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DESIGN AND APPLICATION OF A MEGA-MOMENT ELECTROMAGNETIC DIPOLE SOURCE

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October 1979

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DESIGN AND APPLICATION OF A MEGA-MOMENT ELECTROMAGNETIC DIPOLE SOURCE

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ABSTRACT

An electromagnetic transmitter capable of generating a magnetic dipole moment in excess of 10^6 mks over a wide frequency range was designed and field tested in connection with geothermal exploration surveys. We will deal primarily with engineering aspects of the transmitter pertinent to the design and construction of similar transmitters for various geophysical applications.

Lawrence Berkeley Laboratory, in association with the Engineering Geoscience Group, University of California, has been involved for several years in the Dept. of Energy, Division of Geothermal Energy's Exploration Technology Program. As a result of studies and evaluations of all geophysical techniques, it appeared that the controlled-source EM technique offered certain site-specific advantages over the commonly used dc resistivity and magnetotelluric methods for mapping the subsurface resistivity distribution. This seemed particularly true where it would be difficult to put sufficient current directly into the ground or where complex geology requires many MT stations for even a partial interpretation.

Existing EM transmitters were tested and found inadequate because they were too limited by the inductive nature of their loads to produce a sufficiently large dipole moment. We therefore designed a prototype transmitter specifically suited to, but not requiring adjustments for, the reactive nature of the transmitter loop. This prototype was built around an existing 60 kW motor-generator set mounted on a one-ton 4-wheel-drive truck, and was designated as the EM-60 controlled source.

Field tests were carried out with a horizontal loop transmitter in both Grass Valley, Nevada and on the flanks of Mount Hood, Oregon. During these tests, the magnetic moment exceeded 1×10^6 mks (rms) over the frequency range .02 to 500 Hz, although only 1.4 to 1.6 km of No. 6 welding cable was used. The current was switched between ±63 A. Field tests indicated the transmitter design provides a safe and reliable system. As no special tuning or adjusting is required for frequency changes, the transmitter is easily operated by one person. However, in field tests we found it convenient to operate the entire system with a four-man crew, the same crew size used for dipole-dipole dc resistivity. Crew comments suggested that the EM technique is faster and easier than dc resistivity work in the flat, open terrain of a Basin and Range Valley.

Introduction

The Lawrence Berkeley Laboratory, in association with the Engineering Geoscience Group of the University of California, has been involved for several years in the Department of Energy, Division of Geothermal Energy's Exploration Technology Program. Beginning in 1973, an early segment of this program concerned the study and evaluation of existing geophysical techniques for geothermal exploration. Extensive field work towards this end was done at Grass Valley, Nevada by Beyer, et al. (1976). In connection with this study Jain (1978) suggested that the electromagnetic method showed some promise as an alternative to dc resistivity and magnetotellurics for electrical resistivity surveys. The use of EM appeared particularly attractive in situations where conventional techniques would be difficult to apply; e.g., (1) areas of high surface (contact) resistance where it would be difficult to put current into the ground or where it might be difficult to measure a potential between two electrodes and (2) areas where it would be difficult to lay out and move long wires.

A review of existing technology and available equipment revealed that a suitable frequency-domain transmitter, one capable of creating a strong magnetic field over a wide range of frequencies, did not exist. Among the transmitter designs evaluated at that time were various SCR bridge circuits, already in common use for resistivity surveys. Our limited attempts to use these transmitters were marginally successful. In all cases, these designs failed because of the inductive nature of the load. Successful use of resistivity transmitters requires that the load appear non-reactive. This necessary condition meant tuning or adjustment in the field for each frequency.

To evaluate the use the electromagnetics in geothermal exploration we embarked on a program with DOE support build a prototype transmitter designed specifically to drive a coil antenna. The following criteria for the transmitter were established based on our earlier experience:

1) Large Magnetic Moment -- The maximum magnetic dipole moment should be available at all times, as a function of power, weight of coil, coil radius and frequency.

<u>Left Slide</u> (M vs. turns) Figure 1

<u>Right Slide</u> (M vs. freq.) Figure 2

2) Reliability -- The transmitter must be reliable under the wide range of field conditions.

3) Ease of Operation -- The transmitter must be easy to operate by normally intelligent field crew members, even when they are under physiological stresses that accompany field operations. This criterion excludes tuning or other adjustments to make the coil appear non-reactive.

4) Simplicity -- The transmitter should be easy to replicate and financially attractive to the private sector in view the DOE objective of technology transfer to industry. Later, it became clear the licensing protection would also be desirable and arrangements were made to allow this. (For licensing information, one should contact the firm of Kinney and Kiblack, 55 E. Jackson Blvd., Suite 1645, Chicago, Il, 60604).

