SPECTRUM MEASUREMENTS OF ELECTROMAGNETIC-NOISE IN COAL MINES*

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Abstract

A portable, multichannel battery-operated mine-permissible measurement system was developed to measure the rms magnetic-field noise spectrum in the frequency range from 100 Hz to 375 kHz. During each measurement, the entire spectrum is measured simultaneously through the use of time-domain recordings which are later analyzed by Fast Fourier Transform processing. Dynamic ranges of 60 dB in a 125 Hz bandwidth are obtained for spectra covering the range from 100 Hz to 100 kHz. The method also allows a three-dimensional display of the way spectrum occupancy changes with time. Calibration and correction procedures allow absolute field strength measurement with an uncertainty of not more than 3 dB. We feel that further analysis of the system errors will allow this uncertainty to be reduced to less than 1 dB.

Ambient magnetic field noise spectra covering frequencies from 100 Hz to 100 kHz are given for several underground coal mine locations. Examples are also given of magnetic field noise on the surface above the mine, noise in the mine face area, noise radiated by specific equipment, the voltage spectrum found on a 600 V dc trolley wire, and noise picked up simultaneously on loops and on roof support bolts.

I. Introduction

Measurements of the ambient electromagnetic noise present at the receiving terminal must be made in order to design a communication system usable for routine and emergency communications, either operating through the earth or utilizing wire or wireless links within the mine.

Constraints on the experiment made it necessary to rapidly measure electromagnetic noise over most of the spectrum below 300 kHz. Therefore, broadband, analog, real-time recording for later processing was chosen as the means of study, rather than the more usual but slower, narrow band swept-frequency techniques. The chosen method rapidly and continuously records the entire spectrum. The entire spectrum of an event lasting a few seconds, such as an electric locomotive passing by, can be captured quickly on magnetic tape, and later analyzed in great detail.

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II. Measurement Instrumentation

The system block diagram is shown in Figure 1. Figure 1a shows the field-portable portion of the system. Three data channels were needed to obtain three orthogonal field components at each site. An analog 7-track tape recorder running at 30 inches per second (ips) and weighing 14 kg was used for recording the time series data. Figure 1b shows the laboratory transcription process used to reduce the data bandwidth and transcribe the data to a laboratory-quality analog tape recorder with tape-controlled servo capability. The servo capability accurately controls the tape recorder speed from a stable reference signal recorded on the tape (on a separate channel) at the same time the noise signals were recorded. Figure 1c shows the laboratory digitizing process. During this step, the data bandwidth was further reduced; the tape recorder was run in the tape-controlled servo mode. The digitized data was then processed by a digital computer. The available digitizing instrumentation was not capable of accepting the full bandwidth of the data as recorded. It was therefore necessary to reduce the effective bandwidth of the data by using a slower speed on playback than was used on recording. This process retained all of the original information but traded bandwidth requirements for processing time. A Fast Fourier Transform (FFT) algorithm was used to change the time series data into a frequency series presentation in spectral form. The processed data in its initial form comes from the microfilm plotter and printer, Figure 1d. The FFT routines were developed primarily by L. D. Lewis of the Space Environment Laboratories, National Oceanic and Atmospheric Administration, Boulder, Colorado. Lewis based his algorithm primarily on methods outlined by Welch (1).

III. Typical Coal Mine Spectra

Data were taken in Robena No. 4 Mine, Waynesburg, Pennsylvania. Figure 2 shows a spectrum measured in the face area, about 10 meters behind a continuous mining machine in full operation. The machine was powered by 600 volts dc. For the curve shown, the antenna sensitive axis was oriented for a vertical moment. The field strengths measured were about 39 db above one micro-ampere per meter (39 db μA/m) at 10 kHz and about 0 db μA/m at 100 kHz. The lower curve shows system noise with the antenna terminals shorted. In addition, the two horizontal antennas recorded mine noise spectra (not shown) that were lower in amplitude by about 10 db at 100 kHz and about 35 db at 10 kHz. Spectra taken in haulageways in the mine tended to show magnetic field strengths typically 60 to 70 db μA/m out to a few kilohertz, which then dropped off sharply above 8 to 12 kHz. One exception was a spectrum taken near a dc motor-driven hydraulic pump (car pull). This spectrum peaked at 78 db μA/m at 1000 Hz, dropped to 47 db μA/m at 10 kHz, and was down to 25 db μA/m at 30 kHz.

