A FIELD PROGRAM AND INSTRUMENTATION SYSTEM FOR ELECTROMAGNETIC NOISE MEASUREMENTS

technical memorandum report to

U. S. BUREAU OF MINES
PITTSBURGH MINING AND SAFETY RESEARCH CENTER

APRIL 1972

Arthur D. Little, Inc.

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TECHNICAL MEMORANDUM REPORT

to

U.S. BUREAU OF MINES

PITTSBURGH MINING AND SAFETY RESEARCH CENTER
PITTSBURGH, PENNSYLVANIA 15213

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April 1972

C-73912

Contract No. H0122026

TABLE OF CONTENTS

		Page
I.	SUMMARY	1
II.	CONFERENCE PARTICIPANTS AND TENTATIVE PROGRAM ASSIGNMENTS	8
III.	MEASUREMENT PROGRAM OUTLINE	9
	A. Data Needed	9
	B. Noise Characteristics	9
	C. Data Acquisition and Analysis	10
IV.	INSTRUMENTATION AND DATA PROCESSING SYSTEM	11
	A. Block Diagram	11
	B. System Components	16
	1. Loops	16
	2. Preamplifiers	16
	3. Filters	16
	4. Receivers	17
	5. Recorders	17
	6. Sources	18
	C. Real and Synthetic Calibrations	18
	D. Playback and Processing	19
	E. Equipment List	21
	F. Shaping of Noise Spectrum Signature	21
	G. Logarithmic Compression	22
V.	OPERATIONAL CONSIDERATIONS	22
	A. Equipment Proofing	22
	B. Record Keeping	22
	C. Test Plans	23
VI.	SOME QUESTIONS AND ITEMS TO BE RESOLVED	23
	A. Tape Recorder Suitability	23
	B. System Organization	23
	C. Dynamic Range Considerations	24
	D. Transmission Measurements	24
	E. Conducted Noise Measurements	25
	F. Tape Recorder Cross Talk and Non-linearity	25
	G. Computer-Generated Power Spectra	25
	H. Choice of Mines for Measurements	26
	I. Experiment Design	26
VII.	BIBLIOGRAPHY	28