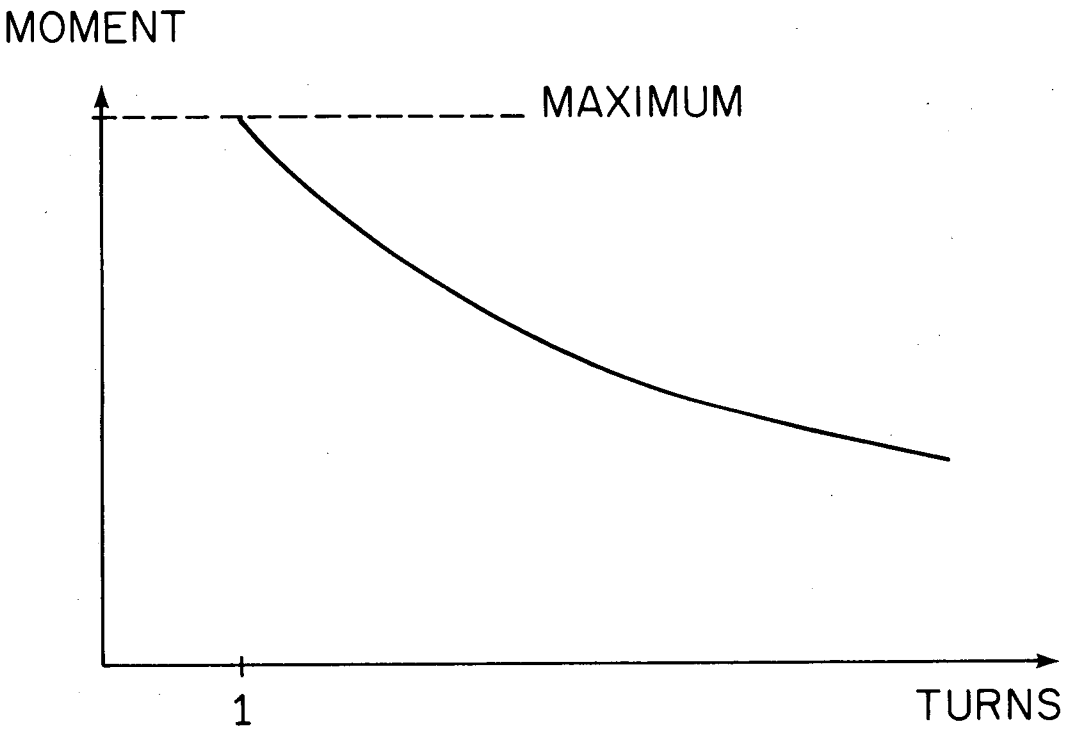

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Figure 1. Magnetic moment as a function of the number of turns for a given length of wire.

