SUMMARY REPORT OF UPLINK AND DOWNLINK COMMUNICATIONS WORKING GROUP

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I. OVERVIEW

The attention of this group was focussed on four through-the-earth communication systems that are presently of high interest to the U.S. Bureau of Mines; four systems for providing operational/emergency communications on the working sections of coal mines, indeed up to the very face of the section. The systems are: uplink-data, downlink-voice, sidelink-call alert coded page, sidelink-roof bolt voice page. Each of these systems makes use of the mine overburden as the signal transmission medium, as opposed to the guiding wires, cables, and tunnels treated by the operational communications working group. Each of these systems satisfies one or more of the Bureau's objectives for mine communications systems; namely

- reliable links for monitoring the mine environment under both operational and emergency conditions.
- reliable links for communicating with miners during emergencies.
- special links for increasing the efficiency of day-to-day operations of the mine.

Each of these systems has been successfully demonstrated on a limited experimental basis, and prototypes of all these systems are installed and operating in the USBM experimental mine in Bruceton, Pa. Each of these systems must now be optimized regarding its performance, and engineered for practical routine application to the working sections of actual operating coal mines, particularly those of the room and pillar type.

This optimization and engineering must take place subject to the principal constraints listed by Howard E. Parkinson in his Workshop paper entitled, "Objectives and Constraints of Through-the-Earth Electromagnetic Communications Systems" and enumerated below.

- Depth of Mine Overburden
- Overburden Conductivity
- Electromagnetic Noise In and Above Mines
- Limited In-Mine Electrical Energy (Stationary or Man Carried) During an Emergency
- Intrinsic Safety for In-Mine Equipment
- Practical and Rugged Equipment for Use Under Both Operational/ Emergency Conditions
- Severe Weight Limitations for Man Carried Equipment
- Reasonably Low Costs Especially for Man Carried Equipment

Part II of this paper provides a brief description of each system, while Part III summarizes the present status of developments related to these systems and some recommendations for future work needed to advance these systems to the practical application stage.

II. BRIEF DESCRIPTION OF THE FOUR PROMISING SYSTEMS

A. Uplink-Data

This is a vertical through-the-earth narrow band data channel for monitoring important parameters of the mine environment under operational and emergency conditions, and for receiving coded messages or replies from miners during an emergency. Operating ranges compatible with 1,000 foot deep mines with $\sigma = 10^{-2}$ mho/m overburden are required. The in-mine transmitter would be located at a key place on the section, such as the loading point, where the present mine pager phone is also terminated. The surface receiver would have to be located in the vicinity of the point directly above the in-mine transmitter, primarily because of the inherent power limitations imposed on an in-mine transmitter during an emergency. This location requirement for the surface receiver may pose a difficulty for some mines with regard to surface access rights over advancing sections, and therefore may restrain such uplink communications to emergency situations during which mobile equipment can be temporarily installed over the known location of the in-mine transmitter. During normal mine operations, the mine environmental data could be monitored by means of a carrier channel over the mine pager phone line.

The limited in-mine transmitter power available during an emergency and the electromagnetic noise levels present on the surface have led to the conclusion that uplink transmission of baseband voice is not a practical goal. Therefore it has been deleted as a requirement until practical, voice bandwidth compression techniques or other types of signal processing become available to change this conclusion.

B. Downlink-Voice

This is a vertical through-the-earth voice channel for transmitting messages, during a mine emergency, to miners carrying a small emergency voice receiver, preferably built into their helmets. As in the case of the uplink receiver, difficulties regarding surface access rights over advancing sections may require a mobile surface transmitter installation that is temporarily installed only during emergencies. However, since the transmitter power available on the surface is much greater than that underground during an emergency, the downlink allows greater operational flexibility in communicating with moving miners, and may reduce the surface access rights problem somewhat, because of the potentially greater coverage area of each surface transmitter. As in the uplink case, operating ranges compatible with 1,000 foot deep mines with $\sigma = 10^{-2}$ mho/m overburden are required.

C. Sidelink-Call Alert Coded Page

This is a horizontal through-the-earth narrow band channel for transmitting a call alert paging signal to key individuals roving on a working section during normal mine operations, to notify them that they are wanted on the mine pager phone. The transmitter, activated by a signal sent over the mine phone line, would be somewhat centrally located near the section loading point as in the uplink system, and conceivably could be integrated with the uplink equipment if desired. The receivers would be carried by the miner, preferably in his helmot as in the case of the emergency voice receiver for the downlink system. In fact the Bureau's present desire is to have this emergency voice receiver serve a dual role, for key supervisory and maintenance people, by also operating as a narrowband call alert receiver under normal operating conditions. Such a call alert system would extend mine phone paging to roving individuals right up to the working face, thereby increasing both safety and operational efficiency. This would require operating ranges on the order of 400 to 800 feet in overburdens of $\sigma = 10^{-2}$ mho/m in order to cover a typical 600 by 600 foot section, depending on the location of the transmitter.

D. Sidelink-Roof Bolt Voice Page

This is a horizontal through-the-earth voice channel for transmitting a more comprehensive voice message or page, as opposed to a simple call alert, to key individuals roving on a working section during normal operating conditions. As in the call alert system the transmitter could also be located at the section loading point, thereby requiring the same operating range as the call alert system. However it most likely would not share equipment with an uplink system as a call alert system might. Being a voice bandwidth system for use under operational conditions when electromagnetic noise levels are high, particularly in the audio band, a significantly higher operating frequency than that possible for a narrowband call alert or uplink system is favored. The receiver for the roof bolt paging system is presently conceived as a pocket-sized unit, but other packages such as a helmet mounted unit are not excluded.

III. PRESENT STATUS AND RECOMMENDED FUTURE WORK

To arrive at a design that is at least acceptable, if not optimum, regarding performance and practicality for any of the above communication systems, one usually must first determine how each of the major elements comprising the system influence its performance, and then use them so as to get the desired results. An often indispensible aid to this process, particularly when design information for one or more of the major system elements is missing, is to put together a breadboard system based on existing related hardware and try it out. Several of the above through-the-earth systems have evolved, with beneficial results, from the latter approach. Concurrently, some of the previously missing design information on transmission loss and noise has been accumulated. Therefore, it will now be possible to better optimize each of these systems by quantitative analysis and comparison of alternative designs.

