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SURFACE MAGNETIC FIELD NOISE MEASUREMENTS AT GENEVA MINE

J. W. Adams
W. D. Bensema
N. C. Tomoeda

Electromagnetics Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302

The views and conclusions contained in this document should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines of the U. S. Government.

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FOREWORD

This report was prepared by the National Bureau of Standards, Boulder, Colorado, under USBM Contract No. HO 133005. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Howard Parkinson and Mr. Harry Dobrowski acting as the technical project officers.

This report is a summary of the work completed as part of this contract during the period June 1973 to June 1974. This report was submitted by the authors in September, 1974.

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SURFACE MAGNETIC FIELD NOISE MEASUREMENTS AT GENEVA MINE

by

J.W. Adams, W.D. Bensema, N.C. Tomoeda

Measurements of surface magnetic field noise were made at various locations over the Geneva Coal Mine near Price, Utah, on June 12, 1973. The locations selected were on the surface over emergency locator beacons underground at depths between 350 meters (1150 ft.) and 488 meters (1600 ft.). The surface terrain where these measurements were made was mountainous, and access was difficult. There were no power lines within several miles, and the weather was clear; therefore, the magnetic noise levels were about as low as will normally occur.

Results of measurements of distant sferics indicate rather sharp cutoff frequencies below which broadband, impulsive noise is attenuated. The mechanism of propagation for this noise above the daytime cutoff frequency of 3500 Hz and the nighttime cutoff frequency of 1700 Hz is deduced to be a waveguide formed by the D or E layers of ionosphere as an upper plane and the earth as a lower plane.

The measurement systems used are similar to those used earlier. The technique is to record broadband, analog signals, digitize the data, and use a fast-Fourier transform to obtain spectral plots. This technique is novel in that it can measure simultaneously all magnetic field energy within a limited portion of the spectrum for a limited time, and, after processing, reproduce the events occurring in that time interval in great detail.

Key words: Earth-ionosphere waveguide; electromagnetic noise; EMI measurement technique; sferic interference.

1.0 Introduction

Magnetic field strength measurements were made on June 12, 1973, over the Geneva Coal Mine in the Book Cliff Mountain Range east of Price, Utah. The locations selected were on the surface over emergency locator beacons underground at depths between 350 meters (1150 ft.) and 488 meters (1600 ft.). The surface terrain where these measurements were made was mountainous, and access was difficult. There were no power lines within several miles, and the weather was clear; therefore, the magnetic noise levels were about as low as will normally occur.

The primary purpose of the measurements was to determine surface magnetic field noise levels so that performance of emergency subsurface locator beacons of the U.S. Bureau of Mines could be better predicted. These emergency locator beacons are located many hundreds of feet underground and when activated, generate magnetic fields in a pulsed-carrier, on-off mode for signaling to the surface, usually in emergency situations. They operate at frequencies below 3 kHz where signal attenuation through the earth is relatively low; however, the beacon signals are greatly attenuated by various effects, and surface noise becomes a limiting factor.

2.0 Measurement System

The block diagram of the field recording measurement system is shown in figure 1. It consists of a balanced, shielded loop antenna, balun, filter, and analog tape recorder. Later in the laboratory, the analog signal is filtered, digitized, fast Fourier transformed, and plotted on microfilm. See figure 2 for the laboratory processing system. This gives an output plot of one component of absolute magnetic field strength versus frequency--a spectral plot. The transform may be repeated to allow three-dimensional plots, where time is the additional variable.

This system is described in more detail in the Robena Mine report [1].

3.0 Earth-Ionosphere Waveguide Effect on Propagated Noise

During the time the measurements were being made, there were no visible thunderstorms or clouds anywhere in sight, and hence, the atmospheric noise was largely that propagated from distant sources. During daylight, strong sferics were present, primarily above 3500 Hz, as shown in figure 3. At night, sferics came in above 1700 Hz, as shown in figure 4. A three-dimensional view given in figure 5 shows more detail of the daytime structure. A similar plot in figure 6 shows the nighttime structure. Note the 2500 Hz and 1900 Hz sub-surface coal mine beacon signals in figure 5. The 1900 Hz beacon is almost obscured by the atmospheric noise at night (see figure 6). Notice the sharp cutoff of noise at 1700 Hz at night and the more gradual cutoff at 3500 Hz during the day.

Ionospheric effects on radio transmission have been widely studied for years, but these measurements with this new system show some fresh insights into earth-ionosphere waveguide phenomena. A dramatic and sharp increase in attenuation of propagated atmospheric noise at frequencies below the waveguide cutoff frequency (as mentioned above) has been observed. About ten dB of signal-to-noise ratio may be gained by operating at a frequency below the waveguide cutoff frequency rather than above the cutoff, as shown by the one example in figure 6.

The probable propagation mechanism is a parallel plate waveguide formed by the D or E layers of the ionosphere and the earth. The TE or TM modes are excited between the parallel planes and have a cutoff frequency of

$$f_c = \frac{nc}{2a}, \; n = 1,2,\cdots,$$

where c is the velocity of light, and a is the spacing between the plates [2].

If a = 88 km, f_c = 1704 Hz, 3408 Hz, ... If the D layer is about 50 km above the earth, and if the E layer is about 100 km high [3], the cutoff frequencies calculated are approximately correct. The height of maximum ionospheric density may vary somewhat, and may not be the exact distance needed for this model. This phenomenon should be further investigated, as it relates directly to what frequencies that should be used for the emergency locator beacons.

4.0 Other Measured Data

A map of the surface is shown in figure 7. Noise at location B1, 463 meters (1520 feet) over the 1900 Hz beacon, is shown in figure 8. Noise at location C1, 442 meters (1450 feet) over a 1700 Hz beacon, is shown in figure 9.

All the remaining figures are of noise at location A1, 1150 feet over a 2500 Hz beacon.

Figures 10 through 18 show spectra of day, twilight, and night noise to 10 kHz. Figure 13 shows a distant sferic.

Figures 19 through 27 show expanded spectra of day, twilight, and night noise. These spectra are valid from 100 Hz to 3 kHz.

Data in figures 8 through 27 is absolute and has an uncertainty of ± 1 dB [1]. This uncertainty only applies over the following frequency ranges: figures 8 and 9, 300 Hz to 2600 Hz; figures 10 through 18, 560 Hz to 10 kHz; figures 19 through 27, 100 Hz to 3 kHz. See section 9.0, Appendix, for the code key to use in determining the meaning of the numbers in the header block at the top of each spectrum. The resolution bandwidth is given on the ordinate of the plots.

5.0 Conclusions

The surface noise at a remote site, away from powerlines, will not be free of powerline harmonics; their amplitudes will be reduced.

The earth-ionosphere may provide a waveguide to propagate distant noise, particularly above 3500 Hz during the day and above 1700 Hz at night. These frequencies are valid only during the period covered by these measurements, as ionospheric phenomena are quite time, geographically, and seasonally dependent.

6.0 Recommendations

These limited results indicate that emergency locator beacon frequencies should be selected below 1700 Hz and between harmonics of the 60 Hz powerline frequency.

Additional measurements should be made over a diurnal cycle and during each of the four seasons. Higher gain baluns and/or amplifiers should be used to lower system noise.

7.0 Acknowledgments

Ed Niesen assisted with the field work, Winston Scott assisted with the data processing, and Sharon Foote and Janet Becker performed typing services.

David Sterns at the University of Colorado assisted with digitizing data.

Carl Fisher and Ruben Mayes of Westinghouse Georesearch Laboratory made arrangements with Mr. Watson of Geneva Mine of U.S. Steel Co. Fisher and Mayes assisted in specifying locations, frequencies, and overburden with respect to emergency locator beacons.

Frank Cowley and Lorne Matheson of the National Oceanic and Atmospheric Administration assisted with computer software and data processing.

8.0 References

[1] Bensema, W.D., M. Kanda, and J.W. Adams, "Electromagnetic Noise in Robena No. 4 Mine," NBS Technical Note 654, April 1974.

[2] Ramo and Whinnery, "Fields and Waves in Modern Radio" (John Wiley & Sons, Inc., New York, New York, Second Edition, p. 328, p. 335, etc., 1959).

[3] Terman, "Electronic and Radio Engineering" (McGraw-Hill Book Co., Inc., New York, New York, Fourth Edition, p. 825, 826, 1955).

