PERFORMANCE OF MANPACK ELECTROMAGNETIC LOCATION EQUIPMENT IN TRAPPED MINER LOCATION TESTS

by

A. J. Farstad
Westinghouse Georesearch Laboratory
8401 Baseline Road
Boulder, Colorado 80303

1.0 Introduction

The use of radio signals for underground communications was considered as early as the mid-1920's [1] - [4]. However, early experiments did not produce promising results with the type of equipment that was available then [5]. With advancements in solid state technology many of the schemes considered impractical in the early days suddenly became practical.

The properties of electromagnetic wave behavior in conducting media have been intensively studied by Wait [6] and others and can be utilized not only in communication with trapped miners, but also as a means of locating their position. This report deals with the development of portable electromagnetic equipment, powered by the miner's conventional lamp battery, which can be used to alert surface rescue personnel of the trapped miner's location. The Westinghouse Georesearch Laboratory (WGL) under BUMINES sponsorship initially approached the trapped miner location problem using seismic techniques. It was learned from this effort that two serious shortcomings of seismic techniques are (1) the extremely weak signals available on the surface from miner generated hammer blows, requiring long processing times at the surface receiver, and (2) the relatively slow procedure of deploying geophone arrays to sense the seismic uplink signals. By contrast, the electromagnetic techniques have proven much more practical from a deployment time standpoint and in most cases have also proven to be more accurate in determining location. Furthermore, these techniques have been successfully tested using a receiver in a helicopter for reconnaissance purposes. However, before any electromagnetic location technique can become fully operational, the miners themselves must be equipped with emergency transmitters to be carried with them on each work shift. Consequently, much emphasis has been placed on the development of extremely lightweight transmitting equipment. The performance of some of the electromagnetic location equipment developed by Westinghouse will be described in the following sections.

2.0 Basic Concepts

Theoretical concepts for locating magnetic dipoles in the earth have been treated by Wait [7] and Olsen [8]. A generalized curve for the attenuation of magnetic fields in a conducting half-space is derived from

Wait's work [7] and is shown in Figure 1. This curve applies only to fields directly above or directly beneath a transmitting source. Experimental verification of the validity of the theory is shown in Figure 2 which compares actual field measurements obtained over the Imperial Mine near Boulder, Colorado with the theoretical curve based on Wait's theory. The value of conductivity used in determining the theoretical curve was obtained from a dipole-dipole conductivity sounding taken over the Imperial Mine.

While the vertical magnetic field over vertical magnetic dipole source reaches a maximum directly over the source, the corresponding horizontal magnetic field experiences a null as shown by the example in Figure 3. This curve was obtained at the Rainbow No. 7 Mine in Rock Springs, Wyoming and depicts close agreement between the measured and calculated field profiles for both the vertical and horizontal fields. This was a relatively shallow (136 feet) mine, and the resulting signal-to-noise ratios at the surface were, in most cases, greater than 40 dB. However, the preliminary equipment used to obtain this data was not sufficient to obtain usable location data at the deeper mines of 500 feet and greater. Consequently, Westinghouse Georesearch Laboratory, under BuMines sponsorship, embarked on a development program aimed at producing portable equipment which would be operable at mine depths as great as 1500 feet. Since geometric spreading accounts for an $(\text{inverse distance})^3$ roll-off of field strength and increased losses in the earth at greater depths could account for up to 40 dB additional attenuation, we were faced with the problem of dealing with signal strengths as much as 100 dB down from those observed in the shallow mine tests. The equipment development and the results of the deep mine field tests are described in the following sections.

3.0 Description of Equipment

3.1 Operating Frequency

It is well known that low frequencies penetrate conductive material better than high frequencies. However, there are also other factors to consider in choosing the best frequency for an uplink electromagnetic location system, among which are (1) natural and man-made background noise, (2) availability of circuit components, (3) suitability of circuit miniaturization, and (4) permissibility restrictions in coal mines. Figure 4 shows a family of curves of expected field strength parametric in mine depth and superimposed on expected atmospheric noise levels for different seasons of the year. Based on signal-to-noise ratio alone, the optimum frequency for a 1500 foot (457 meter) mine would be on the order of 350 Hz. However, in most mining districts, there are strong harmonic interference fields from power lines which make frequencies this low difficult to use in a practical system. Consequently, to avoid the power line interference, our choice of frequencies was considerably higher, covering the band from 900 Hz to 2900 Hz.