No papers evaluating or describing any of the above through-the-earth systems were presented during the Workshop. However, several papers treating two major system elements, channel transmission loss and noise, were given. These and some past work by the attendees of this working group provided the basis for the group's findings and recommendations. We grouped the system elements as follows:

- The Source: its message, modulation or coding, transmitter, and operating frequency.
- The Channel: its transmission loss for each antenna type, and its noise characteristics.
- The Receiver: its pick up sensor, demodulation/decoding, and special processing for signal to noise improvement.

These elements were then discussed in the context of each of the four systems to the level of detail that was possible under the circumstances. The order of treatment for each system will be Channel, Source, and Receiver, which mainly reflects the emphasis of this Workshop's charter and papers. Progress made to date in the Channel area should now allow more emphasis to be placed on overall system design and analysis, thereby calling greater attention to the Source and Receiver areas.

In the discussions below, that for the uplink system is somewhat longer than the others, because certain elements that have common application to several of the systems are first introduced in the uplink treatment.

A. Uplink Data System

This section treats the principal narrowband data uplink application. The more difficult, less practical uplink voice application is treated briefly in the downlink voice section.

1. Overview

To date the combination of overburden transmission loss and available surface noise data have identified the frequency band below 5 kHz as the most favorable for practical narrow band uplink data systems intended for coal mines with overburden depths of up to 1,000 feet and conductivity of $\sigma = 10^{-2}$ mho/m. Though shallower mines allow a somewhat higher frequency limit, and more conductive ($\sigma = 10^{-1}$ mho/m) or deeper mine overburdens demand a significantly lower frequency limit, the under 5 kHz limit should cover most coal mine situations.

a. Nominal Mines

Signal to noise analyses performed by Westinghouse Georesearch Laboratory (WGL) support this under 5 kHz conclusion for 10^{-2} mho/m overburdens, while also identifying the frequency band between 500 Hz-to-3 kHz as a distinctly optimum one for narrowband systems. The WGL analyses were based on Wait/WGL transmission loss curves for loop transmitters and broadband atmospheric noise data (under 10 kHz) taken by WGL in Colorado. Signal to noise analyses performed by Arthur D. Little, Inc. (ADL) reach a similar under 5 kHz overall conclusion, but do not reveal the presence of an optimum frequency band as distinct as the one by WGL. The ADL analyses were based on the same transmission loss curves of Wait/WGL, but different broadband noise data, namely surface atmospheric noise data (under 300 Hz) taken by MIT Lincoln Laboratory (LL) in Florida and early WGL and National Bureau of Standards (NBS) surface noise data (under 10 kHz) taken over four Western coal mines. The differences in the results of the two analyses, regarding the presence or absence of a clearly optimum frequency band between 500-3000 Hz for $\sigma = 10^{-2}$ mho/m overburdens (based on broadband noise levels) should be easily resolved when the large amount of noise data recently taken over coal mines by NBS soon becomes available. However, WGL and NBS field experiences have revealed a potentially more serious noise problem that may tend to favor use of frequencies between 1-5 kHz over coal mines, namely the extremely strong harmonics of 60 Hz and 360 Hz caused by the mine power conversion equipment, harmonic levels that are high enough in some cases to interfere with even narrowband systems operating between the harmonics.

b. Deep Mines

For mines with overburdens deeper than 1,000 feet (such as hardrock mines) or conductivities greater than 10^{-2} mho/m, it is generally agreed that operating frequencies will definitely be forced downward to perhaps 500 Hz or 100 Hz. In some extremely deep hardrock mines that approach 10,000 feet, lower frequencies yet may be needed if direct transmission to the surface is required. The favorable downlink signal transmission test results to depths of 11,000 feet achieved with under 100 watts by Sandia Laboratories, using Develco, Inc. equipment at frequencies below 20 Hz, should be carefully evaluated and exploited if such depths become important to the Bureau. However, it should be kept in mind that such a downlink transmission test has the advantages of power and large antenna size on the surface, and a relatively noise free underground receiver, which is the converse of the mine uplink problem.

c. Equipment

An experimental prototype uplink data monitoring system has been built by WGL for the Bureau. It operates at designated frequencies between 3-5 kHz, utilizes PCM/FSK modulation, a loop transmitter antenna, and is presently installed in the Bureau's experimental mine in Bruceton, Pa. Similar experimental equipment that illustrates the feasibility of uplink data transmission, even with limited available power, has also been built by WGL for miner location applications. An example is the keyed CW electromagnetic transmitter for miner location which utilizes a one turn, 360 foot periphery loop and the miner's 4-volt cap lamp battery to generate a magnetic moment of about 2,000 ampere-meters^2 at 2 kHz. Detection ranges in excess of 1,000 feet have been obtained at several mine sites using this and similar units, as reported during this Workshop. It should be noted that the approximately 80 foot overburden at the USBM experimental mine is not considered by the Bureau as being typical of that found over operating mines.

A multichannel uplink data system of practical design suited for installation and test in an operating coal mine with up to 1,000 feet of overburden will soon be needed. The basic monitoring requirements of the in-mine station are now being formulated, so that an overall uplink data communication system can then be designed and optimized for the operating conditions of this mine.

2. The Channel-Transmission Loss

a. Loops

Uplink communications to date have primarily utilized loop source antennas of vertically oriented magnetic moment. These have consisted typically of one turn loops (up to 500 foot periphery) wrapped around one or two coal pillars; and less frequently a smaller one turn loop (up to 100 foot periphery) placed in an entry. Such loops have been preferred over long wire antennas for in-mine installations because of their lower input resistance, fixed impedance characteristics over time, and convenience of installation and maintenance in the adverse mine environment. The primarily vertical magnetic fields produced by vertical axis loops can also offer a signal to noise advantage on the surface in some cases, depending on the sources of the noise, i.e. natural or man-made.

The theoretical results of Wait and ITS, regarding the field strengths expected on the surface from infinitesimal loops of moment NIA placed in homogenous and layered conducting overburdens, are well established and have been found to be in good agreement with experimental data obtained by WGL and Colorado School of Mines (CSM) at several mine sites. For the large overburden depths of interest and sizes of corresponding loops required, the simplifying infinitesimal loop assumptions apply. Furthermore it has been shown by Wait and ITS that typical conducting obstacles, such as pipes, and inhomogeneities found in the transmission path to the surface should produce only small effects on the resultant magnetic field seen at the surface for the under 5 kHz band of interest. WGL and ITS have also shown that the effects of surface topography on the resultant surface field are also small. Consequently these effects can largely be ignored for communications applications, as opposed to location applications where some of the effects can take on greater importance in some cases.