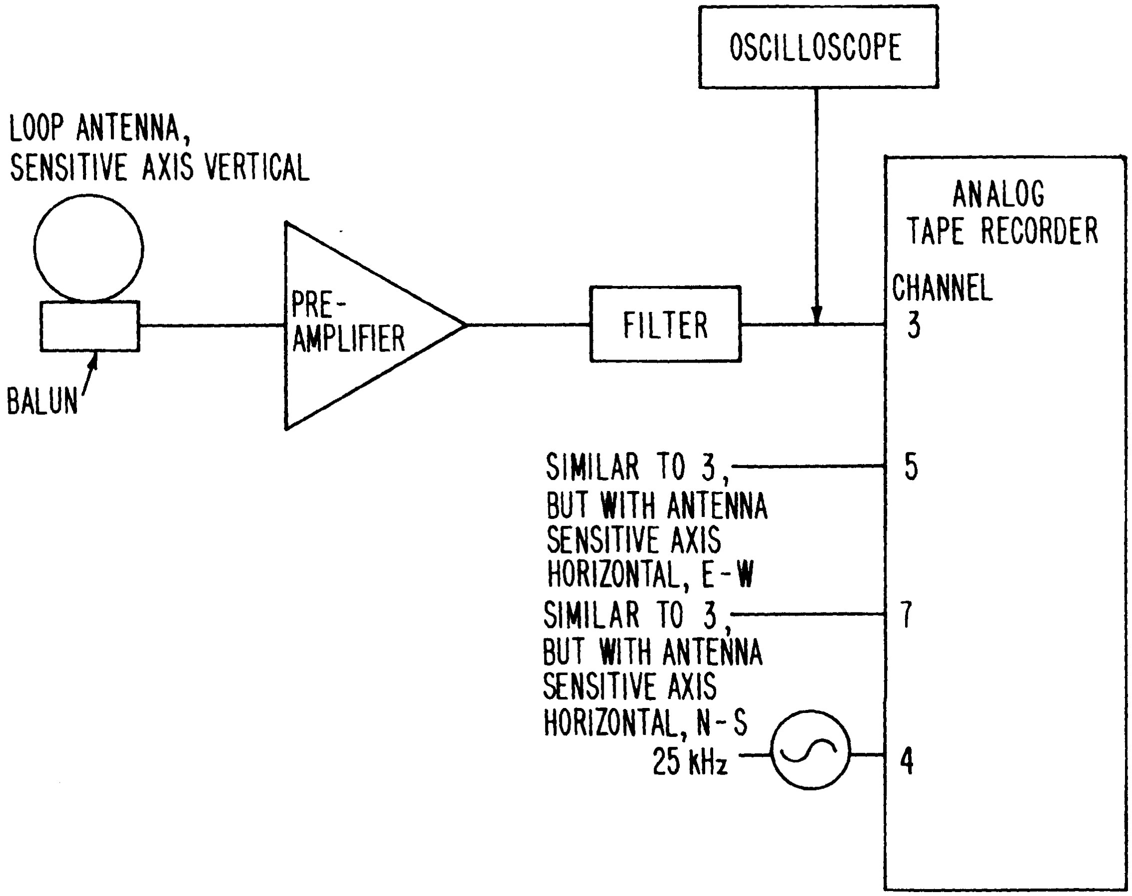

Figure 1. Field Recording System

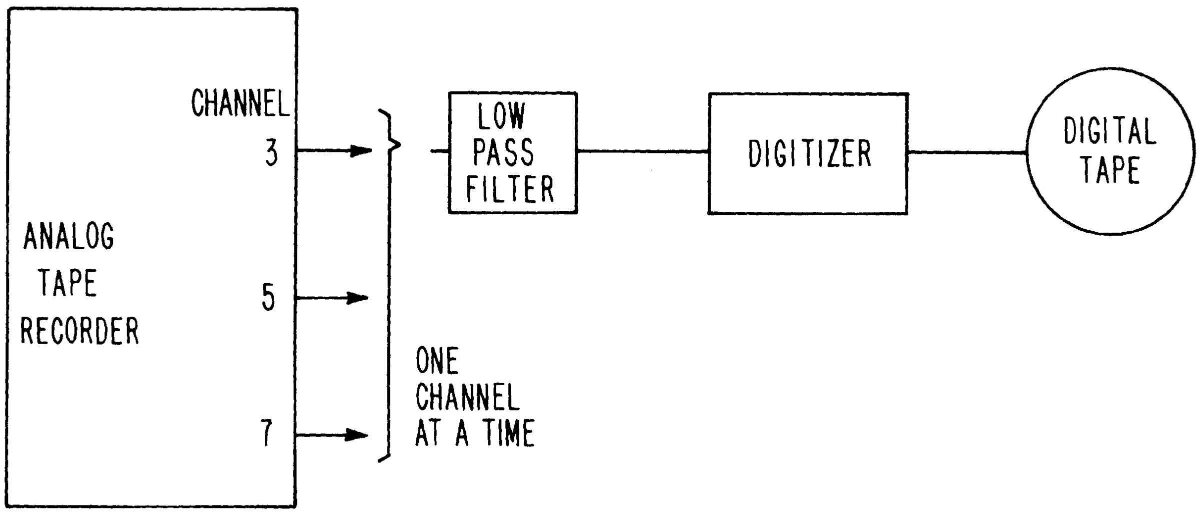

Figure 2a. Digitizing part of data processing system

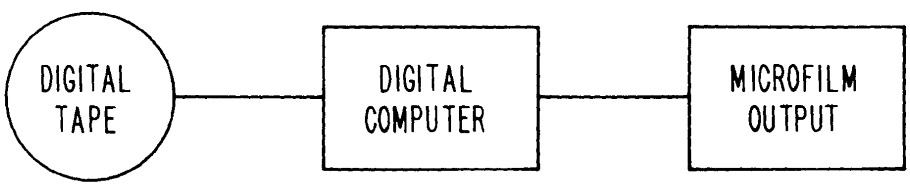

Figure 2b. Fast-Fourier transform part of data processing system

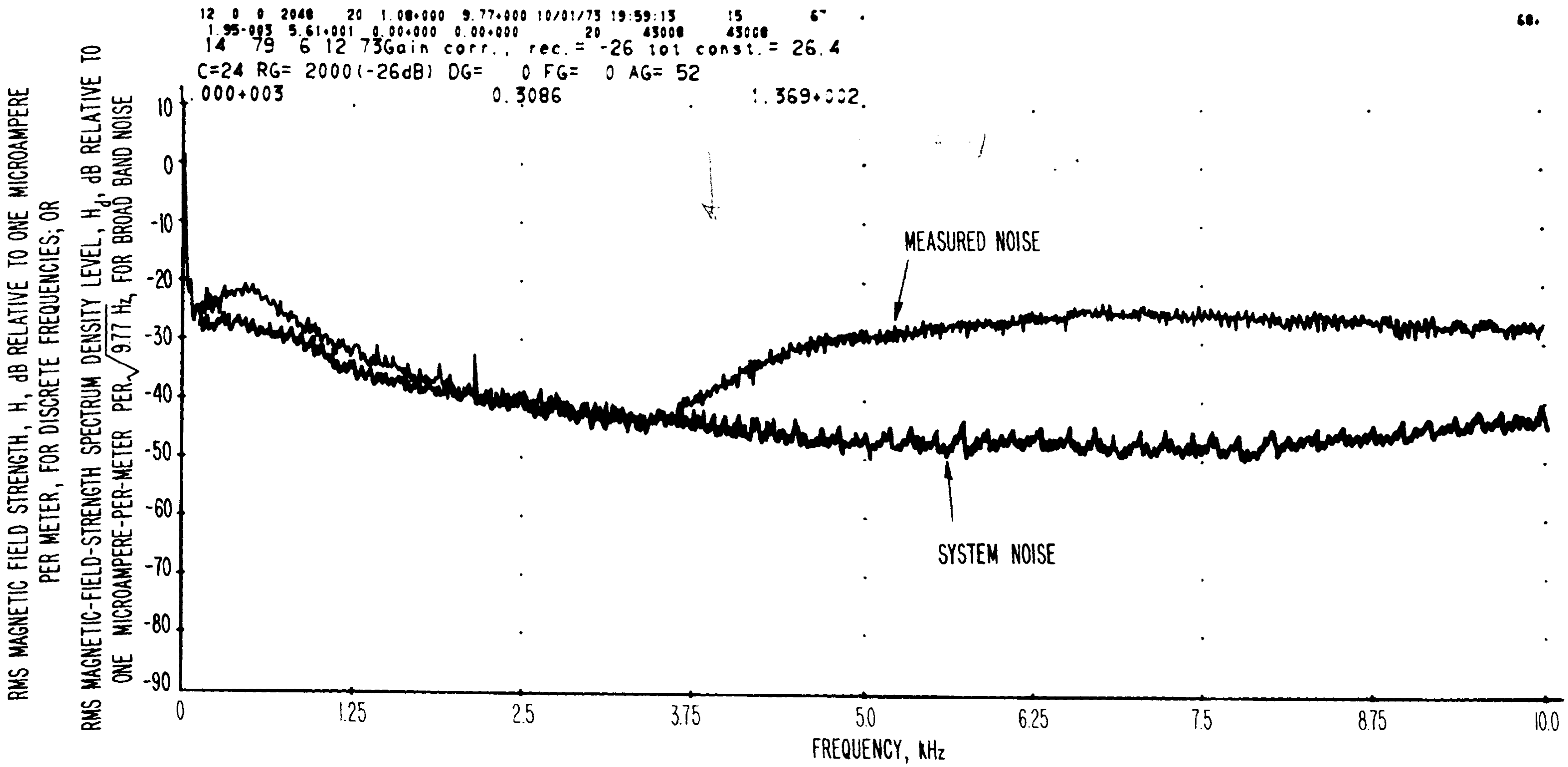

Figure 3 SPECTRUM OF THE HORIZONTAL, E-W COMPONENT OF MAGNETIC FIELD STRENGTH RECORDED DURING DAYTIME ON SURFACE ABOVE GENEVA COAL MINE. PROPAGATION OF NOISE DUE TO DISTANT SFERICS IS SHOWN TO BE ABOVE 3500 Hz.

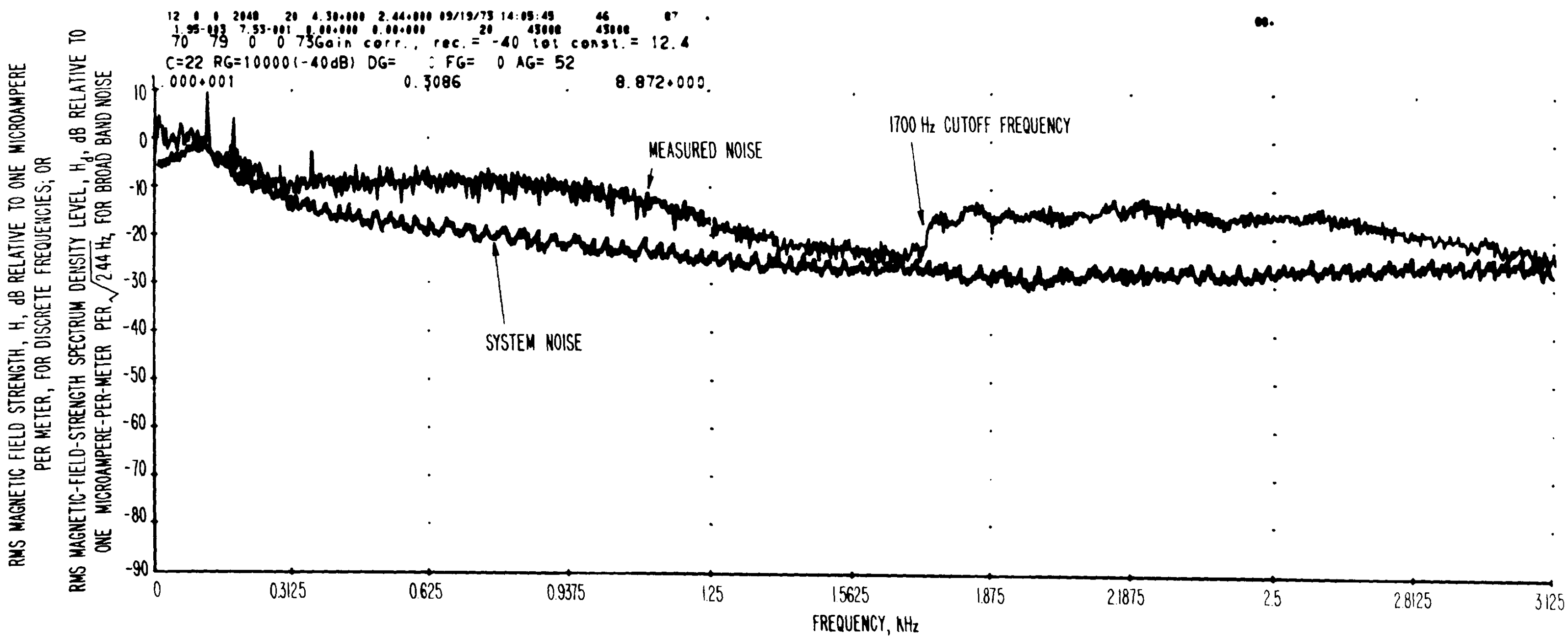

Figure 4 SPECTRUM OF THE HORIZONTAL, N-S COMPONENT OF MAGNETIC FIELD STRENGTH RECORDED AT 2230 HOURS (NIGHT) ON SURFACE ABOVE GENEVA COAL MINE. PROPAGATION OF NOISE DUE TO DISTANT SFERICS CUTS OFF BELOW 1700 Hz.

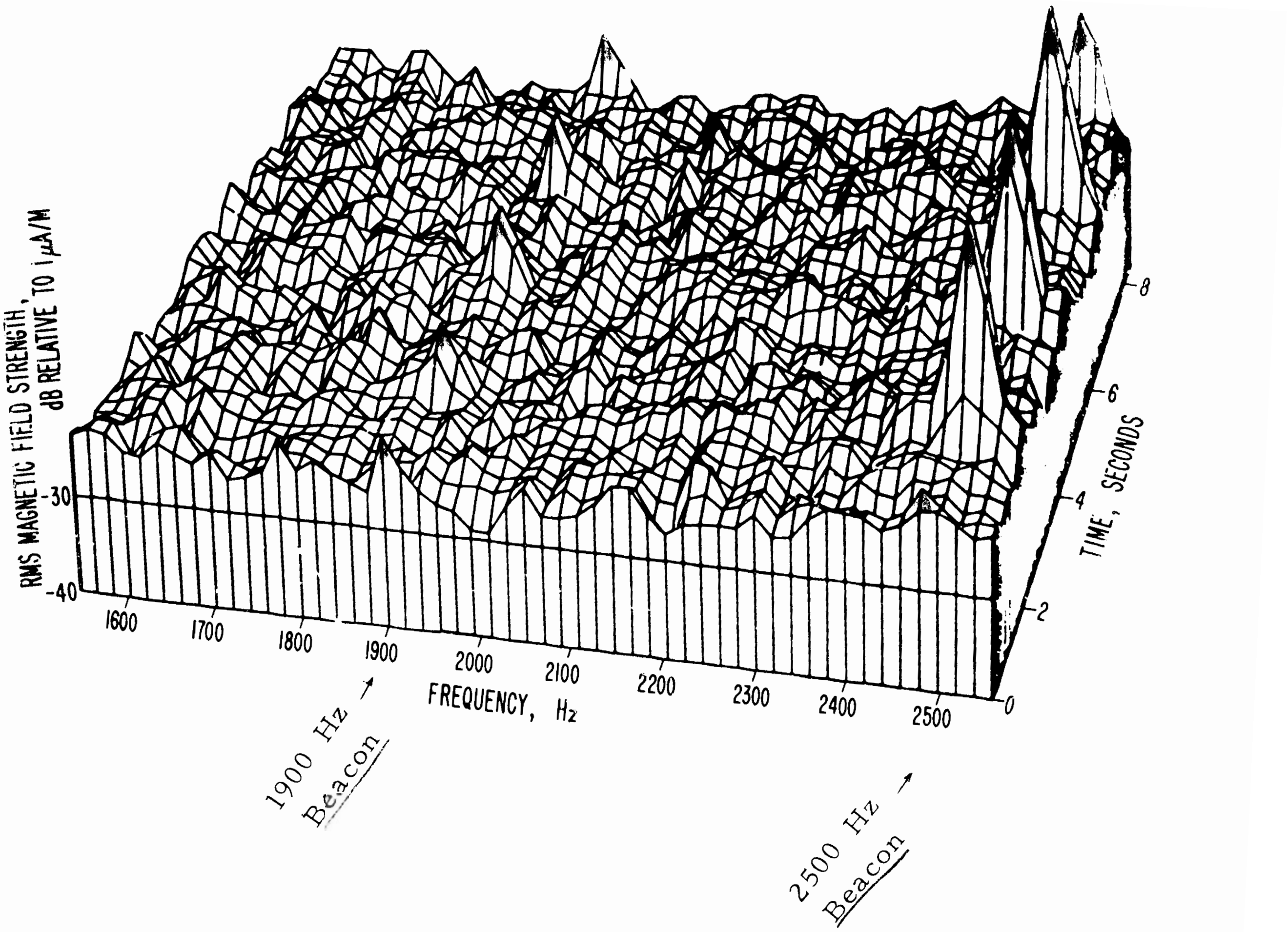

Figure 5 Spectrum of magnetic field strength vs. time. Antenna placed on surface of ground above Geneva Coal Mine, daytime. "Lost-Miner Beacon" pulses showing at 2500 Hz are from a transmitter beacon straight down 351 meters (1150 feet). Pulses at 1900 Hz are from a transmitter 0.8 kilometers (1/2 mile) away under 463 meters (1520 feet) of overburden.

463M

(2500 Hz)

(1900 Hz)

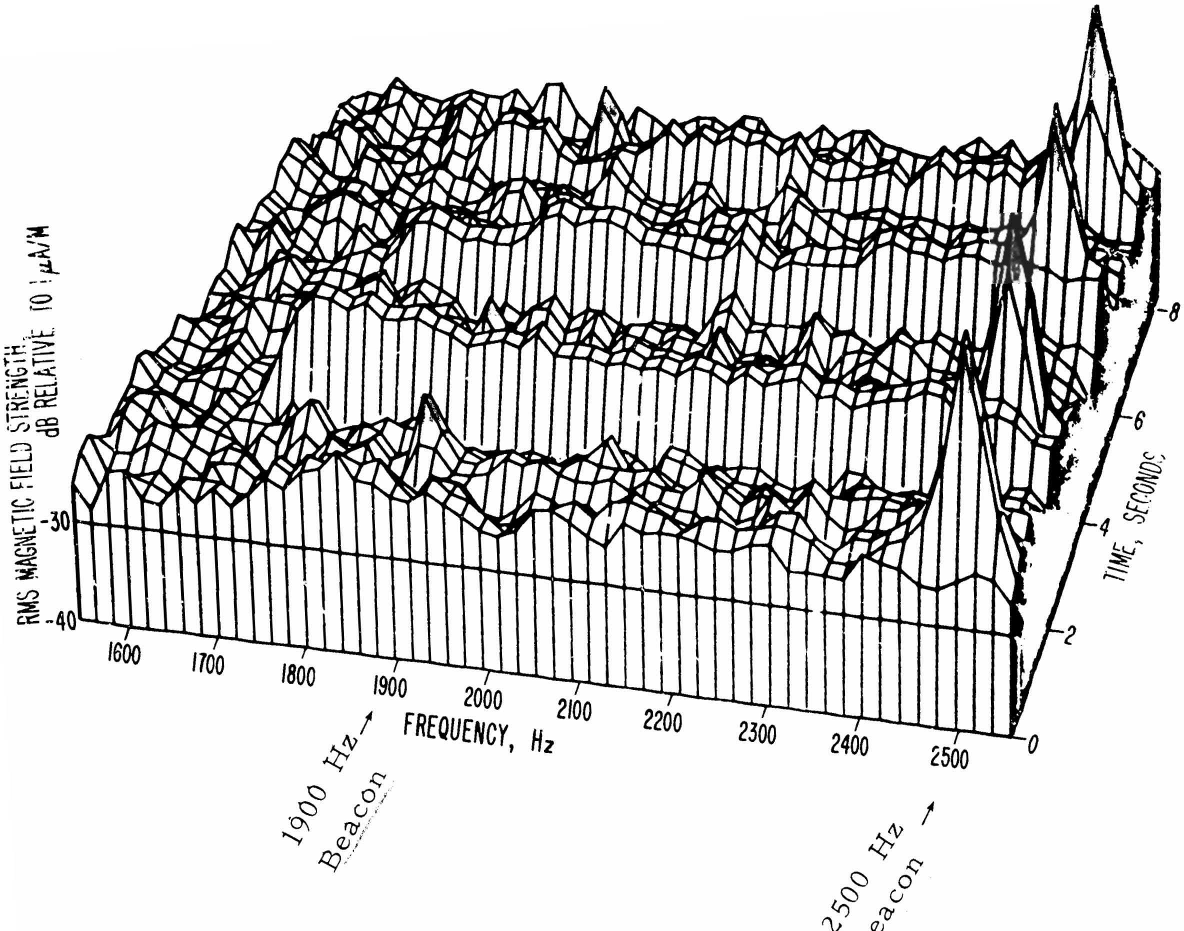

Figure 6

Spectrum of magnetic field strength vs. time. Antenna placed on surface of ground above Geneva Coal Mine, nighttime. "Lost-Miner Beacon" pulses at 2500 Hz can still be seen but those at 1900 Hz are partially obscured by the atmospheric pulses (lightning static) propagating in from over the horizon. This plot shows that by placing transmitter frequency below 1600 Hz, atmospheric interference can be reduced at least 10 dB, a factor of 10 to 1 reduction in power.