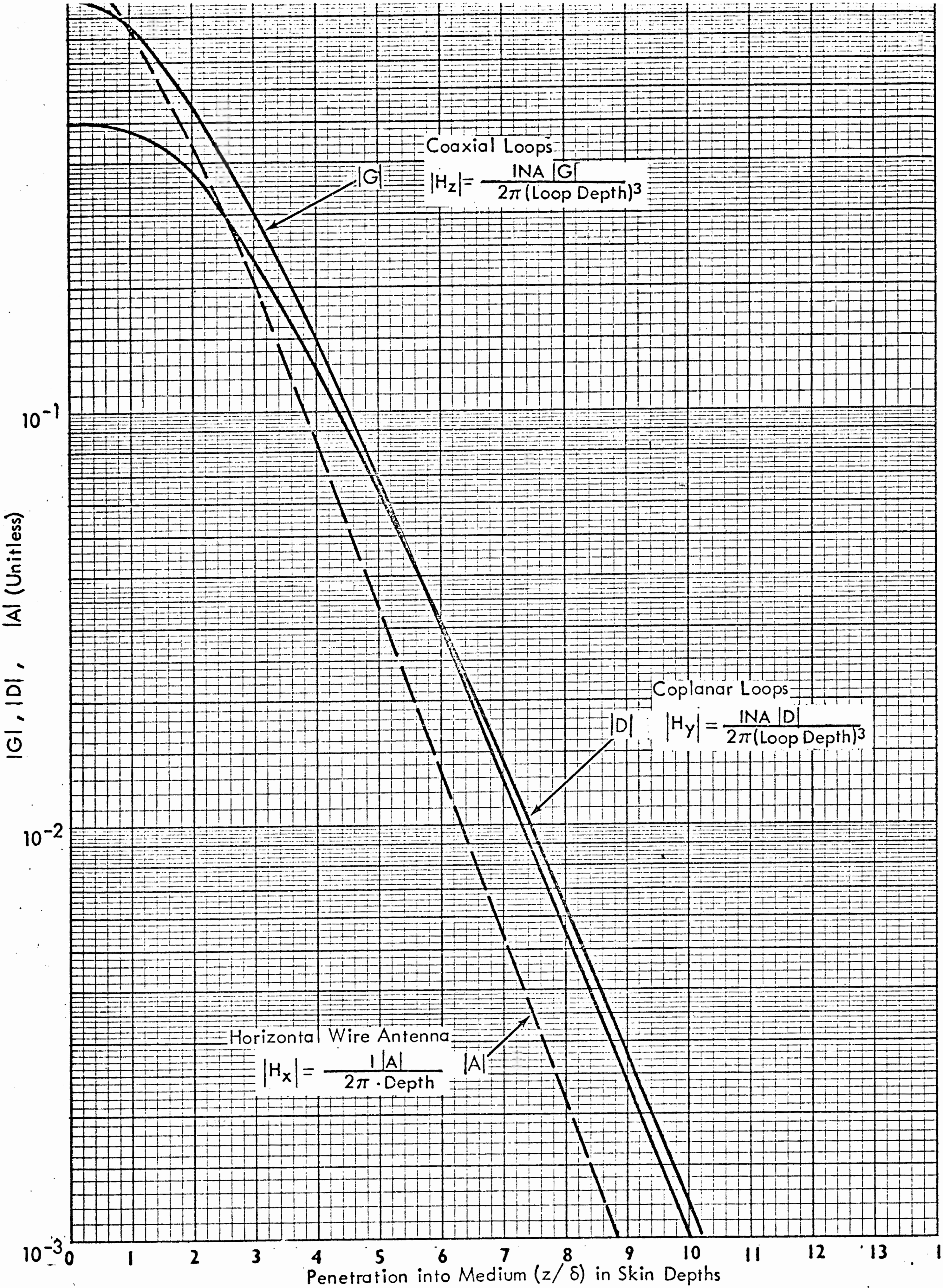


Figure 1. Loop Antenna and Horizontal Coupling Relationships

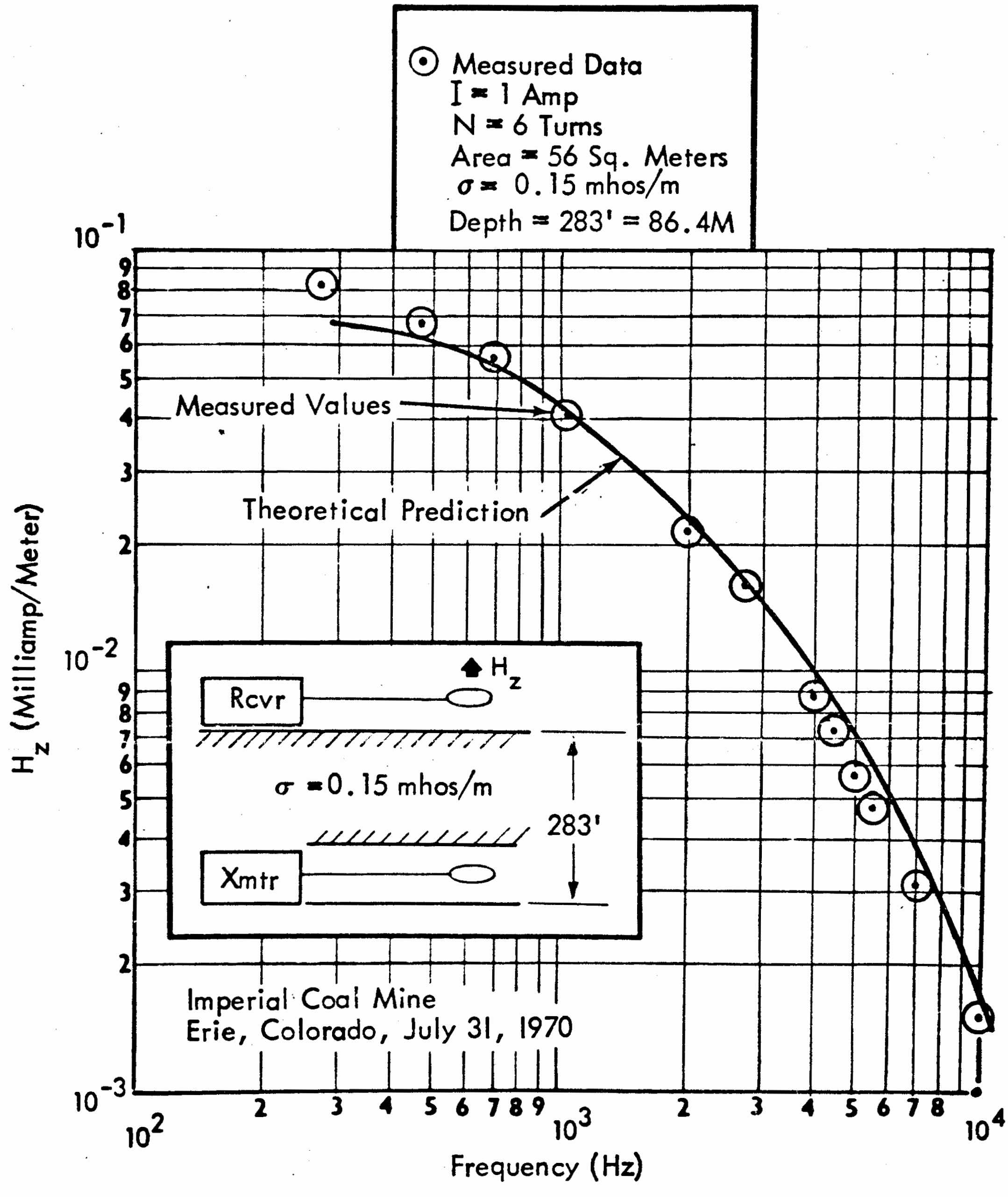


Figure 2. Comparison of Measured Magnetic Field With Theoretical Prediction for Beacon (Uplink) System

