USBM Contract No. HO122026

SURVEY OF ELECTROMAGNETIC AND SEISMIC NOISE RELATED TO MINE RESCUE COMMUNICATIONS

VOLUME I

EMERGENCY AND OPERATIONAL MINE COMMUNICATIONS

Robert L. Lagace — Project Leader
Dwain A. Aidala
Alfred G. Emslie
John J. Ginty
Martyn F. Roetter
Richard H. Spencer
Albert W. Welz

ARTHUR D. LITTLE, INC.
C-73912

USBM CONTRACT FINAL REPORT (Contract No. HO122026)
JANUARY 1974

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON, D. C.

Arthur D. Little, Inc.

USBM Contract No. H0122026

SURVEY OF ELECTROMAGNETIC AND SEISMIC NOISE RELATED TO MINE RESCUE COMMUNICATIONS

VOLUME I

EMERGENCY AND OPERATIONAL MINE COMMUNICATIONS

Robert L. Lagace - Project Leader

Dwain A. Aidala
Alfred G. Emslie
John J. Ginty
Martyn F. Roetter
Richard H. Spencer
Albert W. Welz

ARTHUR D. LITTLE, INC.
C-73912

USBM CONTRACT FINAL REPORT (Contract No. H0122026)
JANUARY 1974

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON, D. C.

FOREWORD

This report was prepared by Arthur D. Little, Inc., Cambridge, Massachusetts under USBM Contract No. H0122026. 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 E. Parkinson acting as the technical project officer. Mr. Francis M. Naughton was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period August 1971 to December 1973. This report was submitted by the authors in January 1974.

VOLUME I

EMERGENCY AND OPERATIONAL MINE COMMUNICATIONS

TABLE OF CONTENTS

VOLUME II

SEISMIC DETECTION AND LOCATION OF ISOLATED MINERS

TABLE OF CONTENTS

INTRODUCTION

This final report documents the work done by Arthur D. Little, Inc. (ADL) on behalf of the U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Center (PMSRC), on Contract H0122026 (which began in August of 1971). Under this contract ADL provided technical assistance to the Bureau on a task basis on virtually all aspects of the Bureau's programs related to present and planned emergency and operational communications and miner location systems for underground coal mines. The work consisted of independent investigations, analyses, experiments, breadboard and prototype hardware development, workshops and technology transfer seminars on mine communications, and on-going evaluations and guidance related to the Bureau's contracted programs on electromagnetic noise, mine communications systems, and trapped miner location. This final report documents the work in two volumes, Volume I, "Emergency and Operational Mine Communications," and Volume II, "Seismic Detection and Location of Isolated Miners." The Tables of Contents of both Volumes are included in each Volume.

Phase I of the contract was devoted to performing an in-depth assessment of electromagnetic noise measurements taken by several contractors and other investigators, and then defining a new noise measurement program and instrumentation system tailored to obtain the necessary but missing noise data. These data are required for use in the design of new emergency and operational communication systems. This work, and the follow-on coordination and guidance activities of ADL on this noise measurement program in subsequent phases of the contract, are treated in Part One of Volume I.

The latter part of Phase I and part of Phase II included preliminary performance predictions related to through-the-earth electromagnetic communication systems. These predictions were based on available theoretical signal propagation results and on recently acquired noise data at several coal mines. This work is treated in Part Two of Volume I.

In Phases II, IV and V, investigations were conducted related to wire, guided-wireless and wireless communications systems for communicating with roving vehicles and personnel underground. This work is documented as follows. Part Three of Volume I treats guided wireless communications via leaky coaxial cable; Part Four treats wireless communications in mine tunnels at UHF frequencies; Part Five treats guided wireless communications down deep hoist shafts; Part Six treats aspects of trolley wire communications; and Part Seven treats a new mine pager telephone to public telephone interconnect system.

Another aspect of Phase V included tasks for providing assistance related to technology transfer seminars on mine communications and to a workshop on through-the-earth electromagnetics. Part Eight of Volume I treats this work. Under Phases II, IV, and V, ADL also provided a wide variety of short-term technical support and consulting services not discussed in the above mentioned Parts. This short-term work is treated in Part Nine of Volume I.

In Phase III of the contract, ADL performed another in-depth assessment on a compressed time schedule, to provide PMSRC with independent technical judgments regarding the potentials and limitations of seismic methods and systems for detecting and locating isolated miners. Volume II of this report is devoted entirely to the treatment of this work.

During the course of this contract we prepared over forty working memoranda, technical reports, seminar papers, and workshop summary reports, in addition to many informal memoranda and the monthly technical reports, to keep PMSRC informed of the progress and findings of our work as they developed. This final report is based on these previous memoranda and reports.

PART ONE

ASSESSMENT OF ELECTROMAGNETIC NOISE
DATA AND DEFINITION OF A NEW
MEASUREMENT PROGRAM

PART ONE

ASSESSMENT OF ELECTROMAGNETIC NOISE DATA AND DEFINITION OF A NEW MEASUREMENT PROGRAM

TABLE OF CONTENTS

PART ONE

ASSESSMENT OF ELECTROMAGNETIC NOISE
DATA AND DEFINITION OF A NEW
MEASUREMENT PROGRAM

TABLE OF CONTENTS
(Continued)

PART ONE

ASSESSMENT OF ELECTROMAGNETIC NOISE
DATA AND DEFINITION OF A NEW
MEASUREMENT PROGRAM

TABLE OF CONTENTS
(Continued)

PART ONE

ASSESSMENT OF ELECTROMAGNETIC NOISE
DATA AND DEFINITION OF A NEW
MEASUREMENT PROGRAM

LIST OF TABLES

PART ONE

ASSESSMENT OF ELECTROMAGNETIC NOISE
DATA AND DEFINITION OF A NEW
MEASUREMENT PROGRAM

LIST OF FIGURES

PART ONE

ASSESSMENT OF ELECTROMAGNETIC NOISE DATA AND DEFINITION OF A NEW MEASUREMENT PROGRAM

INTRODUCTION

The first phase of our work for PMSRC on this contract was devoted to a comprehensive and in-depth assessment of electromagnetic (EM) noise measurements and data taken by several contractors for use in the design of operational and emergency mine communications. Pertinent measurements and data of other selected investigators were also included in the evaluation. This assessment treated the measurements and instrumentation used, the data analysis and presentation methods, and the utility of the final results. This phase concluded with the identification of the most useful results and methods, the remaining data gaps, the contractor most qualified to fill these data gaps, and the definition (with PMSRC and this contractor — NBS, National Bureau of Standards) of a follow-on noise measurement program, instrumentation system, and data processing methods tailored to obtain the necessary but missing noise data. A partial bibliography of references related to electromagnetic and seismic noise and propagation in the frequency bands of interest was also compiled during this first phase. The body of this Part of the final report presents a summary of the findings of our EM noise assessment, together with detailed recommendations regarding the new noise measurements to be taken and the instrumentation and data processing methods to be used. This work was done during the latter part of 1971 and the early part of 1972.

During subsequent phases of the contract ADL was asked to perform on-going evaluations of the continuing program of electromagnetic (EM) noise and propagation measurements made by Bureau contractors, and to utilize pertinent data from these measurements to make performance estimates for candidate operational/emergency EM mine communication and location systems. In this advisory and coordinating capacity, ADL participated in program status and system review meetings with the NBS noise measurement team and others, kept in close touch with this team between meetings, and utilized selected portions of the data as they became available. The principal findings, and conclusions of these meetings have been included in the Appendix to this Part. They serve as a convenient reference to the historical development of the follow-on noise measurement program and associated instrumentation. As of the Fall of 1973 this measurement program has been largely completed, and the instrumentation system and noise data are being documented by NBS.

The material summarized in this Part and its Appendix is based on several technical reports and working memoranda created during the first and subsequent phases of this contract. Performance estimates related to candidate electromagnetic through-the-earth mine communication and location systems are treated in Part Two of this final report.

I. SUMMARY — ELECTROMAGNETIC NOISE ASSESSMENT AND RECOMMENDED MEASUREMENT PROGRAM

Five conclusions that emerged from ADL's Contractor Noise Measurements Assessment done in the winter of 1971-72, and the 7 December 1971 Bureau of Mines Contractors' Round Table Meeting in Boulder, Colorado were:

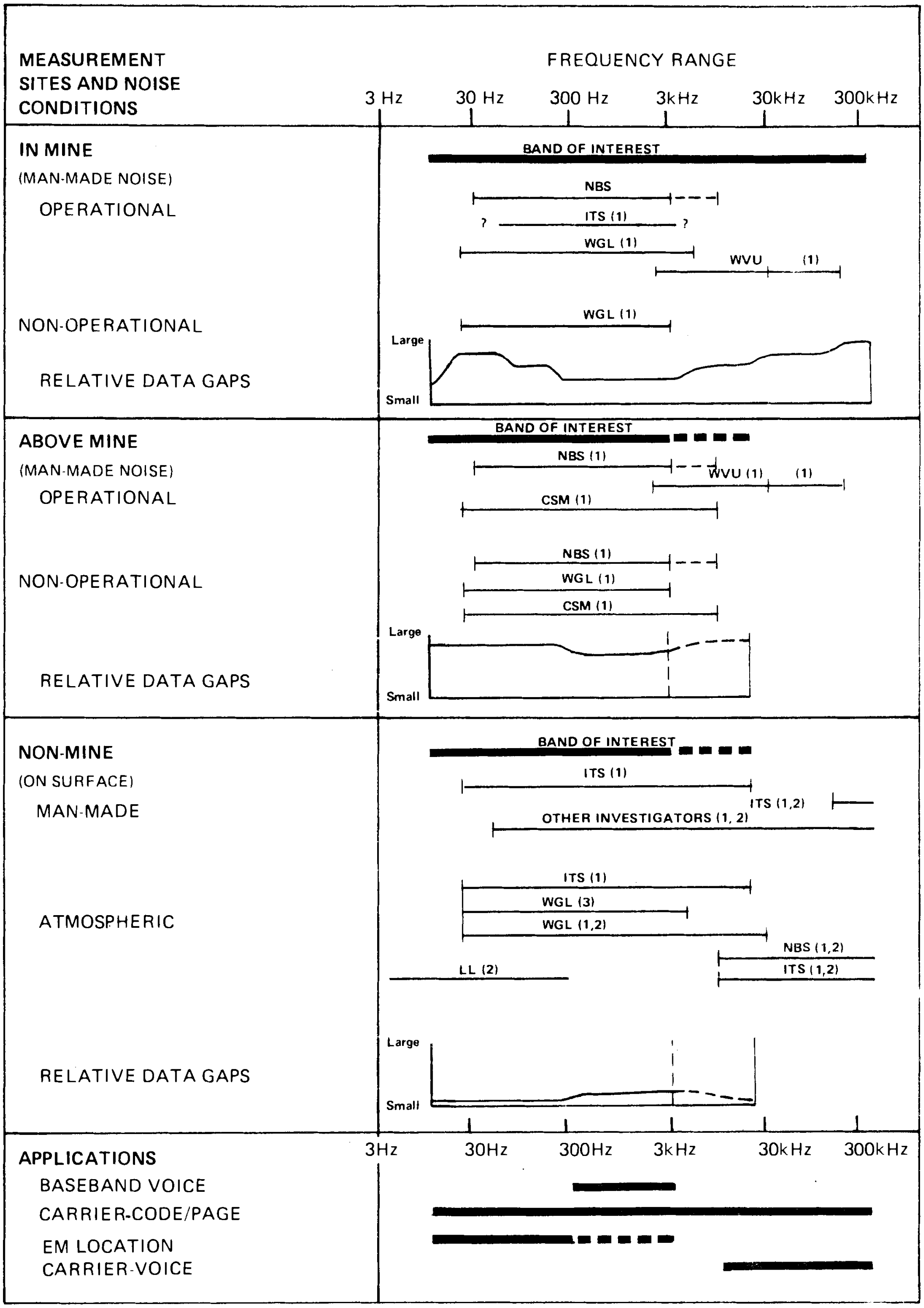
- a limited amount of good data has been obtained for characterizing the noise environment for electromagnetic (EM) coal mine operational/emergency communications systems;
- significant noise data gaps still exist;
- suitable instrumentation and data analysis methods are available for filling these data gaps;
- the immediate and most important data gaps should be filled by means of a timely field measurement effort that is purposely limited in scope and duration;
- this field measurement effort should preferably be carried out by a team knowledgeable and experienced in coal mine EM noise measurements.

Tables 1, 2, and 3* summarize some of our findings and conclusions with regard to the EM noise measurements, processing techniques, and results for each of the Bureau of Mines contractors and for some other investigators. Table 1 depicts the noise measurements made by each of the contractors and investigators with respect to frequency bands covered, mine versus non-mine, and operational versus non-operational conditions; together with a graphical indication of the size of the data gaps remaining in each of the frequency bands of interest. Table 2 is a more detailed listing of specific coal mine locations and noise sources of interest, and an identification of those treated in each investigator's measurements, again with an appropriate rating of the size of the data gaps remaining. Table 3 presents a listing of investigators, an identification of their measurement and data processing

* References to Figures, Tables, and Equations apply to those in this Part unless otherwise noted.