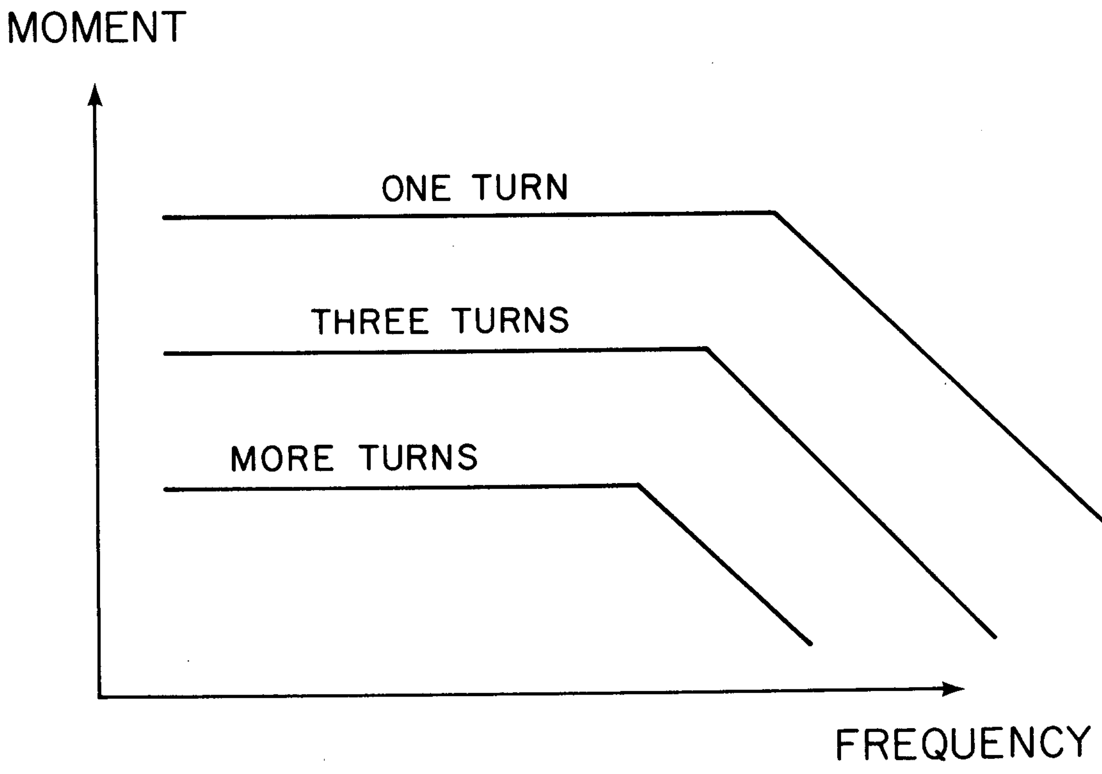

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Figure 2. Magnetic moment as a function of frequency and number of turns.

5) Frequency Range -- The transmitter should supply a square-wave current to the loop over the range 10^{-3} to 10^{3} Hz.

Moment

For the EM method, the single most important parameter is the magnetic dipole moment, $M = N \cdot I \cdot A$. Independent of the magnetic field sensor, SQUID or coil, the signal-to-noise ratio varies with the moment. The larger the moment, the higher the signal-to-noise ratio will be at the receiver. Obviously our objective is to create a large moment, but how is the largest moment created consistent with all the practical limitation of field work?

Let us consider the case of the coil as the antenna. The coil must be carried into the field, laid out in some reasonable configuration and later retrieved. To minimize the field effort and maximize the moment, we need to consider the relationship of the cable gauge, coil weight, coil radius, turns and frequency.

Slide (list) Figure 3

For maximum moment, the following parameters must be minimized:

a) cable resistance,
b) coil inductance,
c) coil turns, (ONE TURN)

and the following parameters maximized:

d) cable length, and/or
e) coil radius.

Clearly these are all closely related. Usually a constraint, such as cable reel capacity, or terrain, places a limit on one of these factors and then the rest are defined.

In our case, the LBL geophysical field crew had experience with cables of various sizes and were already accustomed to using large cables which have the advantage of being easier to lay out than smaller, lighter wire and cable. Large cables were also found to be less sensitive to damage by animals. From the beginning, we planned to use 4/0, 2, 6 or 10 gauge welding cable.

Our next consideration is power. Regardless of the power source available, we want the maximum current in the coil. LBL had a truck-mounted 60 kW motor-generator (MG) set available. This became the basis for the proposed Electromagnetic Controlled Source - 60 kilowatts, or EM-60 for short. We had many problems in refurbishing this used equipment, and I should mention certain aspects of MG sets that can cause problems.

Right Slide (picture of truck) Figure 4

FOR LARGEST MOMENT $(M = N \times I \times A)$

MINIMIZE

- CABLE RESISTANCE
- COIL INDUCTANCE
- COIL TURNS (ONE TURN)

MAXIMIZE

- CABLE LENGTH AND/OR
- COIL RADIUS

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Figure 3. Table.