Therefore it was concluded that no new theoretical derivations were required on uplink transmission loss for loop transmitters; but that appropriate curves, tables, nomographs, etc., based on the available theoretical results should be prepared, as an aid to uplink systems designers who desire to apply the theory to typical mine overburdens. Included in these design aids should be curves that show the additional amount of signal loss suffered as the horizontal displacement between surface and in-mine loops is increased. This will help determine the surface coverage obtainable from a single in-mine loop.

b. Parasitic Structures

All of the above results apply for cases in which no large closed loops of wire, cable, or steel roof mesh are close enough to the finite, relatively large, in-mine transmitter loops to allow significant currents to be induced in these parasitic structures, which in turn might reduce the effective strength or field of the transmit loops. The likelihood of encountering parasitic structures on working sections is high, but the degree to which they could adversely affect system performance, has not been ascertained. Since this may be a potential problem to both the uplink data system and the call alert page system to be discussed below, the practical influence of such structures needs to be assessed. However, until that is done, uplink or call alert system transmit loops should be installed away from such structures as steel roof mesh, trolley lines, and probably power cables, since the effects of their presence will decrease with increasing separation.

c. Grounded Wires

Lastly, should there be a renewed interest in comparing the performance of a loop source uplink system with that for a grounded finite straight wire source that utilizes a wire terminated by a roof bolt ground rod at each end, ITS has derived expressions and curves for the magnetic field produced on the surface by such a buried finite wire source. The results apply to the case of the wire inclined at an arbitrary tilt angle to the horizontal in a homogeneous overburden. They show that small tilt angles made by the wire with a flat or hilly surface do not influence the magnitude of the surface field.

3. The Channel-Noise

a. Past Data

Up until this year very little good noise data pertinent to coal mine environments, underground or on the surface, were available for making comprehensive systems analyses or optimizing uplink or downlink system designs. With respect to noise levels on the surface, the ELF noise measurements made by Lincoln Laboratory for the Navy were the most useful below 300 Hz, even though not taken over coal mines, but in Florida and other parts of the world. Between 300 Hz and 5 kHz the surface noise data were even more sparse, consisting of limited atmospheric noise measurements taken by WGL in Colorado, and limited noise measurements conducted by NBS and WGL at a few coal mines.

These surface data were not considered adequate, because it was suspected that the predominant sources of both broadband and discrete frequency noise on the surface over coal mines would be man-made, since mines were such large power consumers and/or located near industrialized areas. Though broadband atmospheric noise would probably play an important role, broadband noise levels produced on the surface by the mine equipment, and by poorly maintained rural high voltage power lines, were viewed as having a potentially greater influence at a local mine site, except in the case of local thunderstorms. More importantly, even less data were available on the in-mine noise environment for the design of downlink and in-mine systems.

b. NBS Mine Noise Measurements

Therefore, during this past year, NBS conducted a major noise measurement effort for the Bureau of Mines in an attempt to characterize in a practical manner the electromagnetic noise environment in and above several "representative" coal mines. Data has been taken at a 600 volt all DC coal mine; a coal mine with 300 VDC rail haulage and shuttle cars, and AC face machinery and belt haulage; a 300 volt DC longwall mine with AC haulage; and a hardrock AC mine with diesel haulage. The measurments encompass operating and quiet conditions for different machines, locations, power centers and boreholes, in working sections, haulageways and on the surface. Some of these noise data have already been processed and made available, with the remainder to become available within the next six months.

In-mine measurements have included wideband recordings from 100 Hz to 300 kHz of three magnetic field components, and of voltages on telephone lines, trolley lines, and roof bolts; from which noise power spectra are being generated. In addition, narrowband (2 kHz) spot frequency recordings were made at eight frequencies covering the 10 kHz to 32 MHz band, of three magnetic field components; from which noise amplitude probability distributions (APD's) are being generated. On the surface, only the components of magnetic field are required, but over a more restricted frequency range, because of the lower frequencies required for uplink systems. The surface wideband recordings for generating spectra cover 100 Hz to 10 kHz, while the narrowband spot frequency recordings for generating APD's cover four frequencies in the 10 kHz to 150 kHz band.

The preliminary results now available from these NBS noise measurements indicate that high levels of discrete frequency noise at harmonics of 60 Hz and 360 Hz predominate over broadband spectrum levels below about 10 kHz, both in the mine and on the surface, with the broadband noise predominating above about 15 kHz, and the levels of both noise types decreasing with increasing frequency. Furthermore, the discrete frequency surface noise levels are highly correlated with in-mine levels below about 7 kHz, the degree of correlation falling off rapidly above 7 kHz. Noise levels also have a strong dependence on distance from power cables, and can vary over dynamic ranges in excess of 60 dB.

c. Whistler and Geomagnetic Data

A representative from Develco, Inc. stated that "mountains" of atmospheric noise data had been taken some years ago in the 1-30 kHz frequency band by Stanford Research Institute with regard to its whistler work. Though some of this data might possibly be useful for the under 5 kHz band of interest, he was also of the opinion that the data had not been analyzed in a form convenient to the uplink application, and that in any case, access to and subsequent understanding of this old data might involve much more difficulty than any potential benefits would justify.

A representative from University of Alberta claimed the presence of a minimum in the geomagnetic noise spectrum between 0.2-8 Hz, with 5 Hz perhaps being the most favorable frequency. Though there was some uncertainty regarding the level of this noise minimum among the Workshop participants, this claim should be checked out, since it might be worth considering for very deep mines. A book by Campbell and Matsushita was given as a reference.

d. Data Utilization

It was concluded that the NBS noise data taken to date at six coal mines and one hard rock mine, together with the planned NBS measurements at an all AC coal mine and another hard rock mine, when added to past atmospheric noise data taken below 10 kHz, should provide a substantial data base from which the design and optimization of mine communications systems can proceed in an orderly manner. Therefore, it was concluded that no new noise measurements over and above that already planned by NBS were required at this time.

In the under 5 kHz frequency band presently of interest to uplink data systems noise, power spectra and dubs of selected NBS tape recordings of the surface noise will be made available to system designers. Surface data up to 10 kHz will also be available if needed. The uplink system designers will need data on the levels of both discrete frequency and broadband noise components: broadband spectrum levels (and amplitude statistics if possible) for optimizing the coding, modulation, and receiver processing for narrowband data uplink; and discrete component levels for estimating likely levels of out-of-band interference, and ways to combat them by choice of operating frequencies and/or receiver signal processing techniques.