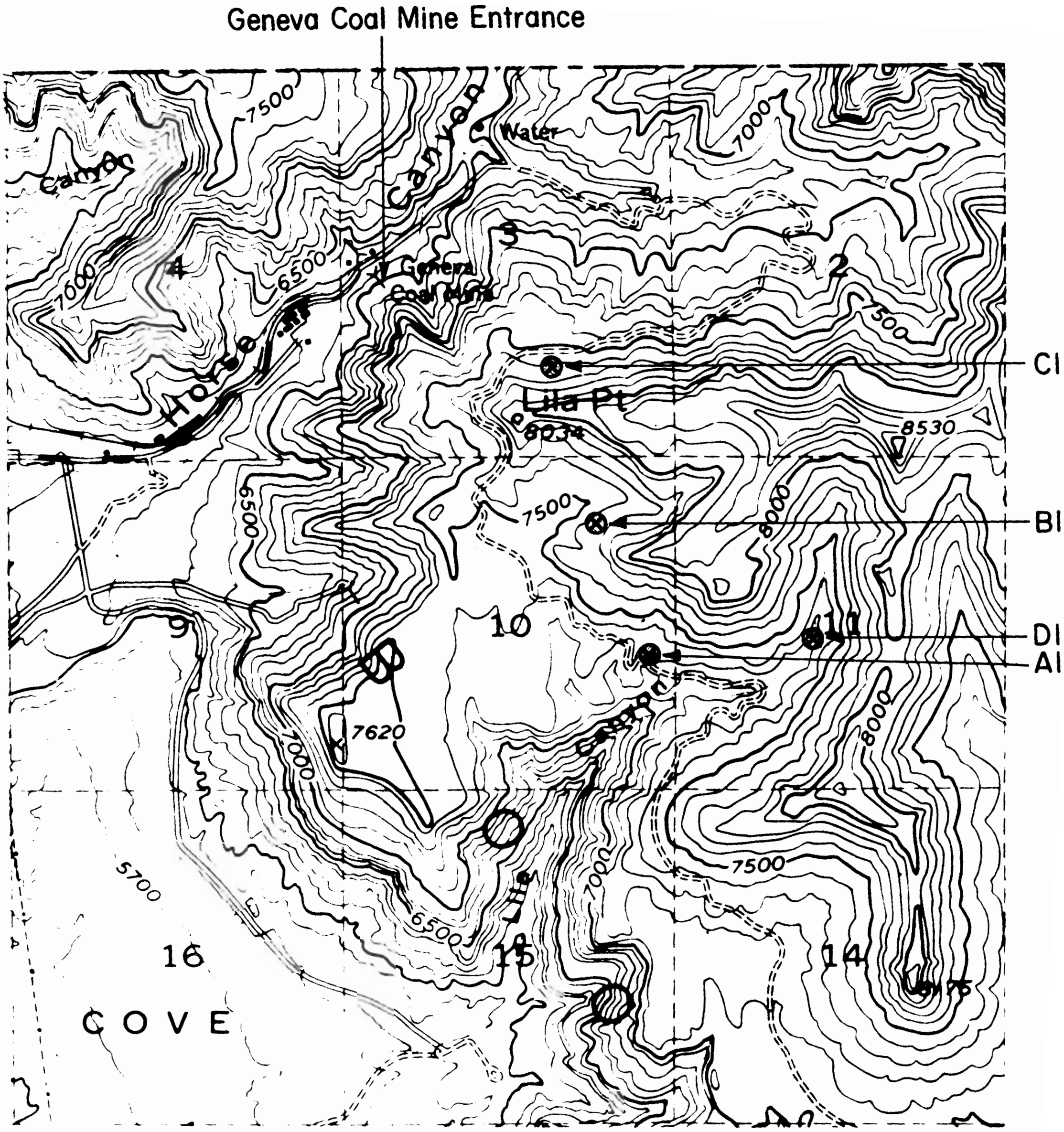

Figure 7   Map of surface over Geneva Coal Mine.

Location Code	Overburden	Beacon Frequency (Hz)
A1	350	2500.0
B1	463	1900.0
C1	442	1700.0
D1	503	922.5

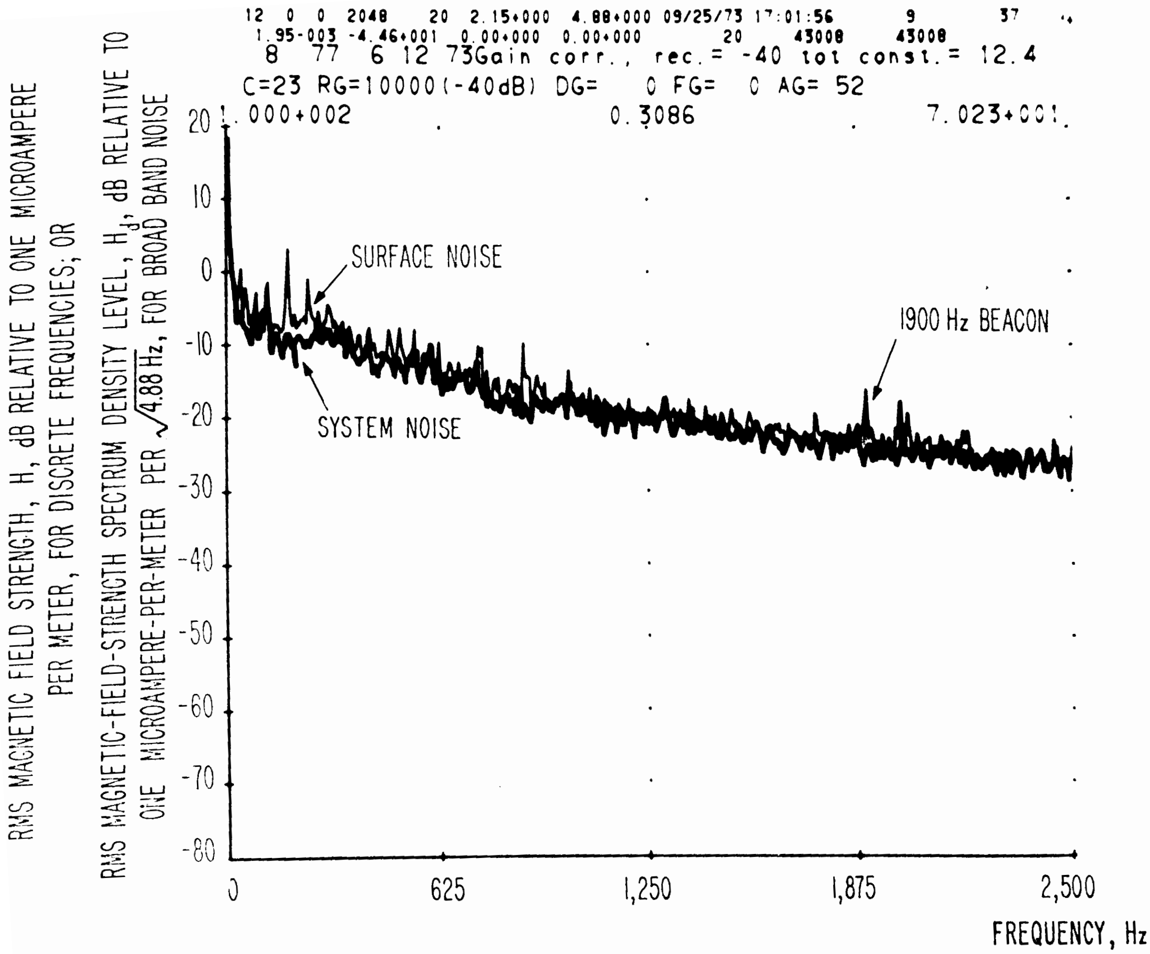

Figure 8 Spectrum of surface EM noise at Lila Flats over Geneva Mine, Location B1 on Figure 7. 1900 beacon coming through 463 meters (1520 ft.) of overburden is barely visible. Antenna sensitive axis was vertical. Daytime. June 12, 1973.

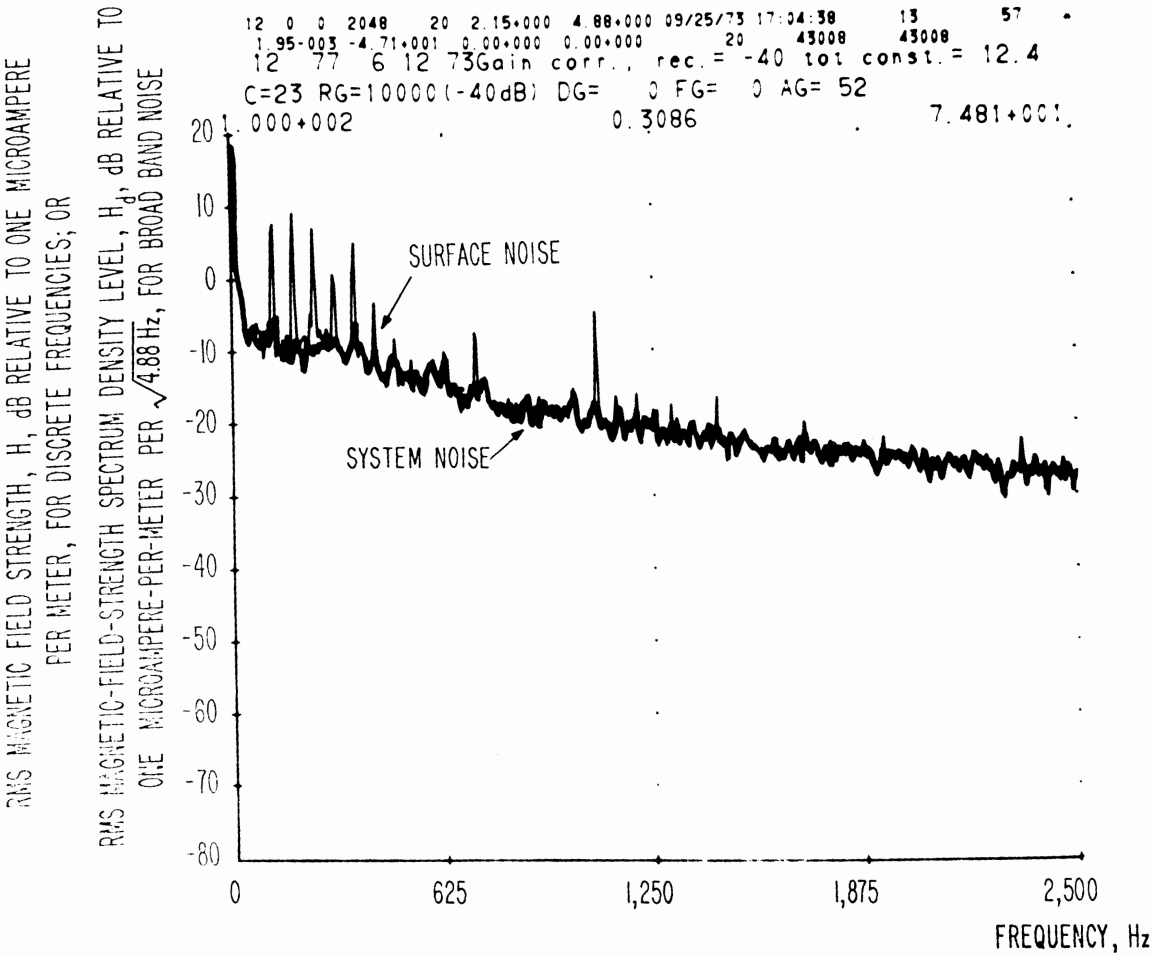

Figure 9 Spectrum of surface EM noise, north side of Lila Point, over Geneva Mine, Location C1 on Figure 7. 1700 Hz beacon through 442 meters (1450 ft.) of overburden is not visible. Antenna sensitive axis was vertical. Daytime. June 12, 1973.