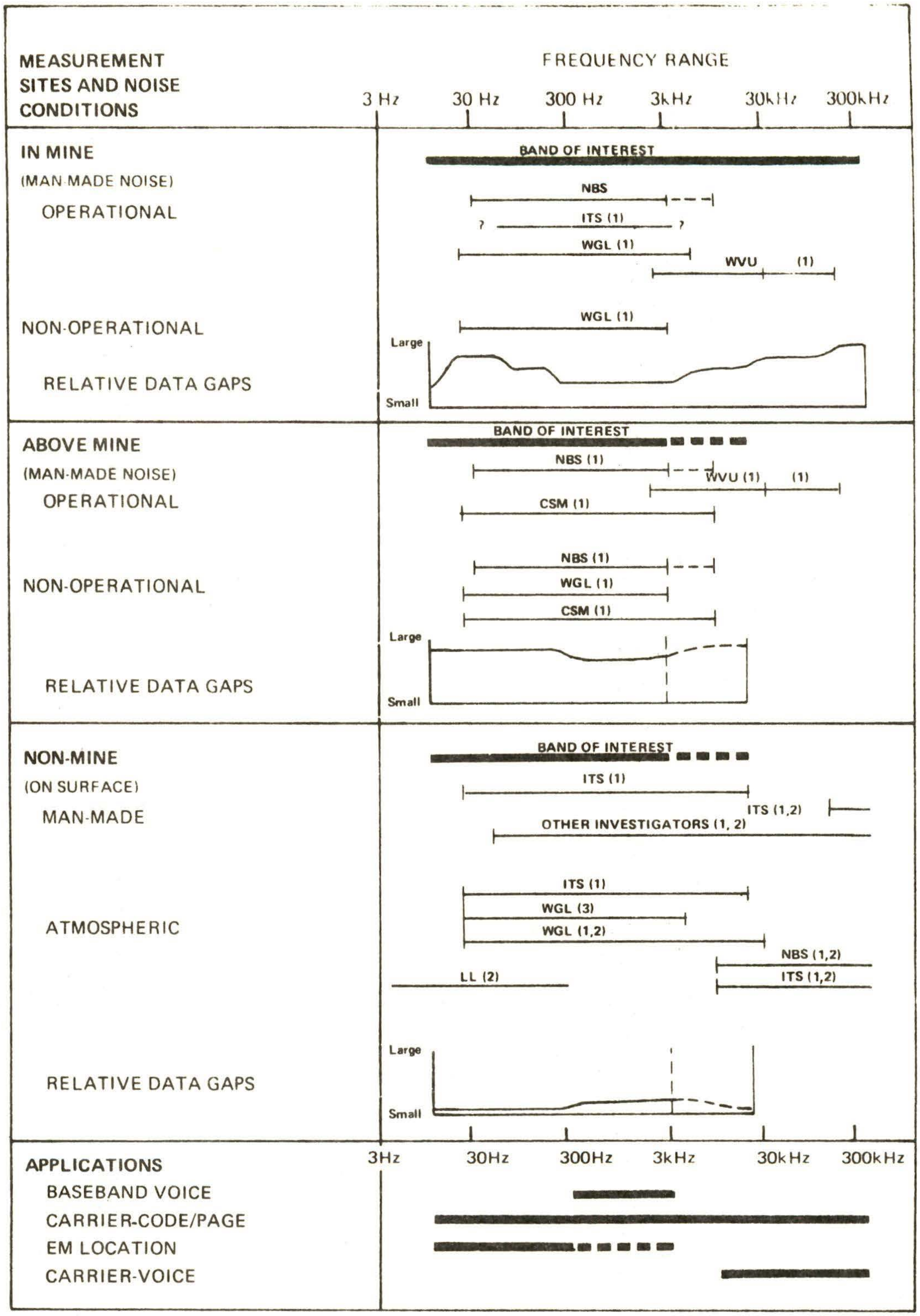
I. SUMMARY

Five conclusions that emerged from ADL's Contractor Noise Measurements Assessment done for the Bureau of Mines 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 I, II, and III 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 I 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 II 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 III presents a listing of investigators, an identification of their measurement and data processing

TABLE I



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 II

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

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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 III

EM NOISE MEASUREMENTS, PROCESSING METHODS, AND RESULTS	INVESTIGATORS: FOR BU MINES (EXC. AS NOTED)							INVESTIGATORS: 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

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(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 report. 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 IV & V. 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

TABLE IV

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 V

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

high priority; because man-made noise is expected to dominate on the surface above coal mines, and because existing atmospheric noise data, though 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 report presents an abbreviated description of, and questions related to, the instrumentation and data processing methods that were discussed at the March meeting in Boulder. The report includes a partial equipment list and block diagrams for the instrumentation to the extent that they are presently defined. This report documents the main findings and conclusions 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 completing the NBS/ITS core team.

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 I and II). 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 IV.

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 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.