To better estimate these noise levels, particularly the broadband noise levels between discrete harmonic components, it was recommended that NBS provide expanded frequency scale spectra, covering only the 0-5 kHz band per spectrum plot, as opposed to the more compressed plots presently being prepared. Spectra for vertical and horizontal magnetic field components on the surface under both operational and "quieter" emergency conditions will be required. Note: these 0-5 kHz expanded spectra will be required not only for the surface noise data, but also for the underground data for use in the design of call-alert and baseband-voice-downlink communications for mine sections. Though not discussed in the working group, amplitude statistics for the broadband levels between harmonics may also be required.

For deep mine applications that may require operating frequencies in the vicinity of 100 Hz and below, the present NBS mine noise data down to 100 Hz and the LL atmospheric noise data down to about 3 Hz may be adequate for designing such systems. The need for additional noise measurements at these low frequencies should be carefully evaluated and justified before embarking on such a measurement program, because of the increased measurement difficulties encountered at these frequencies.

4. The Source - Message, Coding, Modulation, Operating Frequency.

The group agreed that firm conclusions regarding preferred techniques for coding, modulation, and operating frequency for a data uplink were premature, and could only be reached after a detailed overall systems analysis. Such an analysis would need to consider such things as the actual data message requirements, the bandwidth and power available, the transmission loss, characteristics of the noise, etc. Though the frequency band between 1-5 kHz is currently favored, based on past noise data, even this should be re-evaluated in the light of the new and more comprehensive NBS mine noise data.

The present WGL transmitters used for miner location utilize a CW signal that is simply keyed on and off with a ten to one duty cycle, to keep it simple, conserve cap lamp battery life, and to help distinguish it from adjacent power line harmonics. Operating frequencies are located between the harmonics of 60 Hz in the 1-3 kHz band. The present WGL uplink data system installed in the Bureau's experimental mine utilizes PCM/FSK to transmit the monitored data, and operates at select channel frequencies in the 3400 to 4500 Hz band, also placed between 60 Hz harmonics. The location transmitter is described in a Workshop paper, whereas the present experimental uplink data system is described in WGL reports. The specific results obtained with these systems should be reviewed as an aid to future designs.

As mentioned earlier, the data requirements and subsequent systems design have not yet been formulated for the uplink data system that will soon be developed for installation in an operating mine. This system design should benefit from the additional noise data and field experience now available.

5. The Receiver - Sensor, Demodulation/Decoding, Special Processing

As for the source, firm overall conclusions could not be reached, but several suggestions were made. An electrostatically shielded and balanced air core loop was recommended as a sensor. Notch filters were suggested to reduce interference from strong harmonics adjacent to the channel frequency.

The present WGL location receiver utilizes several stages of bandpass filtering to obtain a resultant bandwidth of 6 Hz. Notches as described above apparantly have not yet been required at the mine sites visited to date. The present WGL uplink data system utilizes a phase-locked-loop FSK detector prior to decoding. Neither system was discussed.

Lastly, MIT Lincoln Laboratory (LL) has done extensive signal design and non-linear receiver processing work aimed at optimizing ELF secure narrowband data communications (for the Navy Sanguine program) in the face of highly impulsive ELF atmospheric noise, and occasional discrete power line components. Reductions in required signal power of 10-20 dB have been reported, depending on the level of man-made discrete frequency interference, which apparently makes the techniques less effective. LL has been cooperative in the past by making its noise data and instrumentation information available to the Bureau and its contractors; and by recently offering suggestions regarding computer simulation of receiver design configurations for testing performance in the presence of environmental noise. This work should be reviewed to see if it can be applied to the mine problem in a practical and economic manner, particularly in those cases where transmitter power is at a premium and the noise environment severe. This work has recently been reported in the open literature, and more extensively in LL Technical Reports which are available from LL.

B. Downlink Voice System

1. Overview

a. Experience to Date

The objective of a downlink emergency voice system is to provide coverage of as large an area as possible to mobile miners during an emergency, in mines with nominal overburden characteristics of conductivity $\sigma = 10^{-2}$ mho/m and depths to 1,000 feet; and to do this with as few antennas on the surface as possible within practical limits. This being the case, the overburden transmission loss, the "quiet-mine" noise data available to date, and the greater space and power available on the surface, have favored direct transmission of 500-3,000 Hz baseband voice signals by means of grounded long wire antennas on the surface. Under relatively "quiet" emergency conditions, the present system designed by WGL with a transmitter capacity of 200 watts, has successfully transmitted intelligible voice messages to miners carrying simple manpack receivers to depths of about 1,000 feet. Mine overburdens of low conductivity will of course extend this usable range, while deeper or more conductive overburdens will quickly deteriorate performance or require significantly more power.

The success experienced under emergency conditions led to speculation that such a downlink voice system could have some beneficial operational applications as well, if the surface transmitter power and manpack receiver processing demands did not become excessive. However system performance was discovered to be even more dramatically affected by the in-mine operational noise environment than by the depth and conductivity. Namely, the noise levels severely deteriorated message intelligibility and usable range, demanding greatly increased power to maintain performance. This behavior is predicted by system analyses by both ADL and WGL, using early NBS and WGL in-mine noise data, and has been confirmed several times in operating mines by WGL. The deterioration occurs mainly because of the high levels of 60 Hz and 360 Hz harmonics produced by the mine machinery and DC power conversion equipment, and less often by the broadband impulsive noise near arcing trolleys, levels that can vary over a dynamic range in excess of 60 dB depending on location and machinery operating cycles. By applying simple corrective measures such as varying the orientation of the manpack receiver antenna for minimum noise pickup, which can be an operational inconvenience, and by severely attenuating the large 360 Hz harmonic component by filtering in the manpack receiver, WGL was able to obtain some improvement in performance; but not enough to make it a dependable and practical system under mine operational conditions.

b. Future Developments

The above experience under operational conditions, when combined with the problems associated with gaining surface access rights over advancing coal mine sections (for the installation of long wire antennas, perhaps several thousand feet in length, or smaller loops, which have to be moved more often) make it very unlikely that the permanent surface installations required for operational applications will be a practical possibility in the near future. Thus in the near term, downlink voice will remain an emergency condition mobile system; thereby keeping the communication problem closer to the one originally treated by WGL, but with some added features.