TABLE 1

GENERAL SUMMARY OF PAST MEASUREMENTS, FREQUENCIES, AND DATA GAPS



CSM COLORADO SCHOOL OF MINES
ITS INSTITUTE FOR TELECOMMUNICATION SCIENCES
NBS NATIONAL BUREAU OF STANDARDS
WGL WESTINGHOUSE GEORESEARCH LABORATORY
WVU WEST VIRGINIA UNIVERSITY
LL MIT LINCOLN LABORATORY

(1) DATA LIMITED IN AMOUNT OR UTILITY
(2) PAST WORK – NOT FOR BU MINES
(3) PLANNED BUT NOT STARTED

ALL MEASUREMENTS WITHOUT A (2) NOTE WERE DONE FOR BU MINES

TABLE 2

SUMMARY OF PAST MEASUREMENT LOCATIONS, CONDITIONS, AND DATA GAPS

MEASUREMENT SITES AND NOISE CONDITIONS	INVESTIGATORS							
	CSM	ITS	NBS	WGL	WVU	LL	OTHER	DATA GAPS
IN MINE								
OPERATIONAL		X (1)	X	X (1)	X (1)			
PWR BOREHOLES			X		X			M
AC & DC POWER CENTERS		?	X		X			M
DC TROLLEY LINES		X	X	?	X			M
AC POWER LINES			X		X			M
HAULAGE TRAINS		X	X		X			M
MINE MACHINERY		?	X		X			L
QUIET PLACES/TIMES			X		X			L
WORKING FACES								L
NON-OPERATIONAL				X (1)				
PWR BOREHOLES								L
OTHER PLACES				X				L
ABOVE MINE								
OPERATIONAL	X (1)		X (1)		X (1)			
PWR BOREHOLES	X		X					L
POWER LINES	?		X		?			L
PWR SUBSTATIONS								L
MINE MOUTH PWR STATIONS								L
OVER WORKING FACES	X							L
OVER OTHER SECTIONS	X		X					M
NON-OPERATIONAL	X (1)		X (1)	X (1)				
PWR BOREHOLES	X		X					L
PWR SUBSTATIONS								L
MINE MOUTH PWR STATIONS								L
POWER LINES			X	X				L
NON-MINE								
MAN-MADE		X (1) X (1,2)				X (2)	X (1,2)	S
ATMOSPHERIC		X (1) X (1,2)	X (1,2)	X (3) X (1,2)		X (2)	X (1,2)	S/M

CSM COLORADO SCHOOL OF MINES
ITS INSTITUTE FOR TELECOMMUNICATION SCIENCES
NBS NATIONAL BUREAU OF STANDARDS
WGL WESTINGHOUSE GEORESEARCH LABORATORY
WVU WEST VIRGINIA UNIVERSITY
LL MIT LINCOLN LABORATORY

NOTES ( ) INDICATED AT MAJOR HEADINGS OPERATIONAL AND NON-OPERATIONAL ALSO APPLY TO THE CORRESPONDING SUBHEADINGS

(1) DATA LIMITED IN AMOUNT OR UTILITY
(2) PAST WORK – NOT FOR BU MINES
(3) PLANNED BUT NOT STARTED

DATA GAPS: LARGE – L
MODERATE – M
SMALL – S

TABLE 3

SUMMARY OF PAST MEASUREMENTS, PROCESSING METHODS, AND RESULTS

EM NOISE MEASUREMENTS, PROCESSING METHODS, AND RESULTS	INVESTIGATORS								
	FOR BU MINES (EXC. AS NOTED)							FOR OTHERS	
	CSM	ITS	ITS (2)	NBS	WGL	WGL (2)	WVU	LL ATMOS (2)	OTHER MAN-MADE (2)
METHODS									
ANALOG TAPE RECORD		x	(x)	(x)				(x) (4)	
TUNABLE RCVR/WAVE ANALYZER	x	x	(x)		x	x	x		x
DIGITAL PROCESSING	x		x	(x)	(x)	x		(x)	
FFT POWER SPECTRUM				(x)	(x)			(x)	
STATISTICAL (AMP./TIME)	x		(x)	x		x		(x)	
ON-SITE ANALYSIS	x	x	x		(x)	x	x		x
POST-SITE ANALYSIS		x	x	(x)	x	x	x	(x)	
WIDE BAND (>100 Hz)	x	x	(x)	(x)	(x)		x	(x)	x
NARROW BAND (<100 Hz)		x			x	x			x
TIME AVERAGED (LONG)		x	x		x (3)	x			
SIMULTANEOUS									
FREQUENCIES			(x)	(x)	(x)			(x)	
SENSORS								(x)	
SEQUENTIAL									
FREQUENCIES	x	x	x		x	x	x		x
SENSORS	x	x		x	x	x	x		x
LONG TERM		x	(x)		x (3)	x		(x)	
SHORT TERM	x	x	(x)	(x)	(x)		x	(x)	x
CALIBRATIONS			(x)	(x)	x	x		(x)	
RESULTS	(1)	(1)	(1)		(1)	(1)	(1)		(1)
ANALOG NOISE RECORDINGS		x	(x)	(x)				(x) (4)	
CONTINUOUS POWER SPECTRA (HARMONICS & BROADBAND NOISE)				(x)	(x)			(x)	
HI–RESOLUTION				(x)				(x)	
MOD–RESOLUTION				x	x				
DISCRETE PWR SPECTRUM SAMPLES			(x)		x	x	x		x
HARMONICS					x		x		
SELECT FREQUENCIES			(x)		x (3)	x	x		x
SWEPT PWR SPECTRA		x							x
NOISE SOURCE SIGNATURES				(x)					x
AMPLITUDE STATISTICS	x		(x)	x	x (3)	x		(x)	
TIME STATISTICS			x		x (3)	x		(x)	
SPATIAL VARIATIONS						x (5)	(x)	x (5)	x
TIME VARIATIONS	x	x	x	(x)	x (3)	x	x	(x)	x
ELECTRIC FIELD	x	x	x		x (3)	x		x	x
MAGNETIC FIELD	x	x		(x)	x	x	x	(x)	x

CSM COLORADO SCHOOL OF MINES
ITS INSTITUTE FOR TELECOMMUNICATION SCIENCES
NBS NATIONAL BUREAU OF STANDARDS
WGL WESTINGHOUSE GEORESEARCH LABORATORY
WVU WEST VIRGINIA UNIVERSITY
LL MIT LINCOLN LABORATORY

(1) DATA LIMITED IN AMOUNT OR UTILITY
(2) PAST WORK – NOT FOR BU MINES
(3) PLANNED BUT NOT STARTED
(4) DIRECT DIGITAL RECORDING ALSO
(5) GEOGRAPHICAL
(x) INDICATE THE MOST PREFERRED METHODS AND RESULTS TO CHOOSE FROM FOR FUTURE MEASUREMENTS

methods and noise results, together with an indication of which methods and results should be most suited for future measurement efforts.

Recommendations for the implementation of the next phase* of the Bureau of Mines noise measurement programs are presented in this Part. This next phase will be aimed at filling the most critical data gaps. The following recommendations are based on the above findings and on the conclusions reached during a two-day conference between key staff of the Bureau of Mines, NBS, ITS and ADL in Boulder, Colorado on 13 and 14 March 1972- a conference convened for the express purpose of determining the most efficient and practical means for obtaining the required data.

In brief, a limited noise measurement effort, called a scouting-party expedition, is recommended. Measurements should be concentrated in the frequency band from about 40Hz to 400kHz, with perhaps some limited examination of lower frequencies and of higher frequencies up to about 30mHz. The effort should be one centered around short-term measurements of EM man-made noise, at locations of practical and strategic interest, in and above one or two representative coal mines as summarized in Tables 4 and 5. The main emphasis will be on simultaneous wideband magnetic tape recordings of the noise magnetic field components. Field strength meters modified to measure noise power will be used to a more limited extent, and mainly at the higher frequencies. Highly portable, battery powered, compact equipment will be used to minimize time and confusion in the mines. Data processing and analysis of the noise tapes will be conducted back at the laboratory utilizing available and reliable digital methods and computer software, and some conventional analog methods. High- and moderate-resolution noise power spectra will be obtained, and when appropriate, noise amplitude and time statistics. The noise measurements will be made primarily in locations, and under conditions, where the data gaps are presently moderate-to-large and of high priority; such as in and above working sections, where there is a need to provide wireless communications to supervisory, maintenance, and safety personnel. Long-term measurements of atmospheric noise on the surface are presently not of

* As of the spring of 1972.

high priority; because man-made noise is expected to dominate on the surface above coal mines, and because existing atmospheric noise data, through sparse in some frequency bands, appear to be adequate for making first-order system performance estimates and comparisons. Heavy dependence is placed on the prior demonstrated capabilities of NBS and ITS in recording and analyzing electromagnetic noise.

The "scouting-party" field measurement effort is purposely being designed to be of limited scope and duration in order to: obtain a rapid and better indication of the nature and severity of the coal mine EM noise environment; identify the most critical conditions and parameters; and help identify the most favorable frequencies for mine operational/emergency communications. The remainder of this Part presents an abbreviated description of, and questions related to, the instrumentation and data processing methods that were discussed at the March meeting in Boulder. This Part includes a partial equipment list and block diagrams for the instrumentation to the extent that they are presently defined and in addition documents the main findings and conclusion of the March Boulder meeting, and serves as a framework from which the field measurement instrumentation, data processing, and test plan details can be finalized by the joint NBS/ITS team that will perform the measurements under the guidance of the Bureau of Mines.*

II. CONFERENCE PARTICIPANTS AND TENTATIVE PROGRAM ASSIGNMENTS

The March, 1972, Boulder conference participants were Howard Parkinson of the Bureau of Mines; John Adams, William Bensema and Harold Taggart of NBS; A.D. Spaulding and Robert Matheson of ITS; and Robert Lagace and Richard Spencer of ADL. The following tentative measurement program assignments were agreed upon for a joint NBS/ITS team effort under the guidance and direction of Howard Parkinson of the Bureau of Mines. NBS/ITS program coordinator will be John Adams of NBS; William Bensema will serve as the NBS leader and A. D. Spaulding as the ITS leader; with Robert Matheson of ITS and Harold Taggart of NBS completing the NBS/ITS core team.

---

* ADL's subsequent participation in the noise measurement program was in an advisory and coordinating capacity in behalf of the Bureau. Principal activities of this ADL effort consisted of periodic communications and participation in status and system review meetings with the NBS/ITS team and the Bureau, as described in the Appendix in this Part.

TABLE 4

PLANNED ELECTROMAGNETIC NOISE MEASUREMENT PROGRAM (SCOUTING PARTY)

MINE NOISE MEASUREMENTS (Magnetic field components - highest priority, trolley and phone line currents/voltages - secondary priority) - Short-term of man-made origin

A. Frequencies

In Mine: 40Hz-400kHz highest priority; below 40Hz and 400kHz-30mHz secondary priority
Above Mine: 40Hz-20kHz highest priotity

B. Measurement Locations and Conditions

1. At a few high-roof, bituminous mines with DC trolley haulage systems, 3-phase rectified DC power centers, conventional and continuously mined faces, etc.
2. In Mine - At selected : worst case sites--near trolley lines, working faces, power centers, machines, loading points
   : "quiet" sites that supervisors are likely to frequent
   : sites where no one source dominates, but not "quiet"
   : positions on the trolley and telephone lines

   Above Mine - At selected: sites over working faces, near power bore holes, near overhead power lines and substations
   : attachment points to power cables at the top of bore holes
3. As function of: distance from sources
   : equipment operating mode and load
   : time--during, between, and after work shifts, lunch hours, etc.

