source-receiver separation is progressively increased, so that the first arrival is the refracted wave propagating along the high velocity boundary between the unconsolidated layer and bedrock. Timing of this arrival helps define the depth and velocity of the bedrock layer.

HOW SEISMIC REFLECTION WORKS

Among the differences in the application of seismic reflection for shallow imaging, compared to standard oil exploration techniques, are the type of source and geophones used. For high-resolution shallow investigations, where shotpoints are closer together, seismologists use sources that are inexpensive and fast to operate and that produce sufficient energy at high frequencies, e.g., > 100 Hz. Vertical resolution depends on frequency, the resolution being on the order of about a quarter wavelength. Because higher frequencies are more rapidly attenuated in the earth, the practical vertical resolution decreases with depth.

DESCRIPTION *(cont'd)*

Sources

Sources commonly used include blasting caps, sledge hammers, rifle and shot-gun slugs, soil compactor vibrators (MiniSOSIE), and weight drops. A low-cost, low-energy source such as a sledge hammer might be perfectly adequate for shallow investigations or in cases where only a few hammer blows per point are needed. As noise from ground roll (Rayleigh wave) is a problem in shallow surveys because the ground wave arrives at about the same time as the shallow reflections, some practitioners would select a source that impacts below ground level.

Detectors

Detectors are 40- to 100-Hz geophones. Vertical-component types are most often used, but horizontal and three-component geophones are also available. Geophones include a precision damping resistor to provide relatively flat frequency responses above the natural frequency, sometimes misleadingly referred to as the resonant frequency. The natural geophone frequency is –3 dB relative to peak response; the amplitude response decreases or rolls off at –6 dB or more per octave below that frequency. In paved-over areas, geophones with a flat base are caulked to the concrete or asphalt. One or more geophones per recording site are connected, usually in series if multiple geophones are grouped, to an appropriate amplifier, analog filters, A/D, and data storage system called the seismograph. Single or grouped geophones may be as close as a meter apart.

Groups (subarrays) of geophones are one of the techniques used to reduce noise from the horizontally propagating surface wave or "ground roll."

Choice of geophone-group separation depends on the horizontal resolution desired. For a horizontal reflecting surface, reflections occur at intervals of one-half the geophone separation.

Seismographs

A large number of portable seismographs, weighing 10 to 15 kg, are commercially available. The choice of seismograph is based on the number of channels required, dynamic range, and frequency content of the signal (hence the sampling interval needed), among other factors. To utilize smaller energy sources, one requires greater dynamic range, i.e., at least 12-bit A/D conversion. Many modern systems have 16 bits, 15 for dynamic range plus a sign bit. The number of data channels is a consideration; newer systems have 24,

DESCRIPTION *(cont'd)*

48, and 120 channels, each with switch-selectable, low-cut, high-cut, and anti-alias filters and a very high dynamic range (up to 120 dB) that does away with the need to set gain controls. The seismographs may also have automatic stacking capability. Data are often collected in the common mid-point (CMP) configuration utilizing a roll-along box.

Data Collection

In CMP surveys, the traces are gathered and averaged to accentuate reflections from the same point on the reflecting surface. Gathers depend on finding the normal-moveout (NMO) velocity to correct for differences in travel path. The degree of multiplicity in the gather is called the "CDP fold." Thus, a 12-channel seismograph could yield six-fold CDP data because there would be six reflections from each location on a reflector. Because the signal-to-noise ratio theoretically increases as the square root of the fold, one might argue for the highest fold possible. However, the greater the fold, the greater the error introduced by errors in estimating the best NMO velocity. Steeples and Miller (1990) discuss many common pitfalls in applying the technique.

Data Output

The individual traces are stored on an internal disk, and can be output via one of several type of ports to an external computer, printer, or monitor. Data output is in one of the SEG standard formats.

Drawbacks

Due to the cost and complexity of seismic reflection, plus the fact that magnetics and electrical/EM methods often have greater applicability to environmental site studies, shallow seismics have not been used as much as other geophysical techniques for site characterization.

INSTRUMENTATION AVAILABLE

MANUFACTURERS

Bison Instruments, Geometrics, Scintrex, Oyo-Geospace and several other companies manufacture excellent portable seismographs, sources, and accessory equipment. Geophones, cables, batteries, energy sources, and many other accessory items may be acquired either from the seismograph manufacturer or separately from other vendors.

INSTRUMENTATION AVAILABLE *(cont'd)*

SOFTWARE SUPPORT

All seismographs include the full data acquisition and processing hardware and software.

COST/RENTAL INFORMATION

Purchase

The major cost item of a seismic system is the seismograph, the cost of which depends primarily on the number of data channels. The price increases linearly at $1000 to $2000 per channel. Costs of a few seismographs are tabulated below as examples.

Geometrics SMARTSEIS S12	$13,900
A 12-channel, 16-bit A/D	
Geometrics ES-2401X	
24-channel system, 15-bit A/D	$42,000
96-channel system, 15-bit A/D	$96,000
Bison 9000 DIFP Series	
12 to 48 channels	
15-bit plus 1 bit for sign	
50-ms sampling	
120-dB dynamic range	
12-channel	$24,000
48-channel	$50,000
Scintrex S-2 Portable Seismograph	$ on request
12 or 24 channels	
Comes with a notebook PC-compatible computer for storing, processing, and displaying data. A complete line of software is included.	

Cables may cost another $1500 to $5000, depending on length and number of channels. Geophones are approximately $50 to $100 each for 40- to 100 Hz types.

Cost of the seismic source varies from $10s for a 7.2- or 9-kg sledge, $100s for a 30–06 rifle or 8-gauge shotgun, plus ammunition, and up to $1000s for a weight drop device. Among the weight drop devices, Bison Manufactures accelerated weight drops, the smallest of which (Model EWG-1) is fine for shallow work and sells for $5000.

There is also now a mini-vibrator source, the "minivib," offered by Industrial Vehicles International specifically for environmental

INSTRUMENTATION AVAILABLE *(cont'd)*

work. This is a small vibrator with a sweep signal up to 550 Hz, which operates from the back of pickup truck. Oyo-Geospace has a new vibrator that can deliver sweeps up to 2000 Hz.

Rental

Seismographs and accessory equipment may be rented on a daily basis, depending on availability. The Geometrics rental price is based on the normal purchase price, and is calculated as 1% of purchase for mobilization plus 1/2% per day. The daily rate reduces to 1/3% after 30 days.

For the Bison 9000 Series, rental rates are are based on a daily rate plus a mobilization/demobilization charge. Rental costs for several seismographs are listed below.

	per day	mob/demob
9048 48 Channel	$200	$400
9024 24 Channel	175	350
9012 12 Channel	150	300

Rental costs for cables, source, geophones, a GEOSTUFF roll-along box, etc., could add another $50 to $200 per day. The mob/demob charges do not include shipping and insurance, which are extra.

SURVEY RATE

The survey rate depends on the number of shotpoints one can occupy in an 8- to 10-hour day, and this depends on the source used. For a sledge hammer source, rate is a function of the number of hammer blows per shotpoint and thus the strength, motivation, and endurance of the hammerers. Perhaps 100 to 150 shotpoints per day is a reasonable figure to use. On the other hand, 300 to 700 shotpoints might be possible with a rifle or shotgun source, and 150 with a MiniSOSIE (Steeples and Miller, 1990). Assuming a 1-m station separation with shotpoints at all geophone locations for a high-resolution survey, one can see that survey rates will be on the order of 200 to 1000 m per day.

On the basis of $3000 per day operating costs that include equipment rental, a four-person crew, and their travel/field subsistence expenses, the cost of a seismic-reflection data acquisition system is on the order of $3000 to $15000 per km. This is in rough agreement with 1991 industry data (Riley, 1993), which reports costs of $11,000 to $15,000 per line mile for seismic-reflection surveys done with weight-

INSTRUMENTATION AVAILABLE *(cont'd)*

drop sources for environmental purposes. Normally, costs reported do not include the cost of post-field data processing and interpretation.

CASE HISTORY INFORMATION

Steeples and Miller (1990) and Pullan and Hunter (1990) provide a number of case-history examples of shallow seismic reflection surveys applied to engineering problems.

APPLICABILITY TO THE ESC

Off-the-shelf seismic reflection technology is excellent and still improving, but pricey. The technique does not have universal application to environmental site characterization problems and therefore must be considered on a site-by-site basis.

In regard to seismic reflection for the ESC, there are a number of points to consider:

1. The time and cost to conduct a survey is among the highest of all noninvasive techniques, and therefore the techniques may have only spot application. Before one invests the time and money in a full-scale data-acquisition effort, it is always best to run test surveys over an area to determine the best data-acquisition approach and whether shallow seismic will yield useful information. A test survey entails running a test line with different sources and different combinations of geophones, filters settings, CDP folds, geophone separations, shotpoint separations, NMO velocity corrections, and so on in order to establish the survey parameters for an area.

2. Data processing is a sometimes lengthy process. The number of data bits collected per survey is enormous, but, with in-field computing capabilities, it is possible to produce a seismic section within an hour or two if no trace editing is done and if brute stacks are sufficient.

3. The key to a successful survey lies in the transmission characteristics of the unconsolidated near-surface environment. Loose, dry, sandy, or gravelly surface material may prevent good coupling of the energy into the ground and attenuate the high-frequency energy, thus limiting the depth of investigation. On the other hand, wet, clay-rich soils and rock provide a much better transmission medium for high frequency (>100-Hz) seismic

INSTRUMENTATION AVAILABLE *(cont'd)*

waves. Thus, seismic reflection works best in areas least suitable for GPR.

4. Seismic reflection is not applicable over dug-up and backfilled areas such as landfills (Pullan and Hunter, 1990). Loose, unconsolidated material containing gas is highly attenuating. There are better noninvasive geophysical methods for examining the limits and contents of a landfill.

REFERENCES

Pullan, S.E., and J.A. Hunter, 1990, "Delineation of Buried Bedrock Valleys Using the Optimum Offset Shallow Seismic Reflection Technique," in *Geotechnical and Environmental Geophysics*, S.H. Ward, ed. (Soc. Expl. Geophys., Tulsa, OK), **3**, 75–81.

Riley, D.C., 1993, "Special Report; Geophysical Activity in 1991," *The Leading Edge* **12**, 11, 1094–1117.

Steeples, D.W., and R.D. Miller, 1990, "Seismic Reflection Methods Applied to Engineering, Environmental, and Groundwater Problems," in *Geotechnical and Environmental Geophysics*, S.H. Ward, ed. (Soc. Expl. Geophys., Tulsa, OK), **1**, 1–30.

GAMMA-RAY SPECTROMETRY

DESCRIPTION

APPLICATIONS

Gamma-ray spectrometry is a tool for geologic mapping and uranium exploration and for locating radioactive contaminants at the surface. Because of the short-range penetration of gamma radiation in soils, surface surveys would be unable to detect subsurface concentrations of radioactive waste unless radionuclides had reached the surface via groundwater seeps or as radon gas in a carrier gas.

METHODOLOGY AND INSTRUMENT TYPES

Radiometric surveys are conducted over areas of suspected or known radioactive contamination by taking gamma-ray counts (a) over the affected area and (b) over a large nearby clean area for soil background reference. The DOE protocols for collecting information that satisfies EPA standards for detecting 0.185 bequerels (5 pCi) ^{226}Ra (radium) per gram above background in the first 0.15 m is given by Marutsky et al. (1984). Measurements are usually made at grid points. Hot spots are immediately marked and labeled on the ground, and more detailed follow-up surveys are then conducted around each hotspot. Protocols for conducting radiometric surveys and associated soil sampling are reviewed by Bendix and White (1982) and Marutsky et al. (1984).

Several types of instruments can be used (see Marutsky et al., 1984) for gross gamma and spectral measurements. These consist of scintillation counters, microroentgen (μR) meters, portable gamma-ray spectrometers, pressurized ionization chambers (PIC), and Geiger-Mueller (GM) counters. Each is a small, portable detector carried from a sling and held close to the surface for each measurement. Because the radius of investigation increases as the detector is raised, it is important to maintain the sensor a few centimeters above the surface.

Gross gamma-ray detectors count all the photons in an energy range above a threshold energy level. Counts/per second are converted to EPA standards for ^{226}Ra by calibrating the instrument against ^{226}Ra test pads in Grand Junction, CO. Gamma-ray spectrometers, on the other hand, count photons at discrete energy bands. The simplest spectrometers have four channels; narrow windows for ^{40}K (potassium), ^{214}Bi (uranium), and ^{208}Th (thorium) plus a broad window (0.5 to 5.0 MeV) for total count. There are also portable

DESCRIPTION *(cont'd)*

spectrometers that count and record 1024 channels of data. Because total-count devices give high values for ^{226}Ra over soils naturally rich in potassium and thorium, a spectrometer is the preferred instrument unless one is prepared to go to the trouble of determining and applying potassium and thorium corrections to each measurement. ^{222}Rn (radon) also decays to ^{214}Bi, and thus radon gas diffusing or transported to the surface cannot be differentiated from uranium in soils.

Gamma-ray count is affected by natural cosmic radiation and local soil conditions. Soil moisture and soil density absorb the radiation in a linear fashion, and thus soil moisture or density must be measured *in situ* at a number of locations to get a corrected reading. A collimator may be used to reduce the effects of ambient radiation

For gross gamma scanning, the recommended instrument is the scintillation counter with a separate detector containing a NaI crystal measuring at least 5 cm in diameter by 5 cm in thickness.

The output of the rate meter is given in counts/second (cps). The microroentgen meter is a scintillation detector with a smaller crystal and a meter readout scaled in units of μR/h.

INSTRUMENTATION AVAILABLE

VISTASPEC PORTABLE MULTI-CHANNEL GAMMA-RAY SPECTROMETER

Manufactured by Scintrex, this gamma-ray spectrometer is a hand-held device designed for environmental surveys. It can be used with a variety of NaI (Tl) sensors and includes an integral PC-compatible processor and built-in, DOS-compatible floppy disk drive, serial and parallel ports, graphical display, and a 1024-channel stabilized analyzer.

THE GEOMETRICS MODEL GR-410A

This four-channel spectrometer comes with a standard 21-cubic-inch NaI crystal and has both a four-digit illuminated readout on the front panel and a BNC output for continuous output of any single channel.

Supporting Software

None reported, but a user should be able to display stored data as a series of contour maps using available software.

INSTRUMENTATION AVAILABLE *(cont'd)*

Cost/Rental Information

A simple portable four-channel gamma-ray spectrometer, such as the GR-410A, sells for about $4000 and rents for $550/week.

Survey Rate

A slowly walking instrument operator either moves the detector along the ground in a linear fashion or sweeps it slowly in an "S"-shaped arc 1 to 1.5 m wide. Because the instruments have time constants that are often set to 2 to 3 seconds, the survey rate is usually about 1 km/h. The survey rate is slightly slower when readings at grid points have to be recorded and when hotspots have to be marked on the ground and on a map.

Reported costs of a ground radiometric survey are vary greatly, ranging from $43 to $620/line km. However, using the survey speed of one km/h, a single operator should be able to cover 8 km in an 8-hour day. Thus the cost amounts to approximately $124/line km.

Using larger crystal detectors, up to 0.008 m^3 (512 $in.^3$), one could mount an entire recording system in an off-road vehicle and cover a large area at a much faster survey rate.

Case History Information

No information available.

Application to the ESC

Radiometric surveys are mandatory in areas of uranium-mill tailings and waste dumps and over all areas used for the storage and disposal of mixed waste.

References

Bendix Field Engineering Corp., and M.G. White, 1982, *Review of Selected DOE Remedial Action Field Measurement Procedures for the Summer of 1982*, U.S. DOE, Div. Remedial Action Projects, Tech. Meas. Ctr., Grand Junction, CO, GJ/TMC-02(82), 71 pp.

Marutsky, S.J., W.D. Steele, B.N. Key, and K. Kosanke, 1984, *Surface Gamma-Ray Measurement Protocol*, Bendix Field Eng. Corp., Grand Junction, CO, and U.S. DOE, Grand Junction Projects Office, Grand Junction, CO, GJ/TMC-06.

METAL-SPECIFIC SPECTROMETRY

DESCRIPTION

Conventional geophysical techniques have limited value for detecting concentrations of heavy metals in soils and groundwater. There are several metal-specific spectrometers available that have been developed for metals exploration. Although these are primarily geochemical techniques, a brief mention is made of them here for completeness.

INSTRUMENTATION AVAILABLE

The only field-portable mercury spectrometer on the market seems to be the Scintrex **HGG-3** unit. This unit, carried on a backpack frame, is capable of making rapid analyses of Hg (mercury) in soil, soil gas, and water and can detect as little as 4×10^{-12} g Hg by means of atomic absorption using an intense 0.25-μm (2537-Å) spectral line. Measurements are displayed as a meter reading.

The **ATX-100** portable x-ray fluorescence spectrometer manufactured by Aurora Tech (address unknown but available from GISCO in Denver) has the advertised capability of detecting and analyzing over 60 elements in the field, including cadmium, copper, mercury, molybdenum, selenium, silver, tin, uranium, and zinc.

ACKNOWLEDGMENTS

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APPENDIX A

GEOPHYSICAL INSTRUMENT MANUFACTURERS AND SUPPLIERS

Bison Instruments, Inc.
5708 West 36th Street
Minneapolis, MN 55416-2595
Tel: (602) 926-1846
FAX: (602) 926-0745

Geometrics (formerly EG&G Geometrics)
395 Java Dr.
Sunnyvale, CA 94089
Tel: (408) 734-4616
FAX: (408) 745-6131

Geonics Limited
8 - 1745 Meyerside Dr.
Mississauga, Ontario
Canada L5T 1C6
Tel: (416) 670-9580
FAX: (416) 670-9204
Duncan McNeil, Pres.

Geophysical Survey Systems Inc.
13 Klein Dr.
North Salem, NH 03073-0097
Tel: (603) 893-1109
FAX: (603) 889-3984

GEOSTUFF
19623 Vis Escuela Dr.
Saratoga, CA 95070
Tel: (408) 867-3792
FAX: (408) 867-4900

GISCO
900 Broadway
Denver, CO 80203
Tel: (303) 863-8881
FAX: (303) 832-1461

Oyo-Geospace Instruments, Inc.
7334 N. Gessner
Houston, TX 77040
Tel: (713) 937-9700
FAX: (713) 937-8262

Sensors and Software, Inc.
5566 Tomken Rd.
Mississauga, Ontario
Canada L4W 1P4
Tel: (905) 624-8909
FAX: (905) 624-9365
Peter Annan, Pres.

Phoenix Geophysics, Ltd.
3871 Victoria Park Ave.
Unit No.3
Scarborough, Ontario
Canada, M1W 3K5
Tel: (416) 491-7340
Leo Fox, Pres.

Scintrex, Ltd.
222 Snidercroft Rd.
Concord, Ontario
Canada L4K 1B5
Tel: (416) 669-2280
FAX: (416) 669-6403 and 5132
Abe Rolnick, Pres.

Zonge Engineering & Research Organization, Inc.
3322 East Fort Lowell Rd.
Tucson, AZ 85716
Tel: (602) 327-5501
FAX: (602) 325-1588
Ken Zonge, Pres.

APPENDIX B

GEOPHYSICAL SOFTWARE COMPANIES

GEOSOFT, Inc.
204 Richmond Street West
Suite 500
Toronto, Ontario
Canada, M5V 1V6
Tel: (416) 971-7700
FAX: (416) 971-7520

Interpex, Ltd.
715 14th St.
Golden, CO 80402
Tel: (303) 278-9124
FAX: (303) 278-4007

APPENDIX C

TABLE OF ACRONYMS

CDP	common depth-point data acquisition method
DNAPL	Dense non-aqueous phase liquid
EM	DOE Office of Environmental Restoration and Waste Management, or electromagnetic
E/EM	electrical and electromagnetic methods
ESC	Expedited Site Characterization Program
FEM	frequency-domain electromagnetic methods
FY	federal fiscal year beginning October 1
GPR	ground penetrating radar methods or instrumentation
GPS	global positioning system
IP	induced polarization method
LCD	liquid crystal display
NMO	normal move-out method
OTD	Office of Technology Development
SP	self-potential method or shotpoint in seismics
TEM	time-domain electromagnetic methods or instrumentation
UST	underground storage tank
VOC	volatile organic components

APPENDIX D

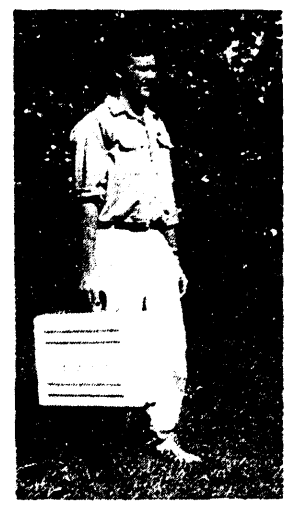
TABLE OF SCIENTIFIC ABBREVIATIONS AND UNITS

A	ampere, also mA for milliAmpere
cps	gamma-ray counts per second
cm	centimeter
d	day
dB	decibel
h	hour
Hz	hertz, cycles per second
kg	kilogram
km	kilometer
lb	pound
m	meter
MHz	megaHertz (10^6 Hz)
ms	millisecond (10^{-3} s)
ns	nanosecond (10^{-9} s)
nT	nanoTesla, 10^{-9} of the earth's field
s	second
S	siemen (SI unit of conductance, 1 S = 1 mho)
pCi	picoCurie, 10^{-12} curies or 3.7×10^{-2} bequerels
R	roentgen, exposure to X- and gamma-rays, $1R = 2.58 \times 10^{-4}$ coulomb/kg
V	volt
ρ_a	apparent resistivity (m/S)
μs	microsecond
Ω	ohm (S^{-1})

APPENDIX E

PRODUCT LITERATURE

This appendix contains representative examples of the types of instruments available for geophysical site characterization. These examples are meant to be illustrative only. Neither LBL nor DOE endorses one instrument over another.