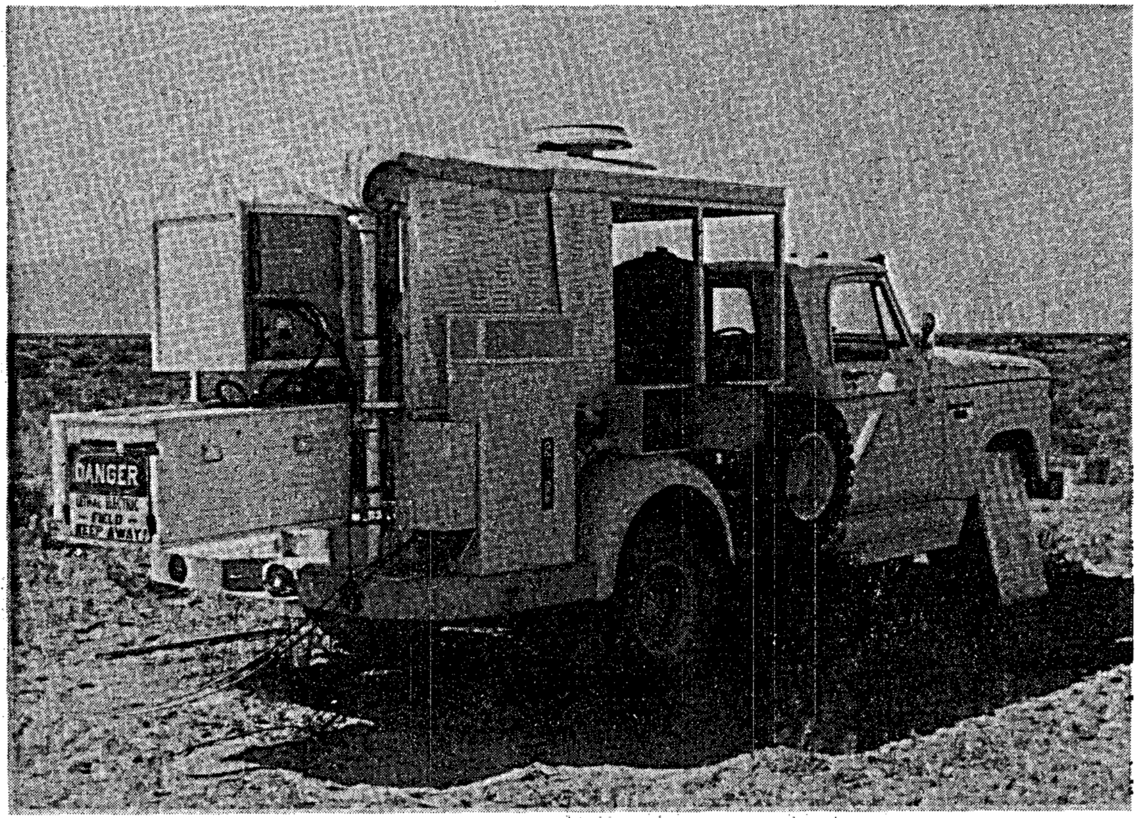

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Figure 4. EM-60 transmitter in operation in Grass Valley, Nevada.

Mounted on a Dodge Power Wagon 300 truck is a Hercules gasoline engine. The engine is linked to a 60 kW, 400 hz, 30 aircraft alternator. Two points about MG sets are important. First, alternators can occasionally have opens, of microsecond duration. Secondly, MG sets perfer constant loads. Even with a governor, it can take many milliseconds for a gasoline engine to compensate for a load change.

I mention these points because they had to be considered in the overall design. To get around the first possible problem, the alternator output was full-wave rectified and capacitor filtered. The capacitors supplied energy during the microsecond-long intervals when the alternator opens.

To get around the second characteristic, we always generated a bipolar magnetic field, with constant amplitude. In other words, we only transmitted square waves. While this excludes on-off-on signals that are used in time-domain studies, it does allow asymmetrical pulse trains, such as pseudo-random sequences.

<u>Left Slide</u> (block diagram) Figure 5

<u>Right Slide</u> (inside truck) Figure 6

So far, I have discussed the load and the MG set. Now let me describe the controls. The controls are both truck mounted and remote. The truck mounted controls are mostly for the engine. They need to be accessed only at the start or the end of a run. Once the engine is running, control is transferred to the remote control box. The noise from the MG set makes remote operation mandatory for humanitarian reasons. It is also necessary if radio communication is desirable. The remote control box allows monitoring of the load current and certain engine functions, and allows the operator to select the fundamental frequency. The frequency is established in the remote control box from a crystal oscillator and dividers. The frequency switches allow three digit selection of periods from 10^{-3} to 10^{+3} seconds. No further adjustment of the electronics is necessary. Also mounted on the truck is a rack for electronics to interface the remote control box and the crate. The crate holds the full-wave rectifiers and the switching transistors. Electronics rack and crate are swung out from within the truck during operation for better cooling.

<u>Right Slide</u> (truck) Figure 7

As mentioned earlier, the EM-60 is basically an inductor current controller. This is different from SCR type transmitters. With inductive loads, SCR's are difficult to turn off, once they are turned on. That is not the case with transistors. Modern transistors are capable of high voltage and currents and fast switching characteristics. The EM-60 was designed to use the IR 5063 series. Less expensive devices can be substituted.

The switch for the EM-60 provides either +150 volts or -150 volts at currents up to 400 amperes. To do this, standard transistors were arranged in electrical parallel on modular heat-sinks. Each module is totally interchangeable. No special selection is necessary for the transistors. The crate holds up to 20 modules.