C. Noise Characteristics

1. 0-10kHz : Dominant Noise - 60Hz and 360Hz harmonics (line spectra) from AC power lines and equipment, DC power centers and trolley lines, etc.
   Secondary Noise - Impulsive broadband - from haulage train trolley poles, and other equipment (can approach levels of harmonics when close to sources)
2. 10-400kHz: Dominant Noise - Uncertain, combination of harmonics and broadband impulsive, harmonics probably smeared out

D. Noise Descriptions Desired

1. Power Spectra: most important; continuous and high-to-moderate resolution desired, particularly below 10kHz; discrete spectrum samples (1kHz-5kHz wide) less desirable, but useful above 10kHz, particularly useful above 400kHz
2. Amplitude and Time Probability Distributions: not useful if noise dominated by harmonics, may be of value otherwise, but secondary in nature
3. Variation of noise field strength with distance, time, sensor orientation

E. Measurement and Analysis Methods

1. Broadband Analog Magnetic Tape Recording - In Mine: 0-375kHz; 0-100kHz FM; 100-375kHz Direct
   Above Mine: 0-20kHz FM

   Broadband(2.5-5kHz wide) reception and recording at discrete frequencies - Primarily In-Mine using Stoddart receivers: NM-25T (150kHz-32mHz)
   NM-12AT (10kHz-250kHz)

   modified to: measure RMS field strength and V_d (ratio of rms to average field strength) and allow analog
   : tape recording of the IF reception band by heterodyning the IF output to baseband
2. Computer FFT and Analog Spectrum Analysis back at lab - highest priority
   APD's and TPD's from tape recordings as needed - secondary priority
   Real-time monitoring at sites with scopes and Stoddart receiver meter outputs

E-M THRU EARTH VOICE TRANSMISSION---------Blackboard Outline of Limited Measurements Suggested to Characterize Noise Environment -- 7 December Boulder Meeting

Wireless Communications Desired to Supervisors, Foremen, and Safety Man in Each Working Section, which Includes the Faces and Loading Centers

DOWNLINK - In-Mine Radiated Noise - Highest Priority

- Frequency Range: Below 10kHz
- Under Operational Conditions
- Harmonic and Impulsive Noise - Short-Term Measurements

- FIRST MEASUREMENTS - Should Be of a Limited Scouting Party Type

  By Visiting Maybe 2-4 D.C. Mines for Some Quick and Simple Measurements at Some Strategic Locations in the Mines: To Build up Confidence in Applicability of Present Results: (i.e., that of Bensema--NBS, and some of WGL's)

- STRATEGIC LOCATIONS IN A D.C. MINE - (Choose High Vs. Low Coal Mines for Convenience of Tests)

  - Alongside D.C. Haulageway Track
  - On Locomotives
  - Near Equipment at the Face
  - Near Power Lines Going to the Face
  - Near Specific Machinery
  - Near Underground Power Substations

- Make Measurements with Air Core Loop, Size of NBS' and with A Small Ferrite Antenna for Comparison
- Behavior Versus Distance from Sources Should Be Examined

UPLINK - Surface Radiated Noise - Lower Priority

- Frequency Range: Below 10kHz
- Under Operational Conditions
- Harmonic and Impulsive Noise - Short-Term Measurements (No Long-Term Atmospherics)
- First Measurements as Above - Limited to Strategic Locations
- Strategic Locations
  - Near Power Boreholes and
  - Near Surface Power Lines and "Mine Mouth" Power Stations
- Again Versus Distance From Sources

TABLE 5

OUTLINE OF SCOUTING PARTY NOISE MEASUREMENT NEEDS FOR THE 0-10kHz BAND
(December 7, 1971-Bureau of Mines Contractors' Round Table Meeting-Boulder, Colorado)

III. MEASUREMENT PROGRAM OUTLINE

A. Data Needed

The Bureau of Mines noise measurement programs to date* have developed considerable data on the character of electromagnetic noise in mining environments. Despite this assembly of data, there still exist substantial gaps in the characterization of the mine noise environment (as shown in Tables 1 and 2). The magnetic field components of the noise are of principal interest. In the mines, there is no EM noise data near the working faces, and only little data of merit near particular equipments, power centers and transmission facilities, and as a function of operating conditions and distance. There is a dearth of noise data in quiet regions of mines. In addition, the modest amount of good data taken to date in mines falls largely in the band from 0-5kHz, thereby creating an even larger gap in the frequency band from 5kHz to 400kHz. In addition, there is the need for obtaining information on the propagation of electromagnetic signals in the regions near working faces, in particular from the working faces to a typical loading point, this distance encompassing about 600 feet. On the surface there is a lack of data in regions directly over the working faces and near power lines and bore holes, again as a function of distance and operating conditions as in the mines. There is also a need for providing data on the correlation of surface noise behavior with in-mine noise behavior. An indication of the data to be obtained by the scouting-party noise measurement program together with an indication of their priorities is shown in Table 4.

B. Noise Characteristics

Measurements made to date* in the mining environment reveal that the noise in the low frequency region from a few Hertz to 5kHz is dominated by 60Hz and its harmonics. Impulsive noise is seldom dominant in this band, assuming high levels only when loaded locomotives with arcing trolley pole contacts pass close by. From the 10kHz region upward the noise, although influenced by harmonic content, does not appear to have power line harmonics that can be separated and isolated as such. Limited data suggest that the noise spectrum levels fall off with frequency in this region

*As of the Spring of 1972.

up to about 100kHz, beyond which the detailed character is unknown. The impulsiveness, dynamic range, and statistics of the noise in the region above 10kHz are unknown at the present time. An objective of the measurement program will be to remove the major uncertainties with regard to these noise characteristics and levels.*

C. Data Acquisition and Analysis

It was the conclusion of the conference participants that the missing noise data could best be obtained by analog tape recording magnetic field noise picked up by loop antennas, and to a more limited extent conducted trolley and telephone line noise by direct pickup. The data on these magnetic tapes could then be reduced to useful forms such as power spectrum plots by digital methods using a computer, for the frequency range below about 20kHz, and by analog or a combination of analog and digital methods, for the higher frequencies. The realization of such a magnetic field noise measurement program can be broken down into several parts:

1. design of the noise measurement system;
2. procurement of the needed parts and components;
3. modification and/or test of components of the system;
4. in-laboratory tests of the completely assembled system;
5. system proof testing by an early field experiment to verify the performance of the system in the mining environment;
6. system modifications based on the findings of this early field trip, if necessary;
7. field trips to specified mines for data acquisition;
8. analysis of the data obtained on these field trips;
9. documentation of the findings of the noise measurement program.

---

* As of the fall of 1973 this measurement program has been largely completed by NBS. The instrumentation system and noise data are being documented by NBS under its noise measurement program Contract H0133005 with the Bureau of Mines.

IV. INSTRUMENTATION AND DATA PROCESSING SYSTEM

A. Block Diagram

Figures 1, 2, and 3 illustrate block diagrams of alternative system configurations as now conceived. It will be apparent in the discussion that follows that certain options indicated on the diagrams may or may not be used dependent on the findings of an early proofing field trip. However, for the sake of completeness, the elements of the block diagram are discussed. It will be apparent in this discussion that details of component selection have not been made at this time, since these must be made after a study of the detailed requirements and available performance of the various elements which comprise the measurement system.

As shown on the block diagram, the sensors for picking up electrical signals related to the noise are loop antennas for the magnetic field components, and direct pickups for currents or voltages on trolley or phone lines. Two loops appears to be a practical compromise for an in-mine system to simultaneously record and examine the behavior of orthogonal magnetic field components. The signals after having been picked up are in most cases passed through preamplifiers, because of the need to operate the recording equipment at a distance from the region in which the noise is being measured. Also shown between the preamplifiers and the pickup loops are the balance to unbalance transitions (baluns) that may be required. A further point of interest in the block diagrams is the injection of calibration signals at the front end of the pre-amplifiers. After the preamplifiers, the signals are fed to a variety of devices.

Starting from the top of Figure 1, it is seen that two loops are indicated as feeding modified Stoddart NM-25T receivers. These receivers convert the broadband noise picked up by loop antennas to relatively narrow band (3.5-5kHz) outputs around a selected center frequency in the ranges of 150kHz to 32mHz. It is further indicated that this narrow band around the carrier is translated to a baseband frequency by the use of a block identified as Heterodyne. This process provides the capability for recording noise centered around a high frequency on analog tape recorders which do not have baseband responses adequate to reach these higher frequencies. Below the receivers in Figure 1, it is seen that noise waveforms are also picked up by two other loops and fed through their preamplifiers to a pair of filters. After filtering, the waveforms enter separate channels of an analog magnetic tape recorder. In this way, for example, a frequency band from a few Hertz to 375kHz would be split at 100kHz, so that the lower frequency part is recorded FM and the upper part direct. Modified Stoddart NM-12AT receivers with bandwidth (100Hz or 2.5kHz) will also be available for examination of the frequency range 10-250kHz as a backup to the wideband analog recording.

The analog tapes that result from the application of the system are played back in the laboratory. Several modes of operation of this playback are illustrated by the block diagram. In one mode the signals resulting from playback pass through a filter, then to an analog-to-digital (A/D) converter, and hence on to a digital tape. This digital tape contains representations of the waveforms being sampled and is then processed digitally with a computer to yield items such as power spectrum level versus frequency by means of a Fast Fourier Transform computational algorithm. Examples of this type of data processing may be found in the Bensema NBS report and in the Evans Lincoln Lab report, which are cited in the bibliography at the end of this report.

In another processing mode the playback results in the creation of another analog tape. The intent of this processing mode is to enable a scaling of the frequency band of the original recorded waveforms to a lower frequency band, which will in turn enable available analog-to-digital converters to process a correspondingly wider range of real frequencies. As an alternative to this kind of processing, it is indicated that analog processing for a quick look and possibly analog spectrum plotting should be available. The recorded voice channel on the original tape is also shown as being played out through a speaker, and provision is made to monitor any channel by a cathode-ray oscilloscope. Individual