The emphasis for future efforts on this system should probably be in the development of a reliable, compact, dual purpose receiver to be carried by a miner, preferably integrated into his helmet and operated from the cap lamp battery, as described by H. Parkinson in his paper. It will function as a downlink baseband voice receiver under emergency conditions, and as a call alert page receiver under operational conditions for key mining personnel, as mentioned in Section II. Though the present surface transmitter is apparently adequate to handle several emergency conditions, it too will probably need to be redesigned and optimized: for truly mobile utilization in the sense of being easily transportable by backpack or helicopter to the desired spots above the mine; for compatibility with the new dual purpose miner carried receivers to be developed; and for the mine emergency noise conditions likely to be prevailing. Since the downlink voice transmitter will have to be transported to and installed at selected locations above the mine after an emergency has occurred, the mine or section of interest will most likely be in a nearly power-down noise condition with only essential,lower-powered,electrical equipment such as pumps, fans, etc. in operation.

c. Deep Mines

The above applies to the nominal coal mine conditions specified. The deep hardrock mine situation is a vastly more difficult one as described in the uplink section, requiring frequencies down to 500 Hz and possibly 100 Hz and below even for narrowband data applications. Therefore, unless practical and economical techniques for dramatically compressing the bandwidth required for intelligible voice transmission become available, downlink voice to deep mines on the order of 10,000 feet will not be practically feasible under any noise conditions.

2. The Channel-Transmission Loss

a. Long Wire Antennas

Downlink communications to date have primarily utilized grounded, horizontal long wire source antennas on the surface, which reportedly give good coverage in the mine to a strip of width about equal to the depth of the mine under the wire, and sometimes wider, depending on the depth and available transmitter power. Antenna lengths have typically ranged from a low of about 1,500 feet up to greater than a mile, WGL field experience indicating that a length greater than about three times the mine depth being adequate to assume infinitely long wire behavior for the transmission loss. In the mine, the wire's magnetic field is primarily horizontal, with a gradually increasing vertical component as one moves away from the wire in a perpendicular direction; as opposed to the field of a surface loop which has primarily a vertical component. In those cases where the position of the miner or communication station is relatively well known and fixed, a large one turn loop, like that for the uplink, placed over the miner's position can offer a performance advantage as well as one of convenience, depending on the orientation of the miner's receive loop and the direction of the maximum noise component in the mine.

Grounding of the long-wire antenna has been accomplished by means of four or more ground rods at each end of the wire, with special care being taken to ensure good connections by the use of mud and copious amounts of rock salt. In this manner, total resistance values between about 50 and 100 ohms can be achieved for the long wire antenna; however, maintaining these values over long periods of time can sometimes be a problem.

To establish values of average overburden conductivity for estimating system operating ranges at different mine sites, the well established dipole-dipole measurement technique has been used extensively, and found to give results that agree reasonably well with system test results in most cases over coal mines.

The theoretical results of Wait and ITS, regarding the magnetic fields expected underground from infinitely long, insulated wire sources, placed on the surface of homogeneous and layered conducting overburdens, are well established and have been found to be generally in good agreement with experimental data obtained by WGL and CSM at several mine sites. Similar results have been obtained for surface loops. However WGL field experiences have also revealed a somewhat greater tendency for occasional experimental deviations, from predicted field strength values for the long wire antennas. A possible cause cited for this behavior was the presence of long conductors such as power cables, trolley wires, or rails in the mine, or large inhomogenieties in the overburden. This bears some further investigation.

A constant current assumption is used throughout these derivations. This has been shown to be valid for the frequencies of interest provided the conductors are insulated, which they are in practical applications of interest. The Navy experience in particular, with the huge Sanguine transmit antenna, provides good testimony to the validity of this constant current assumption.

ITS and Wait have also derived expressions and curves for the underground magnetic and electric fields produced by finite, grounded, insulated wire antennas on the surface of a homogeneous, unlayered half space, and for the converse situation of the surface fields from buried finite grounded wires. These cases are more closely related to actual field installations. Both analyses reveal that a finite grounded wire can be treated as an infinitesimal dipole when the observation distance, or depth, is more than about twice the cable length; and treated as an infinitely long wire when the observation distance is less than about one quarter of the cable length, this latter behavior having been experimentally observed at several mines by WGL. In between these depths neither approximation is good, the exact curves or analytical formulation being required. Examination of these curves also indicates only slight departure from infinitely long wire field values for distances up to half the length of the wire, and a reduction from infinite wire field values of only about 3 to 6 dB up to distances, or depths, equal to the length of the wire. The degree to which this behavior changes as the observation point moves toward and beyond the end of the wire was not discussed, but should be obtainable from the analysis. These results will be quite useful for determining minimum practical lengths for surface and underground antenna installations, and as a means for understanding observed experimental behavior.

It was concluded that no new theoretical derivations were needed for loops or infinitely long wire sources on the surface for downlink transmission loss, but as in the uplink case, appropriate practical curves, tables, nomographs,etc. be prepared based on the above results for homogeneous and layered overburdens. Similar curves, nomographs, etc. are needed of the magnetic and electric fields for the finite wire cases treated by ITS. As in the uplink case, curves should be included that depict the increase in signal loss with horizontal in-mine movement away from the long wire, finite wire, and loop positions on the surface, in order to determine in-mine coverage areas.

The effects of a layered overburden on the fields of finite grounded wires have not been treated yet. If it is concluded that layering is likely to influence the downlink field behavior in a significant manner, this case should also be treated by analysis and corresponding practical application curves produced. A summary assessment of the importance of layering to the fields produced by the other sources would also be desirable. Lastly, new and better ways of quickly making good, and long lasting, ground terminations in different ground covers should receive some attention.

b. Parasitic Structures

Long wire and loop antennas deployed on the surface are not as likely as in-mine installations to encounter parasitic structures in their immediate vicinity, unless they have to be deployed in and across the streets of a town, or perhaps directly over a gas pipe or under power lines in rural areas. In the first case the complexity of the parasitic structure configuration will probably defy analytical treatment, and what is perhaps more needed is a practical strategy for choice of antenna type and its deployment, based on present knowledge. In the second instance, Wait and ITS have examined cases of long wire sources parallel to buried conducting non-insulated cylinders.

These results should be examined for their potential application to the gas pipe structure. However, since the effects of such structures generally decrease with increasing distance and orientation angle, perhaps a practical solution to this potential problem is again a deployment strategy for minimum effect, when the presence of this conductor is known and flexibility in antenna deployment is available.