Digital Instantaneous Floating Point (DIFP)™ Signal Stacking Seismographs, Bison Series 9000 (Patent Pending)

TECHNIQUES

- High-resolution seismic reflection surveys
- High-resolution seismic refraction surveys
- Vertical seismic profiling (VSP) and check shot surveys
- Crosshole and tomography surveys

APPLICATIONS

- Oil, gas, coal, and mineral exploration
- Water resource, aquifer, and contamination studies
- Construction and engineering studies
- Mining, tunneling, and borehole studies
- Research and education
- Vibration monitoring

SPECIFICATIONS: BISON SERIES 9000 DIFP™ SEISMOGRAPHS

Model Numbers: 9012 (12 channel), 9024 (24 channel), 9048 (48 channel).

Number of Channels: 1, 3, 6, 12, 24, and 48. Note: The number of acquisition channels used is keyboard-selectable from 1 up to the number of channels installed (12, 24, 48).

Sample Interval: 50,100, 200, 250, 500, 1000, 2000, 4000 microseconds. Note: 50 microseconds available when recording 24 channels or less.

Record Lengths:
48 channel:500, 1000, 2000, 5000
24channel: 500, 1000, 2000, 5000, 10000
12channel:500,1000, 2000, 5000, 10000, 20000
6 channel: 500, 1000, 2000, 5000, 10000, 20000, 40000
3 channel: 500, 1000, 2000, 5000, 10000, 20000, 40000, 80000
1 channel: 500, 1000, 2000, 5000, 10000, 20000, 40000, 80000, 160000.

Frequency Response: 4 - 4000 Hz. (-3 db)

Analog filters:
LOW-CUT: 4-1020 Hz. in 4 Hz. steps, 2-pole Butterworth (12 db/octave)
HIGH-CUT: 60, 90, 120, 180, 250, 500, 1000, 2000, 4000 Hz., 6-pole Butterworth (36 db/octave)

DIFP Dynamic Range: 120 db.

Digitizer: 16 bits (15 bits plus sign)

K- Gain Range: 0, 20, 40, 60 db. (may be split in any channel combination and auto matically set after one test impact). 12, 32, 52, 76 db optional.

Maximum Geophone Input: +/- 5.0 volts

Equivalent Input Noise: 0.7 microvolts RMS (8-1000 Hz.)

Input Impedance: 1000 ohms (10,000 ohms optional)

Stacker Word: 32 bits.

RS232 Port: Asynchronous serial RS232 1200-115000 baud rate (keyboard selectable).

Parallel Port: Bidirectional - IBM PS/2(tm) compatible (optional).

Output Format: Long - 32 Bit Fixed Gain (4 bytes) Float - 16 Bit Mantissa, 4 bit gain (2.5 bytes).

Printer: 3565 dots/sq cm (23000 dots/sq inch), direct write thermal.

Resolution: Paper width 10.9 cm (4.3 inch).

Print Modes: Fixed Gain Normalized, or AGC, Variable Area, or wiggle trace every sample, or every 2nd sample, or every 4th sample, etc.

Nonvolatile Mass Memory: -Up to 18 megabytes in 3 megabyte increments (optional).
(or) Disk Drive: -One or two 2.5 inch 60 megabyte disk drives (optional).

Display: 4 Lines, 80 column, rugged wide temperature range LCD display.

Keyboard: Sealed tactile membrane with full alphanumeric and seismic function keyboard.

Time Standard: Crystal oscillator ±0.005% (50ppm).

Microprocessor: 68HC000 (C-MOS 68000) 12 megahertz.

Real Time Clock Calendar: Internal clock with battery backup provides calendar, date, and 24-hour time of day. Printed and stored with record.

Noise Monitor: Real-time display of noise on each channel.

Battery Monitor: Displays battery voltage in 0.1 volt increments.

Trigger (Record Initiation): Requires signal from external source (switch closure or open, saturated NPN transistor to ground is provided for controlling an external device such as a source or another seismograph). ARM/DISARM or AUTO-ARM allow for manual or automatic system arming after impact.

Delay: The start of data recording can be delayed up to 9.999 seconds after the trigger (1 millisecond increments)

Special Functions:
HelpKey: Provides instant operation instruction on the proper use of any key or command.
Auto -Gain Key: Allows the instrument to automatically set the proper K-gain after one test impact.
Preset Key: Allows the operator to store up to 10 sets of setup and acquisition parameters.

Physical: Size: 37.6 x 51.8 x 19.0 cm. (9048, 37.6 x 51.8 x 21.5 cm) Weight: 10 - 14kg. (varying with models)

Power: 11-18 volts DC, 9012 - 21 watts 9024 - 32 watts, 9048 - 55 watts

Environmental: Temperature, Storage: -40° to 60° C (-40° to 140° F) Temperature, Operationing: 0° to 50° C (32° to 122° F)

BISON INSTRUMENTS, Inc.

Please note that technical specifications are subject to change without notice.
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Telephone: (612) 926-1846 FAX (612) 926-0745

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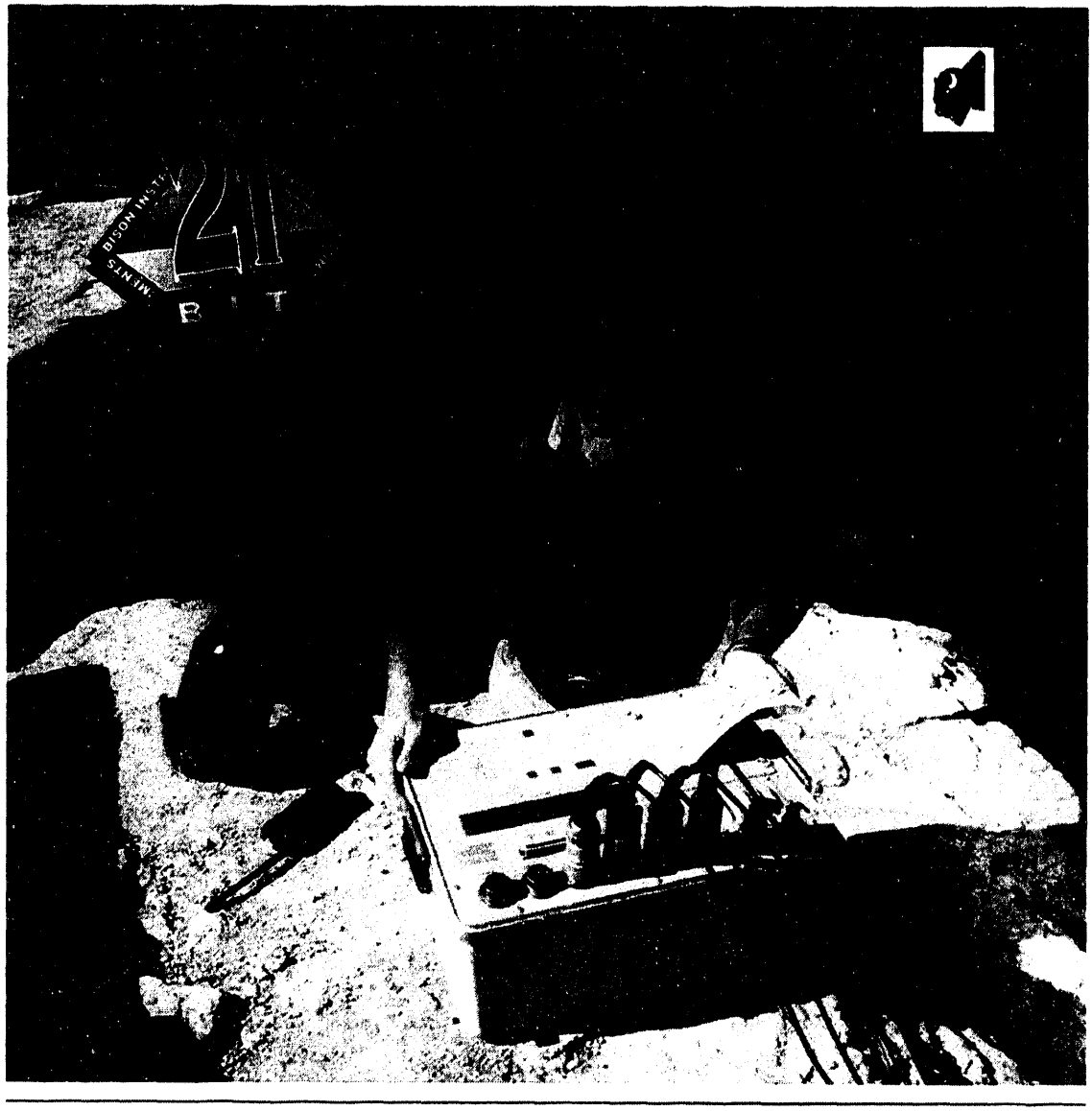

(DIFP)™ Exploration Seismograph Bison Series 9000-A (Patent #4,823,129)

Features Of The 9000-A

- Onboard IBM Conpatible PC
- 21 Bit Dynamic Range
- 12 - 124 Channels in a Rugged Submersible Box
- Smallest 120 Channel
- Lightest 120 Channel
- Lowest Power Requirement 120 Channel
- Highpass **Analog** Filters (4-1020 Hz)
- Expandable 12, 24, 36, 48, 60...124 Channels
- Sample Rates to 50 Microseconds
- Keyboard Selectable Preamp Gain (0-60 dB)
- PC Compatible and Stand Alone Operation
- Field Proven
- 150 G Shock Rated Hard Drive Storage

SPECIFICATIONS: BISON 9000-A DIFP™ SEISMOGRAPHS

Model Numbers:
9012A (12 channel), 9024A (24 channel), 9036A (36 channel), 9048A (48 channel), 9060A (60 channel), 9072A (72 channel), 9084A (84 channel), 9096A (96 channel), 90108A (108 channel), 90120A (120 channel).

Number of Channels:
Keyboard selectable 1, 3, 6, 12, 24, 36, 48, 60, 72, 84, 96, 108, and 120 up to the maximum number of channels installed.

Auxiliary Channels:
4 (optional). Auxiliary channel characteristics are identical to recording channels.

Sample Interval:
1/20, 1/16, 1/10, 1/8, 1/5, 1/4, 1/2, 1, 2, 4, milliseconds. 1/20 - 1/10 not available when recording more than 48 channels. 1/20 - 1/8 not available when recording more than 96 channels.

Record Lengths:
500 - 12000 samples per channel with 120 channels recording. Proportionately longer record lengths are available when less than 120 channels are recording.

Frequency Response:
4 - 4000 Hz. (-3db).

Analog Filters:
Low-cut: 4 - 1020 Hz. in 4 Hz. steps 2 pole Butterworth (12 db/octave). Frequency is keyboard selectable.
High-Cut: 4000, 2000, 1000, 500, 250, 180, 120, 90, 60 Hz. 6-pole Butterworth (36 db/octave), keyboard selectable.

Digitizer:
Two 16 bit analog to digital converters per channel.

Gain:
0, 20, 40, 60 db. Keyboard selectable and may be split in any channel combination.

Maximum Geophone Input:
± 5.0 volts at 0 db gain.

Input Impedance:
Differential: 10,000 ohms in parallel with 5nF capacitance.
Common mode: 2,500 ohms in parallel with 20nF capacitance.

Equivalent Input Noise:
0.75 microvolts RMS, 60 db gain, 8 - 1000 Hz., relative to input
0.4 microvolts RMS, 60 db gain, 8 - 125 Hz., relative to input.

Distortion:
- 80 db (0.01%) S/N+D at 25 Hz., 60 db gain.

Stacker Word:
32 bits.

Printer:
Direct write thermal, 3700 dots/ sq. cm (27000/sq. in.). Paper width 11.4 cm (4.5 in.), fixed gain normalized or AGC, variable area or wiggle trace print.

Keyboard:
Sealed tactile membrane with full alphanumeric and seismic function keys.

Display:
Liquid crystal, 4 lines of 80 characters, rugged, wide temperature range, shock resistant.

RS-232C Port:
1200 - 115000 bps, DB9 connector, for instrument control and data transfer.

IEEE-488 Port:
IEEE-488 compatible port for instrument control and data transfer (optional).

CRT Port:
Standard VGA (640 x 480) and SVGA (1024 x 768) 16 color CRT display of traces, noise, and instrument settings.

SCSI Port:
8 bit asynchronous, single ended, seismograph can control one or more devices including 4mm (DAT), 8 mm, or 9-track tape drives and external hard drives.

Keyboard Port:
Accepts optional PC keyboard.

Floppy Disk:
Standard built-in 3.5 inch, 1.44 Mb for seismograph software update and DOS applications.

Internal Data Storage:
Shock mounted rugged, 2.5 inch disk drive up to 400 megabyte capacity.

Output Data Format:
SEG-2, SEG-Y, Bison 32 bit formats.

Time Standard:
Crystal oscillator ±0.005% (50 ppm)

Microprocessor:
Intel 486DX 33 MHz, 16 megabytes of RAM, operates as a seismograph or standard IBM compatible computer.

Clock/Calendar:
Date and 24 hour time of day, printed and stored in record.

Noise Monitor:
Real-time display of signal levels on all channels. Numeric format on LCD display. Graphic display on CRT (optional).

Battery Monitor:
Warning light for over and under voltage. Numeric display of battery voltage.

Trigger:
Seismograph can be triggered by external contact closure or start geophone, or seismograph can trigger a source. In either case recording can be delayed by 0-9999ms. When the seismograph triggers the source negative delays are possible.

Physical:
Size: 37.6 x 51.8 x 26.5 cm (14.8 x 20.4 x 10.5 in.)
Weight: 11 - 18 kg. (24-40 lbs.) depending on model.

Environmental:
Temperature, Storage: -40° to 80° C (-40° to 140° F)
Temperature, Operating: 0° to 50° C (32° to 122°F)
Humidity: 10% to 90% noncondensing.

Power:
11 - 18 volts DC, 12 channel - 45 watts, 48 channel - 80 watts, 96 channel - 130 watts, 120 channel - 165 watts, approx.

Please note that these specifications are subject to change without notice.

BISON INSTRUMENTS, Inc.
5708 West 36th Street • Minneapolis, MN 55416-2595
Telephone: (612) 926-1846 • FAX: (612) 926-0745

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Bison Portable Proton Magnetometer MMP - 203

The MMP-203 precision portable magnetometer measures the absolute value ("total field") of the earth's magnetic field. The magnetometer can be used for mineral exploration, oil exploration, hazardous waste site studies, archeological mapping, geophysical research and general geologic mapping. It is particulary useful for finding buried metallic drums.

The instrument is simple and reliable and does not require a skilled operator. A one-button operation measures the magnetic field and displays the value on a five character, high-contrast, LCD.

The MMP-203 is based on the Overhauser Effect for greater efficiency and better signal to noise ratios usually found in military grade magnetometers.

A custom-made, light-weight back pack harness is provided such that the sensor and staff are mounted at the operator's back while the console is mounted at chest level providing two free hands while traversing.

The combination of the simple reliable design, wide operating temperature range, low power consumption and low cost make the MMP-203 suitable for a wide variety of applications.

PORTABLE PROTON MAGNETOMETER MMP-203

TECHNICAL DATA

Range:	20000 to 100000 Gammas 10 scale ranges
Display:	Five digit LCD plus Low Battery indicator and polarization indicator
Resolution:	1 Gamma
Accuracy:	± 2 Gamma
Sensor:	Dual Nuclear Magnetic Resonance coils
Sample rate:	1 sample/3 seconds (max)
Battery voltage:	10 to 16 volts
Battery type:	AA cells (10 required)
Power consumption:	0.7 watts (1 sample/10 sec)
Operating temperature:	-30° C to 50° C
Physical:	
Instrument console:	Size: 200 x 85 x 200mm (8 x 3.5 x 8 inches) Weight: 2.0 Kg (4.4 lbs)
Sensor and staff:	Size: 140 x 120 x 910 mm (5.5 x 4.75 x 35.8 inches) Weight: 1.4 Kg (3.1 lbs)
Standard accessories:	console, sensor with staff and sensor circuitry box, backpack (harness), battery belt, one set of batteries, operation manual

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BISON
INSTRUMENTS

EARTH RESISTIVITY METER MODEL 2350B

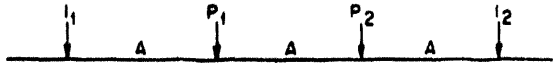
The Bison Model 2350B Earth Resistivity Meter and System is designed for extended shallow depth earth exploration, pollution monitoring, and archaeological problems. Exploration projects include the location of ground water aquifers, gravel or rock deposits, ore bodies, topographic highs or lows on a bedrock surface, areas of weathered bedrock on an otherwise solid rock surface; or determining the variations in depth of subsurface conditions, for example, soil layer overlying gravel or bedrock, or sand overlying clay over bedrock. Pollution monitoring includes continuing studies of ground water levels and salinities, delineation of pollutant plumes, monitoring of landfills, leakage monitoring of storage lagoons, and studies of the movement of organic pollutants. Archaeological sites have been successfully mapped in detail before excavation. Users include geophysicists, geologists, environmentalists, civil engineers, hydrologists, sand and gravel operators, sanitary engineers, mining engineers, highway engineers, contractors, quarry operators, drillers, and archaeologists.

BISON MODEL 2350B SPECIFICATIONS

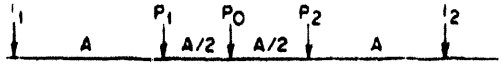
Can be used with ALL electrode spreads.

(Including Dipole/Dipole and Bristow)

WENNER SOUNDING



LEE MODIFICATION OF WENNER



SCHLUMBERGER SOUNDING

SPECIFICATIONS — MODEL 2350B

High Voltage: 720 Volts (peak to peak).

Nominal Excitation Frequency: 11 Hz to minimize cable coupling and skin effect.

Frequency Control Adjustment: ±15% to minimize extraneous "beat frequency" earth current interference.

Direct Digital Reading of Resistance: Quantity Measured $=2\pi\frac{V}{I}$

Resolution: One part in 10,000 maximum.

Accuracy: ±2% per range setting.

Electrode Balance Circuit: On 0.001 multiplier range, to maximize accuracy at high electrode resistance.

Five Range Scales: 0.001; 0.01; 0.1; 1.0; 10.0. To cover all types of sub-surface materials and situations.

Range Extension: Exclusive with Bison instruments (center black push button on panel). For use when unusually high precision is required or when contact resistance at potential electrodes is unusually high (frozen ground or very dry surface condition).

All Solid State: Integrated circuit construction for long service life and stability.

Current: Automatically controlled to a nominal 28 milliamperes.

Current Monitor: Separate 0-30 Milliampere Meter for continuous monitoring of electrode current.

Five Terminal System: The Bison Model 2350B can be used with all electrode spreads: Wenner, Lee, Schlumberger, Dipole-Dipole, Bristow, Pole-Dipole, Mise-a-la-Masse, Gradient, and others.

Operates at the touch of a button automatically without a separate power switch.

Test Circuit: Built in to check operation at any time.

Portable and Lightweight: Weight: 14 lbs. (6.4 kg.). Packaged in a Bison designed weather resistant case, 6 x 12 x 10 inches (152 x 305 x 254 mm). Complete with self-contained power pack.

Model 2350B Earth Resistivity Meter: Provided complete with batteries, instructions and interpretation procedures.

ACCESSORIES

Model 2225 Heavy Duty Reel-Electrode Accessory Kit includes four 24" zinc plated electrodes, four reels with copper-weld vinyl nylon insulated cable for 300 feet (90 meters) "A" spacing plus Lee electrode and cable. 30 lbs. (13.6 Kg.) shipping weight.

Specifications subject to change without notice.

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BISON ELASTIC WAVE GENERATOR I
MODEL 1417-I
PORTABLE SEISMIC SOURCE

FEATURES

- High energy - light weight
- Easy to airfreight
- Connect to standard trailer hitch
- Reliable mechanism
- Noninvasive

APPLICATIONS

- Hazardous waste site characterizations
- Water resource and aquifer studies
- Oil, gas, coal, and mineral exploration
- Construction and engineering studies
- Mining and tunneling studies
- Research and education

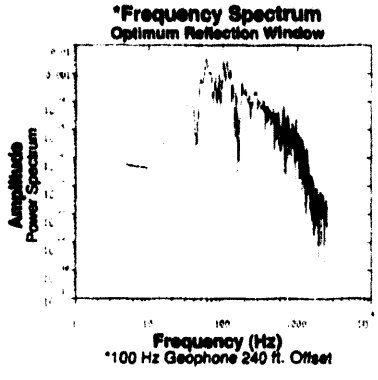
ELASTIC WAVE GENERATOR I SPECIFICATIONS

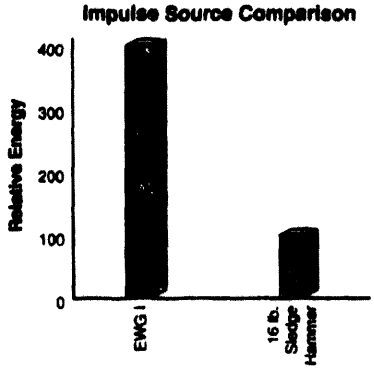
GENERAL:

The Elastic Wave Generator I (EWG I) is an efficient and reliable, accelerated weight drop, seismic energy source which is based on slingshot technology. This simple system for storing and releasing energy allows the generation of high-frequency, high-energy seismic signals. The EWG I mechanism is trouble-free and inexpensive to maintain. The system is designed to quickly dismantle into five light weight pieces which are easy to airfreight. It is compatible with nearly every trailer hitch.

APPLICATIONS

The EWG I is compatible with any exploration seismograph, but is most effective with signal enhancement (stacking) seismographs. On many sites the EWG can be used to explore to depths in excess of 1000 feet using the reflection technique.