Measurements of voltage between roof support bolts showed the same high spectrum occupancy below approximately 10 kHz. Simultaneous measurements of roof bolt voltage and magnetic field showed that noise events were not necessarily correlated. In one case, a noise burst received on the roof bolts was not received on the loop antennas. This problem needs more investigation.

Simultaneous recordings were made of noise underground and on the surface 30 meters away from a 180 meter deep shaft used for ventilation and power distribution. These measurements showed a coherence between surface and underground signals greater than 0.85 over the frequency range from 250 Hz to 6.8 kHz, with rapidly decreasing coherence above 6.8 kHz.

An approximate cross-check of the rms magnetic field noise at 10 kHz was made using data from the system described in the companion paper "Amplitude Statistics of Electromagnetic Noise in Coal Mines" by M. Kanda and J. Adams. Kanda's system uses a different measurement technique and hence gives an independent value for the rms field level. The cross-check is only approximate in that the two measurements were made with about a 3-hour time separation and a 30 meter spatial separation in the same mine. Operating conditions in the mine were essentially the same. With these differences, agreement was within 10 dB.

IV. Conclusion

Two significant results are reported. First, a powerful measurement technique was developed which clearly shows the simultaneous time and frequency variations of complicated signals. The method of making the spectrum measurements combines the convenience of lightweight, portable instrumentation with the power of a large computer FFT package. A singular advantage of the FFT is the unity probability-of-intercept of signals occurring at any time and at any frequency within the bandwidth covered. One consequence of this is the ability to generate 3-D plots showing how spectrum occupancy changes with time.

The second significant result is a set of electromagnetic spectrum measurements made underground in coal mines. These spectra cover the frequency range from 100 Hz to 320 kHz, and along with those reported by Bensema (2), are the first extensive set of spectral measurements made in an underground coal mine environment.

V. References

1. P. D. Welch, (1967 IEEE Trans. on Audio and Electroacoustics, vol. AU-15, No. 2, pp. 70-73).

2. W. D. Bensema, (1972, Coal Mine ELF Electromagnetic Noise Measurements, NBS Report 10739).

Another reference that may be of interest is:

3. R. B. Blackman and J. W. Tukey (1968 The Measurement of Power Spectra, Dover Publications, Inc., New York).

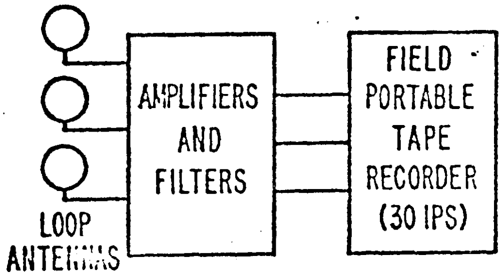

Figure 1a.
Field portable equipment

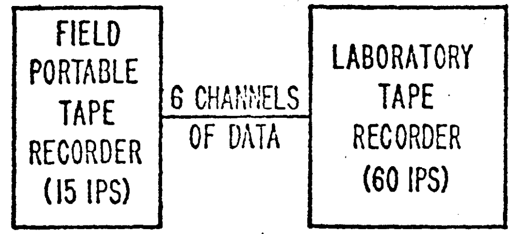

Figure 1b.
Laboratory transcription

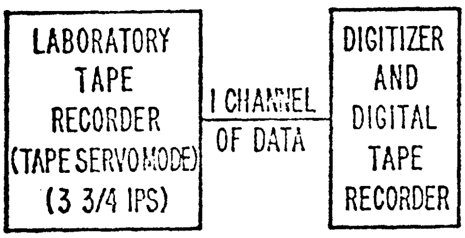

Figure 1c.
Laboratory digitizing

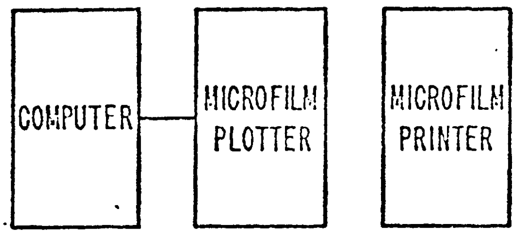

Figure 1d.
Spectral computation, plotting, and printing

Figure 1. System block diagram showing data processing flow.

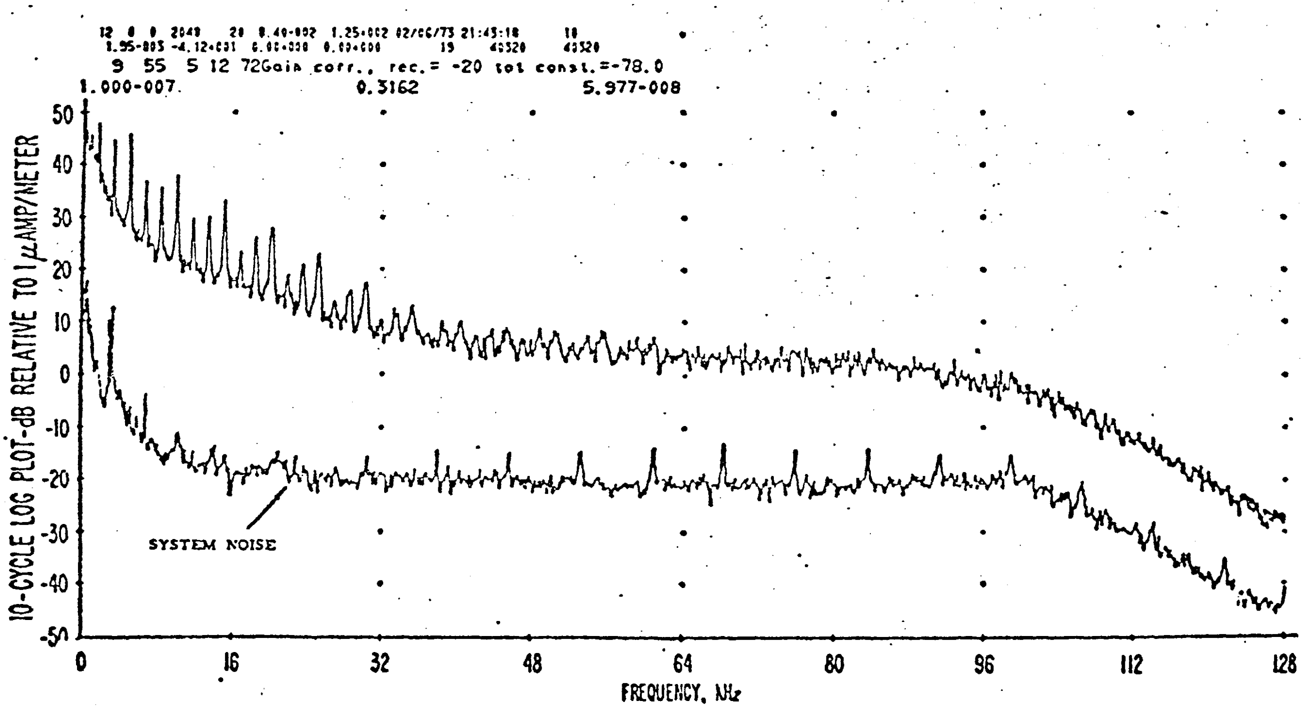

Figure 2. Magnetic field noise measured in Robena Coal Mine face area, 10 meters behind an operating 600 V dc continuous miner. Antenna moment vertical. Do not scale absolute field strengths above 100 kHz. The lower curve shows receiver noise (antenna shorted).