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Underground Mine Communications

(In Four Parts)

2. Paging Systems



UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8743

Underground Mine Communications

(In Four Parts)

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Compiled by Staff—Mining Research



UNITED STATES DEPARTMENT OF THE INTERIOR

Cecil D. Andrus, Secretary

BUREAU OF MINES

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UNDERGROUND MINE COMMUNICATIONS

(In Four Parts)

2: Paging Systems

Compiled by Staff—Mining Research

ABSTRACT

This Bureau of Mines report summarizes the research, development, and evaluation demonstrations conducted by the Bureau of Mines under the Health and Safety Act of 1969 to improve the means of notifying miners underground, who are away from their own phone, that they are being called.

INTRODUCTION

It has been observed that it typically takes 30 minutes for a person on the surface to reach a person underground by phone. The research reported has been directed toward reducing this time so that it will be no longer than is usual for a person responding to a normal surface-to-surface phone call.

The primary operational requirement of a communication system is that an individual must be able to initiate and receive communications as necessary regardless of where that person is within the mine. The fully integrated mine communication and monitoring (MCM) system discussed in the first paper satisfies this requirement. The MCM-101 call alert is a pocket paging receiver that can be used to alert a called party to go to the nearest phone and return the call. In addition to call alert, another subsystem and interface to a wireless radio make it possible for the person to hold a two-way conversation with the calling party, or to initiate a call when a person is remote from a fixed-location phone.

Although much of the research has been devoted to new paging concepts, some research has been devoted to improving performance of existing paging systems. The second paper, Pager-Phone Guidelines and Test Equipment, reports on research that provides guidance information on the installation, operation, and maintenance of pager-phone systems. This work will familiarize operators, miners, and inspectors with practices and procedures that will allow optimum performance of pager phones.

The primary operational requirement cannot be satisfied by adding on to existing mine pager-phone systems, but intermediate paging equipment has been developed that can be added on to existing systems. The Visual Paging System adds on to the pager-phone lines. By posting a coded signal at display boxes

throughout the mine, personnel are notified that they should call the dispatcher or the switchboard operator. An alternative or addition to the visual pager is an electromagnetic pocket receiver that can be activated from the same office equipment used to post a visual page, as discussed in Call-Alert Paging for Pager-Phone Systems.

The radio pager discussed in the final paper is a pocket page receiver capable of receiving a voice page. The advantage of voice paging is the ability to direct a person to return a call to a specific individual, or to deliver other simple one-way messages or instructions.

Throughout this report, reference to specific companies or trade names is made for information only and does not imply endorsement by the Bureau of Mines.

MCM-101 CALL-ALERT PAGING

by

Harry Dobroski, Jr.¹

ABSTRACT

Under a Bureau of Mines contract, an advanced communications and monitoring system, the MCM-101, has been developed for mine use by Collins Radio. When it is equipped with radio transmitters and receivers, the MCM-101 becomes a call-alert system that enables persons remote from telephones to be contacted. Paging can be either selective or general, but both types are controlled by the system center. The selective pager is a small pocket- or belt-carried unit which, when activated by any telephone in the MCM-101 system, sounds a buzzer and lights a lamp. First-generation units have been tested at the Robena mine. The experiences gained in these tests are being applied to second-generation units now under development.

INTRODUCTION

In any paging system, two things are of prime importance. First, the system must have great range, because personnel underground, especially management, may be anywhere in the mine. Second, the system must be capable of being selective; that is, only the person being paged should actually receive the signal. Otherwise, there would be a tendency to turn off or ignore the pager altogether because the large number of calls generated would be a nuisance. In the MCM-101 system, both general and selective paging are possible; that is, all mine personnel can be paged simultaneously, or a single individual can be paged.

DISCUSSION OF SYSTEM

Dual Paging Capability

A system center, usually located on the surface, controls and monitors all of the devices associated with the entire MCM-101 system. The center consists of a minicomputer, interface circuitry, a teletypewriter, and monitor readout devices. Figure 1 presents a diagram of the MCM-101 paging system.²

The most important underground device in the MCM-101 system is the telephone. Besides offering more private, single-channel communication, the

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²Collins Radio Group. Call Alert Receiver Manual--Model 59D-1. June 1975, 4 pp.; available from H. Dobroski, Bureau of Mines, Pittsburgh, Pa.
Collins Radio Group. Call Alert Pager Modification--Model 59D-1. June 1975, 11 pp.; available from H. Dobroski, Bureau of Mines, Pittsburgh, Pa.