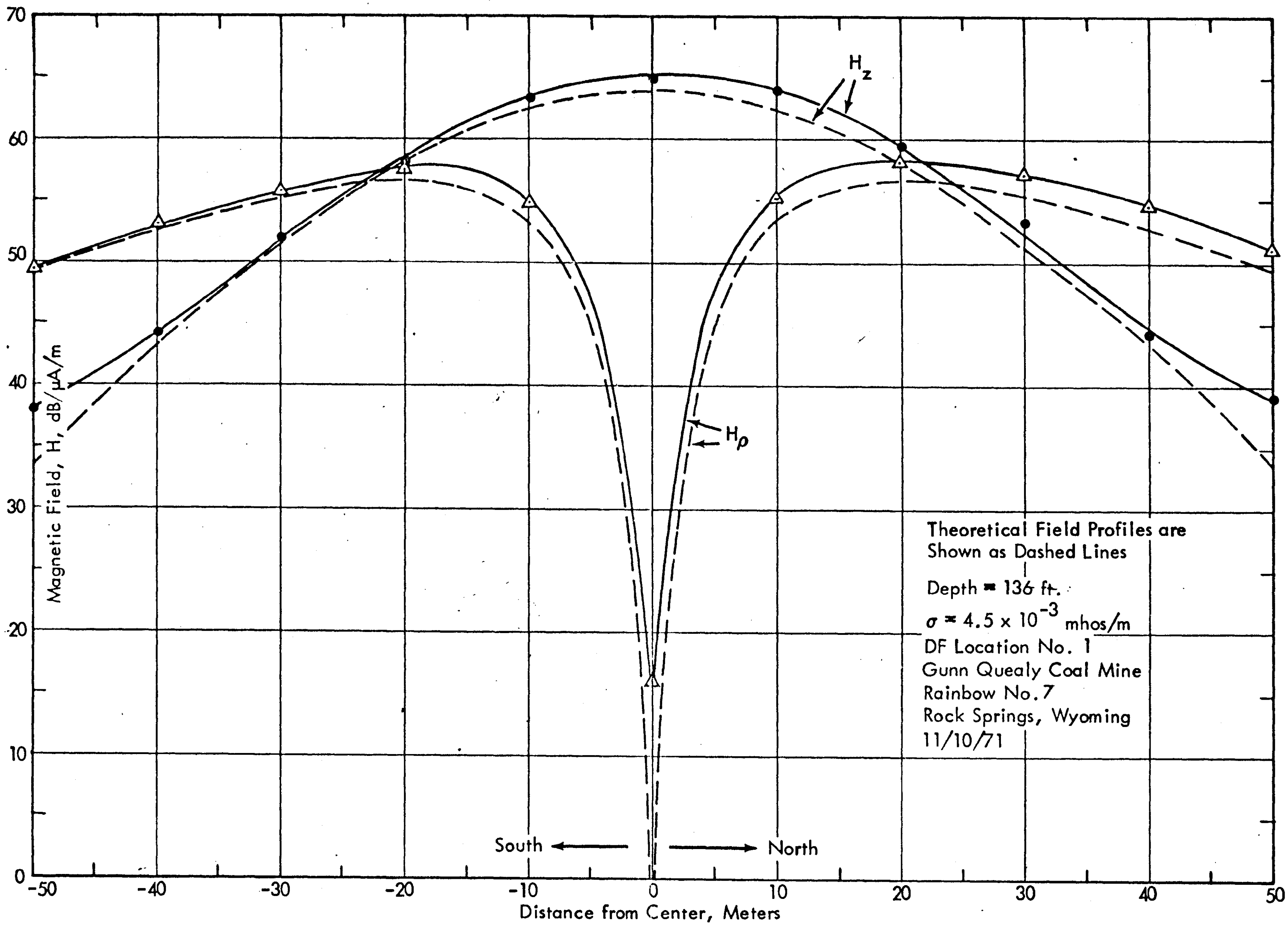
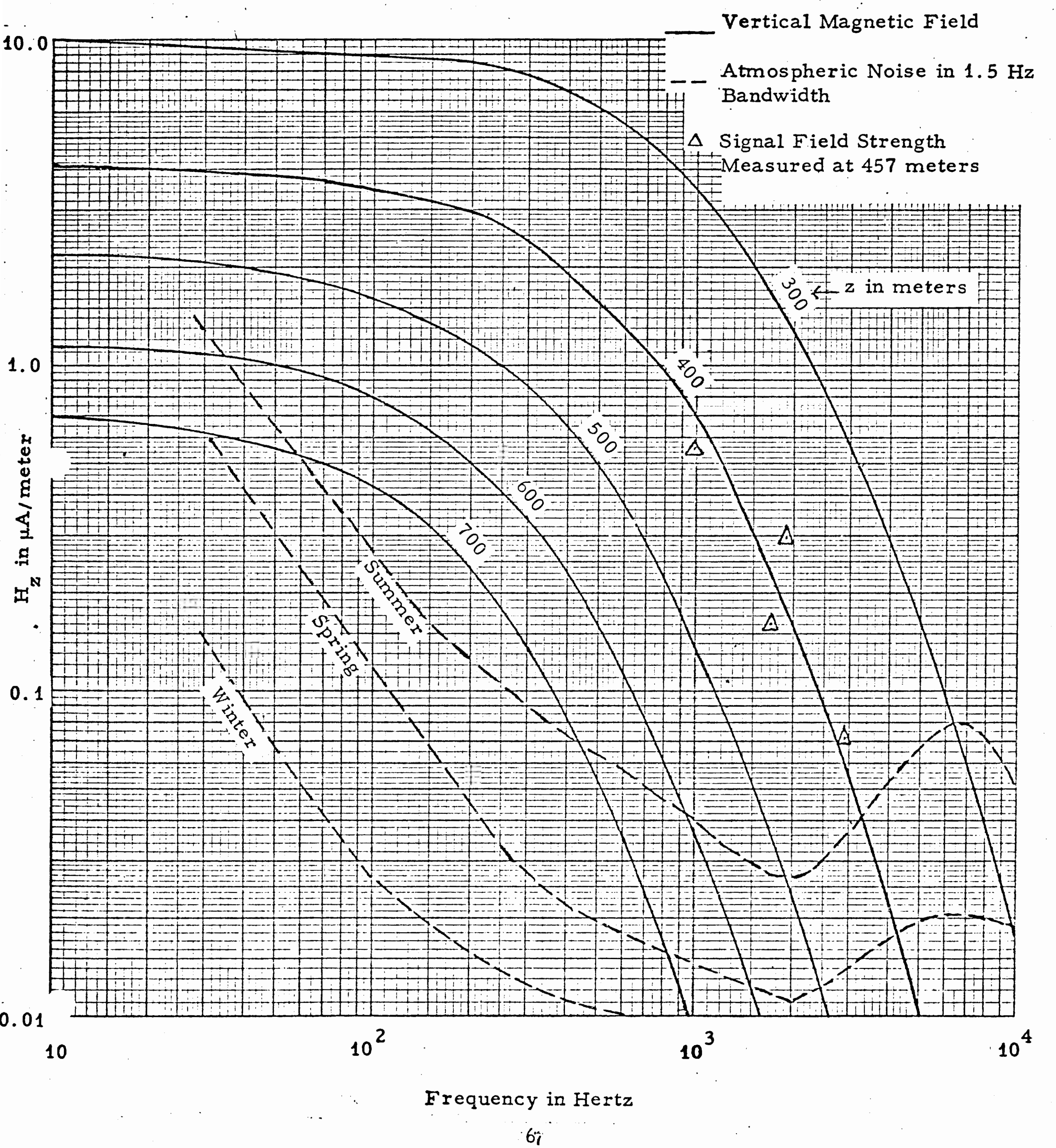