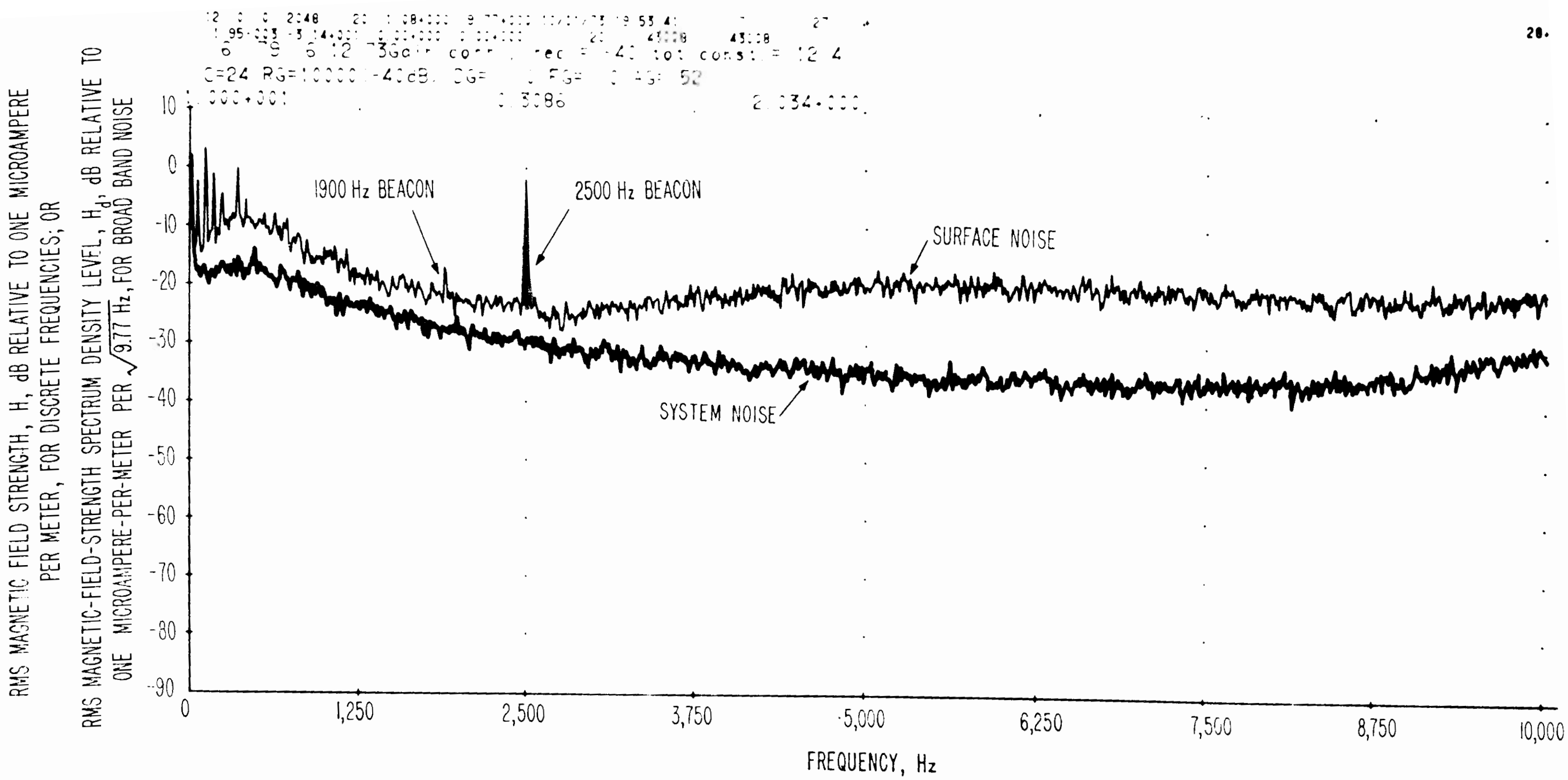

Figure 10 10 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. 2500 Hz beacon through 351 meters (1150 ft.) of overburden is clearly visible. Antenna sensitive axis was vertical. Daytime, 7:40 p.m., June 12, 1973.

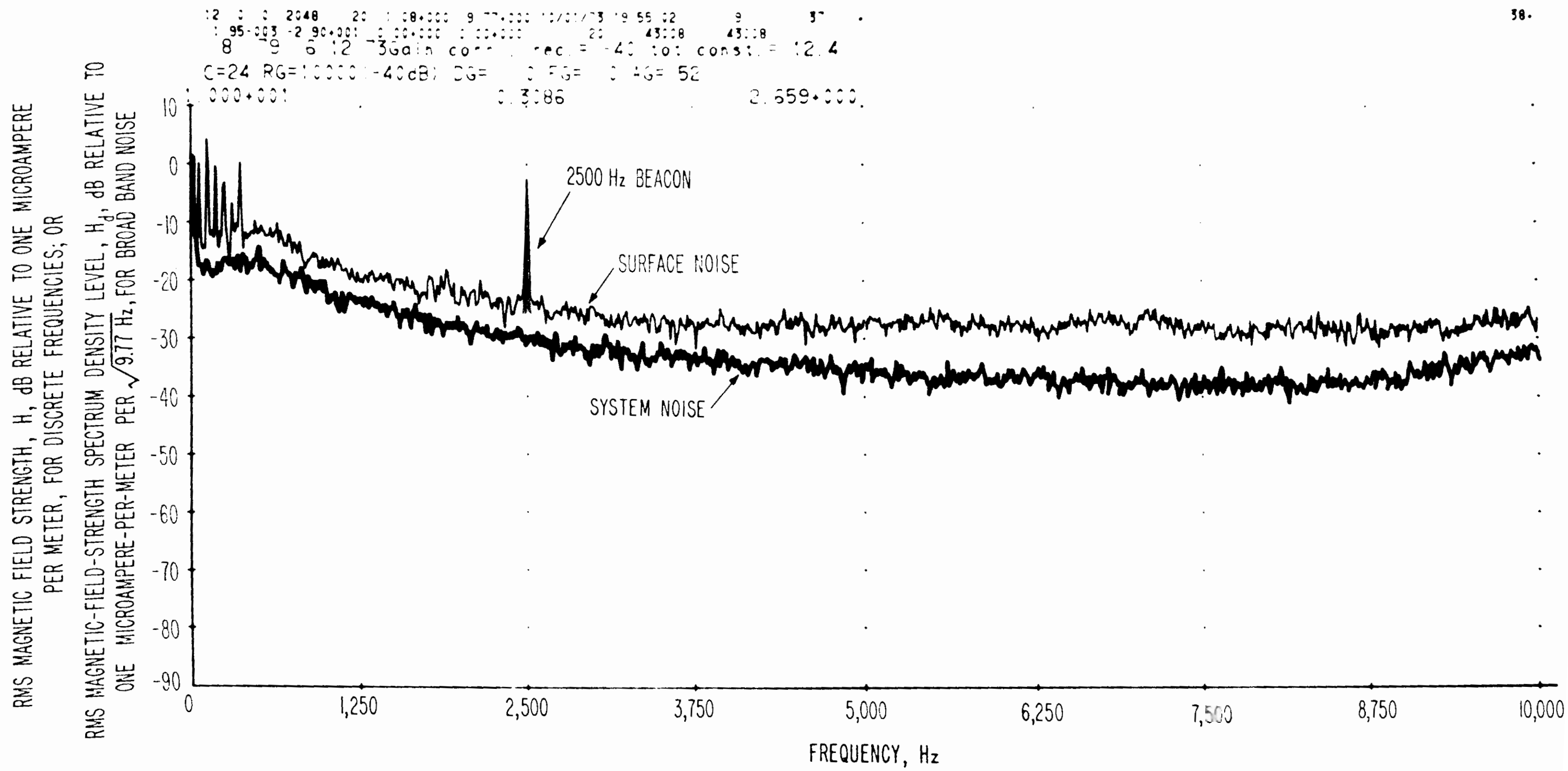

Figure 11 10 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. 2500 Hz beacon through 351 meters (1150 ft.) of overburden is clearly visible. Antenna sensitive axis was vertical. Twilight, 9:35 p.m., June 12, 1973.

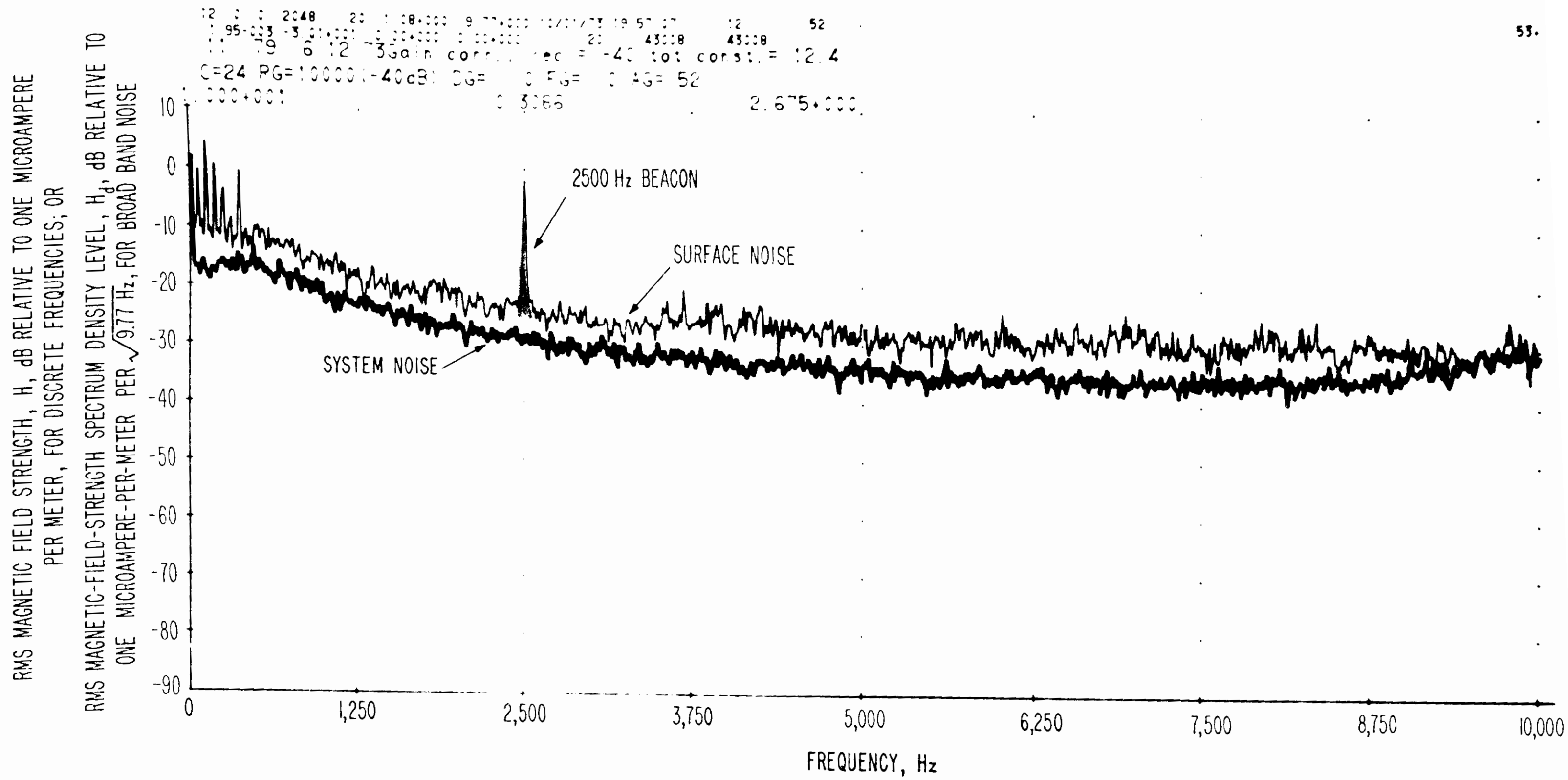

Figure 12 10 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. 2500 Hz beacon through 351 meters (1150 ft.) of overburden is clearly visible. Antenna sensitive axis was vertical. Nighttime, 10:31 p.m., June 12, 1973.

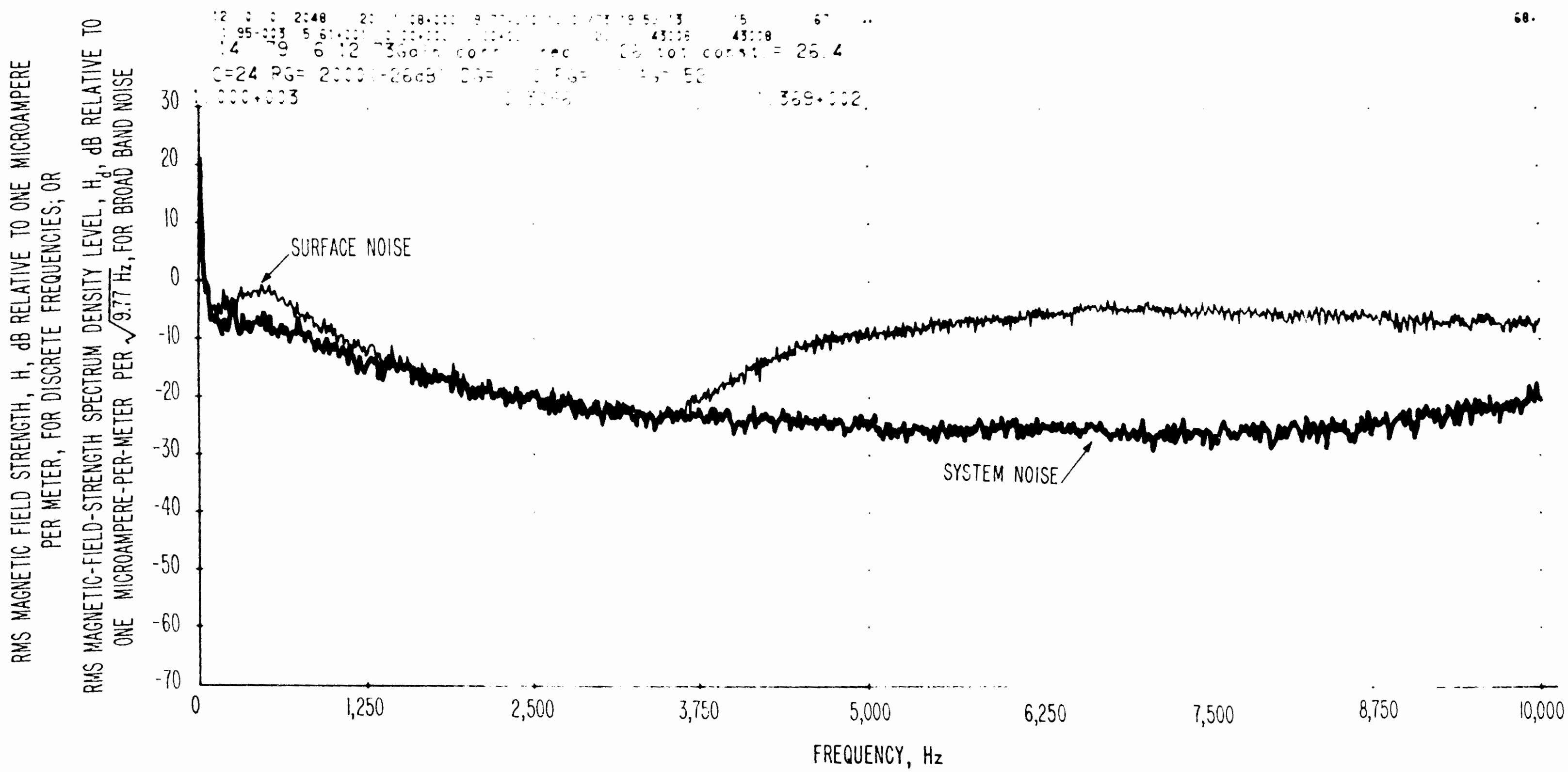

Figure 13 10 kHz *spectrum* of surface noise at *Lila* Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. Distant sferic is shown. Propagation below 3500 Hz is strongly attenuated. Antenna sensitive axis is horizontal (E-W). Daytime, 4:30 p.m., June 12, 1973.