COMPARISON TO OTHER SEISMIC SOURCES

Dynamite and ballistics are becoming increasingly difficult to use. They are dangerous to employ, nearly impossible to stack (sum several shots) and difficult to acquire permits to use. The EWG I is noninvasive and requires no drill hole. The EWG I hammer can be filled with silica sand or steel shot to increase the weight and energy as well as lower the frequency.

OPERATION

A 5.5 hp gasoline engine drives a hydraulic system to reliably and quietly lift a 60 pound hammer loading a large industrial elastic. A reliable mechanism releases the hammer at the top of the hydraulic cylinder stroke. The system is controlled from one hand-operated switch. Using a proven design and fewer moving parts, the EWG I is inexpensive to maintain.

GENERAL SPECIFICATIONS

Model: EWG I
Physical:
- Weight: 240 lbs. (with hammer)
- Mast Height: About 84"
- Hammer Weight: 60 lbs. empty (100 lbs. with silica sand)

Cycle Time: 3 seconds (average)
Power Supply: 5.5 hp gasoline engine
Trailer Hitch Ball Hole: .75 inch (3/4 inch)
Impact Plate: 14" X 16"

Please note that technical specifications are subject to change without notice.

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MODEL	DESCRIPTION	PER DAY RENTAL*	MOB/DEMOB COST**
	9000 Series digital Instantaneous Floating Point Seismograph (DIFP). One 60 megabyte hard drive storage board is included with each 9000 seismograph. (Array cables and geophones are listed below.)		
90120	120 Channel	$500.00	$500.00
9048	48 Channel	$200.00	$400.00
9024	24 Channel	$175.00	$350.00
9012	12 Channel	$150.00	$300.00
	7000 Series Digital Instantaneous Floating Point Seismograph (DIFP). One 6 megabyte solid state storage board is included with each 7000 seismograph. Additional boards can be included at a rate of $32.00 per day. (Array cable and geophones are listed below.)		
7024	24 Channel	$129.00	$350.00
7012	12 Channel	$ 80.00	$300.00
	5000 Series Digital Instantaneous Floating Point Seismograph (DIFP). One 3 megabyte solid state storage board is included with each 5000 seismograph. (Array cable and geophones are listed below).		
5012	12 Channel	$ 70.00	$300.00
1417-3	Elastic Wave Generator III (EWG) accelerated weight drop, seismic source	$150.00	$500.00
1417-2	Elastic Wave Generator II (EWG) accelerated weight drop, seismic source	$100.00	$500.00
1417-1	Elastic Wave Generator I (EWG) accelerated weight drop, seismic source	$ 80.00	$500.00
1406A	Radio Trigger Link	$ 18.00	$ 80.00
1430A	Blaster Box (for use with Models 1570, 1575, 1580, 7000, 8000 and 9000)	$ 5.00	$ 20.00
RLS 120	Roll-Along Box for CDP Data Collection	$ 20.00	$ 50.00
1463	12-Channel Spread Cable 55 feet between takeouts 10 meters (32.8 ft) between takeouts 10 feet between takeouts 5 feet between takeouts	$ 18.00	$ 50.00
1463-24	24-Channel Spread Cable (use with roll box) 10 feet between takeouts 55 feet between takeouts	$ 27.00	$ 50.00
1436-1ST	Geophone, Vertical 8 Hz, 30 Hz, 60 Hz or 100 Hz.	$ 0.50	$ 2.00
1465-1	Downhole Shearwave Hammer, 2.75" diameter and accessories	$ 52.00	$450.00
1462	Downhole Triaxial Geophone	$ 7.00	$ 75.00
2350B & 2225	Earth Resistivity Systems with Accessory Kit for Wenner "A" spacing to 90 meters	$ 20.00	$200.00
GP-81	McPhar Proton Magnetometer, 2-gamma sensitivity	$ 20.00	$100.00
MMP-203	Bison Proton Magnetometer, 2-gamma sensitivity	$ 20.00	$100.00
386	Laptop PC	$ 25.00	$100.00
3101A	Magnetic Susceptibility meter	$ 20.00	$100.00

* Discounted monthly rental rates can be provided upon request

** The mobilization/demobilization fee does not include shipping charges or custom broker fees. It is to cover our expenses of packing, handling and checking the instrument before and after rental for proper operation and/or damage.

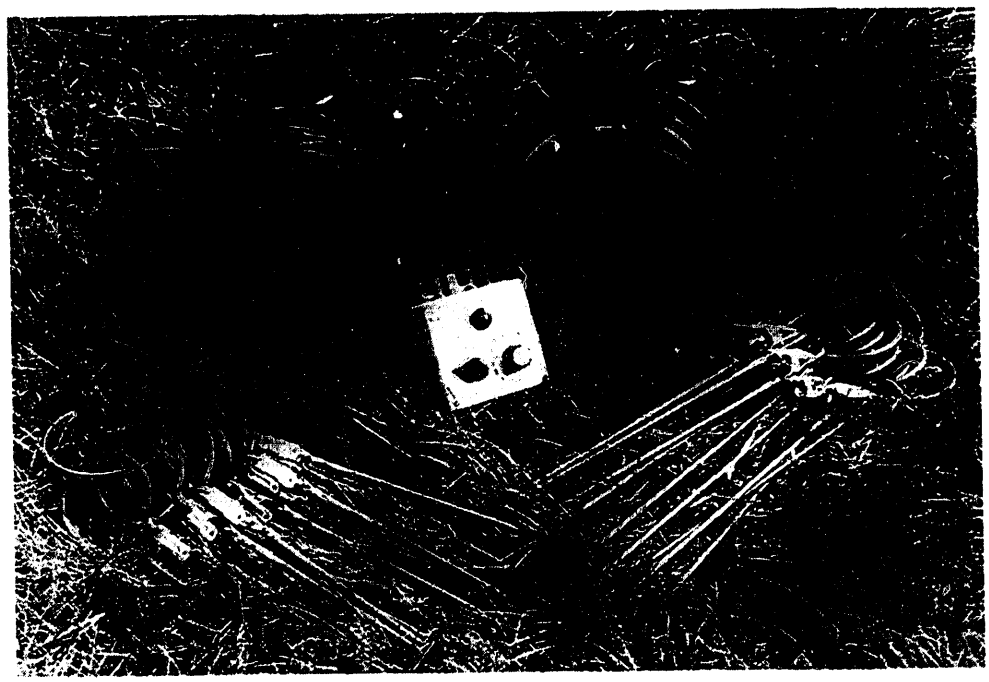
CAMPUS GEOPHYSICAL INSTRUMENTS LTD

OFFSET SOUNDING CABLE SYSTEMS

The BGS OFFSET SOUNDING SYSTEM is a revolutionary new technique for obtaining high quality apparent resistivity sounding data rapidly and with limited manpower. The system is ideal for use in engineering, hydrogeological, archaeological, geological and other applications.

THE OFFSET SOUNDING SYSTEM OFFERS THE FOLLOWING ADVANTAGES OVER TRADITIONAL SCHLUMBERGER AND WENNER SYSTEMS.

- POWERFUL REDUCTION OF LATERAL RESISTIVITY EFFECTS



The BGS OFFSET SOUNDING SYSTEM comprises two multicore cables which are connected at the centre of the electrode line to a switch box and from there to the resistance measuring instrument. A set of 9 electrodes is connected to each cable with a central electrode being also included. With this small number of electrodes it is possible to measure a 16 point true Wenner apparent resistivity curve in which lateral resistivity effects have been substantially reduced. Compare this with the much greater number of electrode positions used in traditional Schlumberger and Wenner soundings and the poorer results these produce.

Resistance measurements are conducted rapidly with electrode spacing being increased merely by switching. Other switch positions permit a field check on the reliability of the observed results.

- GREATLY REDUCED LABOUR COSTS
- SMALLER NUMBER OF ELECTRODE POSITIONS
- INCREASED NUMBER OF SOUNDINGS PER DAY

WITH THE OFFSET SOUNDING SYSTEM

- STANDARD INTERPRETATION TECHNIQUES ARE EMPLOYED
- THE EQUIPMENT IS EASILY CARRIED AND OPERATED BY ONE PERSON
- IMPORTANT FIELD CHECKS ARE POSSIBLE

APPLICATIONS

The high quality of the measurements and the efficiency of this modern sounding system has led to its application in hydrogeological, engineering and other applications where spacings of less than 1000m are employed.

The Campus Offset Sounding System comprises:

1. Two robust polyurethane covered cables with moulded take-outs at each electrode position.
2. 21 lightweight steel electrodes with connectors.
3. Moulded weatherproof switchbox and connecting leads.
4. Manual and data processing software.

SYSTEMS AVAILABLE

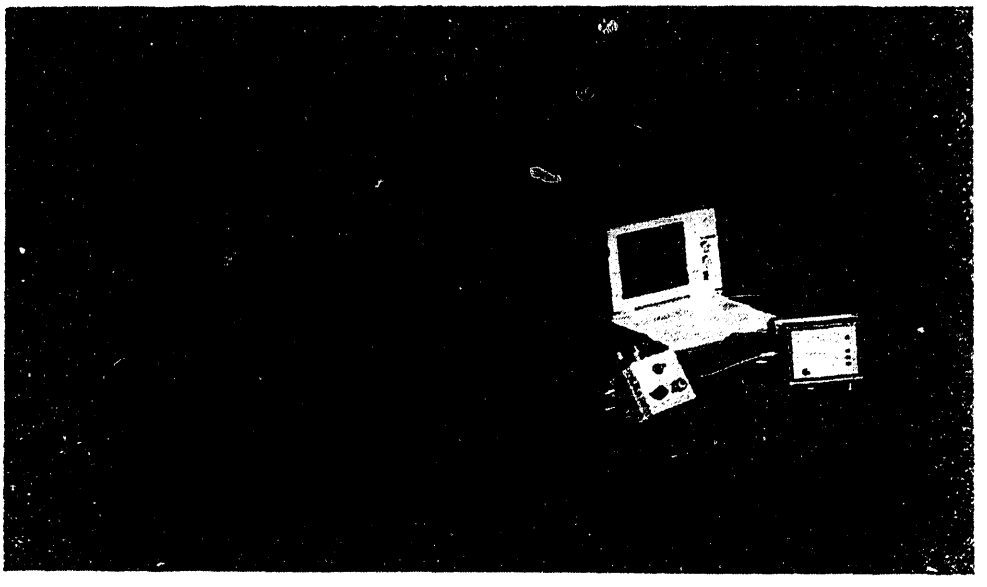
BGS-128 16 Wenner resistivities at spacings $^1/_2$,1,$1^1/_2$,2,.....128m

BGS-256 18 Wenner resistivities at spacings $^1/_2$,1,$1^1/_2$,2,.....256m

BGS-512 Extension cables for use with BGS-256

REFERENCE

Barker,R.D. 1981. The Offset system of electrical resistivity sounding and its use with a multicore cable. Geophysical Prospecting, 29, 128.



Offset Sounding System in use with Campus GEOPULSE Earth Resistance Meter and laptop computer.

SCINTREX
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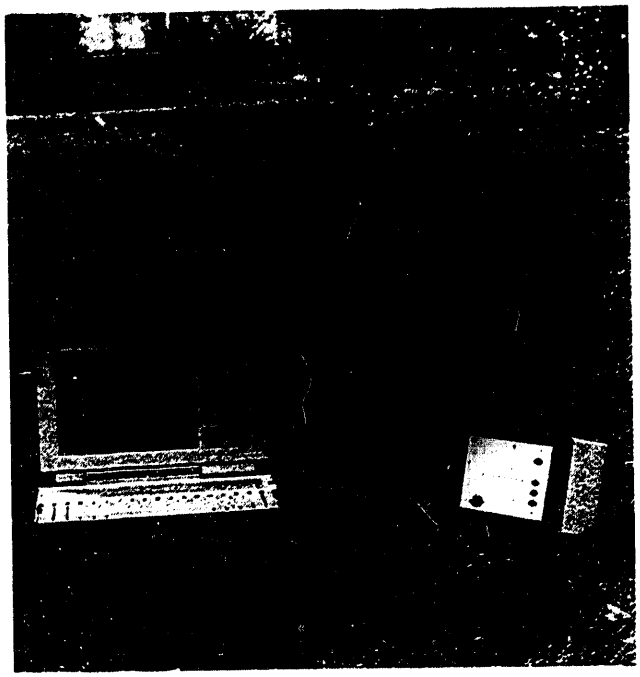
CAMPUS GEOPHYSICAL INSTRUMENTS LTD

ARCHAEOLOGICAL SYSTEMS

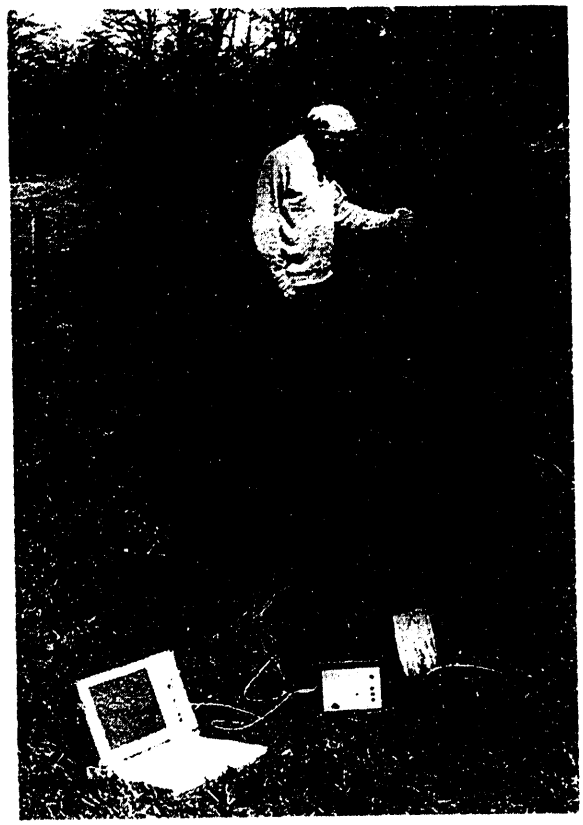


ARCHRES ARRAY

- fast traversing
- manual or computer control
- wide choice of configurations
- resistivity imaging

SQUARE-4 PROBE

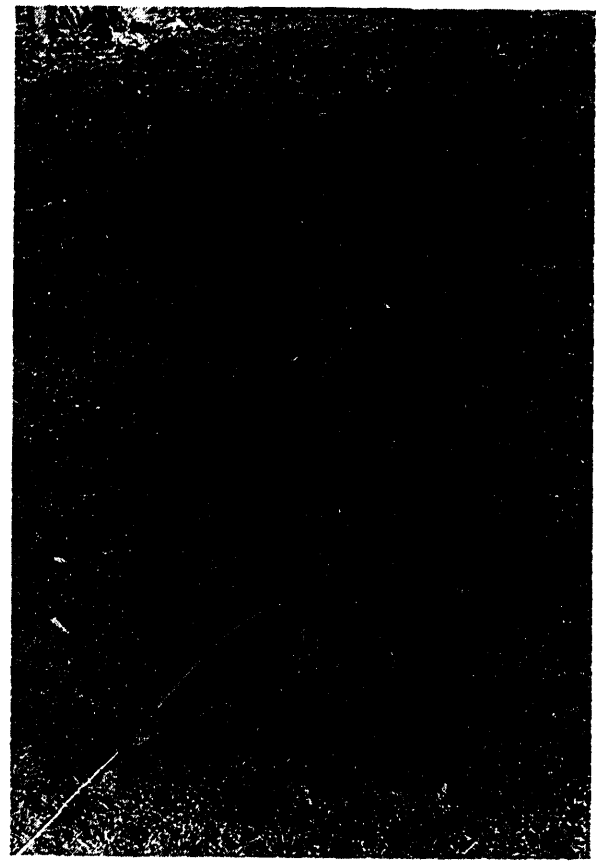
- for shallow detailed surveys
- orientation insensitive
- one man operation
- automatic logging and plotting of data
- easily portable four electrode probe



THE GEOPULSE RESISTANCE METER

Whatever the technique adopted for resistivity surveying, in archaeology or in any other field, it is only as good as the resistivity meter used. For archaeological work this needs to be, above all else, simple to use and fast to read. Accuracy, reliability, portability - these are all features one looks for in a modern instrument, but in addition a data logging facility is also important.

In designing the **GEOPULSE** Campus has paid attention to all these and many other factors. To achieve flexibility the instrument has a modular construction, central to which is the voltage measuring circuitry, display and control panel. Different modules are incorporated in it depending on the purpose for which it is to be used. For archaeological surveys the **GEOPULSE**, fitted with its appropriate module, is a self contained instrument suitable for use with mobile frames or with multi electrode arrays. It is more powerful than many other instruments designed solely for archaeological work and is, therefore, suitable not only for conventional surveys but also for special types of investigation, such as, for example, potential gradient profiling.



THE CAMPUS SQUARE-4 PROBE

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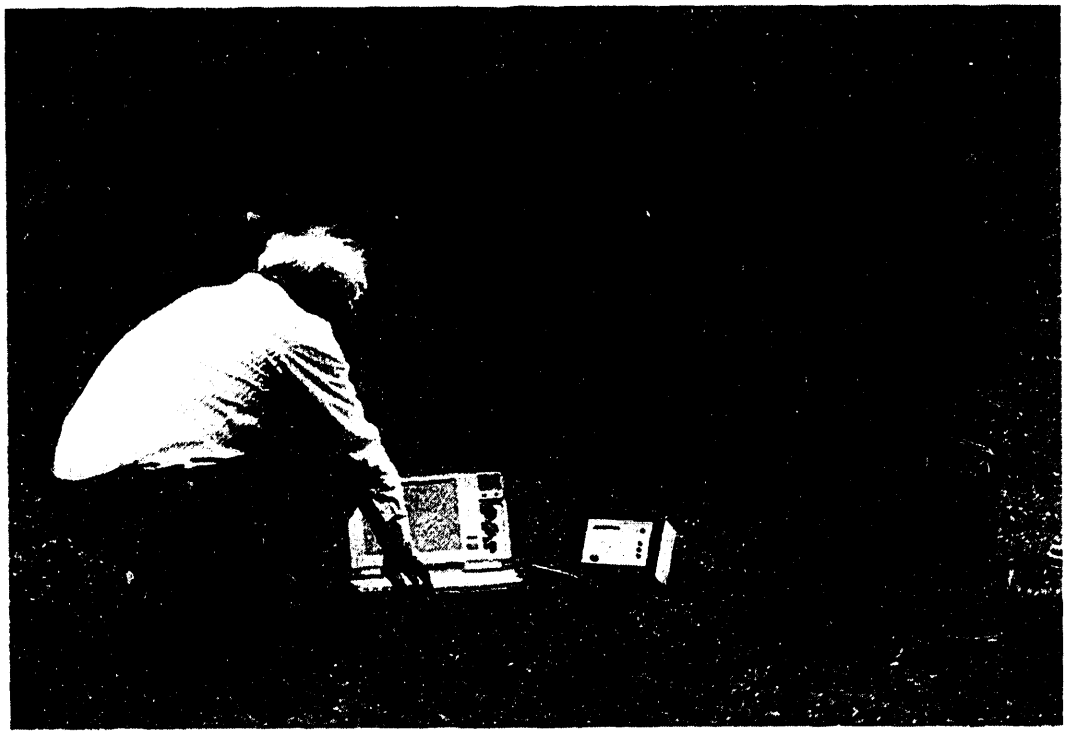
Telephone: (905) 669-2280
Telex: 06-964570
Telefax: (905) 669-6403 / 5132

CAMPUS GEOPHYSICAL INSTRUMENTS LTD

MRT SYSTEM

A MICROPROCESSOR CONTROLLED RESISTIVITY SYSTEM



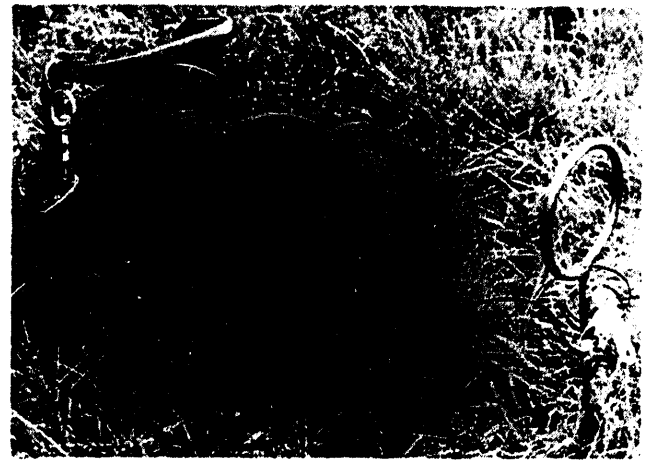
- MULTI-ELECTRODE ARRAY PROVIDES DETAILED DEPTH SECTIONS.
- LIGHT REEL MOUNTED SECTIONED CABLE MAKES FOR PORTABILITY AND RAPID DEPLOYMENT.
- FOR USE WITH ANY BATTERY OPERATED IBM COMPATIBLE P.C. AND RESISTIVITY METER.
- GREATLY EXTENDS THE APPLICATIONS OF THE RESISTIVITY METHOD.

COST EFFECTIVE MULTI-DIMENSIONAL RESISTIVITY SURVEYS WITH THE MRT SYSTEM

The **CAMPUS MRT System** is effectively an electrical ground imaging device. It provides a cross section of the distribution of resistivity in the subsurface down to depths of 150 m or so. The data can be interpreted to produce a two-dimensional geoelectric section. The **MRT System** thus opens the way to a much wider application of the resistivity method than has hitherto been normal practice.