In the section and haulage ways at the receiving end of the downlink, metal structures in the vicinity of the man-carried receiving antennas may play a more important role in altering or providing a shielding effect to underground fields, and, may account for some of the lower than predicted levels experienced by WGL in a few instances. Prime suspects for these infrequently reported anomalies could be closed loops made by two or more vehicle trolley poles across the trolley-track transmission line, say in the vicinity of the section loading point, or steel mesh used for roof support in the entries of some mines. The effects of these structures should be estimated using approximate methods, to see if they, as opposed to large unknown conducting anomalies in the overburden, could account for the significantly reduced horizontal field strength levels observed.

3. The Channel-Noise

As concluded during the workshop and discussed in the downlink overview section, it can be assumed for the purpose of system design and optimization that the mine or mine sections will be in a non-operational, power-down, condition during the operation of the downlink emergency voice system. All major mining and haulage equipment will be turned off, only minor equipment such as pumps, fans, etc., may be left on.

The in-mine wideband noise recordings made by NBS should provide a more than adequate data base from which to optimize the design of the downlink baseband voice system. Expanded frequency-scale power spectra covering the 0-5 kHz band, and depicting discrete frequency and broadband noise levels of both horizontal and vertical components of the magnetic field intensity will be needed. Dubs of selected noise tape recordings are also desired for testing receiver processing techniques and overall system performance in the laboratory. Of particular interest will be data during quiet times and locations on the sections and haulageways, that characterize the emergency power down conditions. Consultation with Bureau of Mines and NBS staff will no doubt be helpful if not necessary in the selection of measurement conditions and data that typify this condition.

4. The Source-Message, Coding, Modulation, Operating Frequency

The source topic was given only brief treatment by the group. It was noted that performance calculations by ADL using early NBS and WGL mine noise data indicate that intelligible downlink baseband voice reception is possible to 1,000 feet in 10^{-2} mho/m overburdens, with under 50 watts of average power under low noise mine conditions. This kind of performance is supported by WGL experience in the field. Indeed, even as little as 5 watts may be required under some highly favorable non-operational conditions. (These reasonable average power requirements can climb to prohibitive levels above 10 kilowatts under operational conditions in DC mines.)

The emphasis for the downlink voice system has remained on the direct transmission of baseband voice signals through-the-earth, particularly under the relatively favorable emergency power-down noise condition. Under this condition, the high-level harmonics of 60 Hz, and particularly those of 360 Hz, will be greatly reduced. Updated performance and overall systems analysis calculations based on the more comprehensive mine noise data recently taken by NBS will help to verify (or deny) the desirability of this frequency band of operation, and better establish the required power levels. These noise data should also help identify transmitter signal conditioning techniques and receiver signal and/or noise processing techniques that can be used to reduce the power, size, and weight required for the mobile, emergency surface transmitter.

The use of pre-emphasized and/or clipped speech upon transmission were suggested for consideration as ways to reduce the peak power requirements of the transmitter, while sacrificing only little intelligibility for the same average speech power transmitted. Means of significantly reducing the bandwidth needed (by more than an order of magnitude) to transmit voice intelligibly have been claimed in the literature. Since such reductions would correspondingly reduce transmitter power, these reported methods should also be investigated.

An alternative method for improving mine communications was also recommended by the group as perhaps a long-term goal for the mining equipment suppliers. Namely, the effective suppression of electrical noise at its source in the equipment whenever practically possible, by means of improved designs and/or addition of special noise suppression equipment.

5. The Receiver-Sensor, Demodulation/Decoding, Special Processing

a. Downlink

As for the source, only brief consideration was given to this topic. A helmet mounted loop antenna design is desired, together with a similarly mounted compact dual-purpose receiver, as mentioned in the system description section. The call-alert function of the receiver will be discussed later.

Use of notch filtering to reduce the interfering effects of high-level harmonics of 60 Hz and 360 Hz, thereby reducing required transmitter power, was the principal suggestion. Such filters have been successfully applied in France, and reference material on these applications will be forwarded to the Bureau of Mines by representatives of the University of Lille. Dramatic improvements in voice reception in the face of harmonic interference have also been demonstrated by ADL in the laboratory, with a breadboard design of a simple electronic commutator-type filter that is particularly suited to rejecting harmonic signals. The French and ADL reported results should be reviewed, together with other reported notch filter work. They should be reviewed for their effectiveness against the mine emergency condition harmonic interference; and for their practical application to a compact helmet mounted receiver, should the measured harmonic levels warrant the use of notch filtering under emergency power-down conditions. In regard to this latter point, it may be necessary to evaluate the effect of pure or complex "tones" of noise, such as those created by harmonics of 60 Hz and 360 Hz, on the intelligibility of received speech. The effect of direct audio noise in the mine environment (which will probably be low under emergency conditions) should also receive brief consideration along with that of the overall speech sound level to be delivered to the miner.

b. Uplink

Performance calculations, similar to those for the downlink discussed above have also been performed by ADL for a baseband voice uplink using a multiturn 100-foot periphery loop transmit antenna instead of a long wire. The results indicate that, except under the most favorable conditions of depth (300 feet) and the quietest of surface noise conditions, the levels of transmitter power, voltage, and current required are well in excess of those demanded by intrinsic safety, long operating life, and practical size and weight for an in-mine emergency unit. These uplink transmitter requirements for voice should be reconfirmed, along with those for the downlink voice system, in light of the more comprehensive NBS mine noise data now available and the larger in-mine loop antennas being considered. However, it appears that an uplink voice system that can operate from available emergency power will continue to remain impractical until an economic and practical way is found to significantly reduce the bandwidth required to transmit intelligible speech.

C. Sidelink Call Alert Coded Page System

1. Overview

The call alert system is a recent by-product of the success experienced with the experimental electromagnetic CW transmitter developed by WGL for locating miners trapped beneath overburdens of 10^{-2} mho/m conductivity to depths of 1,000 feet. As mentioned previously, the location transmitter is intrinsically safe, operates from a miner's 4-volt cap lamp battery into a one-turn loop placed in an entry or wrapped around a coal pillar, and generates a periodically interrupted CW signal in the 1-3 kHz band. This signal is detectable on the surface above the miner and is suitable for locating the miner's horizontal position. The development of this location transmitter has now progressed to where an improved preproduction prototype unit is being manufactured by Collins Radio Co. in limited quantities for testing in some operating mines.