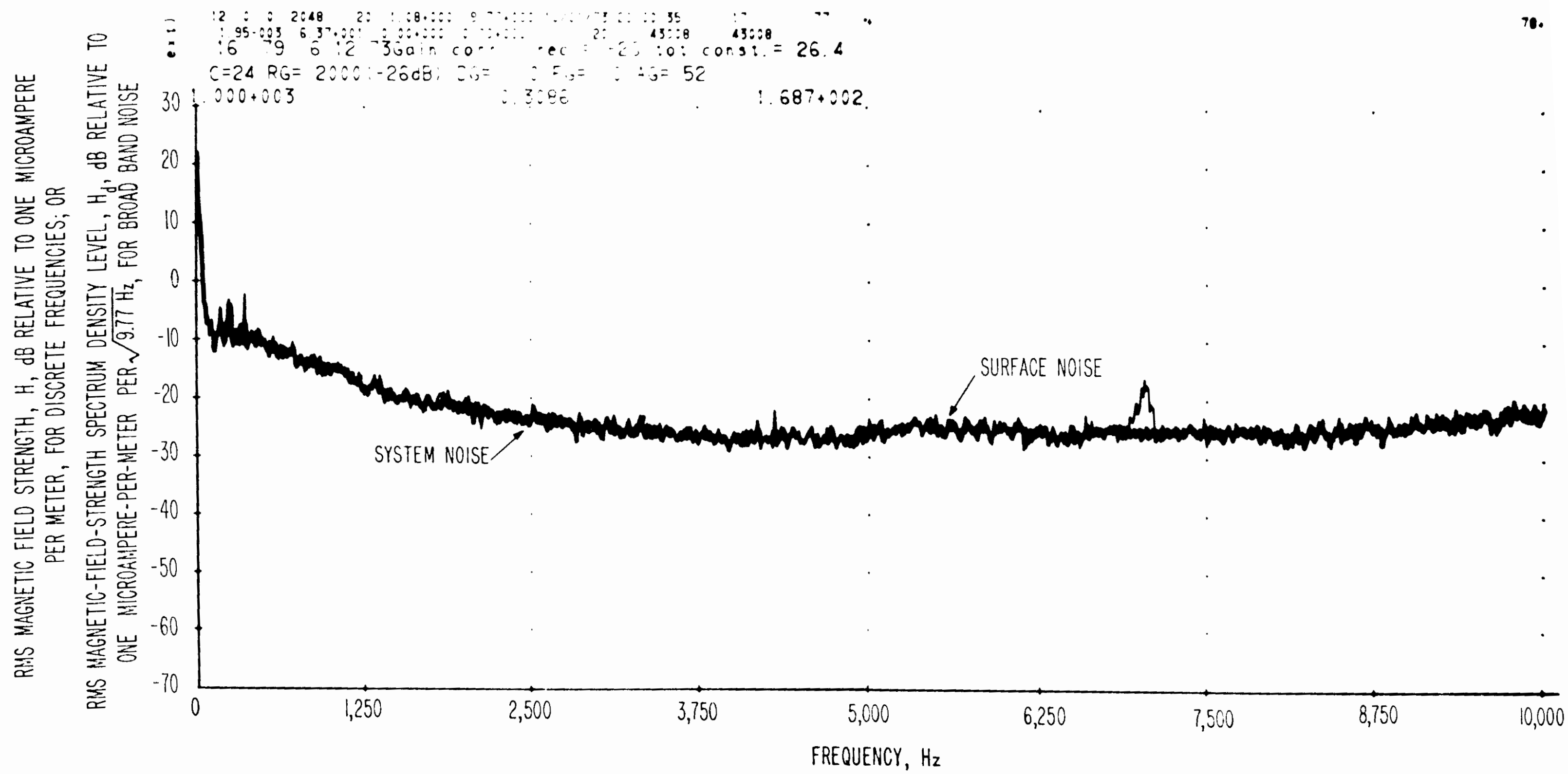

Figure 14 10 kHz spectrum of surface noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. Antenna sensitive axis is horizontal (E-W). Twilight, 9:35 p.m., June 12, 1973.

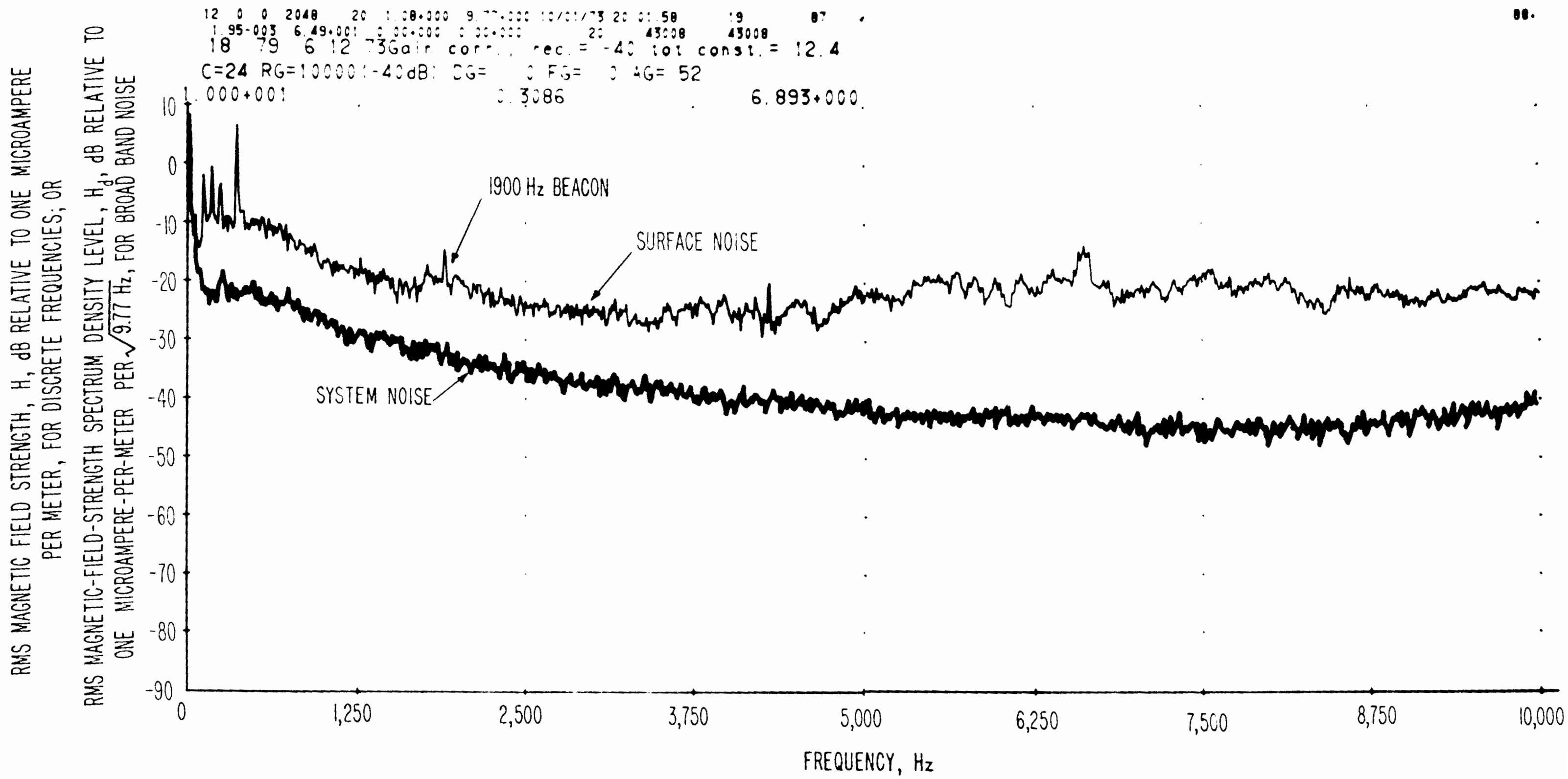

Figure 15 10 kHz spectrum of surface noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. Antenna sensitive axis is horizontal (E-W). Nighttime, 10:31 p.m., June 12, 1973.

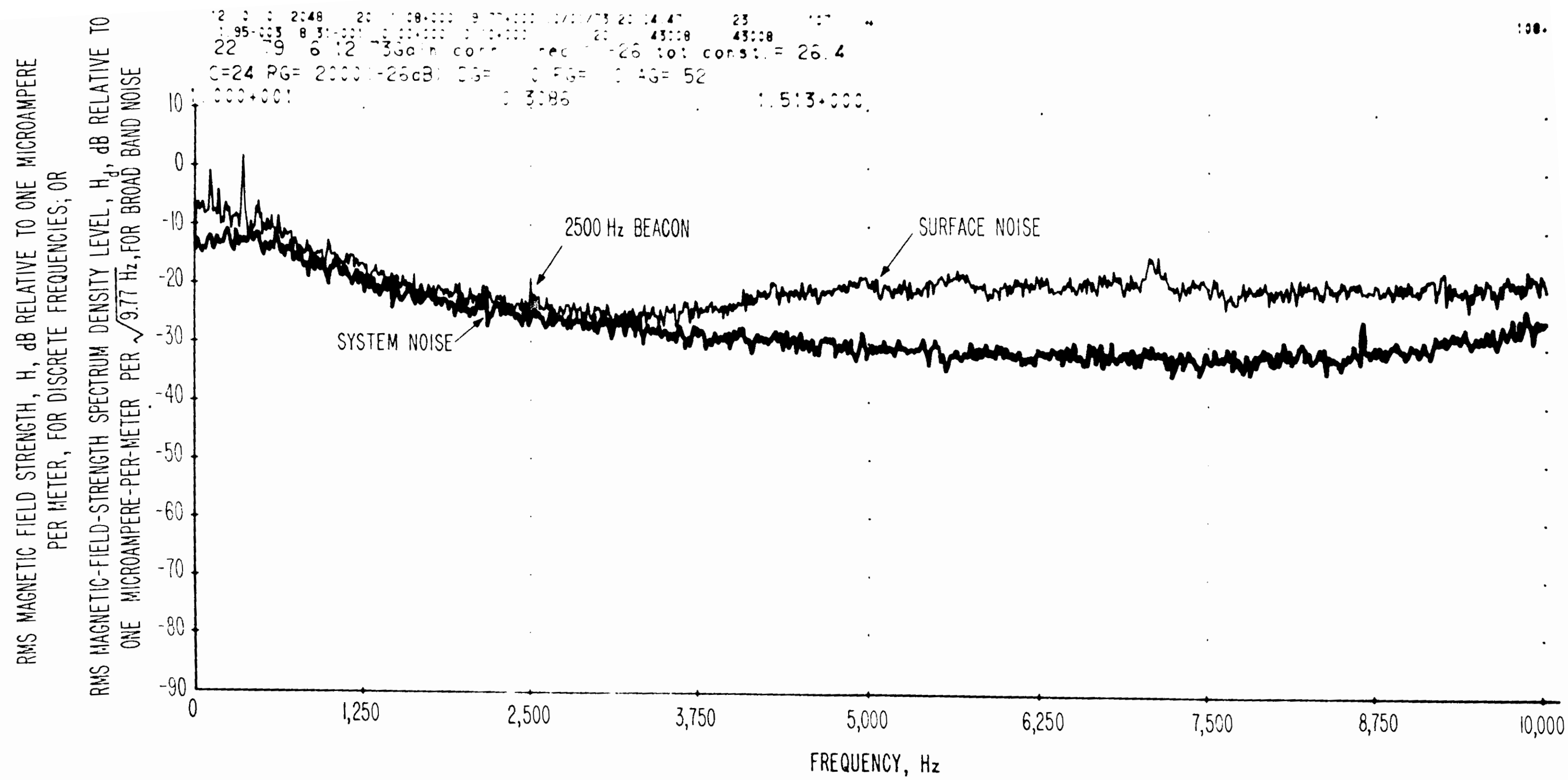

Figure 16 10 kHz spectrum of *surface EM* noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. Antenna sensitive axis is horizontal (N-S). 2500 Hz beacon through 351 meters of overburden is barely visible. Daytime, 4:30 p.m., June 12, 1973.