<u>Right Slide</u> (crate) Figure 8

<u>Left Slide</u> (Moment) Figure 9

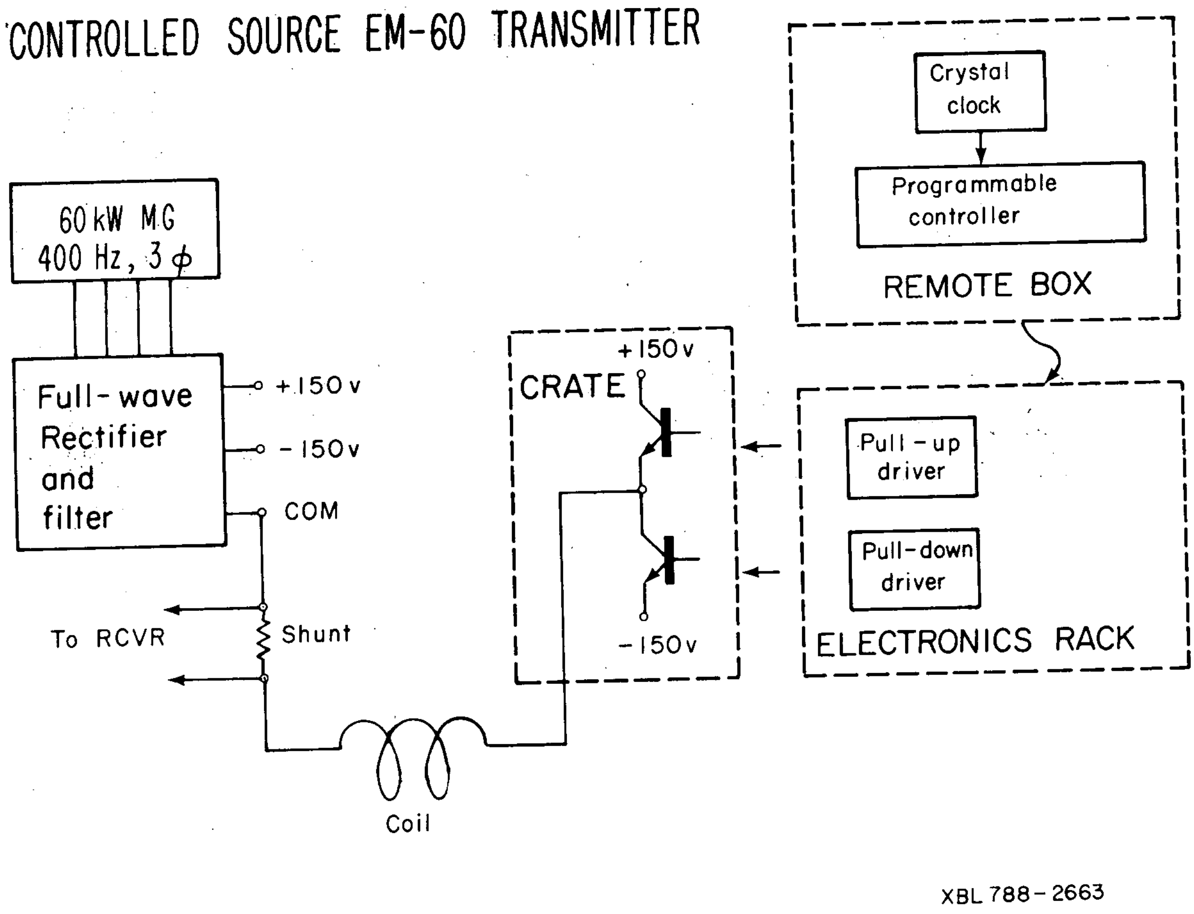

Figure 5. General block diagram of the EM-60 transmitter.