Figure 3 Electromagnetic Surface Pattern from Buried VMD

(North-South Profile)

Figure 4. Signal and Atmospheric Noise Field Estimates for Geneva Mine. (σ = 2.7 × 10^{-2} mhos/meter INA = 2000 amp-turn-meters^2.)



3.2 Manpack Transmitter

The initial development of a manpack location transmitter resulted in a half-wave system packaged inside the miner's battery cap. The transmitting antenna consisted of a 100 foot flat ribbon conductor wound into a tape measure enclosure. Upon deployment, the two-conductor cable was laid out in the form of a circle on the mine floor and connected to the output terminals of the transmitter. Several amperes of rms current were fed into the loop antenna at a duty cycle of 200 milliseconds on and 2 seconds off. It was discovered during tests at the Robena #4 coal mine in Pennsylvania that the system would operate continuously for greater than 72 hours and still be detectable through nearly 1000 feet of overburden. A later version of this transmitter utilized essentially the same on-off duty cycle but incorporated a full-wave push-pull arrangement in the output stage during each 200 millisecond tone burst. With the full-wave transmitter, a tuning capacitor was inserted in series with the antenna at the higher frequencies (1700 Hz - 2900 Hz) giving an increase in current of up to 3 times that of the untuned equivalent. The full-wave transmitter was tested at the Geneva Mine in Dragerton, Utah and generated transmitter moments of up to 2000 ampere-turn-meters squared using a 500 foot length of No. 12 wire wound around a coal pillar as an antenna.