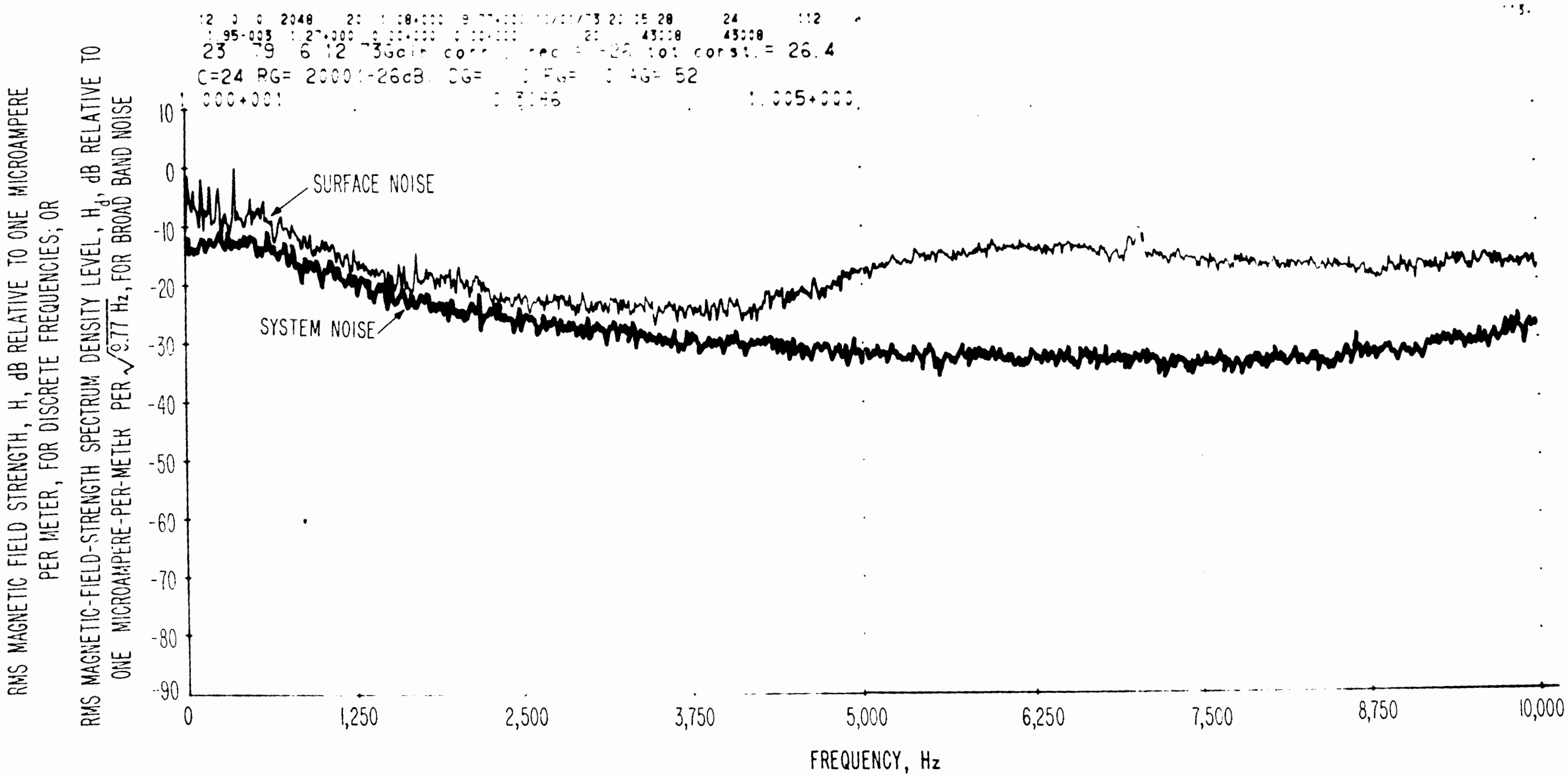

Figure 17 10 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. Antenna sensitive axis is horizontal (N-S). Twilight, 9:35 p.m., June 12, 1973.

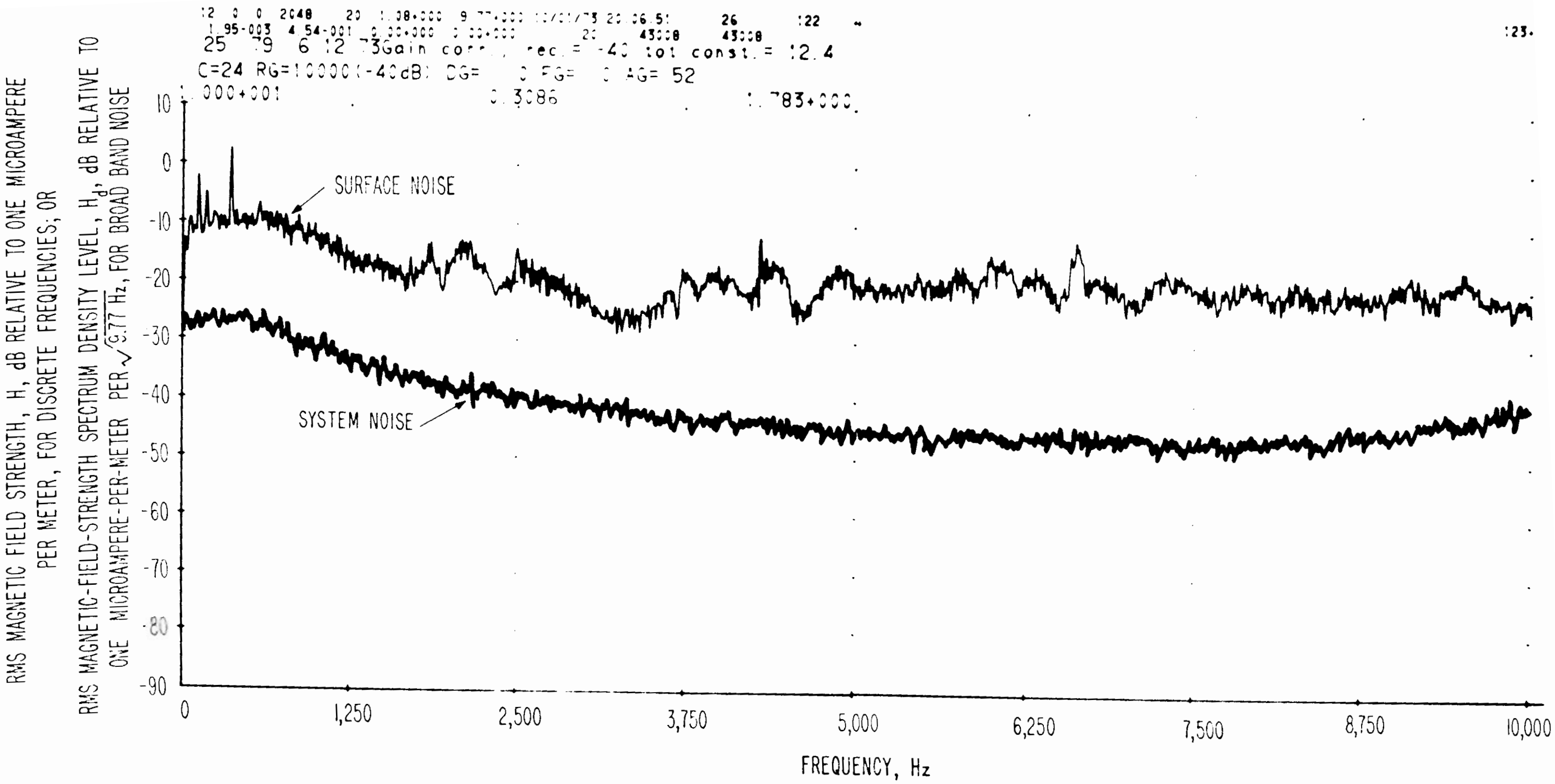

Figure 18 10 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, location A1 on Figure 7. Antenna sensitive axis is horizontal (N-S). 2500 Hz beacon through 351 meters of overburden is barely visible. Nighttime, 10:31 p.m., June 12, 1973.

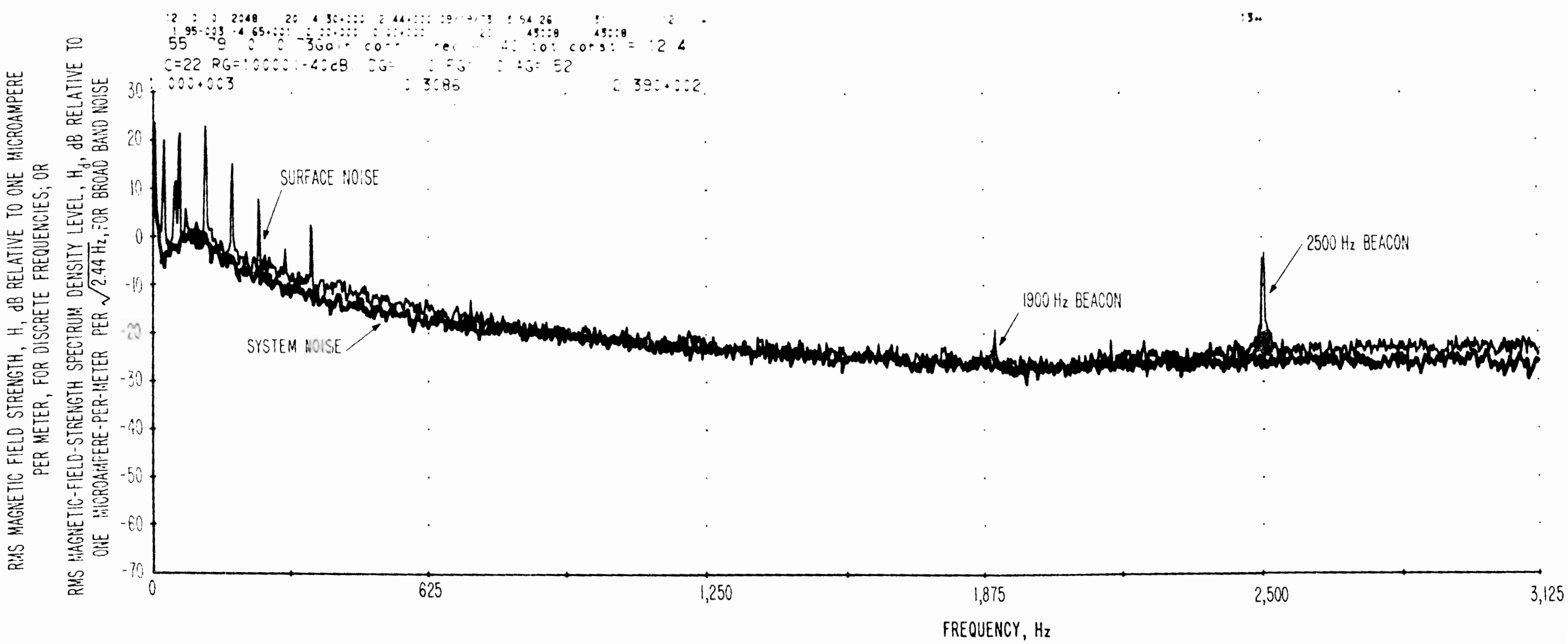

Figure 19

3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. Both the 1900 Hz and 2500 Hz beacons show clearly. The 1900 Hz beacon is displaced laterally about 805 meters (0.5 mile) and is 463 meters deep. The 2500 Hz beacon is vertically displaced 351 meters (1150 ft.). Antenna sensitive axis is vertical. Daytime, 4:41 p.m., June 12, 1973.

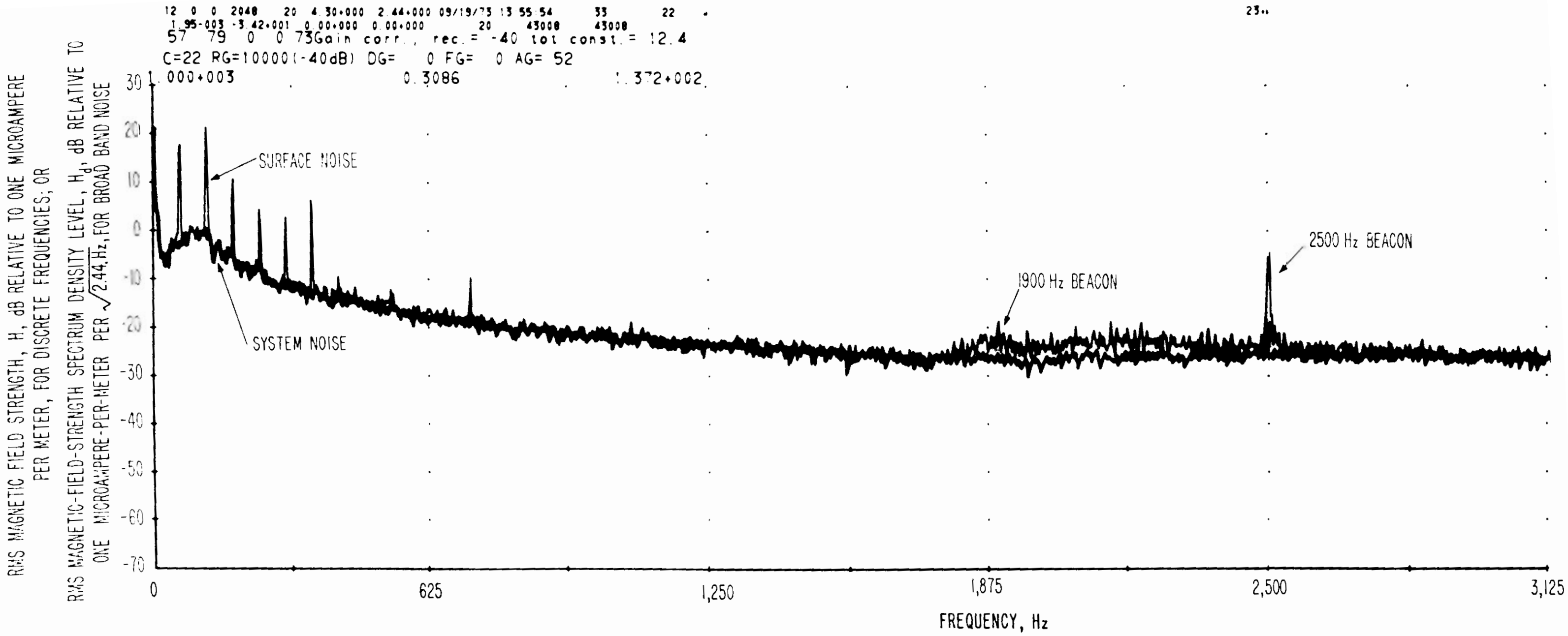

Figure 20 3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. The 1900 Hz beacon is barely visible; the 2500 Hz beacon is clearly visible. Antenna sensitive axis is vertical. Twilight, 9:30 p.m., June 12, 1973.