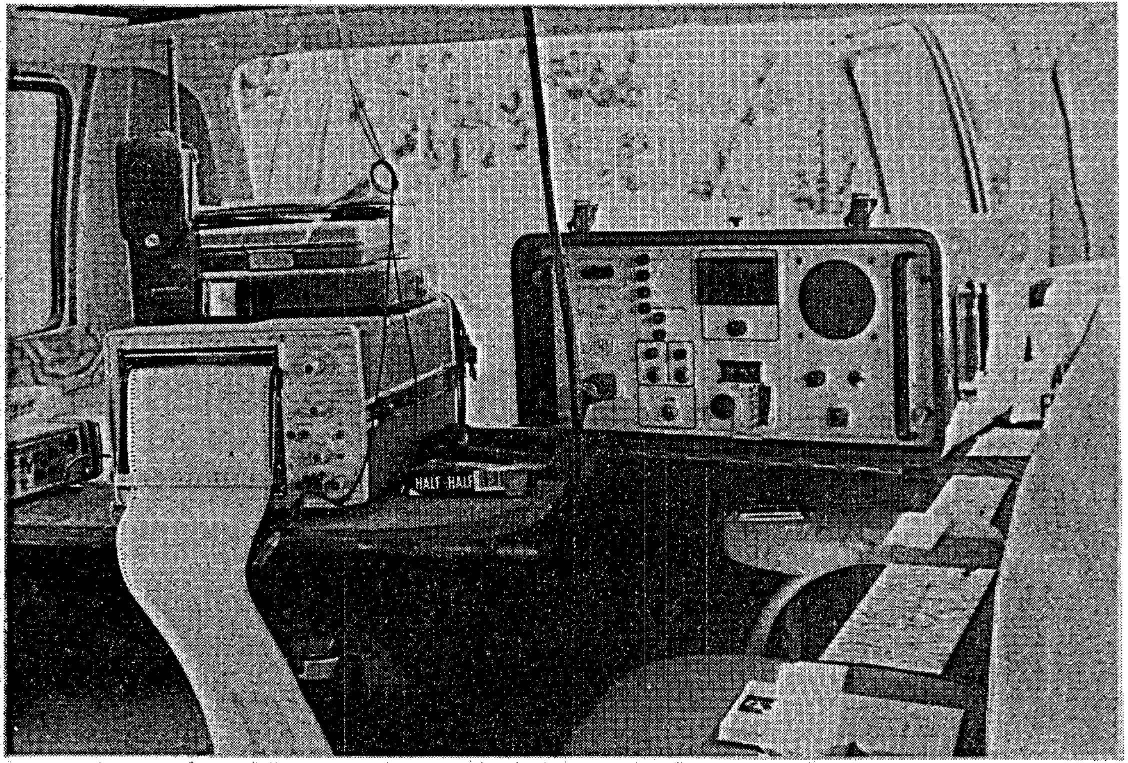

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Figure 6. EM-60 remote box and chart record monitor of current in loop.