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

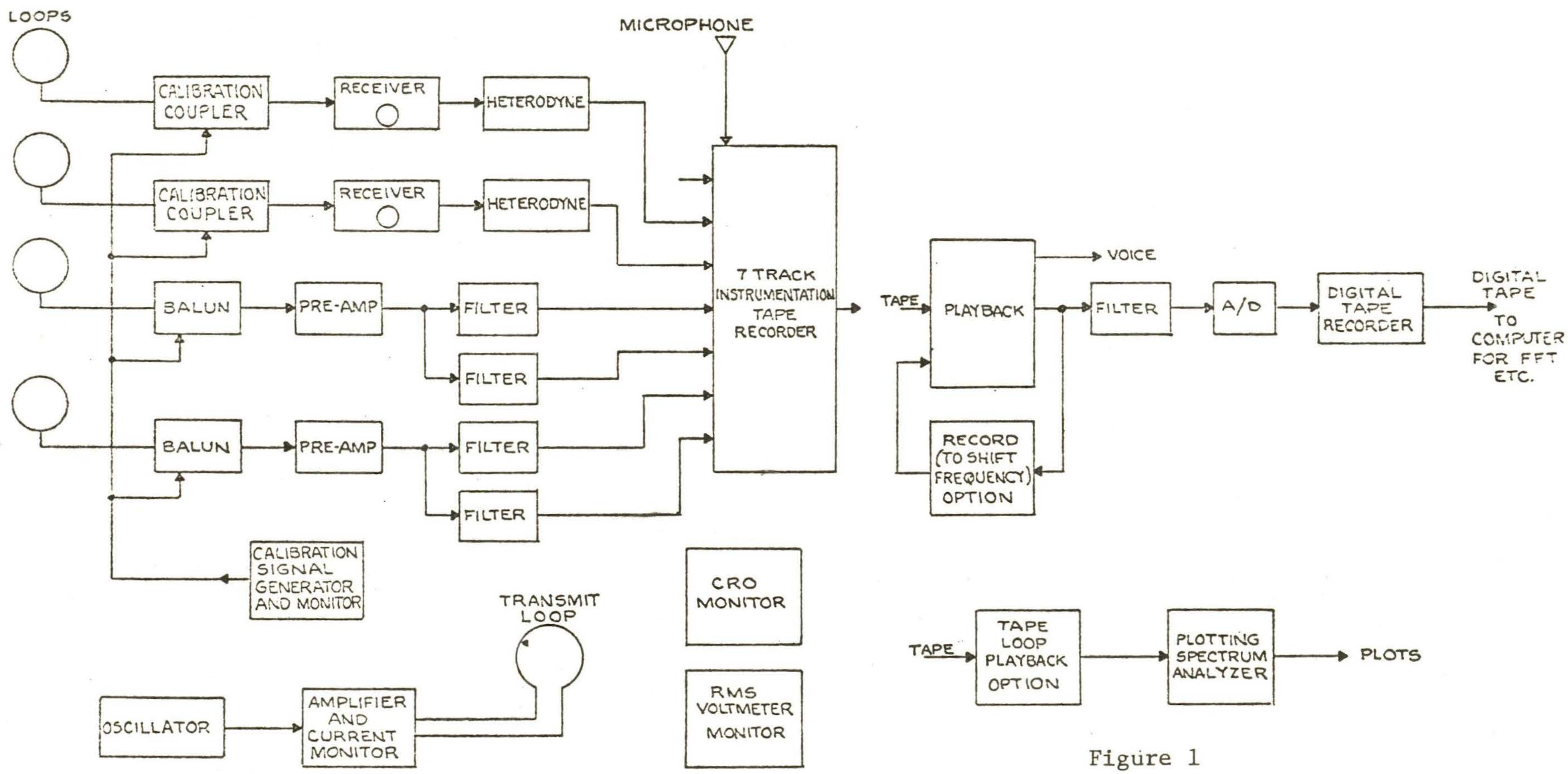

Figure 1

SIMPLIFIED BLOCK DIAGRAM
OPTION I — IN-MINE MAGNETIC FIELDS

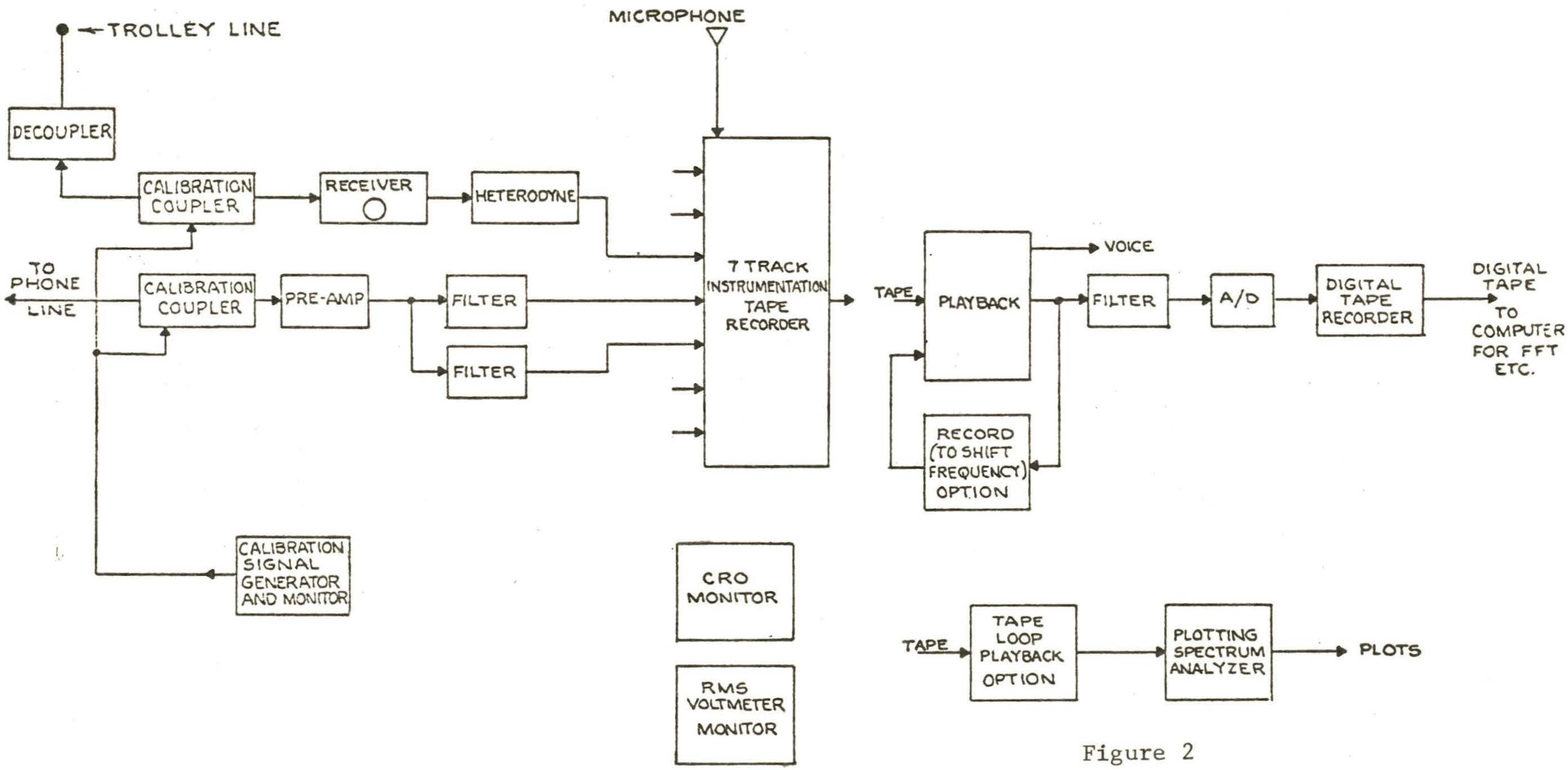

Figure 2

SIMPLIFIED BLOCK DIAGRAM

OPTION II - IN-MINE CONDUCTED NOISE

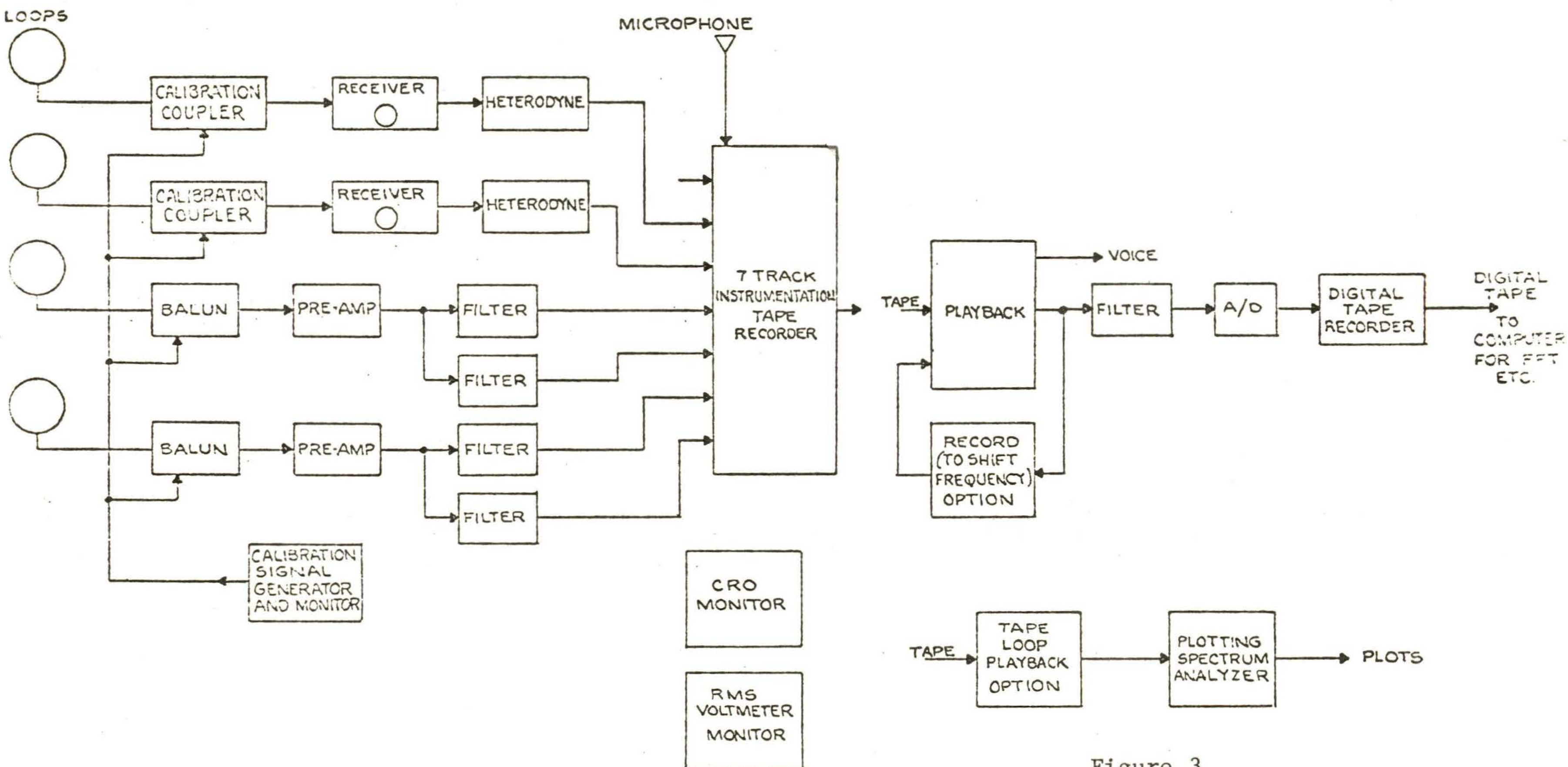

Figure 3

SIMPLIFIED BLOCK DIAGRAM

OPTION III – SURFACE MAGNETIC FIELDS

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 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.

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.

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