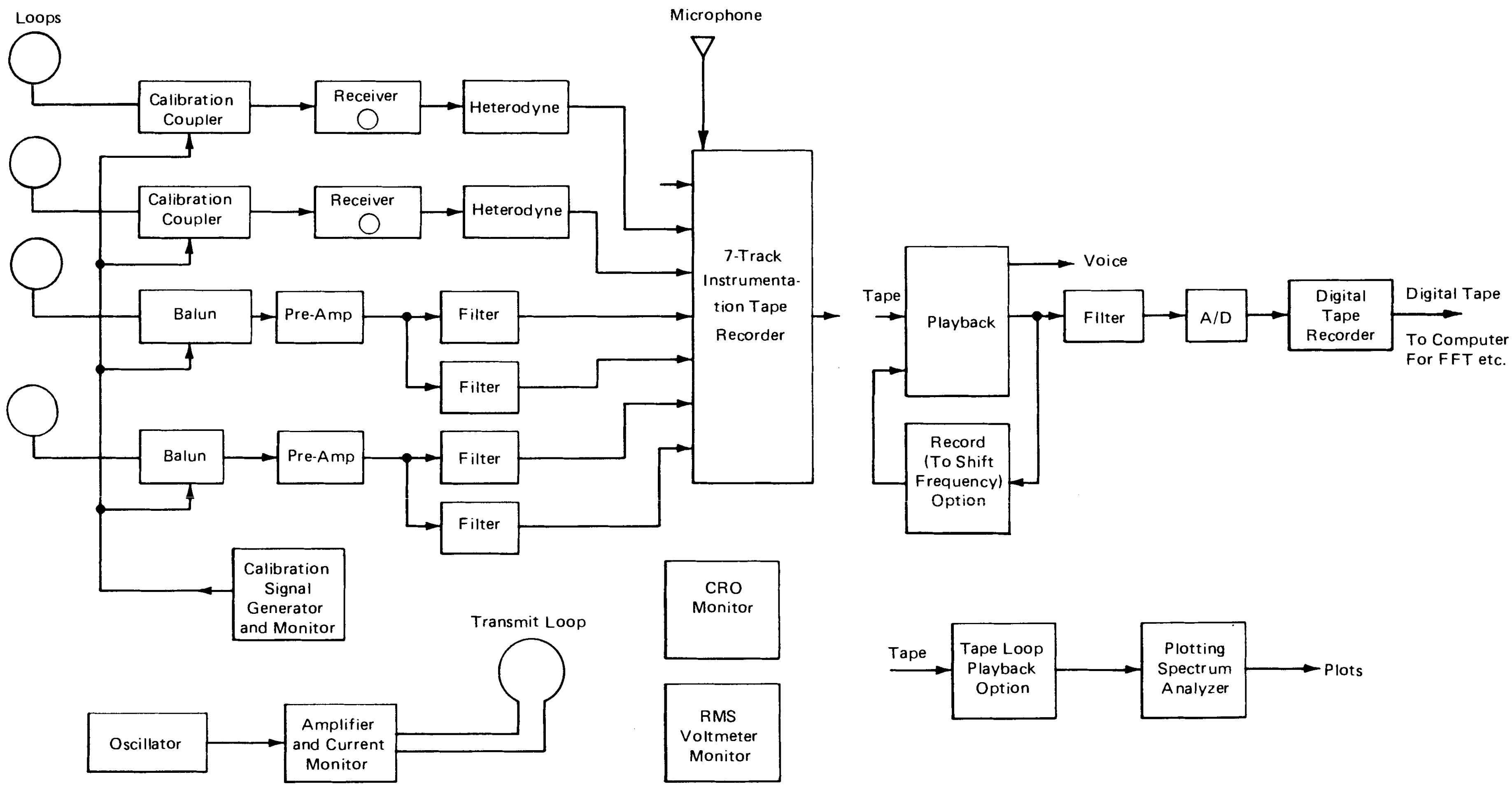


FIGURE 1 SIMPLIFIED BLOCK DIAGRAM
OPTION I – IN-MINE MAGNETIC FIELDS

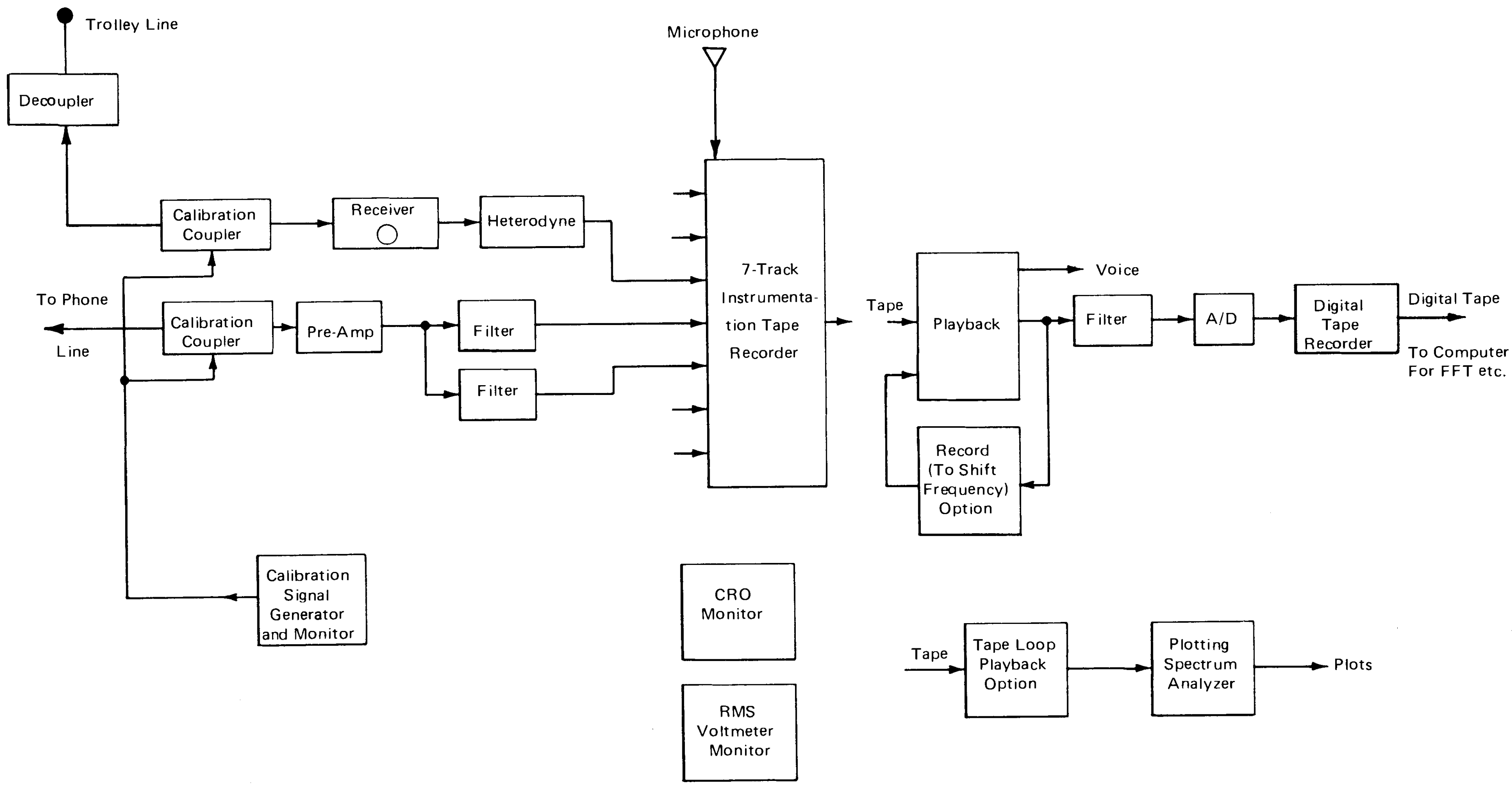


FIGURE 2 SIMPLIFIED BLOCK DIAGRAM
OPTION II – IN-MINE CONDUCTED NOISE

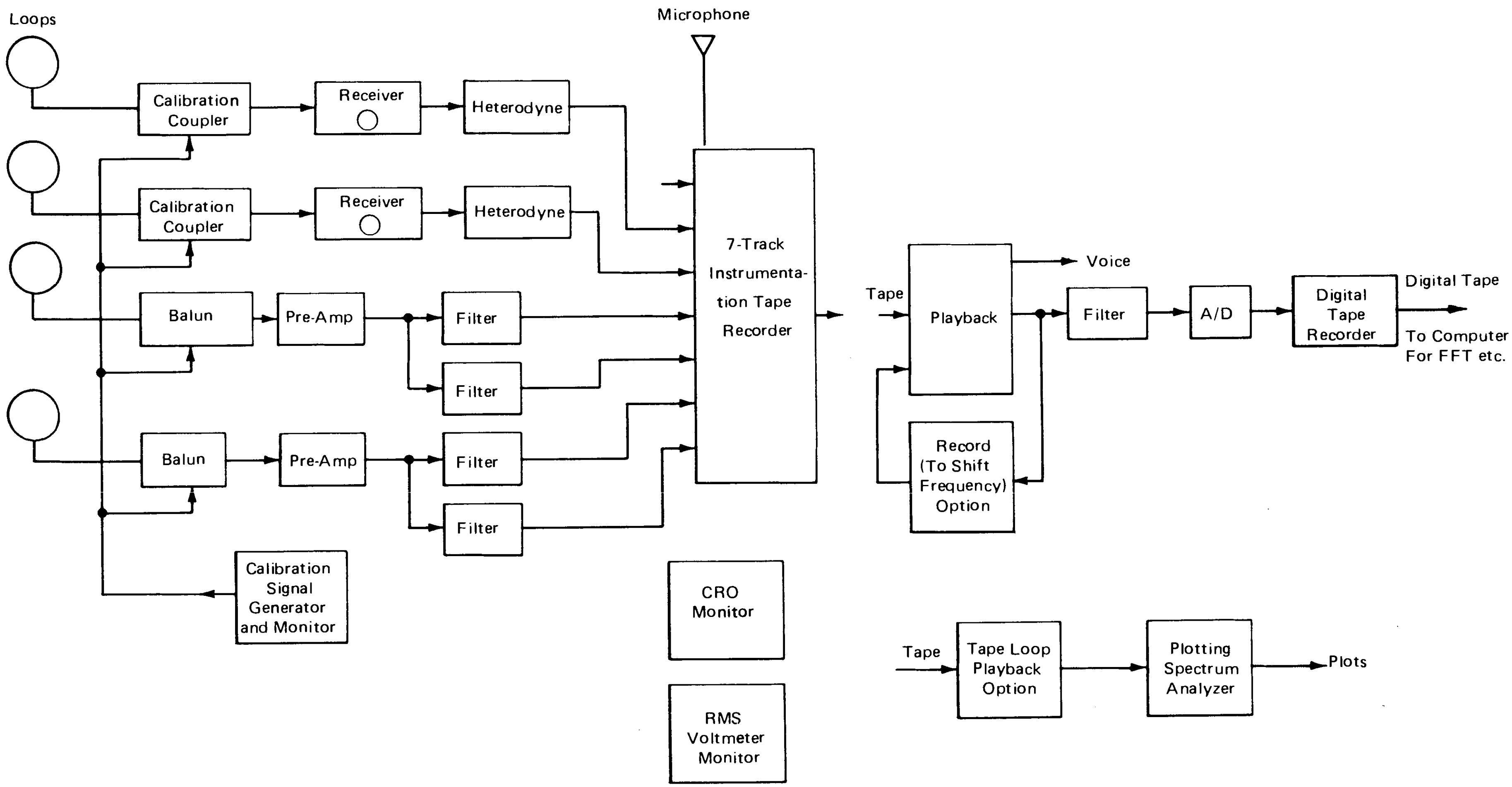


FIGURE 3 SIMPLIFIED BLOCK DIAGRAM
OPTION III – SURFACE MAGNETIC FIELDS

elements that enter this block diagram are discussed below.

B. System Components

1. Loops

It was the consensus that the pickup loops for the measurements should be commercial units of a balanced, shielded nature. Ferrite or other loaded loops were discarded as being subject to significant errors. It was agreed that Stoddart loops of the type used previously by NBS and ITS are acceptable for this use.

2. Preamplifiers

Preamplifiers should be battery-operated units functioning at intrinsically safe voltage and current capacities. This intrinsic safety is needed because these preamplifiers will be used at the working face areas of mines. It is expected that most of the semiconductor-based amplifiers will be operated at low enough voltage levels to meet the requirements, but that care must be used in battery selection to assure that the intrinsically safe limit is not exceeded in terms of battery current capability.

3. Filters

Filters are shown in both the recording and playback parts of the block diagram. The requirements are more severe on filters for recording because these must be battery-operated and should be small in size. The function of the filters is to restrict the bandwidth of the recordings so as to provide maximum use of the available dynamic range of the recorders. The generally required function is that of bandpass with selectable upper and lower band limits. Filter roll-off outside the passband should be at least 48 db per octave. Krohn-Hite Models 3323 or 3343 would be good candidates for this use. A problem arises in the frequency region above 100kHz, because these filters are limited to 100kHz. It may be necessary to add some fixed-frequency passive filters for some particular measurements. Such filters are commercially available from several sources. For operation in the playback mode, where the magnetic tapes are played back at a fraction of the original recording speed, the Krohn-Hite filters are entirely adequate, and are used primarily to prevent aliasing errors in the subsequent sampling and A/D conversion.

4. Receivers

Two receivers are illustrated in the block diagram. It was agreed that these receivers would be Stoddart NM25T receiver units, modified as ITS has previously modified similar receivers to enable them to indicate several measures of noise, in particular, V_d and V_{rms}, as discussed in Matheson's paper. These modifications will permit manual collection of data over a frequency range much greater than can be accommodated with the analog magnetic tape recording system. These receivers can provide important measures of noise properties without the resort to recording.

In addition to this modification of the receivers, it is planned to shift the IF signal (prior to detection) from the IF center frequency to base-band so that analog recordings can be made of a band about 3.5-5kHz wide, centered at any frequency in the receiver range. Thus, recordings of the noise found at various select frequencies beyond the nominal frequency response of the tape recorders can be obtained. These recordings can then be subjected to the same computer-based analysis that Bensema used in the prior NBS noise measurements below 10kHz. On the block diagram this frequency shifting is noted separately as a heterodyne process, while in actual practice this function would be accomplished within the modified receivers.

5. Tape Recorders

It was agreed that the Lockheed 417WB instrumentation recorder is a prime candidate for recording the analog signals. There is still some uncertainty regarding the ability of this recorder to operate in the expected mine environment. There is a considerable body of experience with the Lockheed 417 recorder, and this recorder will be used if the 417WB is found to be deficient in performance. These recorders are well suited to the needs of the measurement program. Both are compact, battery-operated, 7-channel instrumentation recorders that use 1/2 inch wide magnetic tape. The 417 has FM capability from 0-10kHz and a direct capability to 100kHz at 30 IPS. The 417WB is the new wideband version, has FM capability from 0-100kHz and a direct capability to 375kHz at 30 IPS. The use of either of these recorders would avoid the substantial difficulties that Bensema faced in the earlier NBS program, due to the need for a power inverter and large battery supply. The 417WB is preferable because of the wide frequency range accommodated in the FM mode for which high accuracy recording can be relied on.

6. Sources

It was agreed that part of the noise measurement program would include measurements of signal propagation characteristics from the face area to the loading point in a representative mine or mines. For this purpose a portable signal drive system and transmitting loop are required. It is estimated that approximately 10 watts of drive power will suffice for the measurements planned. It is not expected that a good commercial, intrinsically safe 10 watt amplifier of capability to 100kHz can be found, and therefore it may be necessary to develop a portable battery-operated system for this purpose.

C. Real and Synthetic Calibrations

It was agreed that two kinds of calibrations are needed for the noise measurement system: 1) a true calibration for which the pickup loops of the measuring system are immersed in known fields and the measuring system output is related to these known values of field; and 2) an artificial calibration to be used in the field. In the second type of calibration,known signal voltage levels are introduced into the system as near the front end as possible. Such a calibration assures that system drifts and gain changes are monitored and known. Usually such calibrations are not able to verify sensor sensitivity, but verify the performance of the remainder of the measuring system. The true calibrations can be accomplished in the NBS calibration facility at Boulder; the synthetic calibration equipment can be made up of commercially available parts.

D. Playback and Processing

The block diagram illustrates different ways in which the tape can be processed to yield the desired measures of noise. As shown on the block diagram, one of the ways of processing is to play back the tape through a filter and an analog-to-digital converter to generate a digital tape representative of the analog signals from the recorder. This procedure follows directly that of Bensema in his noise measurements for the Bureau of Mines. The playback may be at several different speeds to accommodate the bandwidth of the noise waveforms to the sampling rate of the A/D converter. The filter is to remove noise waveform components beyond a prescribed frequency in order to prevent aliasing in the sampled version of the waveform.