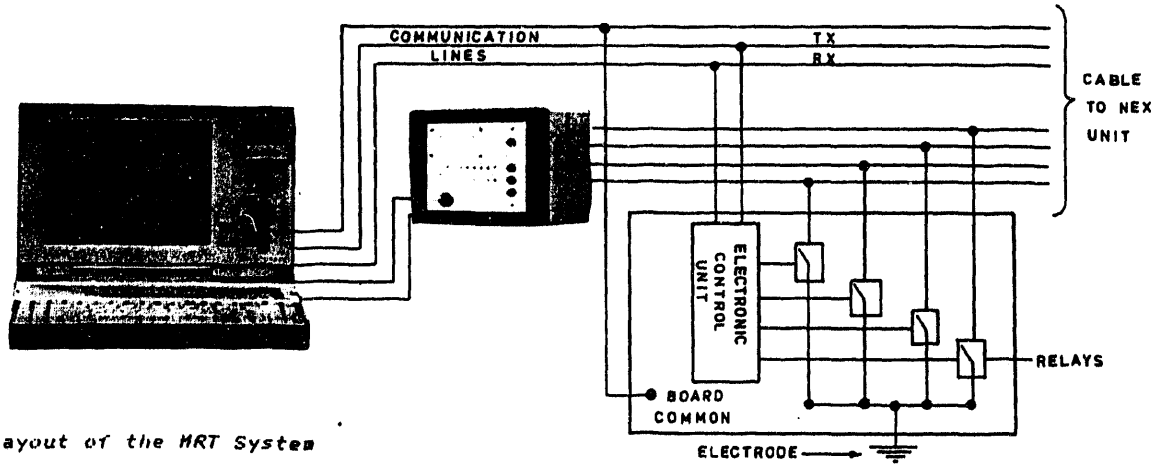
At present depth sounding is by far the most widely used technique, constant separation traversing, though important, being more limited in its applications. Both techniques, however, provide poor, often uninterpretable, data if used in areas where the subsurface shows relatively rapid lateral as well as vertical variation in electrical properties, e.g. where the rocks are strongly faulted, steeply dipping or much folded. Such areas can be explored by repeated constant separation traversing where the spacing is increased at each pass. In this way an apparent resistivity depth section (pseudosection) is built up which, when contoured, provides useful qualitative information about the earth interpretable in terms of geological structure if the electrical properties of the locally occuring formations are known.

The new **Campus MRT System** has been designed to remove the practical difficulties that are inherent in carrying out "two-dimentional" resistivity surveying using conventional equipment. The Campus equipment is portable and easily deployed, even in difficult terrain. It employs a preplanted array of 20 equally spaced electrodes (but can be adapted for use with up to 32), these being linked through 50 m sections of light (seven-core) cable mounted on small reels. Each reel-hub contains an addressable electronic switching unit and power pack, by means of which the electrode can be connected to any one of the four "measuring" lines of the cable.



These four lines, two for current, two for measuring potential difference, run the full length of the array and are connected to the conveniently placed resistivity meter.

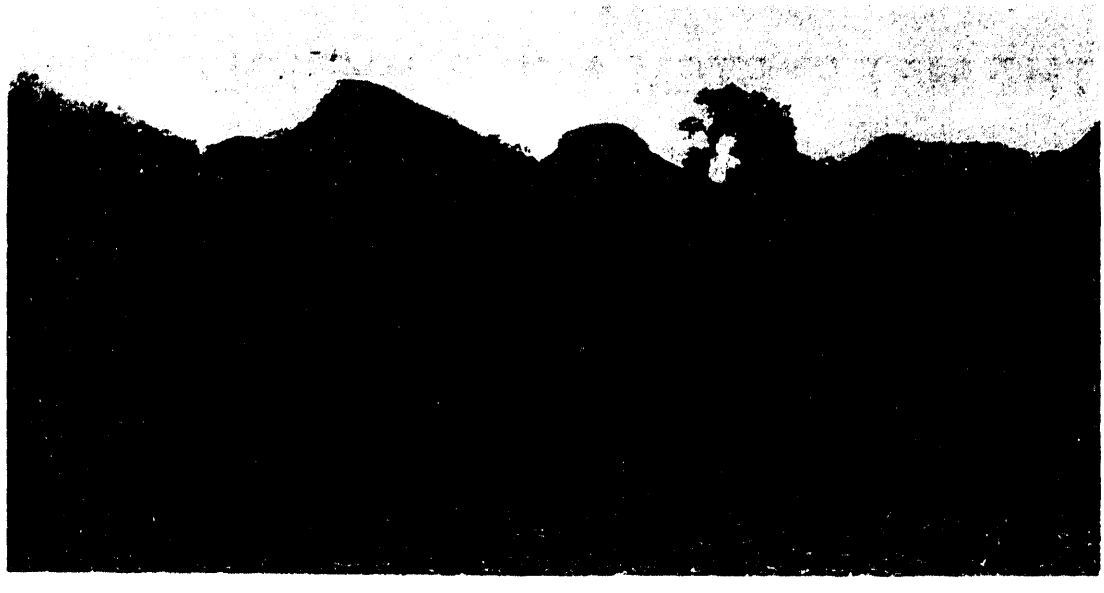
The switching units are controlled by a portable IBM laptop or other compatible computer. At any one time four electrodes are connected to the meter, the software being designed to carry out a series of constant separation traverses along the array, with increasing separation between the "live" electrodes at each pass. A variety of different electrode configurations may be employed although the software has been designed to use the Wenner electrode array in order to reduce the spurious lateral effects common with dipole-dipole arrays.



Layout of the MRT System

In this instance it was possible to measure a reliable sounding over the flat area of the basement, thus providing control for a quantitative interpretation using a finite difference algorithm. The sounding indicated a two layer regolith (47 ohm-m and 320 ohm-m) overlying high resistivity basement, the depth to which was known from the existing borehole. Using these values and boundaries based on the contour pattern, an initial model was drawn up and computed, the differences between the field and calculated apparent resistivities at each point being noted and used as a guide to modify the model. The process was repeated until a satisfactory fit was achieved, the final model (a) and calculated (b) also being shown in the diagram.

Where no control is available, useful semi-quantitative interpretations of weathered basement areas can be obtained using longitudinal conductances together with "pseudo-sounding" data derived from the MRT measurements at suitable stations on the profile.



Mapping the basement in the search for water in Zimbabwe

* * * * * * * * *

SPECIFICATIONS OF THE MRT SYSTEM

Each MRT System comprises:

20 Cable Reels	Dimensions : 310 x 270 x 200 mm. Cable : 7 core polyurethane covered. Cable length : 50 m. Hub mounted electronic switching unit and rechargeable battery pack.
25 electrodes	Mild steel with ring handle and cable clip. Electrode connecting leads.
Junction box	RS232 connection.
Battery charger	Complete with connecting links for 20 reels.
Manual and spares.	

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GEONICS LIMITED

LEADERS IN ELECTROMAGNETICS

GEOPHYSICAL INSTRUMENTATION
FOR EXPLORATION & THE ENVIRONMENT

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FAX: (905) 670-9204

EM31

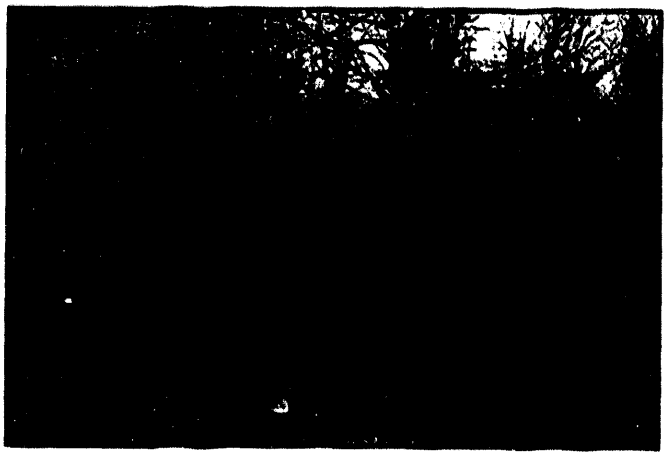
The Geonics EM31 maps geological variations, groundwater contaminants or any subsurface feature associated with changes in the ground conductivity using a patented electromagnetic inductive technique that makes the measurements without electrodes or ground contact. With this inductive method, surveys are readily carried out in all regions including those of high surface resistivity such as sand, gravel and asphalt.

The effective depth of exploration is about six meters, making it ideal for many geotechnical and groundwater contaminant surveys. Important advantages of the EM31 over conventional resistivity methods are the speed with which surveys can be conducted, the precision with which small changes in conductivity can be measured and the continuous readout while traversing the survey area. Two digital meters display both the quadrature-phase (conductivity) and inphase components which can be recorded simultaneously on the DL720 digital data recorder The inphase component is especially useful for detecting shallow ore bodies and, in waste site surveys, for searching for buried metal drums, pipes, and other ferrous and non-ferrous metallic debris.

With the capability of simultaneously mapping contaminant plumes and buried metal the EM31 is the ideal tool for site assessment surveys.

Specifications

MEASURED QUANTITIES	1: Apparent conductivity of the ground in millisiemens per metre (mS/m) 2: Inphase ratio of the secondary to primary magnetic field in parts per thousand (ppt)
PRIMARY FIELD SOURCE	Self-contained dipole transmitter
SENSOR	Self-contained dipole receiver
INTERCOIL SPACING	3.66 metres
OPERATING FREQUENCY	9.8 kHz
POWER SUPPLY	8 disposable alkaline "C" cells (approx. 20 h continuous)
MEASURING RANGES	Conductivity: ± 10, 100, 1000 mS/m Inphase: ± 12 ppt
MEASUREMENT PRECISION	± 0.1 % of full scale deflection
MEASUREMENT ACCURACY	± 5 % at 20 mS/m
NOISE LEVELS	Conductivity: 0.1 mS/m; Inphase: 0.03 ppt
DIMENSIONS	Boom: 4.0 m extended, 1.4 m stored Console: 24 x 20 x 18 cm Shipping Case: 145 x 38 x 23 cm
WEIGHTS	Instrument: 11 kg Shipping: 26 kg



EM34-3

The EM34-3 is a fast, simple to operate, cost-effective instrument for the engineering geophysicist, geologist and hydrogeologist alike and has been particularly successful for mapping deeper groundwater contaminant plumes and for groundwater exploration.

Using the same patented inductive method as the EM31, the EM34-3 uses 3 intercoil spacings to give variable depths of exploration down to 60 metres. With the 3 spacings and 2 dipole modes (horizontal as shown and vertical), vertical electrical soundings can be obtained. In the vertical dipole (horizontal coplanar) mode the EM34-3 is very sensitive to vertical geological anomalies and is widely used for groundwater exploration in fractured, faulted and weathered bedrock zones.

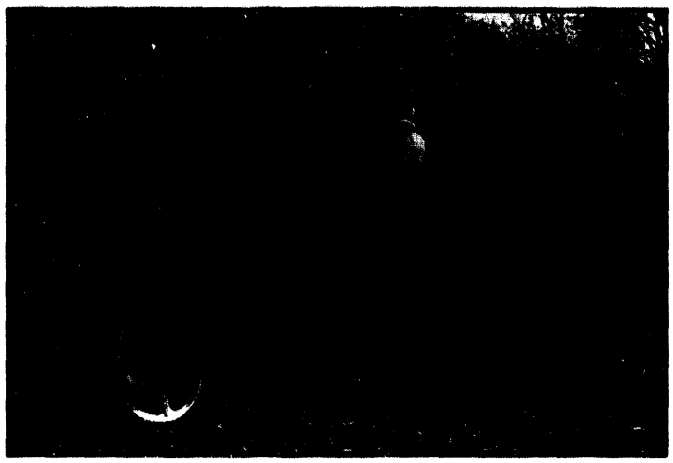
In regions of particularly high cultural and atmospheric noise the higher powered EM34-3XL improves the signal to noise ratio by a factor of 10 at the 40 m spacing and by 4 at the 10 m and 20 m spacing.

The EM34-3 comes complete with an output connector for digital data logging with the DL720 as well as input ports which can be used with a rechargeable battery option.

Specifications

MEASURED QUANTITY	Apparent conductivity in millisiemens per metre (mS/m)
PRIMARY FIELD SOURCE	Self-contained dipole transmitter
SENSOR	Self-contained dipole receiver
REFERENCE CABLE	Lightweight, 2 wire shielded cable
INTERCOIL SPACINGS & OPERATING FREQUENCIES	10 m at 6.4 kHz 20 m at 1.6 kHz 40 m at 0.4 kHz
POWER SUPPLY	Transmitter: 8 disposable or rechargeable "D" cells Receiver: 8 disposable or rechargeable " C" cells
CONDUCTIVITY RANGES	± 10, 100, 1000 mS/m
MEASUREMENT PRECISION	± 2 % of full scale deflection
MEASUREMENT ACCURACY	± 5 % at 20 mS/m
NOISE LEVEL	0.2 mS/m (can be greater in regions of high power line interference)
DIMENSIONS	Receiver Console: 19.5 x 13.5 x 26 cm Transmitter Console: 15 x 8 x 26 cm Coils: 63 cm diameter Shipping Case: 74 x 74 x 29 cm
WEIGHTS	Instrument complete: 20.5 kg Shipping: 43 kg

METAL DETECTOR



EM61

The EM61, one of the newest instruments from GEONICS, is a time-domain metal detector which detects both ferrous and non-ferrous metals. A powerful transmitter generates a pulsed primary magnetic field in the earth, which induces eddy currents in nearby metallic objects. The eddy current decay produces a secondary magnetic field measured by the receiver coil.

By taking the measurement at a relatively long time after the start of the decay, the current induced in the ground has fully dissipated and only the current in the metal is still producing a secondary field. The responses are recorded and displayed by an integrated data logger.

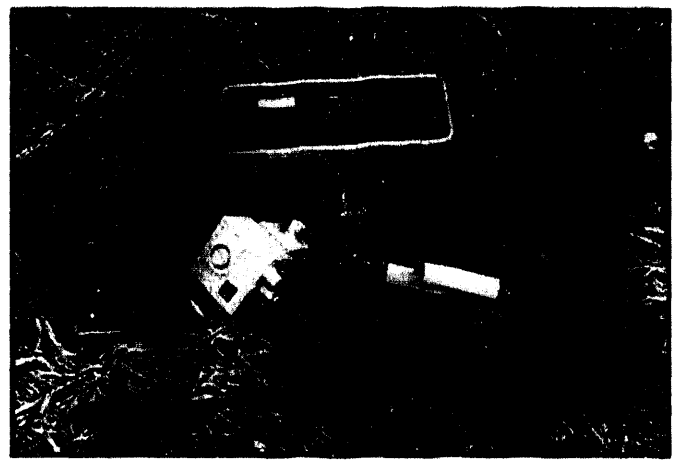
The EM61 detects a single 200-litre (55 gal) drum at a depth of over 3 metres beneath the instrument, yet is relatively insensitive to nearby cultural interference, such as fences, buildings and power lines. The response is a single, sharply defined peak, greatly facilitating quick and accurate location of the target. Depth of the target can usually be estimated from the width of the response.

The system can be pulled around as a trailer with odometer mounted on the axle to trigger the data logger or it can be carried by a single operator with a shoulder harness.

Specifications

MEASURED QUANTITY	Two channels (early and late time) of secondary response in mV
EM SOURCE	Air-cored coil, 1 x 1 m in size
CURRENT WAVEFORM	Bipolar rectangular current with 50 % duty cycle
REPETITION RATE	75 Hz
EM SENSOR	Air-cored coil, 1 x 1 m in size, coincident with EM source
TIME GATES	Gate 1: 0.05 ms wide, starting 0.18 ms after pulse Gate 2: 0.4 ms wide, starting 0.45 ms after pulse
DYNAMIC RANGE	18 bits
DISPLAY	4-line LCD with 16 characters per line
DATA STORAGE	Solid-state memory for up to 10000 records
POWER SUPPLY	12 V rechargeable battery for 5 h continuous operation
WEIGHTS	Operational: Backpack: 10 kg, Coil: 9 kg Shipping: 51 kg (75 kg with trailer)
DIMENSIONS	Backpack: 60 x 30 x 10 cm, Coil: 100 x 100 x 5 cm Shipping: 106 x 106 x 20 cm

VLF INSTRUMENTATION



EM16 / EM16R / TX27

The EM16 is the most widely used EM instrument of all time. It measures the local tilt and ellipticity of VLF broadcasts, and resolves these values into inphase and quadrature components of VLF response. The EM16 has discovered several base- and precious-metal orebodies, and many water-bearing faults.

The EM16R attaches to the EM16 and, using a pair of electrodes, measures the apparent resistivity of the earth. The combined EM16/16R instrument can detect a second earth-layer if the layer occurs within the VLF skin-depth. In addition, the EM16/16R can map resistive alteration for gold exploration.

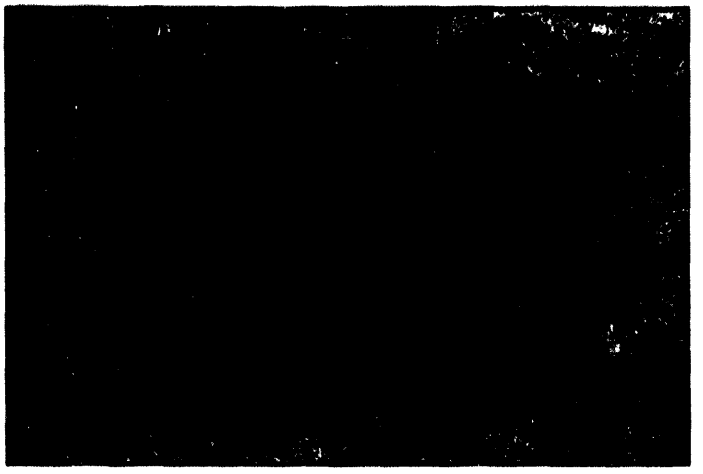
The TX27 is a portable VLF transmitter supplying a VLF field for surveying with the EM16/16R, if remote broadcasts are weak, intermittent or poorly coupled with the target. For EM16 surveys, the TX27 antenna consists of a long (1 km) grounded wire.

Specifications (EM16 / EM16R)

MEASURED QUANTITIES	EM16: Inphase and Quadrature components of the secondary VLF field, as percentages of the primary field EM16R: Apparent resistivity in ohm-metres, and phase angle between E_x and H_y
PRIMARY FIELD SOURCE	VLF broadcast stations
SENSORS	EM16: Ferrite-core coil, tuned by plug-in crystal. EM16R: Stainless-steel electrodes, separated by 10 m; impedence of sensor is 100 MΩ in parallel with 0.5 pF
OPERATING FREQUENCY	15 to 30 kHz, depending on VLF broadcasting station
MEASUREMENT RANGES	EM16: Inphase: ±150 %; Quadrature: ±40 % EM16R: 300, 3000, 30000 Ω-m, Phase: 0-90°
POWER SUPPLY	EM16/16R: 6 alkaline "AA" cells
DIMENSIONS	EM16 and/or EM16R: 53 x 30 x 22 cm
WEIGHTS	EM16: Operational: 1.8 kg; Shipping: 6.2 kg EM16R: Operational: 1.5 kg; Shipping: 6 kg

Specifications (TX27)

PRIMARY FIELD SOURCE	Grounded wire or 500 x 500 m loop, current adjustable, 0 to 2 A
OPERATING FREQUENCY	18.6 kHz
POWER SUPPLY	120/240 V, 600 W motor-generator
DIMENSIONS	88 x 29 x 39 cm
WEIGHTS	Operational: 29 kg; Shipping: 68 kg



PROTEM RECEIVER

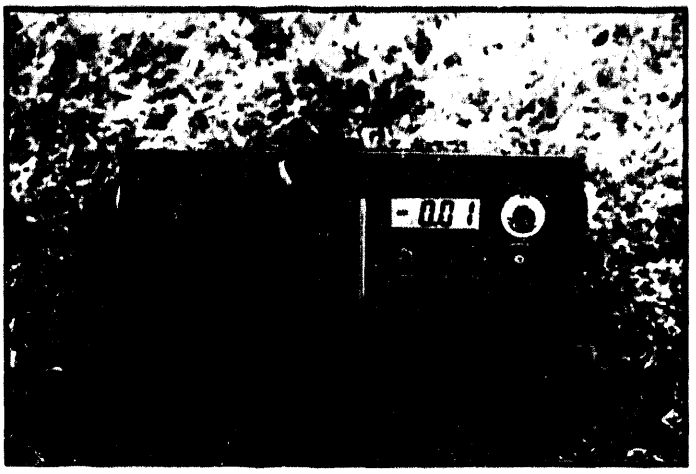
It is well known that there is a trade-off between depth of exploration and target definition in terms of conductivity, extent and orientation. Greatest depth is obtained with large fixed loop Turam-type systems which generate large half space responses and along with current gathering makes target detection difficult. Better spatial resolution is obtained with a moving transmitter configuration with a short intercoil spacing but is limited to a shallower depth of exploration. These variations in survey requirements make system flexibility an important design consideration.

Time Domain systems are also now routinely employed for general geological exploration such as for freshwater aquifers in bedrock fractures, and mapping groundwater contaminant plumes. Mapping to the shallow depths required in these applications requires a very wide bandwidth and many narrow sampling gates.

Recognition of these diverse requirements led Geonics to develop the extremely flexible PROTEM time domain system. The digital, 3 channel receiver is used with any of the 3 TEM transmitters and choice of receiver coil to cover all applications. With its 23 bit resolution, system bandwidth of 500 kHz, microsecond sampling gates and simultaneous XYZ component measurements, the PROTEM receiver provides the ultimate in time domain capability. Used with the Geonics 3-component coil, mineral surveys are greatly speeded up with more data in either the fixed loop or slingram mode. The three component measurement also allows a quick and accurate check on geoelectric sounding data for lateral variations in conductivity which could invalidate a layered-earth interpretation.