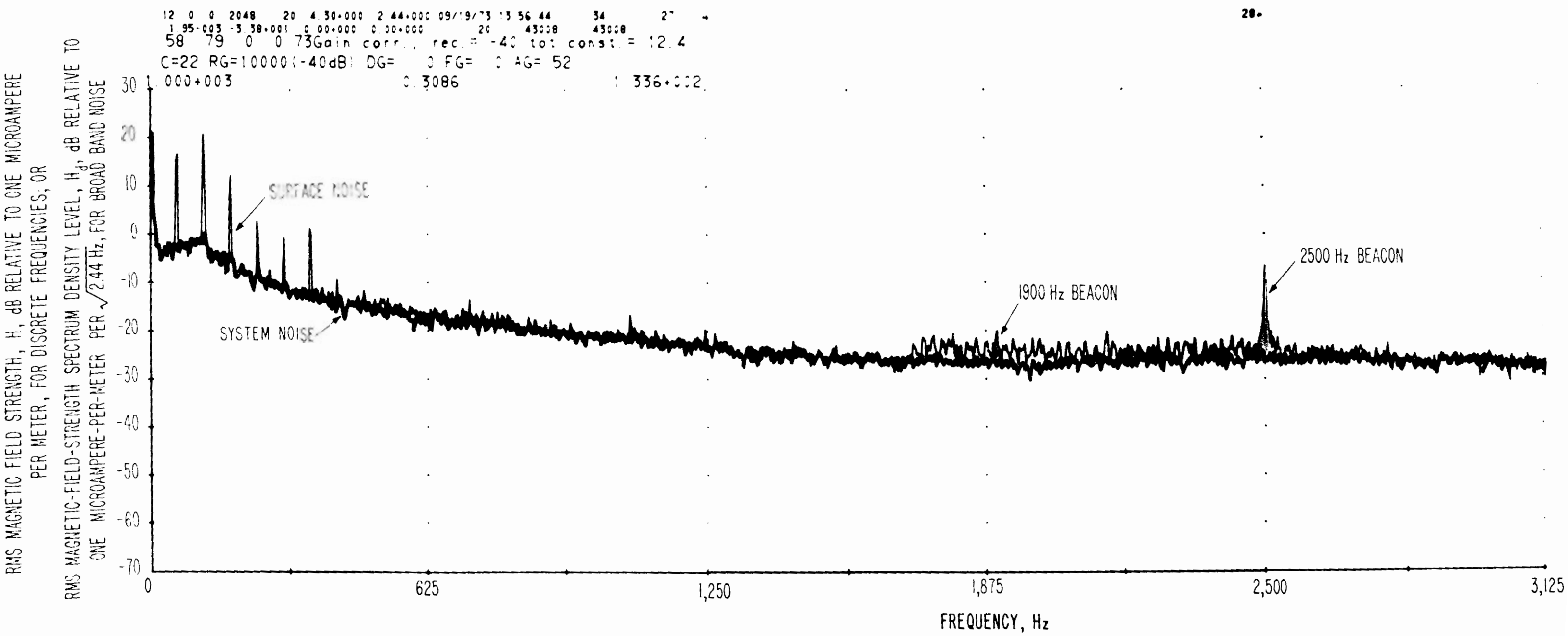

Figure 21

3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. The 1900 Hz beacon is barely visible; the 2500 Hz beacon is clearly visible. Antenna sensitive axis is vertical. Nighttime, 10:30 p.m., June 12, 1973.

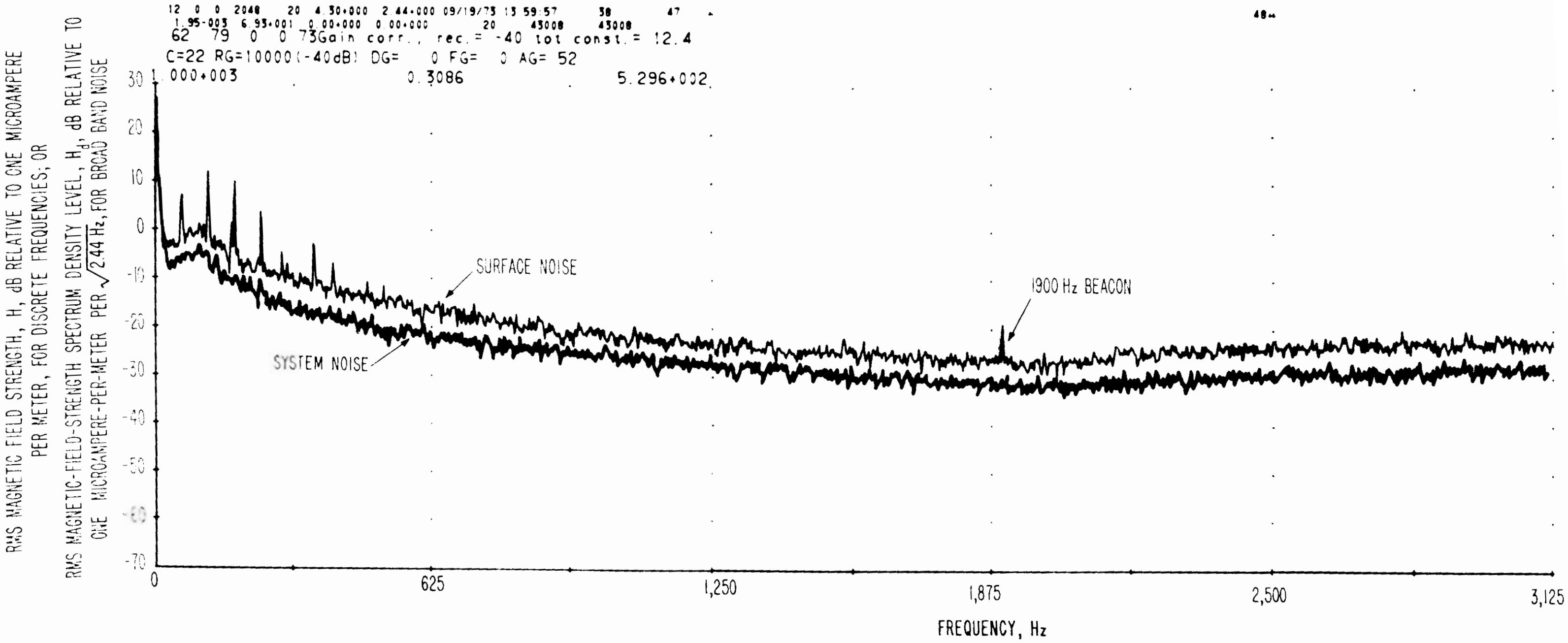

Figure 22 3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. The 1900 Hz beacon is visible. Antenna sensitive axis is horizontal (E-W). Daytime, 4:30 p.m., June 12, 1973.

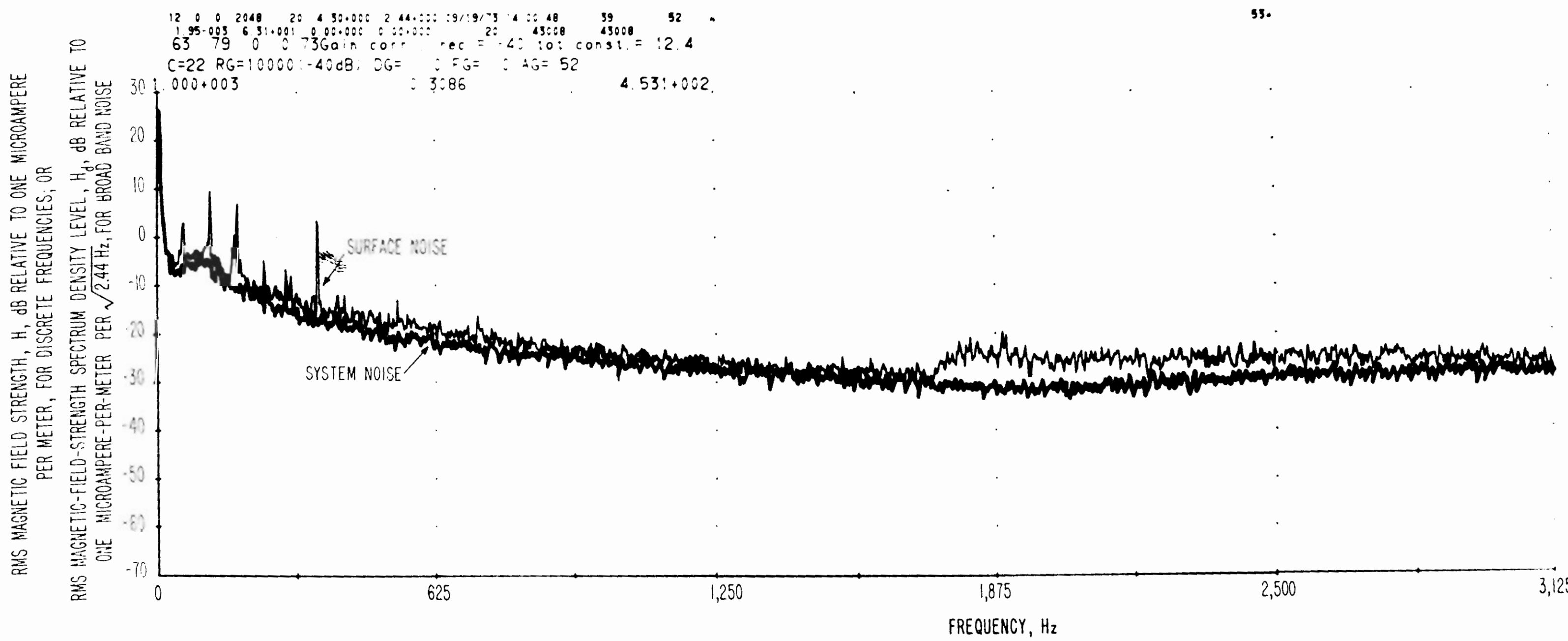

Figure 23

3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. No beacons are visible. Antenna sensitive axis is horizontal (E-W). Twilight, 9:30 p.m., June 12, 197[illegible].

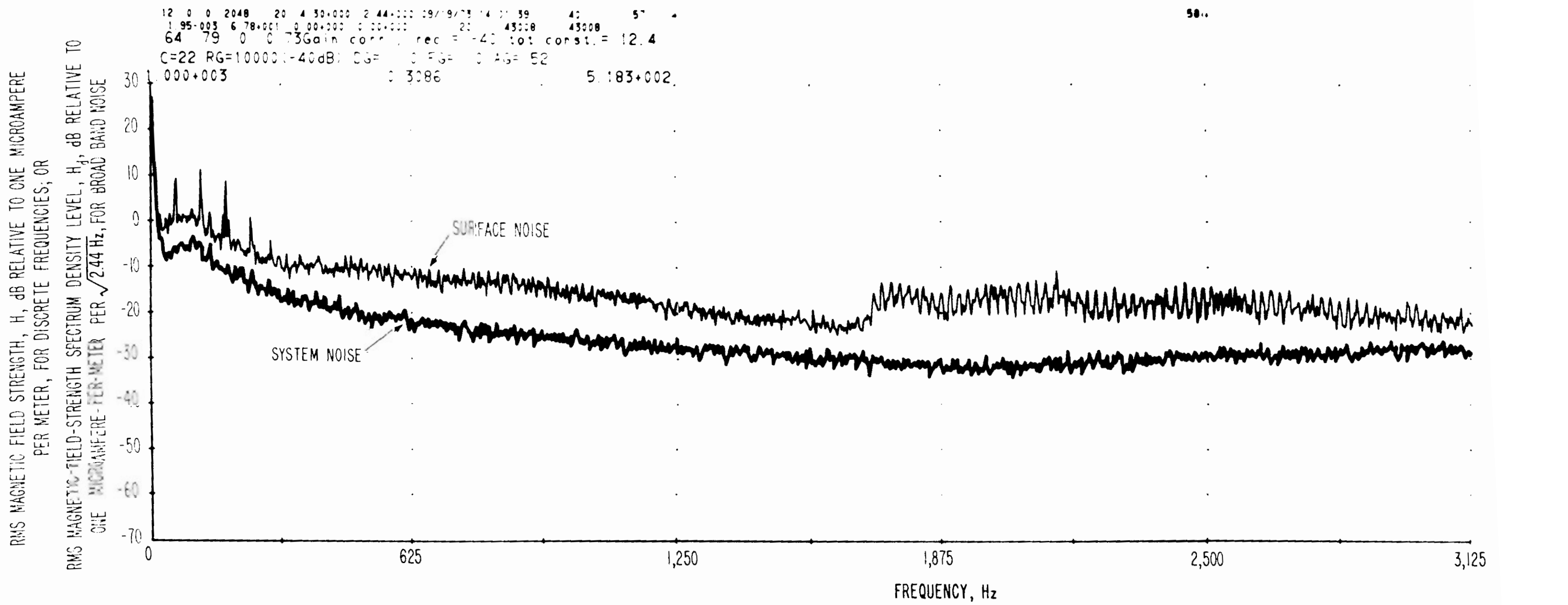

Figure 24

3 kHz spectrum of surface EM noise at Effa Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. No beacons are visible. Antenna sensitive axis is horizontal (E-W). Note sferics above 1700 Hz. Nighttime, 10:29 p.m., June 12, 1971.