3.3 Manpack Locator

The portable receiver used to measure the magnetic field profiles on the surface utilizes a tuned air core receiving loop followed by a six stage tuned amplifier with a gain of approximately 105 dB and an overall sensitivity of 0.02 μA/meter. The bandwidth of this receiver is approximately 0.2% of the tuned frequency. It has a phone jack output which can be used for hook up to earphones for null detection purposes or a portable oscilloscope for measuring field strength profiles.

3.4 Multichannel Receiver

The multichannel receiver consists of six narrowband receiver circuits tuned to different frequencies and packaged in a common enclosure. The outputs of each channel are selectively summed together in a summing amplifier to drive a set of earphones. Also, each channel is individually metered on the front panel. This receiver was designed primarily for helicopter reconnaissance work but also is useful for ground search operations. The antenna used with the multichannel receiver is a 24" square loop with 600 turns of No. 28 wire. A built-in battery operated preamp is included in the antenna enclosure to drive the 35 foot connecting cable between the antenna, towed beneath the helicopter, and the receiver in the helicopter cabin.

4.0 <u>Test Results</u>

4.1 Robena No. 4 Mine, Waynesburg, Pennsylvania

Table 1 outlines the results of the tests conducted at the Robena Mine No. 4 near Waynesburg, Pennsylvania. The overburden at this mine ranged from 725 feet to 990 feet at the location chosen for the tests. Comparison of surveyed locations with locations determined by the electromagnetic null were mostly in agreement within less than 50 feet. This is considered sufficient location accuracy for practical mine rescue applications. Helicopter tests were also conducted here and demonstrated a horizontal detection range of about 1000 feet while flying at an elevation of 100 feet over a location with 725 feet of overburden.

4.2 Geneva Mine, Dragerton, Utah

Tests at the Geneva Mine represented the severest test to the use of the electromagnetic location system of any coal mine visited to date. Not only was the overburden depth considerably greater than the mines in the Eastern coal region, but also the conductivity was higher ($\sigma \approx 2 \times 10^{-2}$ mhos per meter), and the terrain more rugged. The feasibility of using intrinsically safe manpack transmitters in the mine with signals detectable from a helicopter over 1500 feet of overburden was clearly demonstrated. Oscilloscope photographs of the receiver output, recorded in the helicopter, are shown in Figure 5. Location accuracies at this mine were not as good as anticipated but were in most cases within 1 or 2 coal blocks (150-300 ft) of the actual source. Some ambiguities were uncovered in the null technique when operating in extremely rugged terrain such as this. These ambiguities, which consist of secondary nulls, have been verified by comparison with theoretical profiles for the Geneva Mine conditions.

5.0 Conclusions

Results of field tests conducted under "worst case" conditions have demonstrated the feasibility of using through-the-earth electromagnetic signals for detection and location of trapped miners equipped with manpack transmitters. Furthermore, the prototype receiving equipment is lightweight and easy to operate suggesting that unskilled personnel could be used in rescue search operations. Helicopter reconnaissance using a multichannel receiver and a towed loop and preamplifier provides a rapid means of determining the existence and general location of signals emanating from the mine. Signal reception at the mine portal provides another quick method of detecting the existence of signals. Precise location of EM sources over hilly terrain is sometimes hampered by profile ambiguities and secondary nulls. Further research is needed to develop techniques for resolving these ambiguities in the field.