Specifications

MEASURED QUANTITY	Rate of decay of induced magnetic field along 3 axes, in nV/m^2
EM SENSOR	Air- and ferrite-cored coils
CHANNELS	3 in parallel or sequential
TIME GATES	20 geometrically spaced, from 6 µs to 800 ms
DYNAMIC RANGE	23 bits (132 dB)
FREQUENCY	0.3, 0.75, 3, 7.5, 30, 75 and 285 Hz or 0.25, 0.625, 2.5, 6.25, 25, 62.5 and 262.5 Hz.
INTEGRATION TIME	2, 4, 8, 15, 30, 60, 120 or 240 s
DISPLAY	240 x 64 dot graphic LCD
DATA HANDLING	Solid-state memory for 3300 data-sets. RS-232 output
SYNCHRONIZATION	Reference cable or, optionally, highly stable quartz crystal
POWER SUPPLY	12 V rechargeable battery for 8 h continuous operation
WEIGHTS	34 x 38 x 27 cm
DIMENSIONS	13 kg



TEM47 TRANSMITTER

Three interchangeable transmitters - TEM47, TEM57 and TEM37 - are used with the PROTEM receiver and the appropriate receiver coil to make up different PROTEM systems for various applications such as mineral exploration, structural mapping, resistivity sounding and contaminant plume mapping.

The TEM47 is the smallest, lightest battery operated transmitter with a very fast turn-off time to enable the near surface response to be measured. The PROTEM 47 (PROTEM receiver and TEM47 transmitter) is most often used for shallow geoelectric sounding looking for conductive contaminant plumes, saline intrusion or general stratigraphy mapping. In this mode single turn transmitter loops from 5 m up to 100 m on a side with turn-off times as short as half a microsecond can be used to give maximum near surface resolution.

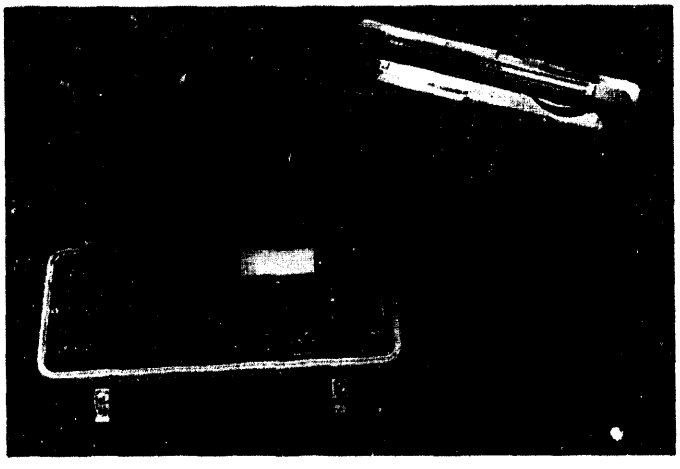
The maximum transmitter output of 3 A into a 100 m x 100 m loop gives a good response and resolution to depths down to 150 m making this the ideal instrument for resistivity sounding over a large area.

The TEM47 uses a reference cable to achieve the high synchronization accuracy required for shallow sounding. Regardless of application, the high-frequency receiver coil is used in PROTEM 47 systems. This receiver coil has the bandwidth necessary to capture the earliest portion of the transient decay.

When the TEM47 is used in a PROTEM 47 system for profiling, it supplies 3 A to an 8-turn, 5 x 5 m moving transmitter loop to provide a dipole moment of 600 ampere square metres. With base frequency of 75 Hz and 20 gates from 49 µs to 2.9 ms this configuration is optimal for Slingram (horizontal loop) surveys for mineral exploration to shallow depths, and for groundwater exploration in bedrock fractures. Electrical sounding is performed simultaneously with the search for fault or dike-like targets.

Specifications

CURRENT WAVEFORM	Bipolar rectangular current with 50 % duty cycle
FREQUENCY	30, 75 or 285 Hz where powerline frequency is 60 Hz. 25, 62.5 or 262.5 Hz where powerline frequency is 50 Hz
TURN-OFF TIME	2.5 µs at 2 A into 40 x 40 m loop. Faster into smaller loop
TRANSMITTER LOOP	5 x 5 to 100 x 100 m single turn loop, or 5 x 5 m 8-turn loop
OUTPUT VOLTAGE	0 to 9 V, continuously variable
POWER SUPPLY	Internal 12 V rechargeable battery
BATTERY LIFE	5 h continuous operation at 2 A output
DIMENSIONS	10.5 x 24 x 32 cm
WEIGHT	5.3 kg



TEM57 TRANSMITTER

The TEM57 and PROTEM receiver are the principal components of PROTEM 57 systems. The design and performance of the PROTEM 57 make it a highly portable, powerful and versatile time domain system.

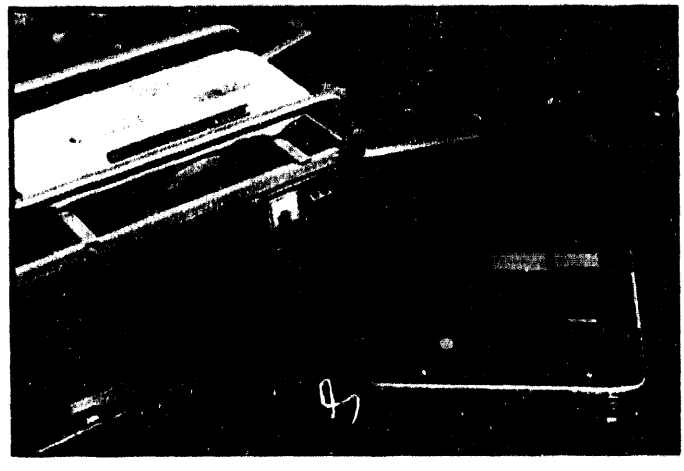
The TEM57 is powered either by a 600 W generator or by rechargeable batteries in a backpack. PROTEM 57 systems are synchronized by either reference cable or quartz crystal, usually determined by the size of the loop and whether they are being used for large loop soundings or profiling.

The PROTEM 57 is used for a wide variety of applications. The system can sound the depth, thickness and conductivity of layers down to 300 m below surface, for applications such as mapping the thickness of aquifers, clay layers and assessing water quality. In coastal areas, the PROTEM 57 has defined the depth to saline intrusion as accurately as chemical samples from wells.

The PROTEM 57, with a short reference cable, portable transmitter and 3-D receiver coil can delineate complex orebodies within 200 m of surface. Deeper conductors can be characterized by profiling with a synchronized receiver and a large, fixed transmitter loop. Modelling provides conductivity thickness, dip and extent of the ore body.

Specifications

CURRENT WAVEFORM	Bipolar rectangular current with 50 % duty cycle
FREQUENCY	3, 7.5 or 30 Hz (powerline frequency 60 Hz). 2.5, 6.25 or 25 Hz (powerline frequency 50 Hz). Rates below 1 Hz available from PROTEM receiver through reference cable
TURN-OFF TIME	20 to 115 µs, depending on size, current and number of turns in transmitter loop
TRANSMITTER LOOP	Single turn: Any dimension (minimum resistance = 1 Ω) up to 300 x 600 m. 8-turn: 5 x 5 or 10 x 10 m
OUTPUT CURRENT	20 A maximum
OUTPUT VOLTAGE	20 or 44 V
SYNCHRONIZATION	Reference cable or, optionally, quartz crystal
POWER SUPPLY	600 W, 120 V, 60 Hz single-phase motor-generator or, optionally, 24 V rechargeable battery
TRANSMITTER PROTECTION	Electronic and electromechanical protection against short circuit
TRANSMITTER SIZE	42 x 20 x 31 cm
TRANSMITTER WEIGHT	13 kg
MOTOR-GENERATOR SIZE	44 x 32 x 21 cm
MOTOR-GENERATOR WEIGHT	21 kg



TEM37 TRANSMITTER

The TEM37 is the most powerful transmitter used with the PROTEM receiver forming the basis of the PROTEM 37 (formerly EM37-3) system. The high powered PROTEM 37 can be used to sound to depths greater than 1 kilometre, and in the large fixed loop profiling mode, detect and delineate ore bodies at several hundred metres.

The transmitter and receiver in a PROTEM 37 system are equipped with quartz crystals for synchronization, although a reference cable can be used if transmitter-receiver separation is less than 200 m. The TEM37 is powered by a specialized motor-generator, which can energize loops up to 2000 x 2000 m in size.

The PROTEM 37 is used to profile deeply buried conductors, which makes the system a principal tool of mineral exploration. Both the 3-D receiver coil and BH43 borehole probe are used routinely with the system. The PROTEM 37 also enjoys widespread application for deep soundings for groundwater exploration, mapping saline intrusion, and for geothermal exploration as well as general regional geological research where structures and layers can be detected at depths greater than 1000 m.

Specifications

CURRENT WAVEFORM	Bipolar rectangular current with 50 % duty cycle
FREQUENCY	3, 7.5 or 30 Hz (powerline frequency 60 Hz). 2.5, 5 or 25 Hz (powerline frequency 50 Hz). Rates below 1 Hz available from PROTEM receiver through reference cable
TURN-OFF TIME	20 to 750 µs, depending on size, current and number of turns in transmitter loop
TRANSMITTER LOOP	Up to 2000 x 2000 m, minimum resistance = 0.67 Ω
OUTPUT CURRENT	30 A maximum
OUTPUT VOLTAGE	28, 28, 40, 44, 80, 110 or 160 V
SYNCHRONIZATION	Quartz crystal or, optionally, reference cable
MOTOR GENERATOR	2800 W, 120 V, 400 Hz, 3-phase, with 8 h continuous operation from full fuel-tank
TRANSMITTER PROTECTION	Electronic and electromechanical protection against short circuit
TRANSMITTER WIRE SUPPLIED	AWG # 10 copper, insulated with PVC
TRANSMITTER SIZE	43 x 27 x 40 cm
TRANSMITTER WEIGHT	20 kg
MOTOR-GENERATOR SIZE	74 x 44 x 51 cm
MOTOR GENERATOR WEIGHT	66 kg

Effective October 4, 1993
our new area code is:
TEL: (905) 670-9580
FAX: (905) 670-9204

GEONICS LIMITED
1745 Meyerside Dr. Unit 8 Mississauga, Ontario Canada L5T 1C6

Tel. (416) 670-9580
Telex 06-968688
Cables: Geonics
Fax: (416) 670-9204

SEPTEMBER 1993 — **GEONICS LIMITED PRICE LIST**
UNITED STATES DOLLARS

GROUND CONDUCTIVITY METERS

EM31	Continuous Reading, Conductivity & Inphase, 6m depth	$ 12,985
EM34-3	Conductivity, exploration to 60m	18,900
EM34-3XL	As EM34-3 with larger dipole moment for greater noise rejection	21,285
EM38	Continuous Reading, Conductivity & Inphase, 1.5m depth	6,250
Optional:	1. For EM34-3 and EM34-3XL: Rechargeable Batteries and dual Rx/Tx Battery Charger (input 110 or 220V)	640
	2. For EM38: Extender Arm for ground-level surveying (including data cable)	570

BOREHOLE INSTRUMENTS

EM39	Borehole Conductivity Probe and Control Console	14,500
EM39RT	Real Time Computer Logging Option	1,895
Gamma39	Natural Gamma Logging Probe	8,280
W39-1	Winch System with 100m cable (including Tripod, Optical Depth Encoder, Digital Depth Readout)	7,350
W39-2	Winch System complete as W39-1 with 200m cable	8,625
Optional:	1. Motor Drive (not including generator) for W39 winches	2,200
	2. Level Wind for W39 winches	1,000

DATA LOGGERS

DL720	Omnidata Digital Datalogger (128kB) with DAT operational and editing software, interconnect cables and case (complete for one instrument)	3,595
DL720M	Modification Packages for using DL720 with other Geonics instruments (includes DAT software and interconnect cable)	495
	Memory upgrade for logger to 256 kB, when ordered prior to delivery	200
	Memory upgrade for logger to 448 kB, when ordered prior to delivery	600

METAL DETECTORS

EM61	High-Resolution Deep-Penetrating Metal Detector, with 256kB data logger	9,975
	Memory upgrade to 448kB, when ordered prior to delivery	500
Optional:	Trailer-mount for EM61	2,100
	Web-net	95

VLF EM EQUIPMENT

EM16	VLF Electromagnetic Receiver	5,665
EM16R	VLF Resistivity Meter Attachment to EM16	3,195
EM16/16R	Complete VLF Receiver and Ground Resistivity Instrument	8,860
TX27	VLF Portable Transmitter	6,165
	Generator for Tx27	1,040

NOTES:
1. All prices quoted F.O.B. Geonics, Mississauga, Ontario, Canada.
2. All applicable import duties and shipping are extra.
3. Warranty on all instruments is for one (1) calendar year.
4. Extended warranty available on all data loggers.

PRICE LIST: UNITED STATES DOLLARS (Continued)
SEPTEMBER 1993

INSTRUMENT RENTAL RATES - Weekly Rates UNITED STATES DOLLARS

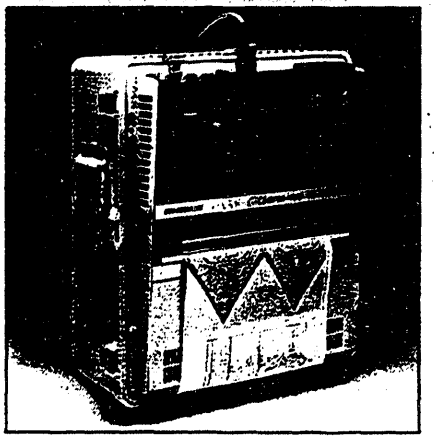
Rental Period - Weeks:	1 to 3 (per week)	4 to 12 (per week)	13 plus (per week)
GROUND CONDUCTIVITY METERS			
EM31	450	340	270
EM34-3	740	560	450
EM34-3XL	825	620	495
EM38	245	185	150
BOREHOLE INSTRUMENTS			
EM39	640	475	385
EM39RT	755	565	455
Gamma 39	385	290	230
Gamma 39RT	500	375	300
W39-1 (100m cable)	340	260	210
W39-1M (100m motorized)	455	340	270
W39-2M (200m motorized and level wind)	560	420	340
DATA LOGGERS			
DL720	260	195	155
Analog Recorder (single channel)	160	120	100
METAL DETECTORS			
EM61	350	265	215
EM61 with trailer-mount	425	320	255
VLF EM EQUIPMENT			
EM16	235	175	140
EM16/16R	370	275	220
Tx27 (incl. generator)	405	305	240
Tx27 (without generator)	345	260	210

RENTAL TERMS:

1. Minimum rental period for instruments is 1 week. Rental period begins the day the equipment is received by the customer and ends the day it is returned to the shipper for delivery to Geonics.
2. For rentals longer than 1 week, the daily charge per business day is 20% of the applicable weekly rate.
3. 80% of rental payments can be credited towards the purchase of the rented equipment while under rental.
4. Consignee is responsible for any loss or damage to rented equipment.
5. When returning rental equipment follow the instructions supplied with the instrument.

DFM-480-4

Field Proven, Dependable, Environmentally Safe, Significantly Faster.



Digital Field Monitors from OYO GEOSPACE have provided reliable service to land, marine and portable seismic crews throughout the world since 1985. Now, the new generation DFM-480-4 has 486 power for significantly increased plotting speed. Advanced software includes multiple-line plotting, near trace gather, vibroseis QC capability, and more.

- 80486DX - 33 MHz CPU Standard
- 80486DX2 - 66 MHz CPU Optional
- Memory 8 MByte. Up to 32 MByte Optional
- Interface with all current data acquisition systems
- Accepts up to 2400 input channels
- 640 x 480 VGA EL Display
- Worldwide service and support

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DAS-1
HI-PERFORMANCE SYSTEM

DAS-1 is a multi-purpose seismic acquisition system that establishes new performance and operation standards for engineering, environmental and oil exploration applications in land or marine environments. Using advanced Sigma-Delta signal processing technology with high speed sampling and dynamic resolution, the system produces true digital representation of analog signals from seismic detectors.

New Performance Standards

Performance Specification	DAS-1	Portable IFP Systems
A/D Resolution	24 bits	15 bits
System Dynamic Range	132 dB	114 dB
Instantaneous Dynamic Range	116 dB	84 dB
Equivalent Input Noise	0.1 µV	0.5 µV
Total Harmonic Distortion	0.005 %	0.1 % (typical)
Sampling Interval	31.25 µsec to 4 msec	50 µsec to 2 msec
Maximum Samples per Trace	80,000 samples	4,096 samples
Number of Channels	24 to 144 channels	24 to 120 channels

Specifications for Portable IFP Systems are taken from published information and are for general comparison only.

Systems Design Approach

DAS-1 is specially designed for adaptation to many seismic projects and can work with both impulse and vibratory energy sources. Configuration options include channel expansion, high capacity internal or external tape storage systems, expanded memory, and external plotters. Run any DOS based seismic application software on the built-in 80486 computer for real-time data analysis. Whatever your needs, from a basic 24 channel unit to a sophisticated 144 channel system, DAS-1 offers a hi-performance, cost-effective solution to your seismic survey requirements.

Call us today for more information. **1-800-824-2319**

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SCINTREX

ENVI-MAG Environmental Magnetometer/Gradiometer

Locating Buried Drums and Tanks?

The NEW ENVI-MAG is the solution to this environmental problem. ENVI-MAG is an inexpensive, lightweight, portable "WALKMAG" which enables you to survey large areas quickly and accurately. ENVI-MAG is a portable, proton precession magnetometer and/or gradiometer, for geotechnical, archaeological and environmental applications where high production, fast count rate and high sensitivity are required. It may also be used for other applications, such as mineral exploration, and may be configured as a total-field magnetometer, a vertical gradiometer or as a base station.

The ENVI-MAG

- easily detects buried drums to depths of 10 feet or more
- more sensitive to the steel of a buried drum than EM or radar
- much less expensive than EM or radar
- survey productivity much higher than with EM or radar

Main features include:

- select sampling rates as fast as 2 times per second
- "WALKMAG" mode for rapid acquisition of data
- large internal memory, expandable to 200,000 readings
- easy to read, large LCD screen displays data both numerically and graphically
- ENVIMAP software for processing and mapping data

ENVI-MAG comprises several basic modules; a lightweight console with a large screen alphanumeric display and high capacity memory, a staff mounted sensor and sensor cable, rechargeable battery and battery charger, RS-232 cable and ENVIMAP processing and mapping software.

For gradiometry applications an upgrade kit is available, comprising an additional processor module for installation in the console, and a second sensor with a staff extender.

ENVI-MAG Proton Magnetometer in operation

For base station applications a Base Station Accessory Kit is available so that the sensor and staff may be converted into a base station sensor.

Features and Benefits

"WALKMAG" Magnetometer/Gradiometer

The "WALKMAG" mode of operation (sometimes known as "Walking Mag") is user-selectable from the keyboard. In this mode, data is acquired and recorded at the rate of 2 readings per second as the operator walks at a steady pace along a line. At desired intervals, the operator "triggers" an event marker by a single key stroke, assigning coordinates to the recorded data.

True Simultaneous Gradiometer

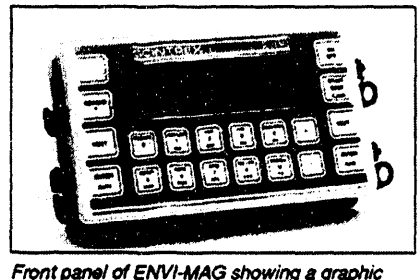
An optional upgrade kit is available to configure ENVI-MAG as a gradiometer to make true, simultaneous gradiometer measurements. Gradiometry is useful for geotechnical and archaeological surveys where small near surface magnetic targets are the object of the survey.

Selectable Sampling Rates

0.5 second, 1 second and 2 second reading rates user selectable from the keyboard.

Large-Key Keypad

The large-key keypad allows easy access for gloved-hands in cold-weather operations. Each key has a multi-purpose function.



Front panel of ENVI-MAG showing a graphic profile of data and large-key keypad

Large Capacity Memory

ENVI-MAG with standard memory stores up to 28,000 readings of total field measurements, 21,000 readings of gradiometry data or 151,000 readings as a base station. An expanded memory option is available which increases this standard capacity by a factor of 5.

Easy Review of Data

For quality of data and for a rapid analysis of the magnetic characteristics of the survey line, several modes of review are possible. These include the measurements at the last three stations, the ability to scroll through any or all previous readings in memory, and a graphic display of the previous data as profiles, line by line. This feature is very useful for environmental and archaeological surveys.

Highly Productive

The "WALKMAG" mode of operation acquires data rapidly at close station intervals, ensuring high-definition results. This increases survey productivity by a factor of 5 when compared to a conventional magnetometer survey.

"Datacheck" Quality Control of Data

"Datacheck" provides a feature wherein at the end of each survey line, data may be reviewed as a profile on ENVI-MAG's screen. Datacheck confirms that the

instrument is functioning correctly and allows the user to note the magnetic relief (anomaly) on the line.

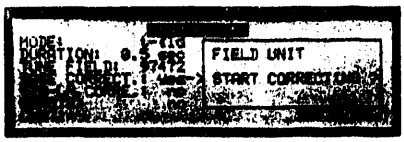
Large Screen Display

"Super-Twist" 64 x 240 dot (8 lines x 40 characters), LCD graphic screen provides good visibility in all light conditions. A display heater is optionally available for low-temperature operations below 0°C.

Close-up of the ENVI-MAG screen showing data presented afer each reading

Interactive Menus

The set-up of ENVI-MAG is menu-driven, and minimizes the operator's learning time, and on-going tasks.



Cose-up of display of ENVI-MAG showing interactive set-up menu

Rechargeable Battery and Battery Charger

An "off-the-shelf" lead-acid battery and charger are provided as standard. The low-cost "Camcorder" type battery is available from electronic parts distributors everywhere.

HELP-Line Available

Purchasers of ENVI-MAG are provided with a HELP-Line telephone number to call in the event assistance is needed with an application or instrumentation problem.