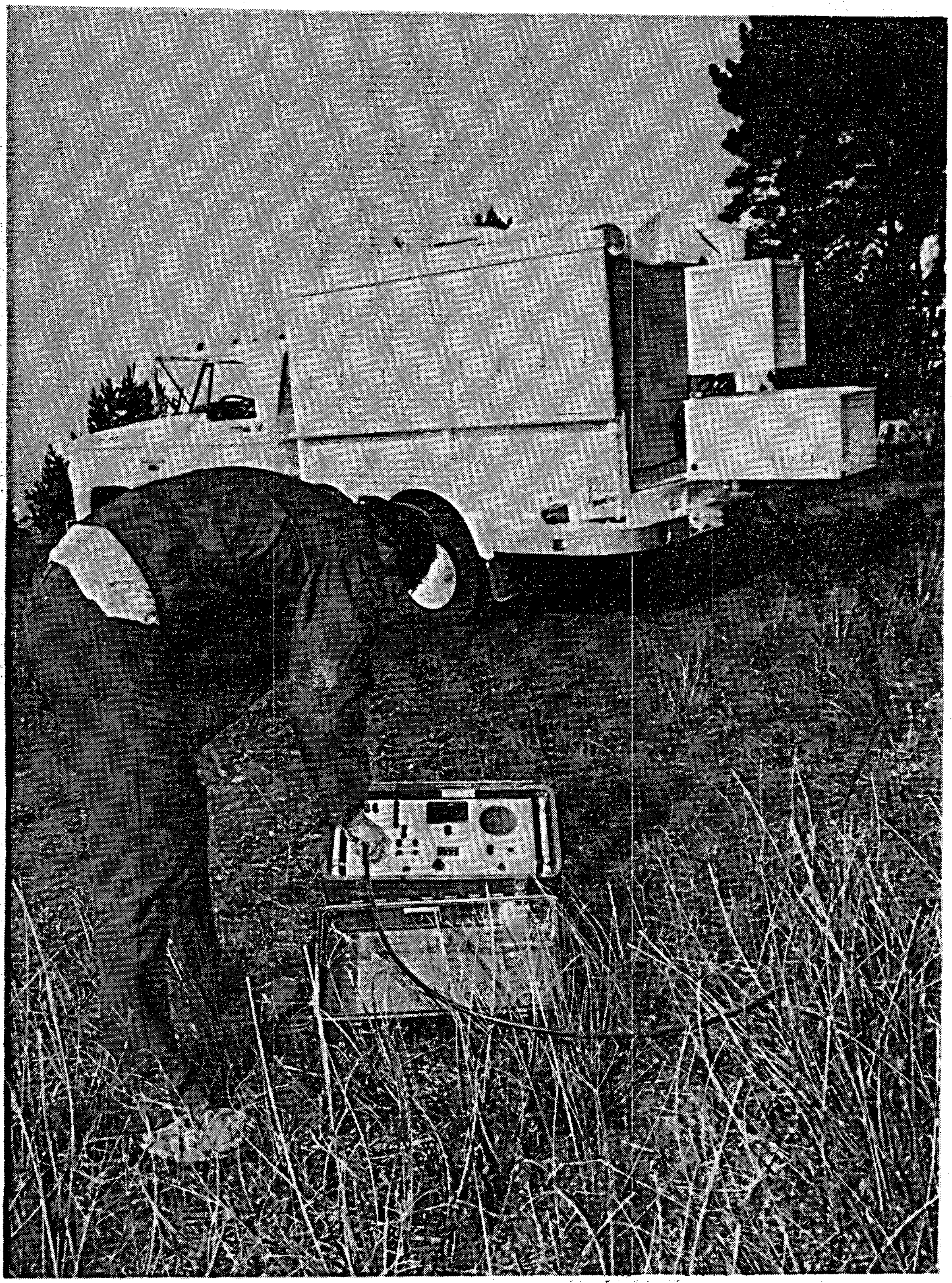

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Figure 7. EM-60 remote box and transmitter truck.

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Figure 8. Switching modules in the crate.

Test Results

The EM-60 was initially tested at Grass Valley, Nevada, during July 1978. For this work 1372 meters (4500 feet) of #6 welding cable was used as the load. The cable was laid out in a nearly circular loop 100 meters in diameter and with 4 turns. The excess cable provided pigtails to the transmitter truck.

For maximum moment the EM-60 is designed for use with #4/0 welding cable carrying 400 amperes. At the time of the test, a vehicle and a cable reel capable of handling the 3.9×10^3 kg (8.5 tons) of cable was not available. Therefore #6 cable was substituted because it could be fielded with existing equipment.

The slide shows the moment versus frequency performance. The actual moment turns out to be slightly higher than the calculated value. The reason is that as the reactance increases, the MG set load decreases. The governor of the engine and the alternator regulator could not compensate enough.

Since we monitor at the receiver station the actual current in the loop via a 0.01 , 0.01% shunt, frequency-dependent variations in current was not a problem. Nominally, the current to the coil was either +63 or -63 amperes. This corresponds to a fundamental frequency component for the moment of about 5×10^6 MKS units, peak to peak.

Since no tuning is necessary for frequency changes, transmitter operation requires only one man. Of course, set up and refueling was simplifed by extra hands. Except for time lost during refueling, continuous operation up to 9 hours in one was possible. The temperature exceeded 42°C (108°F) in the shade during this period. No failures were noted despite the heat and the dust.

Right Slide (truck) Figure 10

Summary

The comparison between this effort and earlier dc resistivity surveys are discussed elsewhere. However, crew comments suggested that the EM technique is faster and easier, at least in open flat country, such as Grass Valley where an experienced crew can obtain three or four soundings per day at frequencies spanning the range 0.05 to 500 Hz. Of course, the production rate depends on the speed and ease of detecting and processing the magnetic field signals, a subject beyond the scope of this talk (see Morrison, et al., 1978).

Since the earliest tests in Grass Valley, the EM 60 transmitter has been used on the flanks of Mt. Hood, Oregon and elsewhere in Nevada. Throughout these surveys the transmitter has worked dependably and valuable experience has been gained in the use of the system.