Since the horizontal ranges desired for the call alert system described in section II are commensurate with the vertical ranges obtained for miner location, the Bureau is presently giving high priority to the development of a call alert page system centered around an adapted version of the WGL location transmitter. As presently conceived, this paging transmitter will be activated by means of a carrier signal sent over the mine phone line from the surface to the desired section. The call alert transmitter will be connected to a loop wrapped around a coal pillar, perhaps at the section loading point, and will transmit a single frequency tone (perhaps simply coded) to a compact, dual-purpose, helmet-mounted receiver worn by the individual being paged to the section's mine phone. Under low noise emergency conditions, this receiver will be operable in a baseband voice mode for downlink message reception. Under high noise operational conditions, it will operate in a narrowband call alert mode, receiving a prearranged CW paging signal spaced between the strong 60 Hz harmonics usually present under these conditions.

A first generation experimental call alert system has been built from existing hardware by WGL, and installed in the Bureau's experimental mine to demonstrate concept feasibility in a non-operational environment. Though the operating frequencies of the present experimental unit are in the 1-3 kHz band, to take advantage of the frequencies available with the present location transmitter, an overall system analysis for an operational noise environment may reveal a more effective operating frequency.

Overall system requirements are presently being formulated by the Bureau. These will form the basis for subsequent systems analysis and optimization of designs that can be converted into practical, intrinsically-safe hardware for day-to-day use in operating mines.

2. The Channel-Transmission Loss

a. Loops

In-mine call alert paging is a sidelink application utilizing two essentially coplanar loops, while miner location is an uplink application utilizing two essentially coaxial loops. Examination of Wait's theoretical coupling curves for infinitesimal loops buried in homogeneous overburdens reveals that the operating range for a horizontal coplanar geometry is reduced by only about 20% over the range for a vertical coaxial geometry, for ranges in the vicinity of three skin depths. This operating range is reduced even less at greater distances. Vertical ranges in excess of 1,000 feet have been obtained with the location transmitter. At 2 kHz (the center of the 1-3 kHz operating band of the location transmitter), the three skin depth range is 1,100 feet, which gives rise to a potential sidelink operating range of 900 feet. This 900 foot range is in excess of the 400 to 800 foot range needed for call alert coverage of the typical 600 by 600 foot section mentioned in section II. The above range conclusions are, of course, based on equal noise conditions for each case. Since the noise environment will likely be more severe for the in-mine, operational, call alert application, its effect on operating range and transmitter/receiver design has to be determined.

At the under 5 kHz frequencies of present interest for the call alert system, the theoretical work of Wait/ITS has shown that the effects of layering (such as that found above and below coal seams) and air-filled cavities (such as tunnels in coal seams) should not be significant for loops, and therefore can largely be ignored for communications applications. Similarly, the infinitesimal loop theoretical results should be adequate for making performance predictions, particularly at the desired range limits, for mine sections free of parasitic influences. At ranges close to the loop installation, the infinitesimal loop results will tend to overestimate signal strengths somewhat. This discrepancy will become important primarily when treating potential coupling to nearby parasitic structures, as discussed below. Therefore, curves, tables, nomographs should be prepared for the vertical magnetic field component in the plane of the transmit loop, based on the available theoretical results for coplanar infinitesimal loops. These can be used temporarily for making preliminary performance predictions until more information is forthcoming on the effects of the conductors prevalent in mine sections.

b. Parasitic Structures

Mine sections typically contain many conductors, such as trolley wires and rails, fixed and trailing power cables, roof bolts, and sometimes steel roof-supported mesh, that can affect the strength and orientation of magnetic fields. Therefore, a series of limited signal strength measurements should be conducted in operational mine sections, and in other mine locations that are relatively conductor-free. These simple experiments are needed; to verify whether the homogeneous-overburden coplanar loop results can be applied with confidence to operational sections, and to formulate practical design guides for operational sections. Preliminary results from field measurements taken by ADL in the Bureau's experimental mine indicate that significant departures from the theoretical results can in fact occur.

In parallel with the above field measurements, corresponding theoretical analyses are needed to predict the degree to which the direction and strength of the magnetic fields produced in the tunnels, by finite loops wrapped around coal pillars, will be affected by the above mentioned conductors in working sections of the mines. Of particular interest will be the effects caused by trailing and fixed power cables, roof bolts, and trolley wire/rail structures, which appear manageable analytically. The potential problems caused by heavy metal mesh occasionally used for roof support were acknowledged, but assigned a lower priority for analytical treatment, because of the infrequent use of this mesh and perceived analytical difficulties.

ITS has done some investigation of the currents induced in a thin, infinitely long, cylindrical conductor by a nearby infinitesimal loop transmitter. This work reportedly is easily extendable; to include the effects of the magnetic field produced by this induced current, and to include the effects produced by a finite loop source. The utility of this approach should be investigated, and pursued if found applicable.

ITS has also examined the influence of buried spherical and prolate spheroidal conducting objects on the fields produced by infinitesimal loop sources. Though originally done in connection with the miner location problem, the results can be applied to the call alert application, to estimate the likely field effects produced by machinery and shuttle cars. For the frequencies, sizes, geometries, and distances of interest, these objects will not significantly alter the magnitude of the fields, but mainly their direction somewhat in the immediate vicinity of the objects. No further investigations of this area were recommended.

c. Roof Bolts

If a finite wire terminated by roof bolts is shown to be a favorable transmit antenna for the roof bolt paging system, a suggestion was made that it also be considered for use in the call alert system.

3. The Channel-Noise

Since this is a narrowband operational system for mine sections, the in-mine wideband noise recordings made by NBS should provide an adequate data base. Of particular interest will be expanded frequency-scale power spectra showing levels of discrete and broadband noise covering the 0-5 kHz band; and representing data taken primarily on working sections in the vicinity of face machinery and power cables and conversion equipment, under representative operating conditions. Vertical field components of the noise will be mose important for this application. Dubs of select recordings will also be desirable as mentioned previously. Although frequencies below 5 kHz are presently favored, data can and should be examined above 5 kHz for this system.

4,5. The Source and Receiver

Only little attention was devoted to this topic, with the group agreeing that a definition of system requirements and an overall system analysis were needed to identify the most favorable and practical system design approaches. However, a few brief comments were made.

The transmitted call alert signal could be a single tone, keyed on and off with a fixed duty cycle, as in the present experimental unit. For a single page signal per section, the simple, single tone system now used in the experimental unit could be adequate. For several pages addressable to different individuals per section, some means of coding the single tone, or use of multiple tones would be needed. The most favorable coding method from practical and noise immunity standpoints needs to be determined.