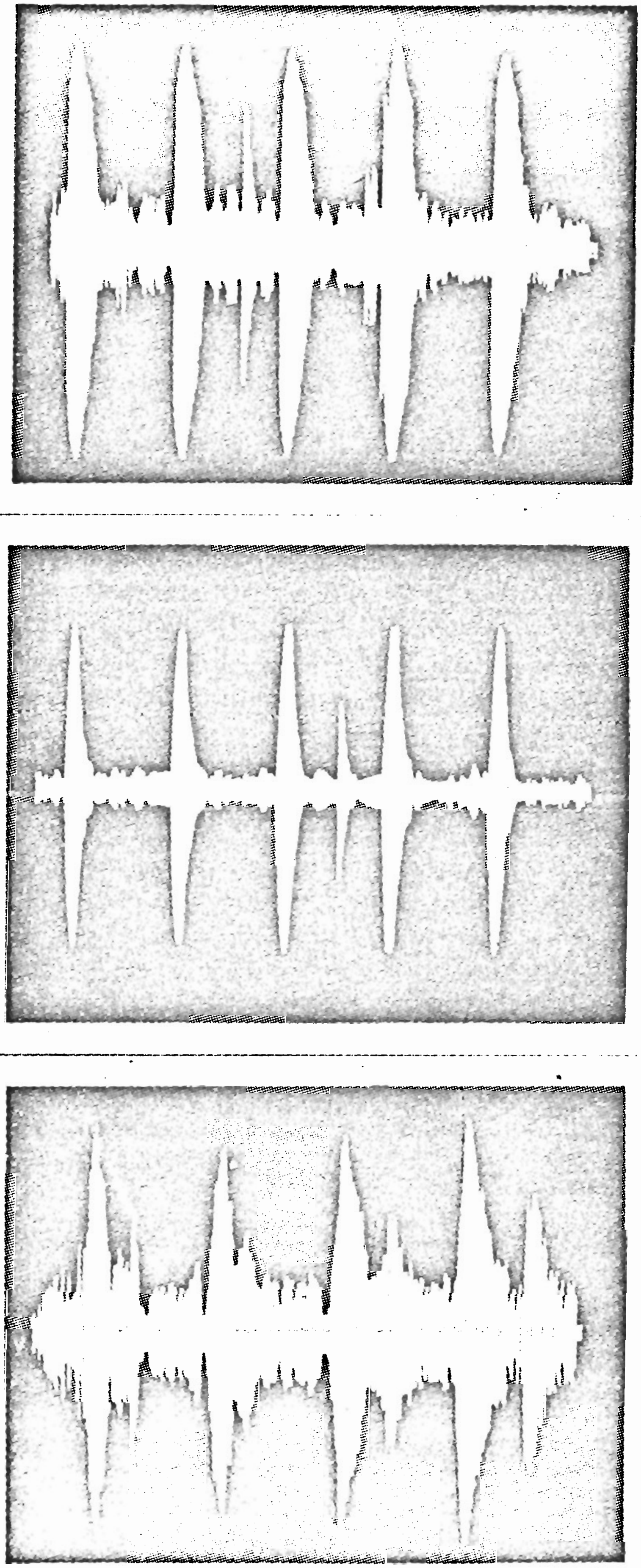
TABLE 1

Results of Robena Mine Tests

Location	f	Transmitting Antenna	Overburden	Slope	Field Strength*	Uncorrected Location Error	Horizontal Detection Range	Correct Locatio Error
A	2070	#10 Wire	800 ft.	16°	-5dB/μA/m	18 ft.	1125 ft.	27 ft.
B	2010	4 Manpack Antennas	725 ft.	0 - 13°	-14dB/μA/m	27 ft.	390 ft.	27' - 3'
C	3030	#10 Wire	725 ft.	0 - 13°	-3dB/μA/m	50 ft.	890 ft.	50' - 2(
D	1050	4 Manpack Antennas	990 ft.	16°	-26dB/μA/m	8 ft.	360 ft.	67'
E	2070	#10 Wire	990 ft.	16°	-15dB/μA/m	17 ft.	800 ft.	58'

* Represents relative field strength indication on the output meter. For pulsed signals, this meter indication is about 20dB low.

		Undetectable Signals			Comments
F	2010	Single Manpack Antenna	800 ft.	16°	Power Line within 200 ft.
G	3030	" " "	800 ft.	16°	
H	1050	" " "	725 ft.	13°	Power Cables and metal Pipes Running up both Sides of Entry.



f = 922.5 Hz
d = 1400 feet
Alt. = 100 feet

f = 1900 Hz
d = 1150 feet
Alt. = 100 feet

f = 982.5 Hz
+ 2900 Hz
d = 1500 feet
Alt. = 100 feet

Figure 5. Received Signals from Multichannel Receiver in Flight

6.0 Acknowledgments

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