Acknowledgements

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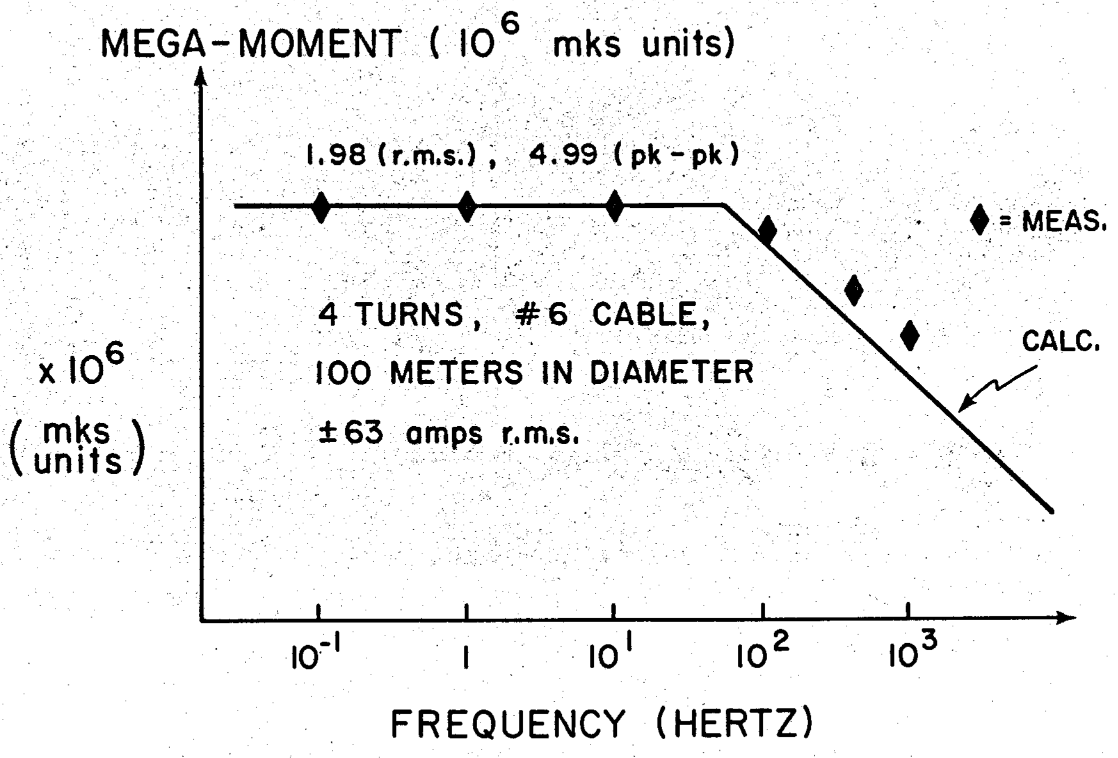

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Figure 9. Measured and calculated moment of the 4-turn loop.

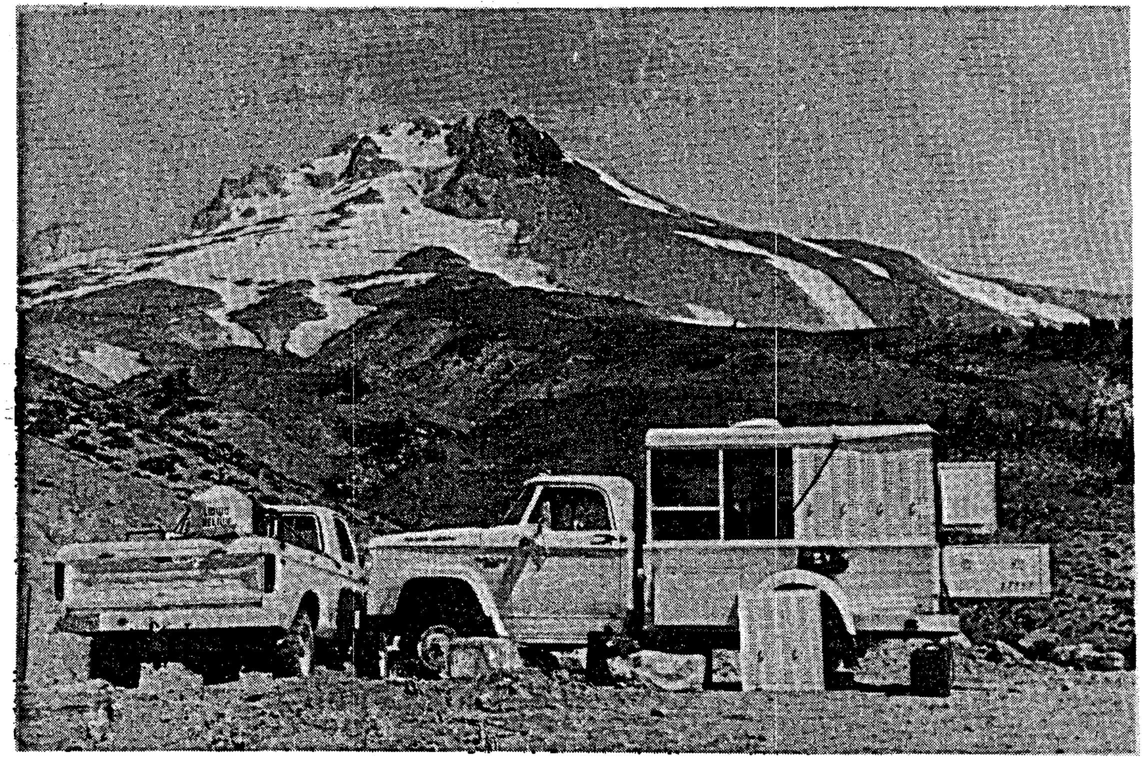

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Figure 10. EM-60 transmitter truck on the flank of Mt. Hood, Oregon.

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