A second processing mode illustrated in the block diagram shows rerecording, or dubbing, of the original tapes. It is intended that this dubbing translate an original frequency range to a lower frequency range, thus making the playback of the dub compatible with the limited 16kHz sampling rate of the A/D converter used by Bensema previously. For example, if the 417WB recorder is found to be acceptable for recording, FM recordings with a bandwidth from 0-100kHz can be made. It appears desirable to be able to process recordings of such an original frequency band using computer FFT techniques. Thus, because the present A/D converter limits waveform analysis to a band of about 0-5kHz, a 20:1 reduction of playback speed is required. This range of speed reduction is not likely from one tape playback unit, and, hence a dubbing process is used to overcome this limitation. The two-step process extends the speed range from a maximum of 8:1 in a single playback unit to 64:1 using the dubbing process, and thus encompasses the range required for reduction of 0 to 100kHz to 0 to 5kHz. The use of playbacks of original and dubbed tapes will provide for the ability to generate in the frequency range 0 to 100kHz the kind of spectrum plots produced by Bensema.

An optional type of processing scheme is also illustrated on the block diagram. This option relates to what is done with the recordings made on the direct channels of the tape recorder, for which analog signals up to 375kHz can be analyzed (if the 417WB recorder is used). It is felt that computer-based reduction would be costly for such extended bandwidth signals, and that the merits of the narrowband analysis will be less applicable to the broadband data, particularly in the upper frequency range of such recordings. For these regions we believe that analog spectrum analysis techniques may suffice to determine the nature of noise. In particular, it is suggested that conventional sweeping spectrum analyzers be used for this purpose in conjunction with a tape/loop playback method. The loop is recommended because it permits analysis of a single time period of the original recorded noise, rather than the use of a long time sequence where time variations could be confused with spectral variations.

The key presentation of noise data will be in the form of power spectrum plots similar to those shown in the NBS Bensema report and the Evans Lincoln Lab report, in which the magnetic field noise components are plotted in db relative to 1 ampere per meter, or db relative to 1 ampere per meter per $\sqrt{Hz}$ versus frequency. Computer-generated FFT outputs are compatible with either presentation, while spectrum analyzer outputs are more suited to the former. These plots can be very useful in revealing characteristic spectrum signatures of specific noise sources. A problem with analog spectrum analyzers is that they are responsive to voltage and thus the spectrum plots become related to voltage, thereby requiring an appropriate calibration. This fact does not trouble analysis of conducted noise, but does pose a problem for magnetic fields for which the generally accepted form of presentation is db relative to 1 ampere per meter in the bandwidth of interest, not voltage out of a loop. Proper system design and calibration will ensure reliable results. Statistical presentations of amplitude and time probability distributions may be desired if the dominant noise in certain frequency bands is found to be impulsive in character. Analysis and presentation methods similar those used by ITS and/or Lincoln Lab can be used if necessary.

E. Equipment List

It was agreed that the following equipment is required in addition to equipment already available at NBS/ITS:

Item	No. Required	Unit Cost	Total Cost	Notes
Lockheed 417WB tape recorder	2	$19,000	$38,000	Estimated costs for fully equipped units
Stoddart receivers (NM-25T & NM-12AT)	4 (2 each)	7,000	28,000	Units supplied with accessories
Stoddart receiving loops (90117-3)	3	333	1,000	These loops are in addition to the ones supplied with the receivers
Filters Krohn-Hite 3323	3	1,225	3,675	
Model 323 Tektronix Scope	2	950	1,900	Or similar
PAR Model 113 Preamplifier	3	795	2,385	
Other equipment (calibrators, oscillators, power source, transmit system, etc.)			3,000	Details to be determined

F. Shaping of Noise Spectrum Signature prior to Recording

There is little data on the character of magnetic field noise within mines in the region from 10kHz to 100kHz. It is expected that early proofing tests will reveal the general nature of this noise, and it may become necessary to shape the spectra of the noise in that region so as to assure equal recording signal-to-noise ratio over the band 10kHz to 100kHz. Whether this shaping is necessary or not will be known only after one of these early trips has been made.

G. Logarithmic Compression

The Boulder conference did include the discussion of the possible application of logarithmic compression upon recording and expansion upon replay as a means of accommodating a wider dynamic range of noise than could otherwise be accommodated by the recording equipment. It seemed to be the feeling in the meeting that for the expected types of noise, specifically the harmonically dominated noise, compression-expansion would raise possible severe difficulties in accurately recovering the noise character from such recordings. It was left that only under the most pressing need would such compression and expansion be planned. Again, the utility of this technique, or the need for this technique, will be clarified by early proofing tests in an operating mine.

V. OPERATIONAL CONSIDERATIONS

A. Equipment Proofing

It was agreed that it is desirable to provide several levels of tests for a complex instrumentation system of this type. The first tests constitute tests of the individual components to assure that they perform according to specifications. The second level of tests are laboratory tests wherein the total system is subject to controlled exercises, revealing any possible shortcomings of the total system itself. These two initial testing phases will be followed by an operating test of the system wherein the equipment is taken to a mine where access is easy and does not interfere with the operations. It has been reported that NBS/ITS have an arrangement with the Lincoln Mine to permit this kind of operation. This test will reveal if there are any operational and environmental problems with the existing system. After such proofing and any modifications brought about by these various levels of testing, the equipment would be ready for use in mines selected by the Bureau of Mines for evaluation.

B. Record Keeping

It is important that a program of this nature provide accurate records from which it may be determined at later dates the exact conditions under which various data were taken. For this purpose it is essential to keep a log-type notebook that clearly identifies times, places, conditions, etc. for future use.

C. Test Plans

It has been recognized by the Bureau of Mines and by NBS/ITS that any field trip into a mine constitutes an interference with the normal mining operations. For this reason it is essential that the field crew be thoroughly schooled in efficient, effective use of time within the mines. This means that the role of each of the field crew must be well-defined and known to him prior to entry into the mines. As an aid to this, it is important that documented test plans be prepared to assure not only that minimum interference with mining operations is had, but that a timely and effective collection of the data necessary is made. These test plans would, therefore, identify the specific purpose of each planned trip to a mine, and include the data gaps which are expected to be filled either fully or partially by such a field trip.

VI. SOME QUESTIONS AND ITEMS TO BE RESOLVED

The Boulder meeting did reveal some areas of concern to the design of the instrumentation system. These questions and items are repeated here for the sake of record. They are not meant to be all-inclusive.*

A. Tape Recorder Suitability

Is the candidate tape recorder (the Lockheed 417WB) suitable for the use intended? a) What is the absolute value of the noise floor in the FM wideband recording mode? b) What is the absolute value of the direct recording mode noise floor? c) Is it expected that the recorder will be sufficiently reliable for use in the mining environment? NBS/ITS will obtain the answers to a,b, and c by means of measurements on a candidate recorder and by means of queries to users of that recorder. If the 417WB is not suitable, the 417 will be used instead.

---

* These and other questions were subsequently addressed and resolved as the instrumentation system was assembled and tested during the remainder of 1972. (See Appendix to this Part.)

B. System Organization

What is the best system organization for recording the data needed? It is expected that the system organization will be pretty much as shown in the block diagrams and in the options thereto. Specific modifications of this may result from early proofing tests of the equipment in an operating mine and may reveal characteristics of the noise as yet unknown, which could result in a need to modify the noise measurement system.

C. Dynamic Range Considerations

There seems no doubt that the dynamic range of the noise voltages that appear at the output terminals of the loop antennas will be such as to challenge the ability to record the voltages with acceptable fidelity. The work of Bensema shows the seriousness of this problem.

Even if the noise were stationary, a very substantial dynamic range of recording capability is required to simultaneously obtain the level of lines (60 & 360Hz harmonics) and simultaneously the base level of noise between the lines. When the time variability of the noise is added, it compounds the problem. Bensema solved this problem by using skilled operators to adjust recording gain to conform to the noise being received. Such skill will be required in the proposed program.

A second problem related to dynamic range, and more particularly to the noise floor, is the effect of the number of bits used for A/D conversion on the computer-generated FFT noise power spectra. The questions to be answered are: How is the quantitizing noise measured? How does quantitizing noise appear as a noise floor in the FFT spectra? Which A/D converter should be used, the moderate sampling rate 12-bit model used previously by Bensema or the higher sampling rate 8-bit model that may also be available?

D. Transmission Measurements

The high priority attached to developing wireless communication from the face area to the loading points, places emphasis on obtaining measures of EM transmission in this area. It is expected that the measurement program will include loop-to-loop transmission measurements. For example, a receive loop could be set up near the loading point, and the transmitting loop then could be moved progressively further away from the receive loop down entries and through cross-cuts. Selected frequencies covering the range to 100kHz could be examined.

E. Conducted Noise Measurements

Data on the conducted noise carried by phone lines and by trolley lines is desired. To obtain such measurements coupling to these lines is desired. Two problems need be resolved in such a program: 1) limiting of the expected powerful voltage transients known to be present on both kinds of lines, and 2) decoupling of the d-c voltage present on the trolley lines.

F. Tape Recorder Cross Talk and Non-linearity

The proposed use of most of the channels of a 7-track recorder imposes a problem associated with cross talk between channels. Measurements need to be made to determine the degree to which this cross talk occurs and how it affects the measurements. There are preferred ways of setting up the channels to minimize such effects, and these should be used.

The non-linearity of the recording process can contribute artifacts to certain types of recordings. In particular, where a single frequency dominates the recorded data it can be expected that the record-playback process will generate harmonics of this frequency. The degree to which the recording system is susceptible to this harmonic generation needs to be determined.

G. Computer-Generated Power Spectra

In order to better estimate the broadband noise floor levels between the harmonics of 60Hz and 360Hz, finer resolution on the computer analysis bandwidths and/or better out-of-band response is desired, particularly for analyzing data below about 5kHz. At the meeting we agreed that these improvements are desired only if they can be realized without major software modifications to existing computer programs at NBS/NOAA. The present out-of-band response apparently includes improvement features already. Analysis resolution can still be improved (made narrower) by a factor of two, with only minor software adjustments according to Bensema. So this may be worth getting. However, the resultant resolution will also be a function of the degree of frequency scaling used to analyze the tapes.

It would also be desirable to be able to increase the number of time segments used to generate the power spectrum estimates, above the 20 used for the previous NBS measurements; again, if this can be done without major changes and expense. In this way the spectrum estimates could be based on longer and perhaps more representative time intervals for assessing the noise impact on voice communications, particularly if the coal mine noise environments are non-stationary. The ability to vary the number of segments above 20 would also allow some coarse assessment of the degree of noise stationarity. Considerations such as the above should be examined in more detail, in order to get maximum utilization of the instrumentation and data processing potential in the most efficient and economical manner.

H. Choice of Mines for Measurements

Tentative criteria have been expressed on which to base the choice of mines for conducting the scouting-party measurements. Some of these are: that they be large bituminous mines in the East, with high roofs, and in Pennsylvania or West Virginia for convenience; with a DC trolley haulage system, conventional and continuously mined faces, and 3-phase rectified power centers. The criteria need to be spelled out in more detail, expanded, and finalized to conform with the measurement program objectives and the requirements of the Bureau of Mines, which also are to be finalized.

I. Experiment Design

It was agreed that long-term measurements over several consecutive weeks or months in a mine were not warranted for the scouting-party measurement program. The mine noise characteristics and levels are likely to be quite similar from work-shift to work-shift and repeated many times during a work-shift. Therefore, measurements need be made in a few different mines, at several representative locations and times throughout a work-shift, over a few consecutive days, in the vicinity of important electrical equipment and facilities, under different operational conditions and loads. Such measurements are expected to provide sufficient data for generating statistically significant power spectrum and amplitude and time distribution estimates that can then be used for making first-order system performance estimates and decisions regarding the candidate mine communication techniques. Detailed plans regarding the locations, equipments, conditions, time durations, etc., of specific measurements have yet to be formulated and integrated into a noise measurement program designed to yield the desired results in an efficient and economical manner.

VII. BIBLIOGRAPHY

Bensema, W. D.
COAL MINE ELF ELECTROMAGNETIC NOISE MEASUREMENTS
National Bureau of Standards (December 1971) (Preliminary)

Disney, R. T., R. J. Matheson, and A. D. Spaulding
RADIO NOISE MEASURING AND ANALYSIS FACILITY
Institute for Telecommunication Sciences, Boulder, Colorado (U.S. Dept. of Commerce Publication)*

Evans, James E.
ATMOSPHERIC NOISE (ELF)
MIT Lincoln Laboratory Data and Computer Programs (1968-69)
Including:

Additional information regarding the first package of 10 digital tapes.
Description of Recording System and Digital Tape Format for "LASA" format tapes (Florida data).
Description of Read Package "IOPAK" for "LASA" format tapes.
Description of Recording System and Digital Tape Format for "NAVCOM" format tapes (Norway and Malta data).
Description of Read Package "CAROLE" for "NAVCOM" format tapes.
Description of Fast Fourier Transform program "FOURT".
Description of Spectral Analysis Program "COH 10".
Description of Digital Filtering Program "FILT 9".
Description of Probability Distribution Program "SAN 3".
Subroutines used by G, H and I that may not be available at other installations.
Listing of Lincoln Lab Digital Wideband Data Tapes from Florida, Malta and Norway.