ENVIMAP Processing and Mapping Software

Supplied with ENVI-MAG, and custom designed for this purpose, is easy-to-use, very user-friendly, menu driven data processing and mapping software called ENVIMAP. This unique software appears to the user to be a single program, but is in fact a sequence of separate programs, each performing a specific task. Under the menu system, there are separate programs to do the following:

a) read the ENVI-MAG data and reformat it into a standard compatible with the ENVIMAP software
b) grid the data into a standard grid format
c) create a vector file of posted values with line and baseline identification that allows the user to add some title information and build a suitable surround
d) contour the gridded data
e) autoscale the combined results of the posting/surround step and the contouring step to fit on a standard 8.5 ins. wide dot-matrix printer
f) rasterize and output the results of step e) to the printer

ENVIMAP is designed to be as simple as possible. The user is required to answer a few basic questions asked by ENVIMAP, and then simply toggles "GO" to let ENVIMAP provide default parameters for the making of the contour map. The user can modify certain characteristics of the output plot. ENVIMAP'S menu system is both keyboard and mouse operable. HELP screens are integrated with the menu system so that HELP is displayed whenever the user requests it.

Options Available

- True simultaneous gradiometer upgrade
- Base station upgrade
- Display heater for low temperature operations
- External battery pouch

Specifications

Total Field Operating Range
20,000 to 100,000 nT (gammas)

Total Field Absolute Accuracy
+/- 1nT

Tuning
Fully solid state. Manual or automatic, keyboard selectable

Cycling (Reading) Rates
0.5, 1 or 2 seconds, up to 9999 seconds for base station applications, keyboard selectable

Sensitivity
0.1 nT at 2 second sampling rate

Gradiometer Option
Includes a second sensor, 20 inch (½m) staff extender and processor module

"WALKMAG" Mode
0.5 second for walking surveys, variable rates for hilly terrain

Digital Display
LCD "Super Twist", 240 x 64 dots graphics, 8 line x 40 characters alphanumerics

Display Heater
Thermostatically controlled, for cold weather operations

Keyboard Input
17 keys, dual function, membrane type

Notebook Function
32 characters, 5 user-defined MACRO's for quick entry

Standard Memory

Total Field Measurements:	28,000 readings
Gradiometer Measurements:	21,000 readings
Base Station Measurements:	151,000 readings

Expanded Memory

Total Field Measurements:	140,000 readings
Gradiometer Measurements:	109,000 readings
Base Station Measurements:	750,000 readings

Real-Time Clock
Records full date, hours, minutes and seconds with 1 second resolution, +/- 1 second stability over 12 hours

Digital Data Output
RS-232C interface, 600 to 57,600 Baud, 7 or 8 data bits, 1 start, 1 stop bit, no parity format. Selectable carriage return delay (0-999 ms) to accommodate slow peripherals. Handshaking is done by X-on/X-off

Analog Output
0 - 999 mV full scale output voltage with keyboard selectable range of 1, 10, 100, 1,000 or 10,000 nT full scale

Power Supply
Rechargeable "Camcorder" type, 2.3 Ah, Lead-acid battery.

12 Volts at 0.65 Amp for magnetometer, 1.2 Amp for gradiometer,

External 12 Volt input for base station operations

Optional external battery pouch for cold weather operations

Battery Charger
110 Volt - 230 Volt, 50/60 Hz

Operating Temperature Range
Standard 0° to 60°C
Optional -40°C to 60°C

Dimensions
Console - 10 x 6 x 2.25 inches (250 mm x 152 mm x 55 mm)
T.F. sensor - 2.75 inches dia. x 7 inches (70 mm x 175 mm)
Grad. sensor and staff extender - 2.75 inches dia. x 26.5 inches (70 mm x 675 mm)
T.F. staff - 1 inch dia. x 76 inches (25 mm x 2 m)

Weight
Console - 5.4 lbs (2.45 kg) with rechargeable battery
T. F. sensor - 2.2 lbs (1.15 kg)
Grad. sensor - 2.5 lbs (1.15 kg)
Staff - 1.75 lbs (0.8 kg)

SCINTREX

Head Office
222 Snidercroft Road
Concord, Ontario, Canada L4K 1B5
Telephone: (416) 669-2280
Fax: (416) 669-6403 or 669-5132
Telex: 06-964570
Canadian area code changes to (905), effective October 5, 1993.

In the USA:
Scintrex Inc.
4600 Witmer Industrial Estates, Unit 4
Niagara Falls, NY 14305
Telephone: (716) 298-1219
Fax: (716) 298-1317

SCINTREX

Scintrex Inc.
4600 Witmer Industrial Estates, Unit 4
Niagara Falls, NY 14305

Tel.: (716) 298-1219
Fax: (716) 298-1317

Quotation/ Pro Forma Invoice

TO: Lawrence Berkeley Lab

Building 50E
1 Cyclotron Road
Berkeley, California
94720, U.S.A.

ATTN: Mr. Norman Goldstein

DATE: 5 October 1993

QUOTATION #: US-0282 **PAGE:** 1

YOUR ENQUIRY:

DELIVERY:	6 weeks After Receipt of Order
QUOTATION VALIDITY:	90 Days
SALES TAX:	Not Applicable
PAYMENT TERMS:	Prepayment by Direct Bank Transfer

Item:	Unit Price	Quantity	Price(US $)
ENVI Environmental Magnetometer / Gradiometer System			
1. **ENVI MAG Total Field Magnetometer (console includes 0.5MB memory, the instrument can be used as a total field or base station magnetometer) (788-001) Including:**	5,450.00	1	5,450.00

1 (788-011) ENVI Electronics Console
1 (788-020) Total Field Sensor
1 (780-550) Sensor Cable
1 (788-022) Sensor Staff
1 (788-023) Carrying Harness
1 (788-024) Back Plate
1 (745-081) RS232 Cable
1 (400-078) Rechargeable Battery
1 (400-139) Battery Charger 110/220 VAC
1 (788-030) Minor Spare Parts Kit
1 (788-032) ENVIMAP Software Package
1 (788-711) Operations Manual
1 (788-148) Packaging

See Reverse for Terms and Conditions of Sale

SCINTREX

Scintrex Inc.
4600 Witmer Industrial Estates, Unit 4
Niagara Falls, NY 14305

Tel.: (716) 298-1219
Fax: (716) 298-1317

Quotation/ Pro Forma Invoice

QUOTATION #: US-0282 PAGE: 3

Item:	Unit Price	Quantity	Price(US $)
Options and Accessories:			
2. ENVI GRAD Magnetic Gradiometer (console includes 0.5MB memory, the instrument can be used as a magnetic gradiometer or base station magnetometer) (788-002) Including:	6,995.00		Not Included
1 (788-012) ENVI Gradiometer Console			
1 (788-020) Total Field Sensor			
1 (788-021) 0.5m Gradiometer Sensor			
1 (788-028) Gradiometer Sensor Cable			
1 (788-022) Sensor Staff			
1 (788-023) Carrying Harness			
1 (745-081) RS-232 Cable			
1 (400-078) Rechargeable Battery			
1 (400-139) Battery Charger 110/220 VAC			
1 (788-030) Minor Spare Parts Kit			
1 (788-032) ENVIMAP Software Package			
1 (788-711) Operations Manual			
1 (788-216) Foam Cushion			
1 (788-148) Packaging			
3. ENVI Magnetic Base Station Accessories Kit (includes 50m base station extension cable, staff supporting kit, 12 volt power supply cable, null modem) (788-025)	380.00		Not Included
4. ENVI GRAD UPGRADE KIT (upgrades the ENVI MAG total field magnetometer to a simultaneous gradiometer) Including:	1,620.00		Not Included
1 (788-021) 0.5m Gradiometer Sensor			
1 (788-059) Gradiometer Board			

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4600 Witmer Industrial Estates, Unit 4
Niagara Falls, NY 14305

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Fax: (716) 298-1317

Quotation/ Pro Forma Invoice

QUOTATION #: US-0282 PAGE: 4

Item:	Unit Price	Quantity	Price(US $)
1 (788-028) ENVI Gradiometer Sensor Cable 1 (788-084) Gradiometer PCB Ribbon 1 (788-216) Foam Cushion			
5. ENVI Transit Case (140-161)	265.00		Not Included
6. ENVI External Heavy Duty Battery Kit (recommended for cold weather use and walking gradiometer, 7.2 Ah) (788-026)	275.00		Not Included
7. Spare Rechargeable Battery and cable for ENVI (2.3 Ah) (400-078)	95.00		Not Included
8. MAPPING PROCESSING SYSTEM (MPS) (#140) (Graphics System #1003, RANGRID #102, CONTUR #103, GRID Utilities 1 #105A, MAPPLOT #106, CPLOT #111, MAPEDIT #117)	3,410.00		Not Included
9. MAPPING PROCESSING SYSTEM (MPS) UTILITY KIT (#141) (GRID Utilities 2 #105B, XYZ Utilties #112A, XYZ Utilities 2 #112B, CALCULATOR #118)	2,115.00		Not Included

See Reverse for Terms and Conditions of Sale

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Quotation/ Pro Forma Invoice

QUOTATION #: US-0282 PAGE: 5

Item:	Unit Price	Quantity	Price(US $)
10. VGA-VIEWSHAD (#113)	470.00		Not Included
11. HCONTUR (#108) (for huge grids up to 1,000,000 points)	585.00		Not Included
12. GEOSOFT POTENTIAL FIELD MODELLING PACKAGE (#404) (includes MAGMOD #401, GRAMOD #406, PMODEL #420)	3,130.00		Not Included
13. MAGMOD (#401)	1,235.00		Not Included
14. GM-SYS Basic Digitiser Support (#407)	2,500.00		Not Included
15. GM-SYS 2.5D Upgrade (#408)	1,425.00		Not Included
16. GM-SYS Utility Package (#410)	295.00		Not Included

See Reverse for Terms and Conditions of Sale

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Niagara Falls, NY 14305
Tel.: (716) 298-1219
Fax: (716) 298-1317

Quotation/ Pro Forma Invoice

QUOTATION #: US-0282 PAGE: 6

Item:	Unit Price	Quantity	Price(US $)
17. POTENTIAL FIELD INTERPRETATION (PFIS) SOFTWARE PACKAGE (includes GRIDEPTH #421, SYPLOT #120, MAGMAP 2-D Fourier Processing #114)	6,265.00		Not Included
18. GEOSOFT 1 YEAR SOFTWARE MAINTENANCE PACKAGE (price is calculated as 15% of the total value of software purchased)	0.00		Not Included

See Reverse for Terms and Conditions of Sale

SCINTREX

Scintrex Inc.,
4600 Witmer Industrial Estates, Unit 4
Niagara Falls, NY 14305

Telephone: (716) 298-1219
Fax: (716) 298-1317

1993 INSTRUMENT RENTAL RATES

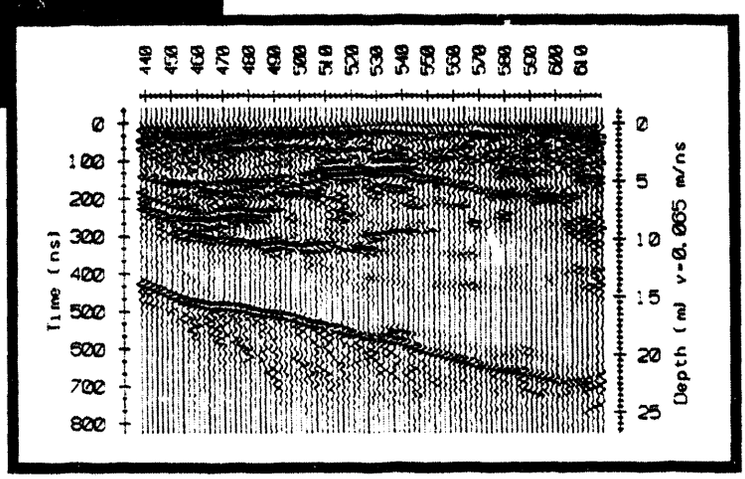
Prices effective July 1 1993

MAGNETOMETER/VLF	Daily US $	Monthly US $	BASE CHARGE US $
ENVI Total Field Mag. Also Configured as a Base Station	30.00	850.00	175.00
ENVI Gradiometer Unit	35.00	1,000.00	180.00
OMNI PLUS Total Field MAG/VLF	75.00	1,500.00	380.00
OMNI PLUS Gradiometer MAG/VLF	80.00	1,600.00	400.00
GRAVITY METERS			
CG-3 Auto Grav/Gravity	120.00	3,000.00	1,000.00
Cold Weather Accessary Kit (1 battery belt, 4 batteries, 2 chargers)	12.50	320.00	N.C.

IP RECEIVERS	Daily US $	Monthly US $	BASE US $
IPR-12	80.00	2,000.00	350.00
TRANSMITTERS			
TSQ-3 with Motor Generator and Field Accessary Kit	250.00	2,800.00	900.00
RADIOMETRICS			
GRS-500 7.5 cubic inch	12.00	300.00	55.00
UG-135 4.0 cubic inch	12.00	300.00	55.00
GAD-6/GSP-Sensor with calibration Sources 22 cubic inch	28.00	700.00	250.00
MAGNETIC SUSCEPTIBILITY METERS			
K-2	12.00	300.00	55.00
HIGH SENSITIVITY MAGS.			
H-8 Cesium Magnetometer Sensor	80.00	2,000.00	225.00
CS-2 Cesium Magnetometer	84.00	2,100.00	280.00

pulseEKKO™ IV

GROUND PENETRATING RADAR TECHNOLOGY



Sensors & Software Inc.

Sensors & Software Inc.

Introduces

pulseEKKO™ IV

The **Ground Penetrating Radar** designed
to exploit **Seismic Processing.**

Years of practical experience in rugged field conditions have created the **lightweight, modular** and totally **battery powered** pulseEKKO™ IV system. The **fully digital** system with **fibre optic** data links guarantees the highest possible performance available.

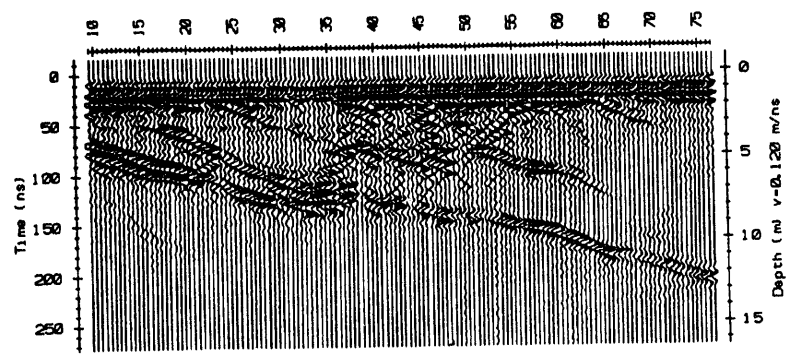
Modular design using **interchangable antennas** to select operating frequency provides you with a **cost effective** route to system enhancement.

With **advanced control software** you can operate the system from any MS-DOS* computer and exploit the latest advances in **PC† technology**. Full **digital data storage** gives you instant access to your data and the ability to exploit proven **seismic processing** techniques.

The **advanced user interface** combines simplicity with total system control. **Non-volatile** configuration parameters, and **automatic configuration** maximize data quality, minimize set up time, and assure survey repeatability.

*MS-DOS Trademark of Microsoft Corp.
†PC Trademark of International Business Machines Corp.

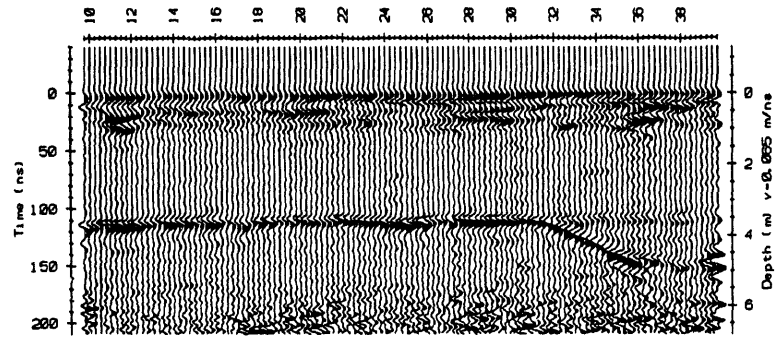
Fracture Mapping in Rock



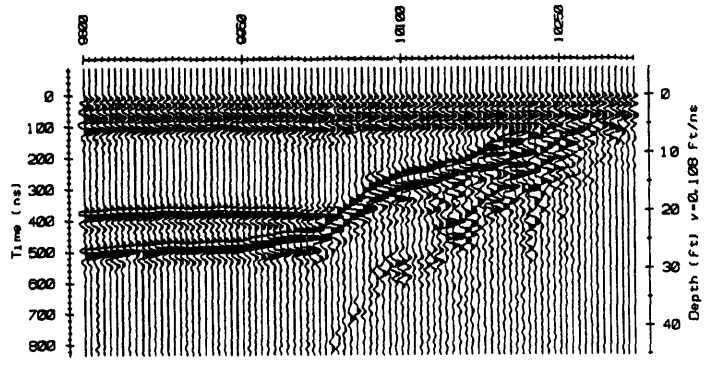
pulseEKKO™ Features

- Digital acquisition
- Light weight
- Fibre optics
- Signal averaging
- Computer controlled
- Interchangable antennas
- Seismic software compatible

Mapping Soil Stratigraphy



Lake Bottom Mapping



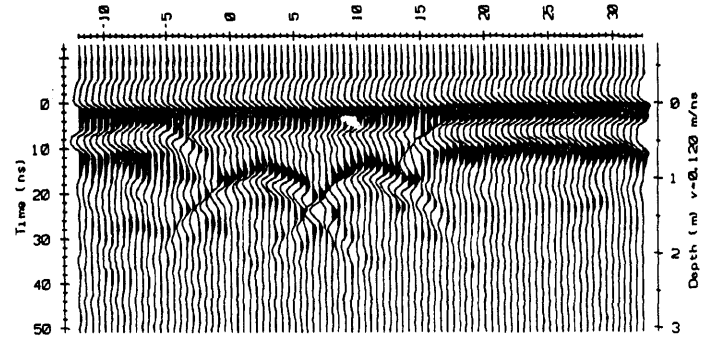
pulseEKKO™ Processing

- Wiggle trace display
- FFT filtering
- AGC and SEC gains
- Seismic processing software
- Topographic compensation
- Processing history

pulseEKKO™ Application

- Bedrock depth
- Buried tanks or drums
- Rock fractures
- Mine workings
- Mineralized zones
- Glacier thickness
- Archaeological sites

Detection of Buried Tanks



Sensors & Software Inc.

Sensors & Software Inc.

pulseEKKO™ IV EQUIPMENT SPECIFICATIONS

RADAR PARAMETERS

System Performance	155 dB
Programmable Time Window	32 - 2048 ns
Programmable Sampling Interval	800 - 8000 ps
Programmable Stacking Range	1 - 2048 stacks

CONTROL CONSOLE

Size	35 x 26 x 15 cm
Weight	3 Kg
Power	12V DC (0.6 Amp)
Control and Data Port	RS232 Serial Port

TRANSMITTER ELECTRONICS

Output Voltage	400V (1000V - optional)
Repetition Rate	30kHz
Size	28 x 28 x 11 cm
Weight	3 Kg (battery included)
Power	12V DC (0.5 Amp)

RECEIVER ELECTRONICS

Size	28 X 28 X 11 cm
Weight	3 Kg (battery included)
Power	12V DC (0.5 Amp)

CABLES

Control Console Power	1.5m power cable
Transmitter Trigger	20m fibre optic
Receiver Timing and Data	20m dual fibre optic
Computer Interface	2m RS232 cable

CONTROL & DISPLAY

Computer	MS-DOS* PC†, 640Kbytes RAM, RS232 port.
Data Storage	PC floppy, hard, or RAM disk
Hard Copy	Most PC printers
Software	EKKO_RUN EKKO_PLOT EKKO_EDIT EKKO_SEGY EKKO_RANG EKKO_FILT EKKO_CMP EKKO_SYNTH

ANTENNAS

25 MHz	50 MHz	100 MHz	200 MHz
10.5 x 368 x 0.8 cm	10.5 x 184 x 0.8 cm	10.5 x 92 x 0.8 cm	10.5 x 46 x 0.8 cm
4 Kg	2 Kg	1.5 Kg	1 Kg

* MS-DOS Trademark of Microsoft Corp. † PC Trademark of International Business Machines Corp.

Sensors & Software Inc.

5566 Tomken Road
Mississauga, Ontario
Canada L4W 1P4

Phone: (905) 624-8909
Fax: (905) 624-9365

August, 1993

US RENTAL PRICE LIST
pulseEKKO IV GPR Products

	Per Day	Per Month	Mob.
BASE SYSTEM:	200.00	4,800.00	350.00

INCLUDES:

1. 1- pulseEKKO IV Control Unit
2. 1- pulseEKKO IVTransmitter Module (400V)
3. 1- pulseEKKO IV Receiver Module
4. 1- Set 100 MHz (nominal) Centre Frequency Antennas
5. 2- Single Transmitter Fibre Optic Cable (20 m)
6. 2- Dual Receiver Fiore Optic Cables (20 m)
7. 1- Control Unit to Computer Cable
8. 1- Battery Cable for pulseEKKO IV
9. 2- Antenna Carrying Handles
10. 8- Rechargeable Batteries (6V, 4 Ah)
11. 2- Battery chargers (6V)
12. 1- System Collection Software
13. 1- Standard Plotting and Editing Software
14. 1- System User Manual

OPTIONAL ITEMS:

	Per Day	Per Month	Mob.
Electronics:			
Transmitter Module (400V)	33.75	816.00	90.00
Transmitter Module (1000V)	45.00	1087.50	90.00
Receiver Module	72.00	1740.00	90.00
Antennas:			
set 25 MHz:	34.00	825.00	90.00
set 50 MHz:	24.00	562.50	90.00
set 100 MHz:	17.00	412.50	90.00
set 200 MHz:	11.50	277.50	90.00
Cables and Batteries:			
Spare Single Fibre Optic:	2.50	24.00	30.00
Spare Dual Fibre Optic:	4.50	48.00	30.00
Spare 6V Battery:	1.50	10.00	10.00
Spare 6V Charger:	2.00	14.25	15.00
Software:			
Standard Plotting and Editing:	15.00	300.00	75.00
Color Plotting Program:	15.00	300.00	75.00
Bandpass Filter Program:	3.00	75.00	75.00
EKKO_TOOLS Basic GPR Processing	15.00	300.00	75.00
VISTA GPR Seismic Processing	84.00	2025.00	75.00

Sensors &
Software Inc.
pulseEKKO™
1000

Sensors & Software Inc.