On the receiving end, it was noted that notch filters may be needed to minimize interference from 60 Hz harmonics adjacent to the signal frequency. The most practical and effective noise processing techniques suited to a compact, helmet-mounted receiver need to be determined.

As mentioned in section II, this system could conceivably share equipment with an uplink data station also located on the mine section.

D. Sidelink Roof Bolt Voice Page

1. Overview

The roof bolt voice paging system is a system conceived and recently developed by the Bureau for transmitting voice messages to key individuals carrying small pocket pagers on working sections under operational conditions. A prototype, using readily available commercial equipment, is presently installed in the Bureau's experimental mine to demonstrate its feasibility in a non-operational environment. The system concept developed as a result of some successful in-mine experiments performed by the Pittsburgh Mining and Safety Research Center; whereby a 20-watt trolley phone 88 kHz FM transmitter was connected to two roof bolts approximately 50 to 100 feet apart in an operating mine, and its voice transmission then received at distances up to about 600 feet away with a small pocket pager utilizing a ferrite loop stick antenna.

Limited field experience to date indicates that operating ranges commensurate with the 400 to 600 feet required to provide section coverage may be achievable, under operational conditions, with an operating frequency in the vicinity of 100 kHz. At this point in time a more quantitative understanding of the transmission loss and what affects it is needed; in order to determine the most favorable operating frequency, to develop practical guidelines for tailoring installations and estimating performance in different mines, and to eventually develop an improved system.

2. The Channel-Transmission Loss

a. Finite Wire Antennas Terminated by Roof Bolts

The finite wire antenna in this case is an insulated wire that runs along the roof of a tunnel and is terminated at each end by attachment to a roof bolt. Field experience to date has found the total termination impedance for such roof bolt pairs, separated by 50 to 200 feet, to fall in the range of 120 to 50 ohms resistive. Theoretical curves and supporting experimental data are needed, to adequately describe the behavior of the magnetic fields produced in the tunnels throughout a section in which such a finite wire transmitter is located.

The theoretical work of Wait and ITS on finite wire antennas buried in homogeneous overburdens, described in sections IIA2c and IIB2a, should be particularly useful in this regard and for estimating system coverage areas in mine sections. Though the present results are for the electric and magnetic fields produced on the surface from such buried antennas, ITS maintains that the desired field strengths in the coal seam tunnels can be easily obtained from its present buried-finite-wire analysis. This case of interest corresponds to receiver locations below, but in the immediate vicinity of, the plane of the finite wire.

Frequencies presently being investigated for this voice page application range from 10 kHz to 300 kHz, with present experimental systems operating around 100 kHz. Although the frequencies in the upper part of this band are higher than originally anticipated for buried finite wire applications, ITS believes that its present analysis should apply.

Therefore, it was concluded that the ITS theoretical analysis of the fields from buried finite wires should be used to determine the desired magnetic fields in the coal seam, in the 1-300 kHz band; and to prepare appropriate practical curves, tables, etc. for use by system designers. In addition, since the overburden is usually layered above and below coal seams, and since layers of varying conductivity can potentially influence the fields from finite wire antennas more than those from finite loops, a theoretical analysis to determine the effects of a simple, representative, layered model should be performed.

The non-conducting volumes created by the grid of tunnels in the coal seam were considered too difficult for exact analytical treatment at this stage; and in fact may not create significant effects on the magnetic fields in the tunnels, because the tunnels are relatively narrow and the currents can still flow without much alteration through the wider coal pillars.

Collins Radio and Spectra Associates are also reported to have performed theoretical analyses of the fields from buried wires, for the infinitely long and infinitesimally small cases. This work should also be reviewed, compared with the ITS results, and utilized if applicable.

Collins Radio has also conducted some limited measurements of the magnetic fields produced by 52 feet long, finite wire roof bolt antennas in an operating mine. Three field components were measured at three distances between 300 and 700 feet away from the finite wire, in both the broadside and axial directions, and at five frequencies in the 1-50 kHz band. Though these measurements do not fully characterize the expected transmission loss behavior, the data serve as a good starting point for comparisons with theory and establishing practical design guidelines. More measurements are needed, covering a greater range of distance, frequency, and roof bolt spacing, and particularly in mine working sections.

b. Parasitic Structures

As in the case of the call alert system, a roof bolt system installed in a working section can be expected to encounter many conducting parasitic structures that may alter the directions and magnitudes of the signal magnetic fields. These effects may even be magnified for finite wire systems operating at the higher frequencies anticipated. Indeed, some limited field measurements taken at 88 kHz by ADL, for a roof bolt antenna installation in the Bureau's experimental mine, indicate an extremely high variability in the levels of the measured vertical field component at comparable ranges from the roof bolt antenna. Therefore, and for the same reasons given for the call alert system, a similar experimental and theoretical effort is recommended to resolve the issues concerning the effects of parasitic conducting structures found in representative working sections of operating mines.

3. The Channel-Noise

Since the roof bolt system is a voice paging system for use under operational conditions, its operating frequency will most likely be above about 10 kHz, where the operational noise levels decrease to more tolerable levels. Present consideration is being focussed on the 10 kHz to 300 kHz band. The present experimental system operates at 88 and 100 kHz, but since these frequencies are already utilized by mine trolley wire carrier systems, alternative non-interfering frequencies are also desirable.

As for the other systems, the recently obtained NBS in-mine noise data should serve as a more than adequate data base for systems analysis and optimization in the 10 kHz to 300 kHz band. From the wideband tape recordings, power spectra for horizontal and vertical magnetic field components will be available, depicting discrete and broadband noise levels over the frequency range from 0-100 kHz and 0-300 kHz. In addition, noise amplitude probability distributions and rms levels will be available from the narrowband (2 kHz) spot frequency noise recordings, at eight frequencies over the 10 kHz to 32 mHz band, four of which fall below 300 kHz. Appropriate dubs of selected tape recordings for both types of noise measurement should also be available. Detailed reports documenting these measurements and data will soon be published by NBS.

4,5. The Source and Receiver

The present experimental system is designed around a commercially available 20 watt, mine trolley wire phone transmitter that employs conventional FM modulation and an industrial pocket pager FM receiver that operate at a carrier frequency of either 88 or 100 kHz. Lack of time prevented discussion of the overall system by the group, but it was concluded that the degree to which this system can or should be optimized or otherwise improved with regard to performance, practicality, intrinsic safety, etc. will eventually be determined by the system requirements and a subsequent system analysis.