Evans, James E.
PRELIMINARY ANALYSIS OF ELF NOISE
MIT Lincoln Laboratory Technical Report, TN 1969-18 (March 1969).

Little, Arthur D., Inc.
ELECTROMAGNETIC AND SEISMIC NOISE AND PROPAGATION
A Bibliogaphy for U.S. Bureau of Mines, Pittsburgh Mining and Safety Research Center, March, 1972.

Matheson, Robert J.
INSTRUMENTATION PROBLEMS ENCOUNTERED MAKING MAN-MADE ELECTROMAGNETIC NOISE MEASUREMENTS FOR PREDICTING COMMUNICATION SYSTEM PERFORMANCE
IEEE Trans. on Electromagnetic Compatibility EMC-12 (4), 151-8 (November 1970).

Spaulding, A. D., W. H. Ahlbeck, and L. R. Espeland
URBAN RESIDENTIAL MAN-MADE RADIO NOISE ANALYSIS AND PREDICTIONS
Telecommunications Research and Engineering Report OT/TRER 14, Institute for Telecommunication Sciences, Boulder, Colorado (June 1971) (U.S. Dept. of Commerce Publication).

Taggart, Harold E. and John L. Workman
CALIBRATION PRINCIPLES AND PROCEDURES FOR FIELD STRENGTH METERS (30Hz to 1GHZ
National Bureau of Standards, Technical Note 370, (March 1969) 151pp.

APPENDIX

SUMMARY REPORTS OF ELECTROMAGNETIC (EM) NOISE MEASUREMENT PROGRAM REVIEW MEETINGS

I. INTRODUCTION

From May of 1972 through October 1973 ADL staff served PMSRC in an advisory and coordinating capacity with respect to the Bureau's measurement program for obtaining quantitative noise data to characterize the EM noise environments of underground coal mines. In this capacity ADL staff kept in close touch with the NBS measurement team, and participated in periodic status report and system review meetings with this team and PMSRC, during both the system implementation phase and the subsequent noise data acquisition and reduction phases. This Appendix presents for historical reference a collection of memoranda prepared by ADL for PMSRC to record the principal findings and decisions of these meetings.

II. EM NOISE MEASUREMENT PROGRAM MEETING AT NBS, BOULDER, COLORADO ON 24 MAY 1972

The EM Noise Measurement Program status report meeting at NBS, Boulder, Colorado, on 24 May 1972, was attended by H. Parkinson of Bureau of Mines; R. Lagace and R. Spencer of ADL; J. Adams, W. Bensema and H. Taggart of NBS; W. Stout and H. Kuchera of Collins Radio; and D. Spaulding of ITS (only for a short time). The principal findings and decisions are summarized below.

A. TEST DESIGN AND PLANNING

Program Schedule

BuMines prefers that tests in mines be started by August, but NBS estimates it will be at least four months before it will be ready to do in-mine tests. At very latest, BuMines wants in-mine work started well before November because of the problems of snow and adverse weather after that time.

The long lead time equipment has been ordered by NBS with negotiations still in progress with Stoddart regarding receiver modifications. Though the program has moved forward, several equipment related details and many planning and test design items have to be resolved. Previous commitments of NBS and ITS staff are expected to taper off by July, at which time substantial effort will be devoted to the BuMines noise instrumentation and measurement program.

Coal Mines for Tests and Their Electrical Environments

Tests are being planned for three big Eastern mines:

a. U.S. Steel - Robena Mine in Uniontown, Pennsylvania

- Continuous mining with 600V DC rail haulage
- Depth - 1,000 feet

b. Island Creek - North Branch Mine, Charleston, W. Virginia

- Continuous mining with 300V DC rail personnel haulage and 440V AC belt haulage
- Depth - 400-500 feet

c. Island Creek - Alpine Mine, Charleston, W. Virginia

- Conventional mining with 300V DC rail personnel haulage and 440V AC belt haulage
- Depth - 400-500 feet

Frequencies present in many mines are given below:

Telephone Frequencies: in Hz:

300Hz to 3000Hz Voiceband

Trolley Line Frequencies: in kHz:

			(MSA)	(FEMCO)	FM Carrier Deviation
61,	72,	85,	88,	100	±3% Carrier
116,	113,	114,	163,	190	± 3kHz

(Trolley phones usually on for 10-15 second bursts)

Fan Signaling and Pump Control Frequencies: in kHz:

24.5, 28, 33, 39, 47, 61

(Sent over surface AC power lines by pulsing carrier 15 seconds on, 5 seconds off)

Hoist Frequencies: in kHz:

163 typical, though some use trolley phone frequency of 88, 100.

Noise measurements should be made realizing that mine communication transmissions on these frequencies, and also some from surface transmitters, will be picked up by the noise measurement equipment, so that appropriate precautions must be taken to ensure the collection of unambiguous noise data.

Test Site Communications

BuMines wants a communication link for test coordination between the surface and underground teams. This link should not monopolize the baseband mine telephone. Instead it should make use of a carrier on the mine telephone line. This will be coupled to an independent base station which will relay the messages via radio to mobile units of the surface team. Motorola gear is being purchased by BuMines to provide this coordination.

Noise Data Desired

In reference to the noise characteristics of interest listed in Table 4 of the ADL April 1972 Noise Program Report, the Collins Radio people were asked to comment on what noise parameters were most important for their work. They responded that the high resolution power spectra were most important. With regard to APD's, they are not interested in the 3-D short-term ones in the NBS report, but want longer term statistics that can be used to identify good, average, and worst case noise conditions. Time statistics on the duration between noise bursts and burst duration are also of interest, but considered to be of secondary importance relative to the power spectra and APD's. The question of what will constitute long enough time samples for specifying "long term" APD's that exhibit the important characteristic variations found in coal mines has still to be resolved. NBS also recommends such long-term APD statistics, but with about an equal emphasis on time distribution statistics (TPD's) if low data rate code systems are of interest.

Conducted Noise Measurements

It was agreed that very little thought has been given to this topic, with regard to exactly what data are required, what equipment is needed, and where, when, and under what conditions are the data to be taken. Conducted noise on both the DC trolley lines and the telephone lines (and perhaps power lines) are of interest to BuMines. Concerns were expressed regarding the effects of moving loads, such as locomotives and jeeps on the measured data, and what locations on the lines make most sense to make the measurements. Much more consideration must be given to these measurements, but this task was not specifically assigned to anyone.

Transmission Measurements

Very little thought had been given to this topic, so BuMines assigned the task of devising meaningful transmission measurements over the frequency band of interest to Collins Radio. As a minimum, BuMines wants measurements of transmission loss between section loading points and locations throughout a working section, including the face area; and between working sections and the surface above. These measurements should be coordinated with the noise measurements. In particular, BuMines expressed a desire for a surface loop for transmitting to the face area during the acquisition of noise data. The section-to-surface measurements are expected to assist in the design of a low bandwidth digital through-the-earth parameter monitoring link that Collins is working on for BuMines. Collins is to coordinate its transmission measurement test plans closely with the NBS noise measurement efforts.

A transmitter-power amplifier is still required for these measurements. Two potential sources were cited to be checked: two amplifiers owned by BuMines, one owned by D. Aldridge of WVU. A power amplifier capable of 10 watts CW output over the 300Hz to 400kHz band is desired for these experiments.

B. EQUIPMENT

Tape Recorders

A battery-powered Lockheed 417WB recorder has been ordered for use in the mines as planned. However, a somewhat larger Honeywell Series 5600 unit with a 0-40kHz FM and a 0-300kHz Direct record capability has been substituted for the second Lockheed 417WB planned for use on the surface. The Honeywell unit was chosen for the surface because better reduced-speed tape dubs could be generated by the Honeywell unit, since it offered the capability of getting rid of wow and flutter by servo-controlling the playback to a CW tone recorded on the tape with the measured noise.

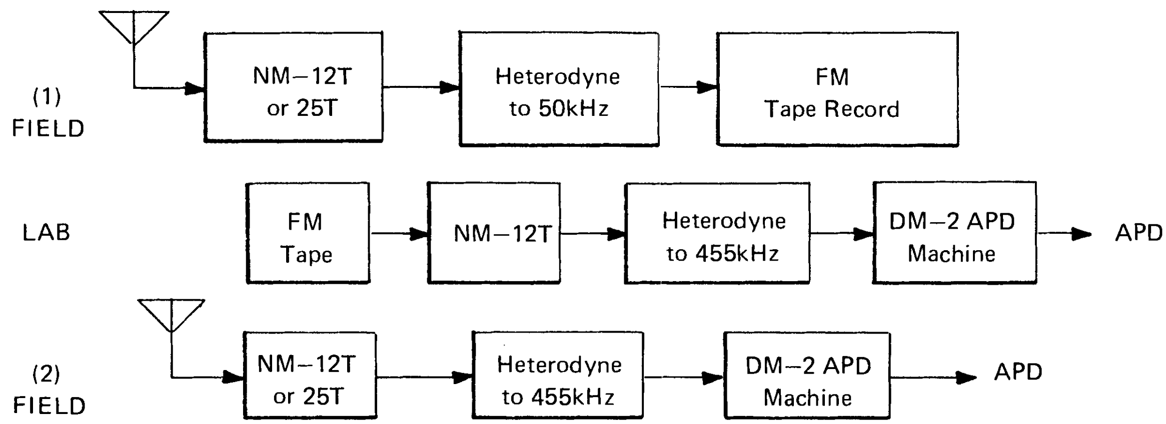
The plan is to playback the Lockheed 0-100kHz FM recordings on the Honeywell at 1/2 speed, thereby compressing the noise spectrum into the band from 0-50kHz. The means for obtaining further reductions to enable processing by the A/D converter were not discusssed. NBS is still not sure how the noise spectra will be affected when the Lockheed 0-375kHz Direct recordings are played back into the Honeywell 0-100kHz Direct at reduced speed.

NBS was concerned about potential dynamic range problems if recordings were made across the total 0-100kHz FM on 0-375kHz frequency ranges. It was decided that single frequency CW dynamic range calibrations could be made on H. Taggart's loop calibration facility. There is still a question regarding how seven record-level settings can expeditiously be made in the field.

As a result of (a) the above discussion, (b) questions concerning sensor response and system noise limitations imposed on dynamic range versus frequency, (c) 300Hz being the lower cutoff frequency normally used for voice communications, and (d) the availability of Lincoln Lab surface noise data to frequencies down to 3Hz; it was decided that (1) the lower frequency limit of the noise measurement system would be raised from 40Hz up to 300Hz, (2) the 60Hz noise component would be filtered out before recording, (3) consideration would be given to filtering out the 360Hz component too, but perhaps to lesser degree than the 60Hz, and (4) W. Bensema would choose the appropriate signal conditioning electronics to produce the desired favorable noise recordings. To accomplish (4) the 300Hz to 400kHz band may have to be split up into a high and a low band. The tape recorders had not been received and tested as of this visit.

Stoddart Receivers

The NM-12T and NM-25T receivers, and associated (6) 30-inch loops and (2) 12-inch loops have been ordered, but the question of who, ITS or Stoddart, is going to make the required modifications (rms power and V_d outputs, and heterodyning to baseband) had not yet been resolved. R. Matheson of ITS (not present) is to follow this up. In Matheson's absence, J. Adams gave a thumbnail sketch of developments to date. Two possible configurations for field use of the receivers have been proposed by ITS.



The provisions for generating the indicated noise APD's within the receiver passband at specific carrier frequencies of interest look sound. But the system as shown deviates in one major respect from that originally proposed. Namely, the receiver IF output is being heterodyned down to 50kHz instead of to baseband prior to being recorded. The original system specification to use baseband, would allow for direct compatible processing of the recorded Stoddart waveforms by the NBS spectrum analysis system. Since this change to a 50kHz carrier does not allow such convenient analysis, reasons for the change were requested. In the absence of all ITS personnel, the answer was not available, so J. Adams agreed to check this out later with R. Matheson.

Field Components and Sensors

NBS recommended some simultaneous measurements of all six field components, three magnetic and three electric, as opposed to just magnetic fields as originally planned. Six 30" and two 12" shielded Stoddart loops have been purchased for the magnetic field. The 30" loops are self-resonant at approximately 390kHz, which may be far enough removed from the highest frequency to be recorded. Special electric field sensor antennas are to be made for the electric field. ADL expressed concern about the difficulties normally associated with taking calibrated E-field "near-field" noise measurements in adverse environments, such as mines. Such closed environments that contain many conducting structures can easily change the response characteristics of whip antennas and distort the electric fields to be measured, thereby making the results difficult to interpret. The limited number of available tape channels may also impose dynamic range limitations for such measurements. NBS acknowledged these difficulties and therefore plans to limit the measurements of all six field components to a small number of the tests. Great care will have to be taken in choosing, calibrating, and using an appropriate E-field sensor antenna. NBS feels that these E-field measurements may help determine the relationships between the strengths of the E- and H-fields in near-field coal mine environments. ADL has reservations concerning the value of these E-field measurements, and feels that the subject should be discussed in more detail.