Digital Ground Penetrating Radar for High Resolution Applications

New to our pulseEKKO family, the pulseEKKO 1000 extends the premier digital ground penetrating radar system to new levels of excellence. From 10 MHz to 1000 MHz we have a system to match your application.

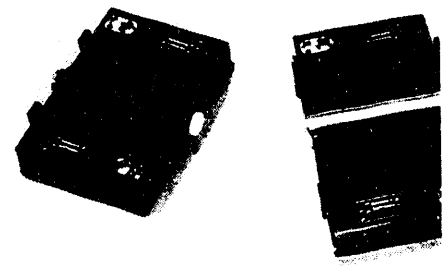
Use the pulseEKKO 1000 for:

- ▼ pipe and cable detection
- ▼ road bed and shallow stratigraphy
- ▼ archaeological investigations
- ▼ building structure integrity
- ▼ non-destructive testing

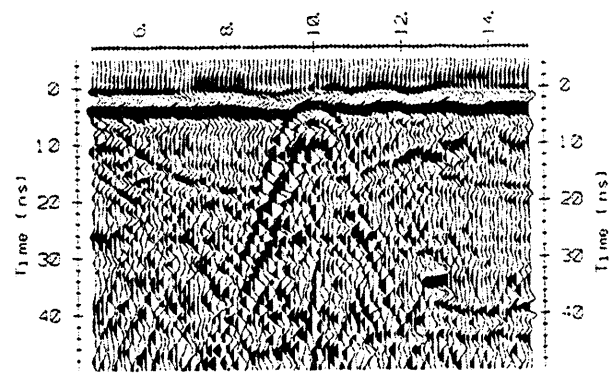
The pulseEKKO 1000 features the same user friendly operation and high performance levels as other members of the pulseEKKO family.

Lightweight, shielded antennas make the pulseEKKO 1000 ideal for operation in urban and indoor survey applications.

900 MHz - 450

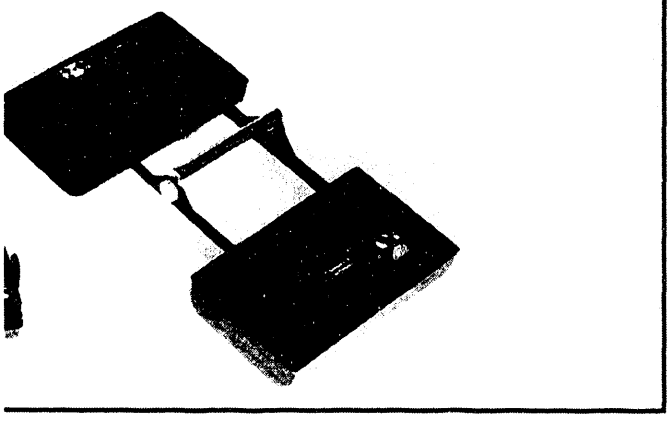


CULVERT

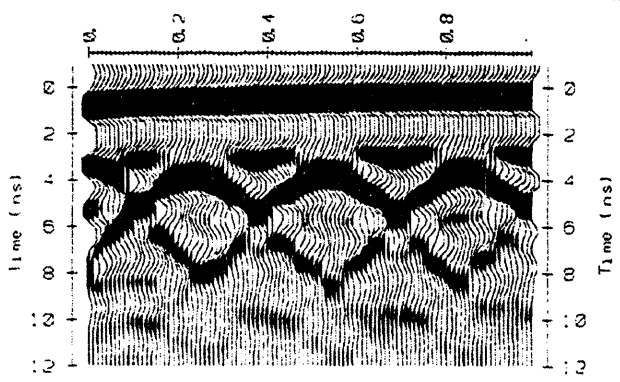


REFLECTION

MHz - 225 MHz



RE-BAR



TRANSILLUMINATION

A variety of fixed or fully independent antennas combined with modular and flexible design optimizes the system for velocity sounding and tomography applications in addition to conventional reflection survey.

The pulseEKKO 1000 is a completely digital package with trace stacking and unprocessed data recording. Data processing and display are totally independent of data acquisition.

pulseEKKO 1000 minimizes your dependence on skilled and experienced operators by minimizing user adjustments, recording all system setup parameters with each profile and digital storage of unprocessed data.

Remote control ports give you the flexibility of operating with manual or fully automated positioning systems.

Audio/visual indicators at both antennas make transillumination and tomography surveys simple.

pulseEKKO™ 1000

5566 Tomken Road, Mississauga, Ontario, Canada L4W 1P4, Phone: (905) 624-8909 Fax: (905) 624-9365

Sensors & Software Inc.

SPECIFICATIONS

RADAR PARAMETERS

System Performance	133 dB
Programmable Time Window	10 - 250 ns
Programmable Sampling Interval	100 - 1000 ps
Programmable Stacking Range	1 - 2048 stacks

CONTROL CONSOLE

Size	25 x 16 x 16cm
Weight	2.8 Kg
Power	12V DC (2.5 Amp)
Control & Data Port	RS232 Serial (optional Parallel)

TRANSMITTER ELECTRONICS

Output Voltage	200V
Repetition Rate	30 kHz
Size	23 x 16 x 5cm
Weight	1.6 Kg

RECEIVER ELECTRONICS

Size	23 x 16 x 5cm
Weight	2.0 Kg
Data Resolution	16 bit

CONTROL & DISPLAY

Computer	MS-DOS* PC**, 640Kbytes RAM, RS232 port
Data Storage	Floppy, hard or RAM disk
Hard Copy	PC** compatible printers
Software :	EKKO_RUN, plus a complete line of processing programs

ANTENNAS

	225 MHz	450 MHz	900 MHz
Size	40 x 23 x 7cm	23 x 16 x 6cm	23 x 16 x 6cm
Weight	1.0 Kg	0.7 Kg	0.7 Kg

* MS-DOS Trademark of Microsoft Corp. ** PC Trademark of International Business Machines Corp.

pulseEKKO™ 1000

5566 Tomken Road, Mississauga, Ontario, Canada L4W 1P4, Phone: (905) 624-8909 Fax: (905) 624-9365

CP

ZONGE ENGINEERING & RESEARCH ORGANIZATION

3322 EAST FORT LOWELL ROAD, TUCSON, ARIZONA 85716 U.S.A.
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October 11, 1993

Mr. Norman E. Goldstein
Lawrence Berkley Laboratories
Earth Science Division
1 Cyclotron Road
Berkley, California 94720
Mailstop 50E

Dear Mr. Goldstein:

Thank you for your call and interest in Zonge Engineering. Attached you will find a brochure package, rental rate sheet, and some general information you may find helpful in your equipment search. Below is a sample quotation for a TEM system that includes NanoTEM.

1.	GDP-16/3	3 Channel Receiver	$ 34,874.00
2.	NTEM-16	NanoTEM Analog Card	3,985.00
3.	NT-20	24V. 20A TEM/NanoTEM Transmitter	9,234.00
4.	BR 12/w	Breast Reel W/610 M Wire	1,191.00
5.	PPE/1	Porous Pot Electrodes (2)	208.00
6.	SW-TEM	TEM Processing	1,135.00
7.	SW-PLOT	Contour Plots/Psuedosections	895.00
8.	SW-TEM1D	1D Inverse TEM	1,645.00
	STEM-Source		2 500.00
	Total		$ 53,167.00

When you look over the enclosed literature, please contact me if I can help further. I would be pleased to help in any way.

With regards,

Bill Perry
General Manager

BP/dlm

THE NT-20 TRANSMITTER

Multi-function Battery-Powered TEM Transmitter

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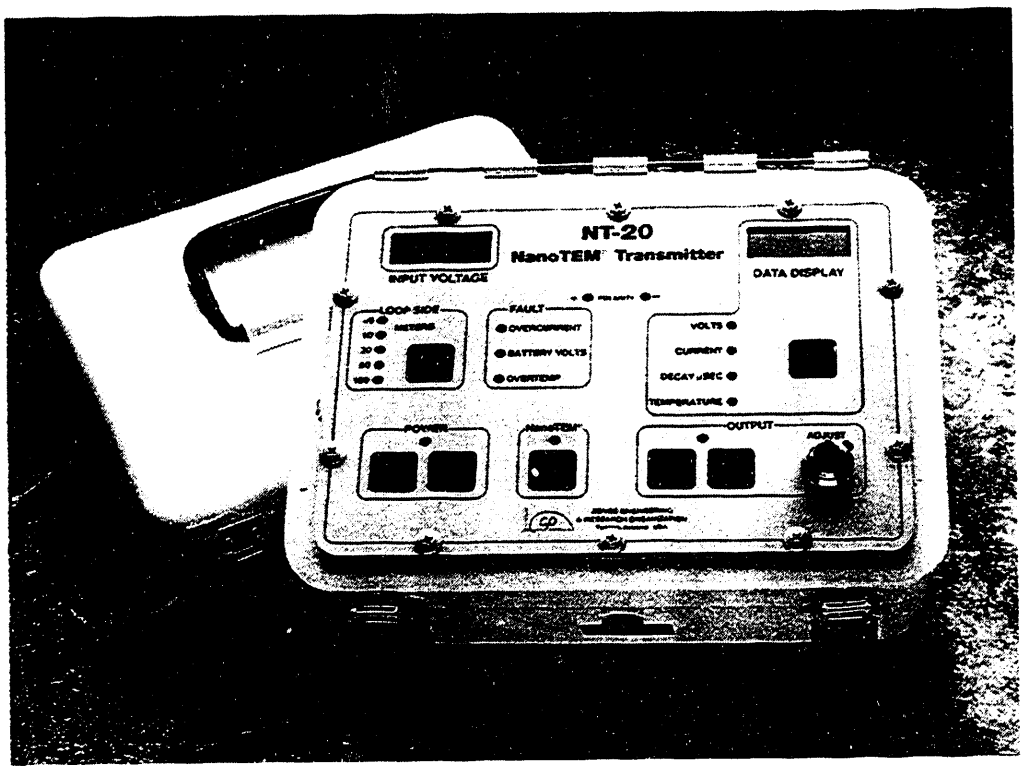

FEATURES

- Dual output: NanoTEM® or ZEROTEM
- Bipolar current output up to 20 A
- 50 or 100% duty cycle
- Less than 2 microsecond shutoff into 20 meter loop (NanoTEM®)
- Less than 50 microseconds turnoff into 100 meter loop (ZEROTEM)
- Lightweight, battery powered

·7 µsec
1.9 µsec sampling

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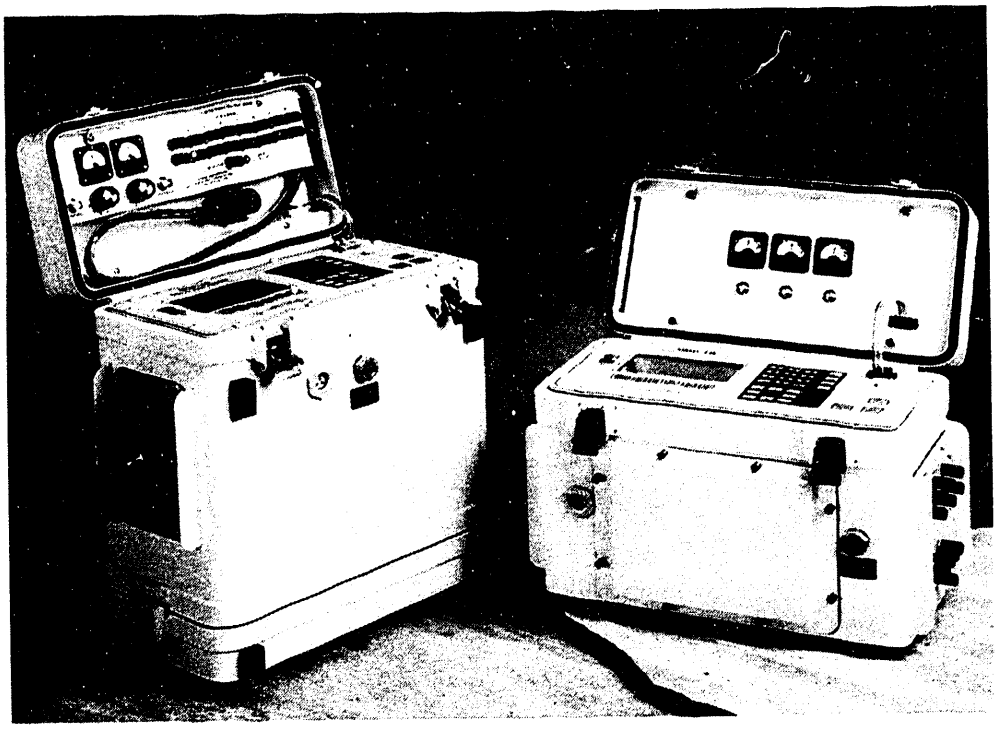
THE GDP-16
Multi-Purpose Receiver



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FEATURES

- 1 to 8 channels, field-expandable
- 80C186 MPU, 80C187 math coprocessor
- Simple to use menu-driven software
- All programs resident in memory
- Resistivity, Time/Frequency Domain IP, CR, CSAMT, HACSAMT & TEM capability (optional AMT and MT)
- Screen-graphics: decay curves, contoured pseudosections on 256 x 128 pixel LCD
- Use as a data logger for analog data, borehole depth data, etc.
- 0.001 Hz to 8 kHz frequency range (standard)
- One 16 bit A/D per channel for speed & phase accuracy
- 256 KB ROM, 256 KB RAM for program execution
- 896 KB RAM for data storage standard, stores several days' worth of data—non-volatile RAM expansion up to 6 MB
- Real-time data & statistics display
- Anti-alias, powerline notch & telluric filtering
- Automatic SP buckout, gain setting & calibration
- Rugged, portable & environmentally sealed
- Modular design for easy upgrades & board replacement
- In-field data processing on a personal computer
- Complete support: field peripherals, service network, software, training
- Easy to use menu-driven software

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SPECIFICATIONS: GDP-16 MULTI-PURPOSE RECEIVER

General

Description: Broad-band, multi-channel, multi-function, digital receiver
Frequency range: 0.001 Hz to 8 kHz (standard)
Number of channels: 1 to 8 (field expandable)
Survey capabilities:
- Resistivity
- Time domain IP
- Frequency/phase domain IP
- Complex resistivity
- CSAMT (scalar, vector, tensor)
- Harmonic CSAMT
- Frequency domain EM
- Transient electromagnetics (TEM)
- Magnetotellurics (MT, AMT)
- Other user-programmed functions

Software language: C and assembly
Size:
- Large case:
  41 x 20 x 45 cm (16 x 8 x 17.5 in)
- Small case:
  41 x 20 x 31 cm (16 x 8 x 12 in)

Weight: (including batteries and meter/connection panel):
- Large case:
  - 8-channel, 20 kg (43.5 lb)
  - 8-channel, large battery pack, 23.4 kg (51.5 lb)
- Small case:
  - 3-channel, 14.3 kg (31.5 lb);

Enclosure: Heavy-duty, environmentally-sealed aluminum case
Power: 12 V rechargeable batteries in removable battery pack (field-replaceable without loss of synchronization). Over 10 hours nominal operation at 20°C with 8 channel unit; additional batteries mounted internally or external battery input for extended operation in cold climates.
Temperature range: −40° to +60°C (−40° to +140°F)
Humidity range: 5% to 100%; operable in direct rain
Time base: Oven-controlled crystal oscillator; aging rate $<5 \times 10^{-10}$ per 24 hours

Displays & Controls

LCD alphanumeric/graphics display, 41 characters by 16 lines, with continuous view-angle adjustment, optional heater for use down to −40°C.
Sealed keyboard with 10 numeric and 25 function keys
Analog signal meters and analog outputs
Crystal on-off
Crystal adjust

Analog

Input impedance: 10 MΩ at DC
Dynamic range: 180 dB
Minimum detectable signal: .03 μV
Maximum input voltage: ±32 V
SP offset adjustment: ±2.5 V in 76 μV steps (automatic)
Automatic gain setting in binary steps from 1/8 to 65,536
Input: True differential for common-mode rejection
Phase Accuracy, ±0.1 milliradian (0.006 degree)
Adjacent channel isolation at 100 Hz: >90 db

Filter Section

Four-pole Bessel anti-alias filter (software-controlled)
Quadruple-notch, specified by user (e.g., 50/150/250/450 Hz, 50/150/60/180 Hz, 60/180/300/540, etc.)
Digital telluric filter

Analog to Digital Converter

Resolution: 16 bits ±1/2 LSB
Conversion time: 17 μsec
Continuous self calibration
One A/D per channel for maximum speed and phase accuracy

Digital Section

Microprocessors: 80C186 with 80C187 math coprocessor
NEC V40 for keyboard, LCD display and I/O control
Memory: 256 KB ROM, 256 KB RAM for program use; 896 KB RAM data storage (standard)
Memory Expansion: 1.5 MB increments to 6 MB
On-board calendar clock
Serial ports: Two RS-232 ports
Parallel port: Two IBM/Centronics compatible printer ports one standard, one bi-directional

Options

Number of channels (between 1 and 8)
RAM disk for extended data storage
High-precision rubidium crystal oscillator with aging rates of $\leq 5 \times 10^{-11}$ per month
External battery and LCD heater for −40° operation
IR filter for LCD

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THE GDP-32

Broadband Electrical Methods Receiver

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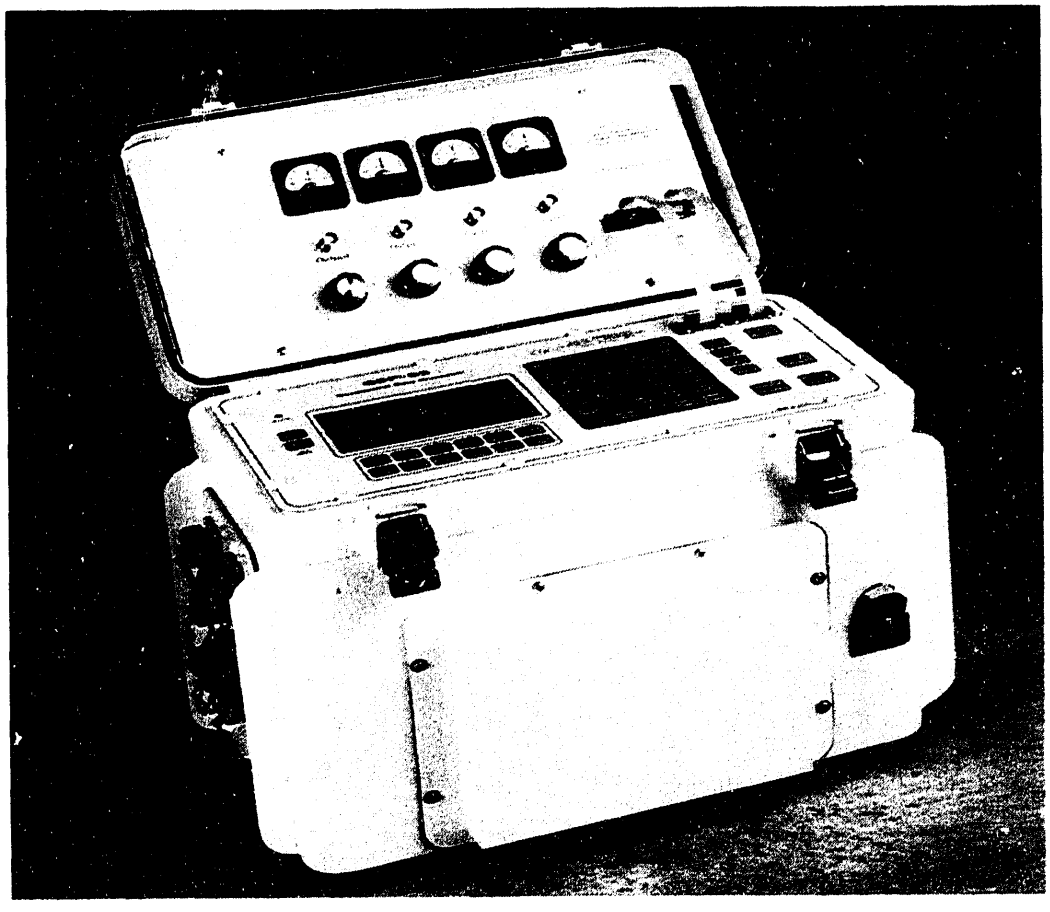

FEATURES

- 1 to 16 channels, user-expandable
- 386SX MPU, 387SL math coprocessor
- Easy to use menu-driven software
- All programs resident in memory
- Resistivity, Time/Frequency Domain IP, CR, CSAMT, HACSAMT & TEM
- AMT, MT & NanoTEM® optional
- Screen-graphics: decay curves, contoured pseudosections on 256 x 128 pixel LCD
- Use as a data logger for analog data, borehole data, etc.
- 0.001 Hz to 8 kHz frequency range
- One 16 bit A/D per channel for maximum speed & phase accuracy
- 4 MB ROM, up to 16 MB RAM for program execution
- 896 KB RAM for data storage standard, stores several days' worth of data—non-volatile RAM expansion up to 4 MB
- Real-time data & statistics display
- Anti-alias, powerline notch & telluric filtering
- Automatic SP buckout, gain setting & calibration
- Rugged, portable & environmentally sealed
- Modular design for upgrades & board replacement
- Complete support: field peripherals, service network, software, training
- Full compatability with GDP-16 series receivers