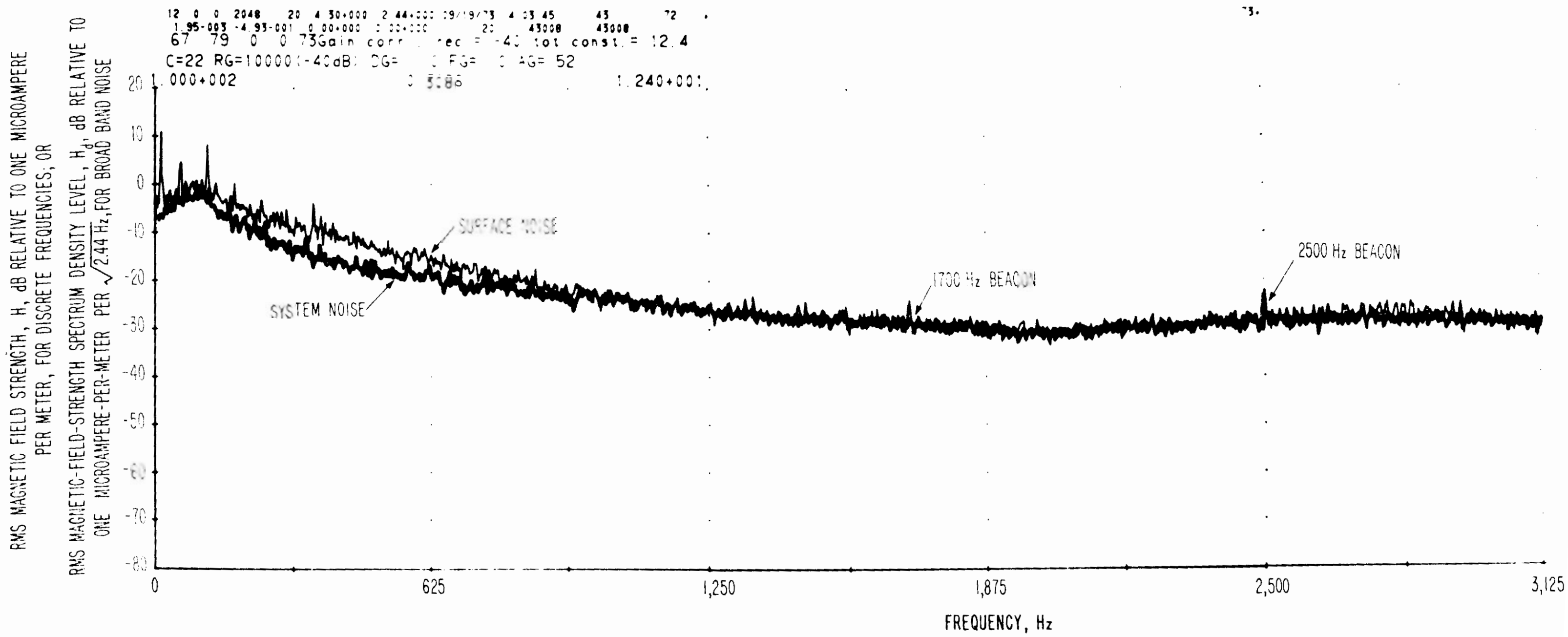

Figure 25

3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. Both the 1700 Hz and 2500 Hz beacons are visible. The 1700 Hz beacon signal is coming from about 1610 meters (1 mile) horizontal displacement and through 442 meters (1450 ft.) overburden. The 2500 Hz beacon is directly below, through about 351 meters of overburden. The antenna sensitive axis is horizontal (N-S). Daytime, 14:41 p.m., June 12, 1973.

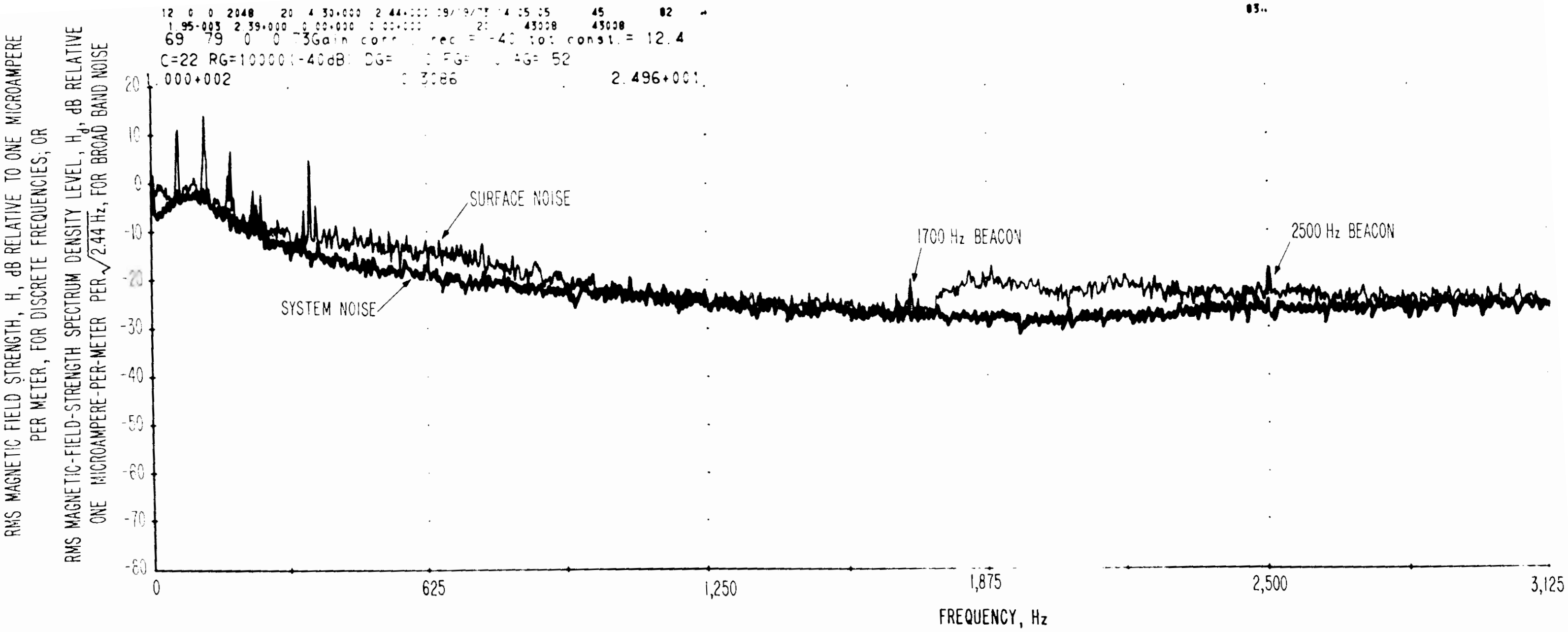

Figure 26

3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A2 on Figure 7. Both the 1700 Hz and 2500 Hz beacons are visible. The 1700 Hz beacon signal is coming from about 1610 meters (1 mile) horizontal displacement and through 442 meters (1450 ft.) overburden. The 2500 Hz beacon is directly below, through about 351 meters of overburden. The antenna sensitive axis is horizontal (N-S). Twilight, 9:30 p.m., June 12, 1973.

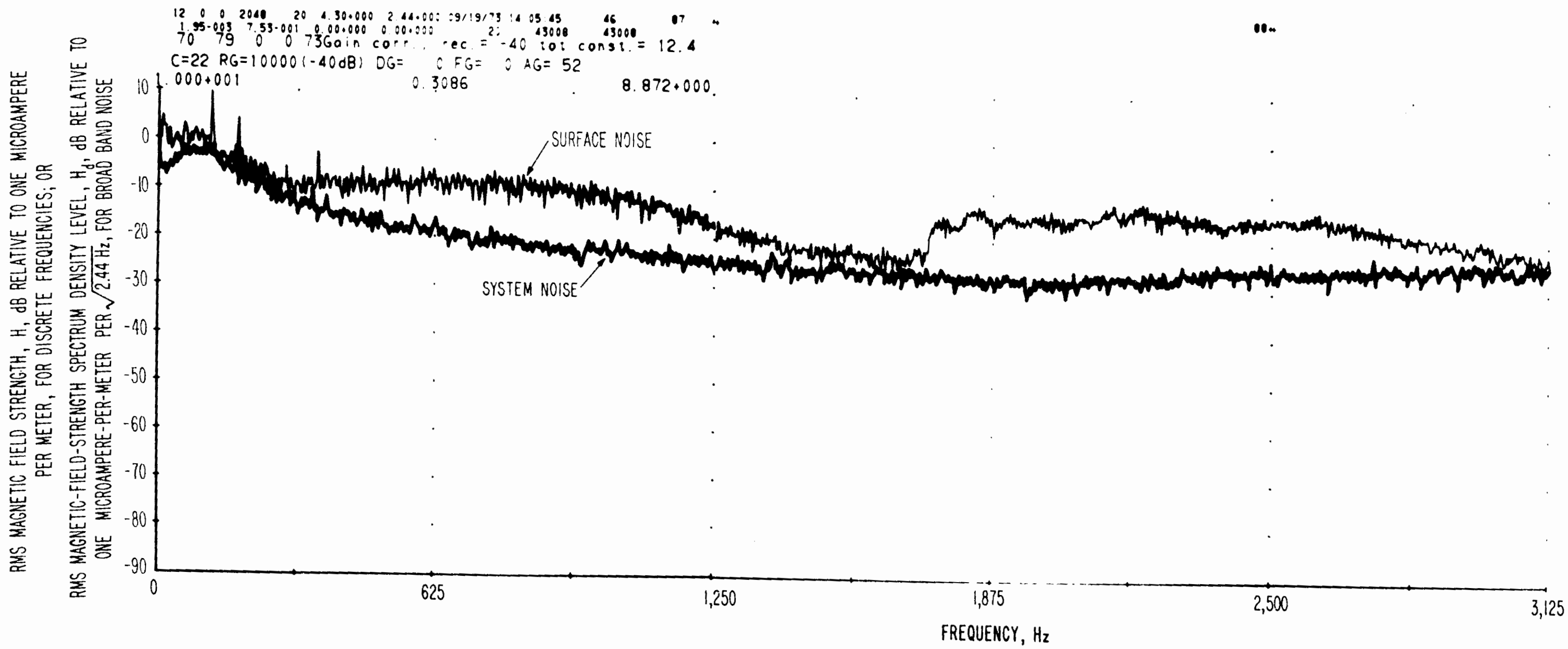

Figure 27

3 kHz spectrum of surface EM noise at Lila Canyon Overlook, over Geneva Mine, Location A1 on Figure 7. No beacons are visible. Notice effect of sferics. Antenna sensitive axis is horizontal (N-S). Nighttime, 10:29 p.m., June 12, 1973.

9.0 Appendix

Decoding of Spectrum Captions

Spectrum captions are generally organized into the following format:

First line: MP NDT NZS NDA NPO RC DF date, time, frame, serial, where

MP = Two's power of length of Fourier transform, example, 2^{MP} where MP = 12

NDT = Detrending option, example, 0 (dc removed)

NZS = Restart spectral average after output, example, 0 (restarted)

NDA = Data segment advance increment, example, 2048

NPO = Number of spectra averaged between output calls, example, 20

RC = Integration time in seconds per spectra, example, 0.168

DF = Resolution bandwidth, spectral estimate spacing in hertz, example, 62.5

Date = Date of computer processing, example, 03/21/73

Time = Time of computer processing, example, 15:06:34

Frame= Frame set number, example, 10

Serial = Film frame serial number, example, 42.

Second line: DTA DA(1) DA(2) DA(3) NSA NRP NPP, where

DTA = Detrending filter parameter α, example, 0.00195

DA(1) = Detrending filter average, K=1, example, 59.4

DA(2) = Detrending filter average, K=2, example, 0

DA(3) = Detrending filter average, K=3, example, 0

NSA = Number of periodograms averaged, example, 20

NRP = Number of data points processed since spectrum initialization, example, 43008

NPP = Number of data points processed since data initialization, example, 43008.

Third line: RUN, SESSION, MONTH, DAY, YEAR Gain corr., rec. = tot. constr. =, where

Run and Session = the title of the portrayed frame identifying the digitizing session and run number, example, 21 83

Month, Day, Year = date data were recorded in the mine, example, 8 25 73

Gain corr. rec. = receiver gain correction, example, -6

tot. const. = constant gain correction of entire system, example, 46.4

Fourth line: C =, RG =, DG =, FG =, AG =, where

C = correction curve used with data, example, 25

RG = receiver gain and accompanying correction in dB added to the data, example, 200 (-6 dB)

DG = digitizer gain, example, 0

FG = filter gain in dB, often rounded to nearest single digit, example, 0

AG = absolute gain correction added to data, example, 52

Fifth line: Top of Scale, Standard Error, Spectral Peak, where

Top of Scale = largest scale marking for computer drawn graph, example, 1.000+004 (1.0×10^4)

Standard Error = standard error of curve, example, 0.3162

Spectral Peak = largest spectral peak observed, example, 4.108+003 (4.108×10^3)

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12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)* U. S. Bureau of Mines Pittsburgh Mining and Safety Research Center 4800 Forbes Avenue Pittsburgh, Pennsylvania	13. Type of Report & Period Covered 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Measurements of surface magnetic field noise were made at various locations over the Geneva Coal Mine near Price, Utah, on June 12, 1973. The locations selected were on the surface over emergency locator beacons underground at depths between 350 meters (1150 ft.) and 488 meters (1600 ft.). The surface terrain where these measurements were made was mountainous, and access was difficult. There were no power lines within several miles, and the weather was clear; therefore, the magnetic noise levels were about as low as will normally occur.

Results of measurements of distant sferics indicate rather sharp cutoff frequencies below which broadband, impulsive noise is attenuated. The mechanism of propagation for this noise above the daytime cutoff frequency of 3500 Hz and the nighttime cutoff frequency of 1700 Hz is deduced to be a waveguide formed by the D or E layers of ionosphere as an upper plane and the earth as a lower plane.

The measurement systems used are similar to those used earlier. The technique is to record broadband, analog signals, digitize the data, and use a fast-Fourier transform to obtain spectral plots. This technique is novel in that it can measure simultaneously all magnetic field energy within a limited portion of the spectrum for a limited time, and, after processing, reproduce the events occurring in that time interval in great detail.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Earth-ionosphere waveguide; electromagnetic noise; EMI measurement technique; sferic interference.

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