Permissibility Considerations

NBS would like to bring all its measurement gear, instead of just the loops and preamps, into working sections, including face areas. The topic was discussed, with a tentative agreement that it may be possible. However, to be sure NBS should send equipment descriptions and circuit diagrams to Bob Wolfe at PMSRC, who is the BuMines man concerned with the requirements for safe electrical circuits.

C. ANALYSIS

Noise Power Spectra

ITS commented on that part of the second paragraph on Page 20 of the ADL Instrumentation System Technical Memorandum of April 1972, regarding the outputs of spectrum analyzers relative to those of computer-generated power spectra. Namely, when referring to conventional spectrum analyzers that utilize successive logarithmic detection of the envelope of the input waveform, the analyzer can be calibrated for CW signals, such as harmonics, but not for broadband noise. Therefore the output of the analyzer will agree with the computer spectra only for the CW harmonic noise levels, but not for the broadband noise spectrum levels between the harmonics. ADL agreed with ITS's comments.

NBS reported that it had not yet examined how the number of bits in the A/D quantization process affected the FFT generated broadband noise spectra. But NBS suggested a good experiment to get the answer; namely, take the present tapes of quantized noise data, and look for changes in the computed FFT spectra as the least significant bits in the data are deleted one at a time. ADL agreed to ask Evans of Lincoln Lab for his judgment on the matter. It appears that Evans did not have to face this problem, because his large A/D dynamic range was dictated not by harmonic versus broadband noise spectrum level dynamic range, but by the large dynamic range required to produce APD's to the accuracy desired by Lincoln Lab.

D. MISCELLANEOUS

H. Parkinson heard that additional noise data has been recently released by Lincoln Lab--and that ADL should verify this with J. Evans of Lincoln.

According to Keller's experiments and studies, an overburden conductivity of $\sigma \leq 10^{-2}$ mho/meter is a good value to assume for coal mines ≤1000 feet in depth. Values as high as $\sigma = 10^{-1}$ mho/meter are seldom found except perhaps in small pockets.

H. Crary of ITS suggests that frequencies around 1.5gHz may be suitable for wireless point-to-point transmission in mine entries, haulageways, etc., as a result of higher-order waveguide propagation modes.

Radio communication ranges in excess of 2000 feet were obtained by a Sunshine Mine rescue team using 1 watt Motorola walkie talkies at a frequency of 460mHz, with the assistance of a #12 wire deployed on the mine floor as the team advanced into the mine.

H. Parkinson has experienced very favorable wireless along-the-roof communication on working sections on several occasions to ranges of several hundred feet. This was accomplished by connecting a trolley phone 25-watt 88kHz transmitter output to two roof bolts and receiving with a Reach pocket pager. The impedance between two roof bolts stayed pretty constant at about 20-25 ohms* when the separation between them exceeded about 30 feet in the Pittsburgh coal seam. Roof bolts range from 3 to 7 feet in length, 3/4 to 1 inch in diameter, with a 9-inch square roof plate, and a 4 to 5 inch diameter expansion section near the upper end. They are typically spaced 4 feet and greater apart, depending on roof conditions.

---

* Data taken since then indicate that the total termination impedance for roof bolt pairs separated by 50-200 feet falls mainly in the range of 50-120 ohms.

III. EM NOISE MEASUREMENT PROGRAM MEETING AT NBS, BOULDER, COLORADO ON 17 AUGUST 1972

On 17 August 1972 the EM Noise Measurement Program status report meeting at NBS in Boulder, Colorado was attended by Howard Parkinson of the Bureau of Mines; R. Lagace and R. Spencer of ADL, John Adams and William Bensema of NBS, Don Spaulding and Bob Matheson of ITS; and Bill Stout and Dean Anderson of Collins Radio. The principal findings and decisions are summarized below.

A. TEST DESIGN AND PLANNING

Schedule and Test Plans

The present schedule calls for making system proof-test noise measurements in the Lincoln mine during the last week in September 1972, and noise measurements in Eastern mines starting at the end of October 1972.

It was agreed that NBS would prepare test plans for their visits to the Eastern mines, and these test plans would be submitted to the Bureau of Mines and to Arthur D. Little, Inc. A copy of the test plan for the Lincoln mine preliminary proof-tests would also be forwarded to Arthur D. Little, Inc.

Objectives of Noise Measurement Program

It was agreed that the objectives of the present measurement program are to obtain as output presentations the following items, listed according to their priorities:

1) Noise Power Spectra
2) Noise Amplitude Probability Distributions (APD's)
3) Signal Attenuation Curves — Primary

---

4) Noise Pulse Duration Distributions (PDD's) — Secondary
5) Noise Correlations

Communications Gear for In-Mine Experiments

Howard Parkinson asked Collins Radio to provide ideas, lists of equipment, and utilization details for interfacing surface hand-held radio sets with the mine telephone system, such that experimenters on the surface can talk to experimenters in the mine. The Collins effort is to give PMSRC an alternative to some of Motorola's suggestions. The intent is to provide an independent phone line-to-radio interface at the surface end of the mine telephone line, and quick-connect loud speaking type phones for temporary connection to telephone lines in the immediate vicinity of EM noise measurement areas. Radio units in the 27 mHz or 416 mHz bands are preferred on the surface. Cabling on the order of 1000 feet may be required to run from the surface telephone line termination to a local high spot to provide adequate radio coverage on the surface. The voice signals sent over this communications link should be translated to a carrier frequency that the phone line will pass without interfering with normal base band voice mine communications.

NBS/ITS requested the use of equipment now held by the Bureau of Mines to help conduct the noise measurement experiments. This equipment consists of the Motorola 416 mHz walkie-talkie radio sets. Howard Parkinson agreed to provide this equipment to NBS/ITS in time for the Lincoln mine tests.

Long Term Statistics of Noise Within Mines

NBS commented that they expect to progress through a learning curve as the experiments proceed in terms of their judgment of recording times required at specific locations and equipment in the mine. They expect to sample the noise from different equipment under various load conditions, and to sample separate units of each equipment type. Howard Parkinson noted that 15 minutes represents a typical cycle-time of the equipment, and that lunch breaks and shift changes also represent times of major changes in mine activity to be examined. It was also decided that leaving the noise equipment in a mine for a continuous 24 hour monitoring period, to ensure that nothing important noise-wise was missed, was neither desirable nor necessary.

Conducted Noise Measurements

A considerable discussion of conducted noise and its measurement took place with mention of the work of WVU (Sierra RF Voltmeter) and Lee Engineering (GR Microvolter) in coal mines as possible guides. It was decided that for the phone lines, appropriate measurements would result if line #1 to ground, line #2 to ground, and line #1 to line #2 conducted noise voltage measurements are made. Concerning trolley lines, it was agreed that the trolley line to ground noise voltage is to be used. It was also agreed that some noise measurements be made on roof bolts, in particular these will be voltage measurements roof bolt to roof bolt as a function of roof bolt separation. The need for measurement of noise current remained unresolved. NBS agreed to develop a plan for obtaining conducted noise measurements. This plan will include treatment of problems of calibration, methods of location of attachments, problems associated with impedances of the sources, and the utility of current probe or nearby magnetic field measurements.

Impedance Measurements

After considerable discussion, it was agreed that the noise measurement program of NBS/ITS will not be required at this time to make telephone or trolley line impedance measurements. ADL was asked to devise practical means for taking trolley line impedance measurements for separate tests to be performed at a later date.

Transmission Measurements

A considerable discussion ensued concerning transmission measurements. It was first agreed that NBS/ITS would design and conduct the specific measurements, and welcome any and all suggestions. It was agreed that one surface loop would be used to transmit to the receiving equipment in the mine, and that this would be at an audio frequency. It is possible that this surface loop could first be used to provide a single sweep of frequency over a wide operating range, and then left to transmit at a single low frequency near 450 Hz for the remainder of the measurements.

It was agreed that if an in-mine transmitter is used, it will be operated at a single high frequency, and used only for in-mine face-area lateral transmission measurements, in order to keep the measurement program within both manageable and safe limits. The in-mine frequency should be either just above or below the trolley phone frequencies of 88 and 100 kHz found in mines. Howard Parkinson suggested that 116 kHz might be most suitable, with an alternative being between 92 - 95 kHz. A stable transmitter of 20 watt capacity should be used for these tests since it approximates that of present trolley phone equipment.

The main objective of these in-mine experiments is to provide firm signal strength experimental data in those section areas where noise measurements are being taken, in order to help establish transmitter power requirements for wireless communications in the face area at trolley phone frequencies. Howard Parkinson suggested that NBS/ITS examine the mine transmission data of Dayne Aldridge of WVU taken in six mines and reported in the WVU 2nd annual report to PMSRC, since they may be able to profit from WVU's experience.

Manning

NBS/ITS confirmed that no manning problems are anticipated, and that three full time technicians will be used in the manning of this measurement program in addition to the required engineering staff.

Discussion of Collins Memorandum of 15 August 1972

The comments and recommendations offered by Collins Radio were discussed at length and the following agreements were reached on each topic.

1) "Power-Down Measurements" - It was agreed that mine power-down measurements are not essential to the noise measurement program. In addition, power shutdowns create a major inconvenience to mine operators, which the Bureau does not want to impose. Therefore, the sampling of "quiet" EM noise conditions will be restricted to finding relatively "quiet" spots, EM-wise, in out-of-the-way places in the mine or measuring during between-shift periods, maintenance shifts, or other operationally "quiet" times.

2) "Concurrent Signal Attenuation Measurements" - It was agreed that there is no need of performing extensive surface-to-mine attenuation measurements at present; in view of the acceptance of conductivity values obtained for generalized mining areas from similar measurements by other Bureau contractors, and the acceptance as adequate, the theory developed so far by Wait for vertical, coaxial loop-to-loop coupling. Only some limited loop-to-loop measurements from surface-to-mine, and laterally from face areas to section loading points are viewed as desirable and appropriate to the present NBS/ITS effort, as described above under Transmission Measurements.

3) "Noise Pick-up from Earth Probes" - It was agreed that noise pick-up from roof bolt earth probes within mines as a function of roof bolt separation is worth measuring by the NBS/ITS team, as discussed above under Conducted Noise Measurements. Surface probe noise measurements are not necessary.

4) "Earth-Probe Signal Attenuation and Related Measurements" - It was agreed that these probe measurements would not be undertaken by the NBS/ITS team on this present noise measurement effort. Much of this data has already been generated by the Bureau and its contractors (PMSRC, CSM, WGL), and such well-experienced teams will be enlisted to acquire additional data that may be required in the future. Howard Parkinson also stated that Bureau experience to date had shown surface probe transmitters used with in-mine loop receivers to be easier and more practical than surface probe transmitters used with in-mine probe receivers.

5) "Theoretical Investigations" - It was agreed that Wait's present work assignment for the Bureau on finite length earth probe transmitters should provide adequate coverage of this topic.

B. EQUIPMENT

Tape Recorders

NBS reported that everything is presently under control with the tape recorders. The delay in delivery of the Lockheed recorders, not received as of the meeting, was not viewed as serious. Filters have been bought to cure any recorder-aliasing problems caused by poor out-of-band response above the desired recording band. A bandwidth compression capability of 128 to 1 is available from the Honeywell-Lockheed tape recorder set. This will be adequate to cover all of the noise recording manipulations envisioned. NBS also noted that in terms of recording time, the equipment to be taken into the mines is capable of recording 14 minutes at the highest tape speed and 56 minutes at the lowest tape speed, per reel of tape.

It is the hope of the NBS/ITS team to be able to record the full frequency band (300 Hz to 375 kHz Direct, 300 Hz to 100 kHz FM) on a single track of the tape recorder, for each sensor. However, if it is found that this is not possible, two channels per sensor will be used to cover the frequency range. The capability of achieving single track operation will be determined by experiments in the Lincoln mine. Recordings of the noise will be made simultaneously wideband (up to 300 kHz) and narrowband (in 3 kHz slices). The output noise distributions of each will be compared to obtain a measure of the impulsiveness of the noise, and therefore, the dynamic range requirements. The narrowband 3 kHz spectrum slices will be produced by passing the noise, picked up by loop sensors, through a modified Stoddart receiver before recording.

It was agreed that the noise measurements need not be made to frequencies below 300 Hz. NBS would still like to reserve the option to go below 300 Hz, if it can be done without introducing system complexity or deterioration of the noise recordings in the required frequency bands (300 Hz to 375 kHz Direct, 300 Hz to 100 kHz FM).

Stoddart Receivers

After considerable discussion, it was agreed, pending a possible change of heart by Bill Bensema of NBS, that 50 kHz is an acceptable center frequency to heterodyne the Stoddart receiver IF output down to, prior to recording the narrowband (3 kHz)slices of high frequency noise to be obtained from the modified Stoddart receivers. Noise recorded in this manner will be utilized to generate APD's using equipment now available at ITS, and to generate some spot spectra, approximately 3 kHz wide and centered at frequencies of interest, using the NBS playback and processing equipment. ITS noted that the modifications to the Stoddart receivers were underway,and expected that all the required modifications will be completed and instruments checked out within five weeks.