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SPECIFICATIONS: GDP-32 MULTI-PURPOSE RECEIVER

General

Description: Broad-band, multi-channel, multi-function, digital receiver
Frequency range: 0.001 Hz to 8 kHz
Number of channels: 1 to 16 (user expandable)
Standard Survey capabilities:
- Resistivity
- Time domain IP
- Frequency/phase domain IP
- Complex resistivity
- CSAMT (scalar, vector, tensor)
- Harmonic CSAMT
- Frequency domain EM
- Transient electromagnetics (TEM)

Optional Survey capabilities:
- MMR, Magnetic IP
- Magnetotelluric (MT, AMT)
- NanoTEM®
- Other user-programmed functions

Software language: C and assembly
Size:
41 x 20 x 33 cm (16 x 8 x 13 in)
Weight: (including batteries and meter/connection panel):
8-channel, 16 kg (36 lb)
16-channel, 19 kg (42 lb)
Enclosure: Heavy-duty, environmentally-sealed aluminum case
Power: 12 V rechargeable batteries in removable battery pack (field-replaceable without loss of synchronization). Over 10 hours nominal operation at 20°C with 8 channel unit; external battery input for extended operation in cold climates, or for more than 8 channels.
Temperature range: −40° to +60°C (−40° to +140°F)
Humidity range: 5% to 100%; operable in direct rain
Time base: Oven-controlled crystal oscillator; aging rate $<5 \times 10^{-10}$ per 24 hours

Displays & Controls

LCD alphanumeric/graphics display, 41 characters by 16 lines, with continuous view-angle adjustment, optional heater for use down to −40°C.
IR/UV filter for LCD
Sealed alphanumeric keyboard
Analog signal meters and analog outputs
Crystal on-off
Crystal adjust

Analog

Input impedance: 10 MΩ at DC
Dynamic range: 190 dB
Minimum detectable signal: .03 μV
Maximum input voltage: ±32 V
SP offset adjustment: ±2.25 V in 69 μV steps (automatic)
Automatic gain setting in binary steps from 1/8 to 65,536
Input: True differential for common-mode rejection
Phase Accuracy, ±0.1 milliradian (0.006 degree)
Adjacent channel isolation at 100 Hz: >90 db

Filter Section

Four-pole Bessel anti-alias filter (software-controlled)
Quadruple-notch, specified by user (e.g., 50/150/250/450 Hz, 50/150/60/180 Hz, 60/180/300/540, etc.)
Digital telluric filter

Analog to Digital Converter

Resolution: 16 bits ±1/2 LSB
Conversion time: 17 μsec
Continuous self calibration
One A/D per channel for maximum speed and phase accuracy

Digital Section

Microprocessors: 386SX with 387SL math coprocessor
Memory: 4 MB ROM, 2 MB RAM for program use; 896 KB RAM data storage (standard)
Memory Expansion: to 16 MB
On-board calendar clock
Serial ports: Two RS-232 ports
Parallel port: One IBM/Centronics compatible printer port

Options

Number of channels (between 1 and 16)
RAM Disk for extended data storage
60 MB Hard Disk
External High-precision rubidium crystal oscillator with aging rates of $\leq 5 \times 10^{-11}$ per month
External battery and LCD heater for −40° operation

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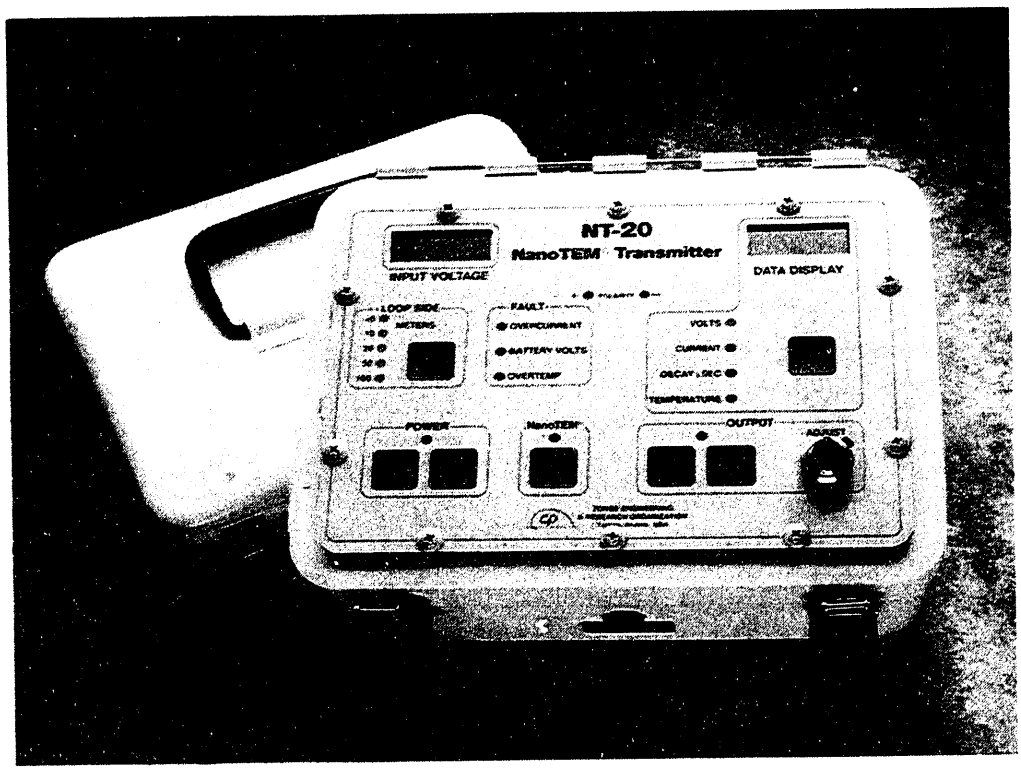
THE NT-20 TRANSMITTER

Multi-function Battery-Powered TEM Transmitter



FEATURES

- Dual output: NanoTEM® or ZEROTEM
- Bipolar current output up to 20 A
- 50 or 100% duty cycle
- Less than 2 microsecond shutoff into 20 meter loop (NanoTEM®)
- Less than 50 microseconds turnoff into 100 meter loop (ZEROTEM)
- Lightweight, battery powered

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SPECIFICATIONS FOR THE NT-20 TEM TRANSMITTER

Mechanical

Waterproof case with sealed front panel and connectors
25 ampere rated output current connectors
Case size: 22 x 28 x 18 cm
Weight: 5 kg (without batteries)

Electrical

Input voltage: 10 to 30 VDC
Peak output current: 20 A
Transmit control from GDP receiver or XMT-series transmitter controller (10m maximum separation)
Receiver control of transmitter ON/OFF
Current monitor outputs:
- 0.1 ohm ZEROTEM
- 1.0 ohm NanoTEM®

Automatic overcurrent shutdown (set for 25 A)
Mosfet IGBT power output current switch
Automatic fault detection

Controls & Displays

Lamps to indicate state of transmitter: power on, transmitting, fault, polarity
Power OFF/ON
Transmit/Reset
Current Set
NanoTEM®/ZEROTEM
Loop Size:
- 5m
- 10m
- 20m
- 50m
- 100m

Meter Select
LCD displays:
- Input voltage
- Output voltage, current
- Turnoff time, internal temperature

Fault Indicators

Over/Under Voltage
Over Current
Over Temperature

Output Jacks

Current monitor terminals (100 mV/A, 1 V/A)
Output current terminals

Power

External battery: 10 to 30 V
Power connector: four-pin military twist-lock

Option

Fiber optic control link for 100m or 200m separation between XMT/GDP and transmitter

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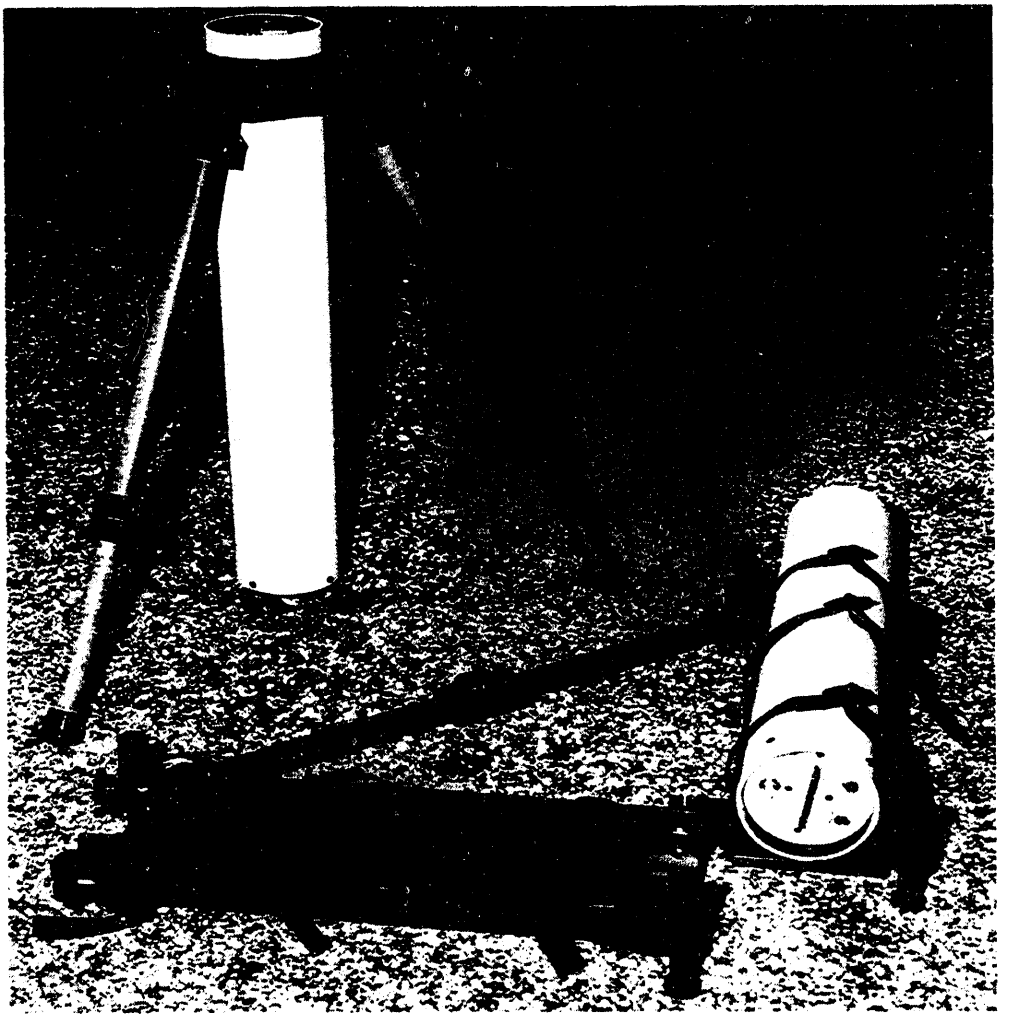
TEM/3
Magnetic Antenna



The TEM/3 antenna is a single channel magnetic field antenna useful for transient electromagnetic (TEM) controlled source audio-frequency magnetotelluric (CSAMT), and other types of EM geophysical surveys measuring vertical or horizontal fields. Multiple units may be used simultaneously to measure multiple axes.

Optional stands for the TEM/3 available:

STAND/Z for vertical measurements,

STAND/XY for horizontal perpendicular measurements, and

STAND/XZ for a combination of one vertical and one horizontal measurement.

The TEM/3 is provided with frequency domain calibrations and can be used inside or outside the transmitting loop.

SPECIFICATIONS: TEM/3 MAGNETIC ANTENNA

General

Power: Two 9V alkaline batteries
Battery life: 7 days at 12 hours per day
Amplifier gain: 33
Number of turns: 4000
Effective Area: 10,000 m^2
Minimum Detectable Signal: .007 gamma•Hz
Maximum signal without saturation: 68,000 gamma•Hz
Delay constant: 15 microseconds
Multiple unit crosstalk: > 60db isolation
Electrical response: dB/dt, DC to above 8 KHz.

Physical

Length: 61 cm
Diameter: 11 cm
Weight: 4.5 kg
Core: ceramic ferrite, 2.54 x 45.7 cm

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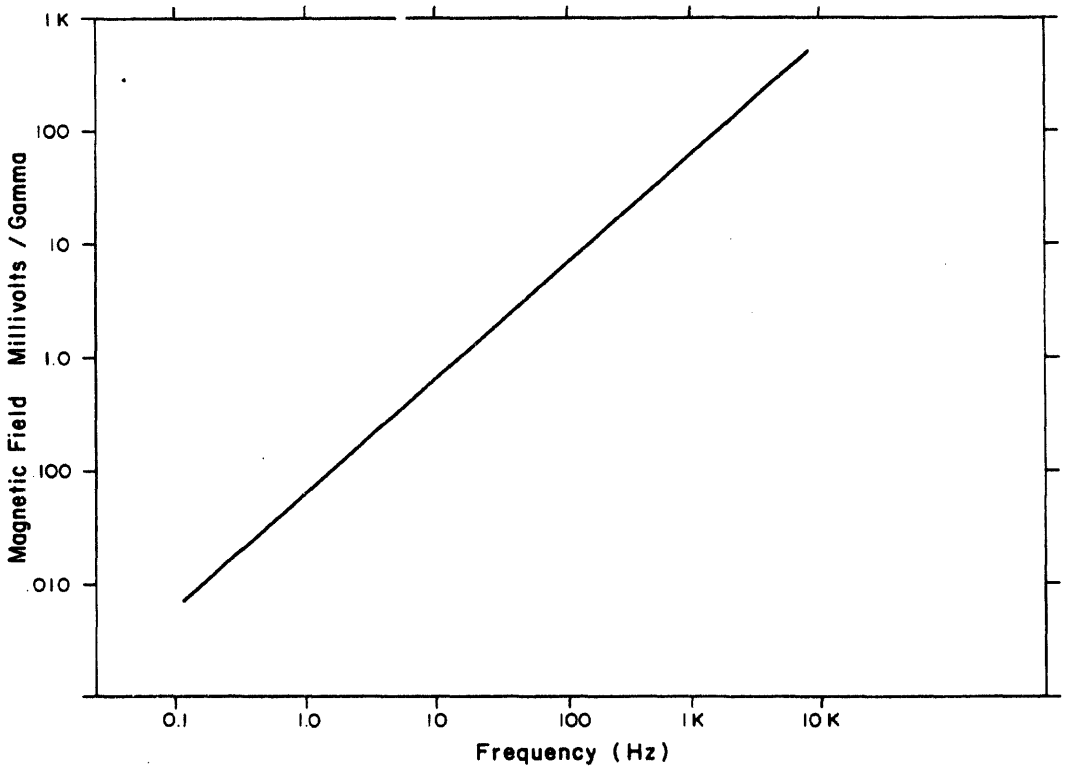

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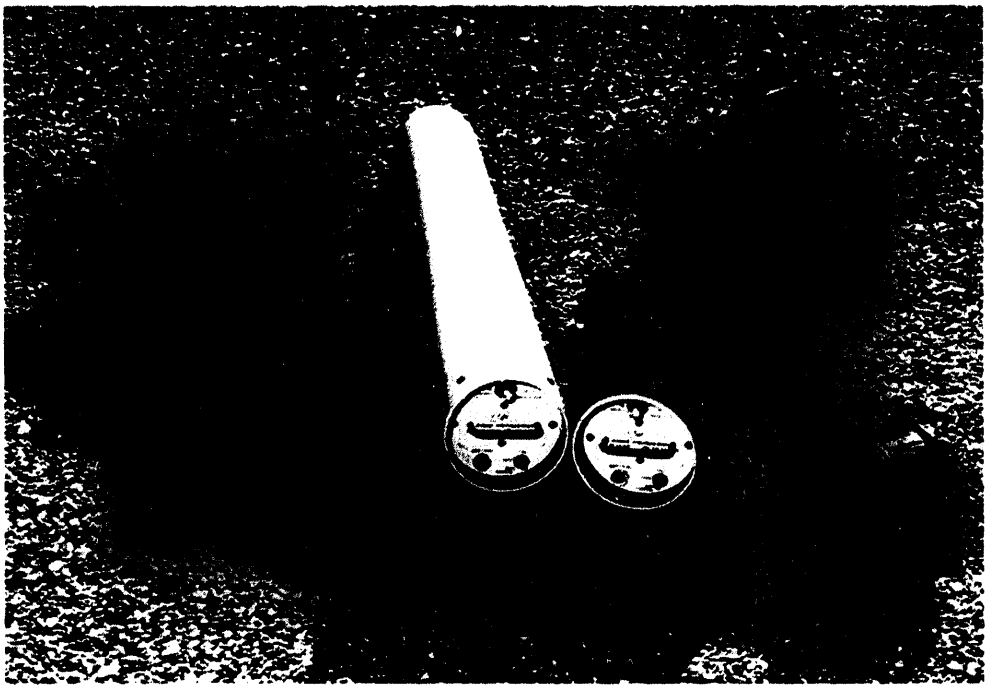
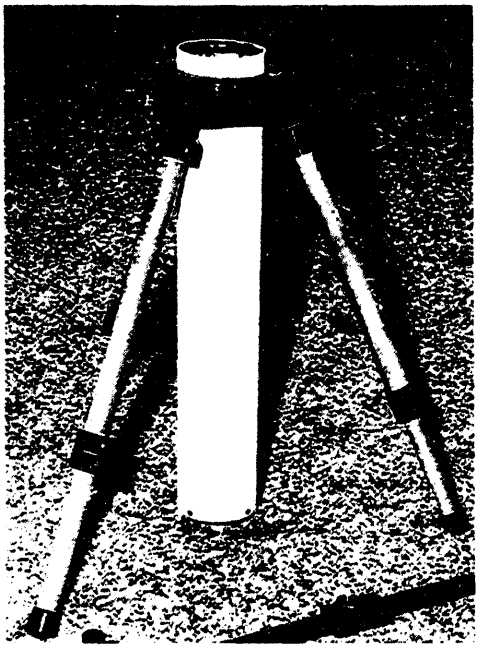
ANT/1
Magnetic Antenna



The ANT/1 antenna is a single channel magnetic field antenna used for controlled source audio-frequency magnetotelluric (CSAMT), and other types of frequency domain EM geophysical surveys measuring vertical or horizontal fields Multiple units may be used simultaneously to measure multiple axes. The ANT/1 is provided with frequency domain calibration for both harmonic and single frequency applications.



Optional stand for vertical measurements—STAND/Z.

SPECIFICATIONS: ANT/1 MAGNETIC ANTENNA

General

Power: Two 9V alkaline batteries
Battery life: 14 days at 12 hours per day
Amplifier gain: 101
Number of turns: 8000
Effective Area: 82,000 m^2
Minimum Detectable Signal:
.004 gamma•Hz for dB/dt response
.00016 gamma/Hz at 4 kHz
Maximum signal without saturation:
8000 gamma•Hz for dB/dt response range
37 gammas at 4 kHz

Physical

Length: 80 cm
Diameter: 9.5 cm
Weight: 8.0 kg
Core: ceramic ferrite, 2.54 x 61 cm

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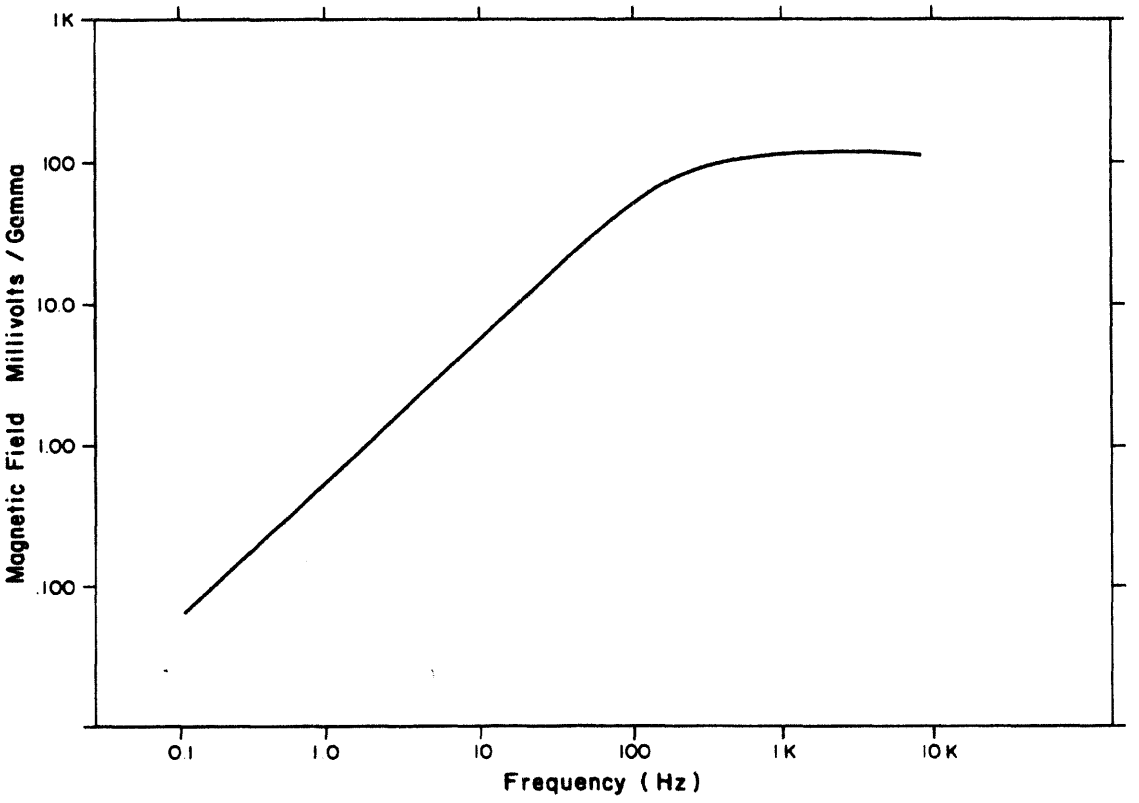

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