Field Components and Sensors

It was agreed that NBS would probably need to measure at most, two magnetic components simultaneously, the vertical component and the horizontal component perpendicular to the entry direction. In some cases it may be adequate to orient the loop for maximum output and just measure that field strength. The Lincoln mine tests with three loops are expected to settle this question. ADL recommended that the loops not be laid on the floor, but centered about half-way between floor and roof as a realistic standard position for the measurements, if possible.

It was agreed that electric field measurements, if made, will be at frequencies above the baseband response of the recording system, namely above 375 kHz. Loops will be used for the tape recorded noise measurements below 375 kHz. NBS noted that some manually recorded E-field measurements could be made, at least in the early trips into the Lincoln mine, to help determine performance of systems operating at frequencies beyond those presently envisioned for the noise tape recordings.

NBS will utilize the modified NM-25T Stoddart receivers to examine frequencies up to 32 mHz, and an available battery powered EMC-25 field strength meter to examine frequencies up to 1 gHz. Interest in this upper frequency range has increased in view of the highly favorable transmission performance obtained by PMSRC with 416 mHz walkie talkies in coal mines. The EMC-25 noise measurements are not intended to give accurate noise measures, because of the instrument's design for CW signals, but are expected to give a quick approximate picture of the noise activity at these higher frequencies.

Permissibility Considerations

NBS/ITS has decided that all the noise measuring equipment should be brought into the face area, thus precluding the use of pre-amps and sensors at the end of long cables separating them from the recording system. Therefore all the equipment must be integrated in a permissible manner for use in the face area, and approved by Bob Wolfe in Pittsburgh. It was agreed that Howard Parkinson would help NBS expedite this permissibility design and approval process.

C. ANALYSIS

Noise Power Spectra

NBS reported on the results of its experiment to determine the effects, on the FFT generated broadband noise spectra, of discarding the least significant bits in the A/D conversion that precedes the noise spectrum computations. The results agree with the classical theory, which predicts an increase in the spectrum level with the deletion of each bit. So it has been determined that all 12 bits of the present A/D converter are required to make adequate power spectrum computations for this program.

Noise Pulse Duration Distributions and Correlations

The methods have not yet been defined for obtaining these two lowest-priority secondary items from the planned noise recordings.

IV. EM NOISE MEASUREMENT PROGRAM MEETINGS AT COLLINS RADIO, NBS, AND PMSRC

Three additional meetings were held in 1973, during and after the period in which the NBS EM noise measurements were conducted, to discuss preliminary findings and the implications of these findings on the instrumentation system and future measurements. The major findings and decisions of these meetings, primarily as they relate to the measurement instrumentation, are briefly summarized below.

A. Meeting at Collins Radio Co., Cedar Rapids, Iowa on 21, 22 February 1973

This meeting was held to discuss the results of the NBS noise measurements in the first major Eastern coal mine (Robena No. 4). Representatives of NBS, PMSRC, Collins Radio Co., Spectra Associates, West Virginia University, and ADL were present.

The meeting and subsequent telephone conversations led to the following principal findings and decisions regarding the instrumentation and future measurements.

- The underground wideband Lockheed FM recording system became system noise limited above about 10 kHz in the Robena mine as a result of the gain settings required to prevent the unexpectedly high levels of harmonic-type noise below 10 kHz from saturating the recorder. To overcome this potential problem at other mines, it was decided to high pass filter the noise waveforms, prior to recording, for two of the three FM channels, while retaining the full bandwidth as before on the third channel. A filter cut off around 10 kHz was chosen. Therefore, the following recordings would be made on the three FM channels of the Lockheed recorder:

Field Component	Noise Bandwidth
Vertical	100 Hz to 100 kHz (as before)
Vertical	10 kHz to 100 kHz
Horizontal (Max.)	10 kHz to 100 kHz

<u>instead</u> <u>of</u> the originally planned recordings below.

Vertical	100 Hz to 100 kHz
Horizontal (x)	100 Hz to 100 kHz
Horizontal (y)	100 Hz to 100 kHz

The 3 kHz to 300 kHz wideband recording of the vertical component on the direct channel would also still be made as originally planned.

- To obtain more noise data close to the working face area of mine sections, it was decided to make the narrowband direct recording system permissible, and to increase the number of frequencies at which measurements would be made with this system which utilized the NM-12 and NM-25 receivers and a different Lockheed recorder. The number of frequencies would be increased, without increasing the total measurement time, by taking readings of two field components (vertical and the maximum horizontal) at six pairs of frequencies, instead of three orthogonal field components at four pairs of frequencies;

Namely		Instead of	
10 kHz	500 kHz	10 kHz	500 kHz
19	1.15 MHz	30	2 MHz
36	2.64	70	8
69	6.0	130	32
131	13.9		
250	32.0		

  It was also decided that a 20-minute duration would be used for each of these recordings, unless a particular mine situation or operating condition was clearly more suited to a shorter duration. The 20-minute duration appeared to be the most practical choice, at this point in the program, for generating most of the desired APD and rms level statistics.

- The Robena results indicated that simultaneous surface and underground measurements were not as important as obtaining additional underground noise data covering different locations and operating conditions. Therefore, it was decided that the surface wideband recording system (using the Honeywell recorder) would be modified to allow wideband recording from 10 kHz to 150 kHz on the direct channel and 100 Hz to 20 kHz on FM, at a speed of 30 ips, for use underground. Since this system would still not satisfy permissibility requirements, its underground use would have to be restricted to fresh-air ways.

  Detailed information regarding the instrumentation used at the Robena mine and the noise data obtained is available in an NBS report covering the Robena noise measurements.

B. Meeting at NBS, Boulder, Colorado on 22 May 1973

This meeting was held to discuss preliminary results of the additional noise measurements made in March and April of 1973 at one Western mine (Lincoln) and three more Eastern mines, (McElroy, Itmann, and Grace) with the modified instrumentation system prescribed as a result of the above meeting at Collins Radio. Representatives of NBS, ITS, Collins Radio, PMSRC, and ADL were present.

Discussions covered some additional reduced data from the Robena mine, hoist shaft signal and noise measurements made at the Grace iron mine, descriptions of the types and locations of measurements made at each of the three additional Eastern mines, general observations regarding the EM noise environments at these mines, and plans for measurements at the Lucky Friday hardrock mine in Idaho. Reduced data such as wideband spectra were not yet available for examination for the latest mines visited because of unanticipated delays caused by problems with the data processing equipment. The Grace mine hoist shaft data had been manually reduced, so it was available for use by Collins Radio on its hoist shaft communication system project. No problems with, or additional changes to, the instrumentation were reported or recommended at this time.

The following priorities were set for reducing the remaining data; 1) Robena, 2) McElroy, 3) Itmann, and 4) Grace. In addition, the following chart was drawn up to indicate the kind of processed noise data expected for each of these four mines.

Robena Mine

	Wideband		Narrowband	
	Power Spectra	Correlation	APD's	0.1%, RMS, Ave., and 99% Levels
Loops				
In-Mine (Hi-Freq.)	Yes	Yes (In-Mine and Surface)	Yes	Yes
Surface (Lo-Freq.)	Yes		Yes	Yes
Roof Bolts	Yes	NA	No	No
Telephone Lines				
Voltage	Yes	NA	No	No
Current	Yes		No	No
Trolley Lines				
Voltage	Yes	NA	No	No
Current	No		No	No

NA-Not Applicable

McElroy, Itman, and Grace Mines

	Wideband		Narrowband	
	Power Spectra	Corre- lation	APD's	% RMS Ave. 99% Levels
Loops				
In-Mine (Hi-Freq.)	Yes	No	Yes	Yes
Surface (Lo & Hi-Freq.)	Yes (McElroy Only)		No	No
Roof Bolts	Yes	NA	Yes (Itmann Only)	Yes
Telephone Lines	No	NA	No	No
Trolley Lines	Yes (Itmann Only)	NA	No	No

NA-Not Applicable

C. Meeting at PMSRC, Bruceton, Pa., on 10 October 1973

This meeting was held after noise measurements were made late in the summer of 1973 at the last two scheduled mines (Lucky Friday and Geneva) to examine and disseminate additional reduced noise data, review and summarize the overall noise measurement program to date, and define what yet needs to be done. Representatives of NBS, Collins Radio, Westinghouse Georesearch Laboratory (WGL), PMSRC, and ADL were present.

Considerable amounts of reduced data in the form of noise spectra, APD's and other plots for the Robena, McElroy, Itmann, and Grace miners were presented by NBS and discussed by the attendees. All of this data is or soon will be documented in NBS reports. A large chart was drawn up to summarize the EM noise measurements made in mines to date -- as an aid to potential users in identifying data of interest to them, and as an aid to the process of assimilating and correlating this data for characterizing representative noise envirionments. This chart is included as Table A1.

Several conclusions were also reached regarding what needs to be done. Namely:

- Additional EM noise measurements in mines are not required at this time. One possible exception to this might be an AC-type coal mine, but even this is not certain.

TABLE A1

SUMMARY OF NBS EM NOISE MEASUREMENTS*
(Results of the Planned EM Noise Measurement Program)

Name & Type of Mine	Types of Equipment	Type of Haulage	Mine Voltage AC Volts	Mine Voltage DC Volts	Surface	Under-ground	Noise Parameter H	Noise Parameter E	Noise Parameter i	Noise Parameter Voltage Tel	Noise Parameter Voltage Troll	Noise Parameter Voltage Roof Bolt	Spectra Recorded Freq	Spectra Recorded Mode	APD	Frequencies of APD's	Spectra Processed to What Freq	Additional Information Available
Mid Continent Colo. (coal)	AC	Belt	?	--	Y	N	Y	N	N	N	N	N	10 kHz	FM	N		750 Hz	no
Lincoln Colo. (coal)	AC & DC (Motor Generator)	Belt & Rail	440	250	Y	Y	Y		N	N	N	N	10 kHz 100 kHz	FM FM	N N		750 Hz 3 kHz 100 kHz	no yes
Allen Colo. (coal)	AC & DC (Rectifier)	Belt & Rail	4160 480	310	Y	Y	Y	N	N	N	N	N	10 kHz	FM	N		750 Hz 3 kHz	no
Robena #4 Penn. (coal)	DC (with one AC section (Surface rect)	Rail & Belt on Surface	--	600	Y	Y	Y	N	Y	Y	Y	Y	100 kHz 375 kHz	FM Dir	Y	10 kHz, 30k, 70k, 130k, 500k, 2M, 8M, 32M	100 kHz 320 kHz	yes
McElroy W. Va. (coal)	AC & DC (Rectifier, underground)	Belt & Rail	7200 480	300	Y	Y	Y	N	N	N	N	Y	100 kHz 375 kHz 20 kHz	FM Dir FM	Y	10k,30k,70k, 130k, 160k, 250k,500k,1M 2M, 6M, 14M, 32 MHz	100 kHz 20 kHz 180 kHz	yes
Itmann #3 W. Va. (coal)	AC & DC Longwall	Belt & Rail	1000	250	N	Y	Y	Y	N	N	Y	Y	"	"	Y	"	"	yes
Grace Penn. (iron)	AC & Diesel	Belt & Hoist	4160 480 110	--	N	Y	Y	Y	N	N	N	Y	"	"	Y	"	"	yes
Geneva Utah (coal)	AC & DC	Rail & Incline Slope	2500 550 440	300	Y	N	Y	N	N	N	N	N	3 kHz 10 kHz 100 kHz	FM FM FM	Y	10 kHz	3 kHz 10 kHz 100 kHz	yes
Lucky Friday Idaho (Pb, Zn, Ag)	AC & DC Battery locomotive	Battery loc, Hoist & DC Hoist	2400 480 120	600 120V	Y	Y	Y	N	N	N	N	N	10 kHz 100 kHz	FM FM	Y	30 kHz,70 kHz, 150 kHz, 250 kHz	10 kHz 100 kHz	yes

Y-Yes, N-No

* **Drawn up at the 10 October 1973 meeting between NBS, PMSRC, Collins Radio, and ADL staff at Bruceton, Pa.**

- Highest priority has been assigned to completing the processing of the present noise data, writing reports associated with these data, and disseminating these reports and data to system designers.

- System designers and other users who need access to or interpretation of these data, particularly before they have been published, should contact NBS directly. In this matter, dubs of select NBS noise recordings may also be obtainable for testing breadboards, prototypes, etc. However, special arrangements will probably have to be made with NBS to generate these tape dubs.

- Finally, the data must now be assembled, analyzed, interpreted, and correlated in a comprehensive manner to determine and understand the important relationships, parameters, sources, etc., that best characterize mine EM noise environments under different operating conditions. This can, and should, also be done on a somewhat less-complete and piece-meal basis to solve certain specific, localized problems, or ones that cannot wait for the more comprehensive approach.