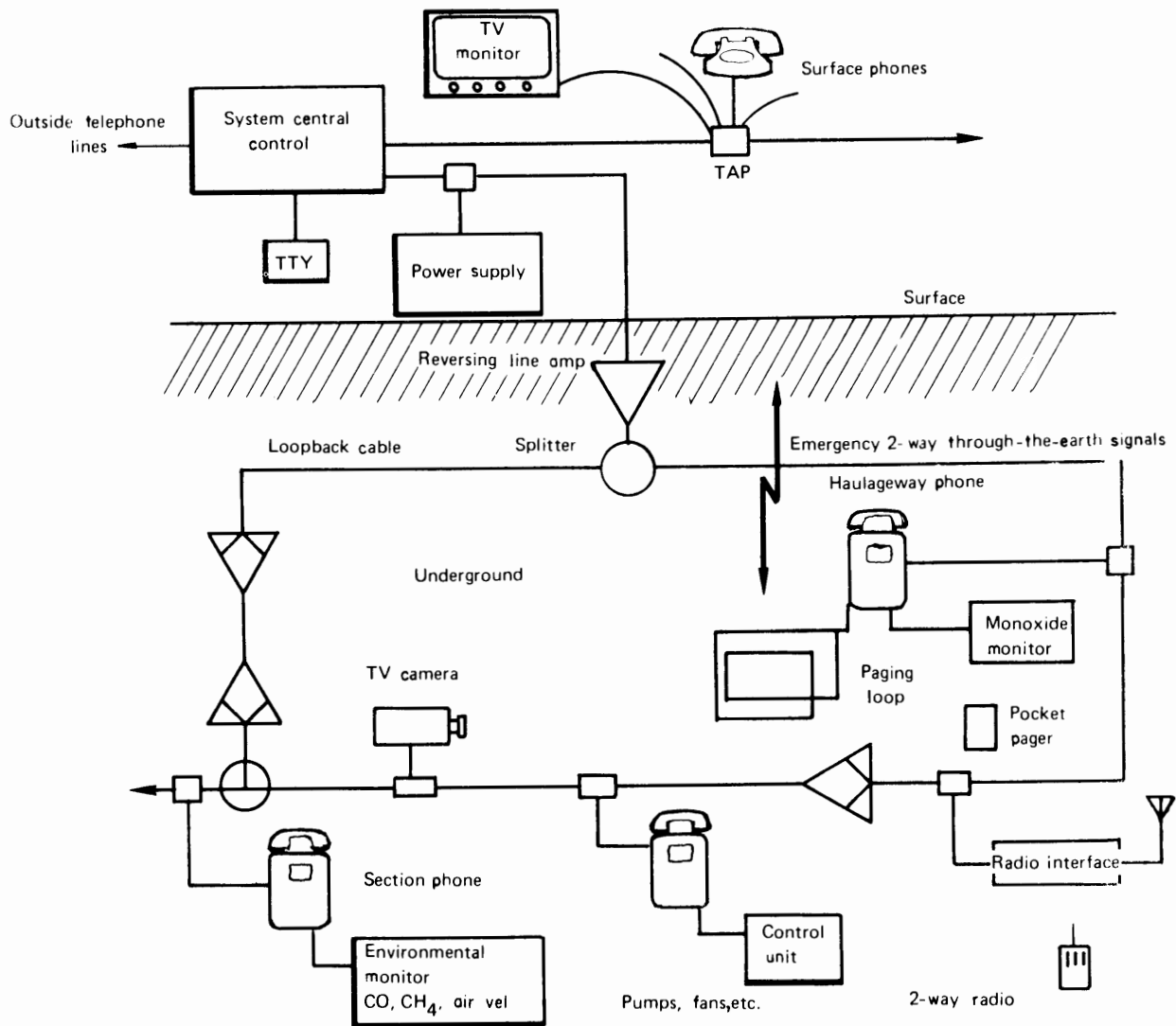


FIGURE 1. - Diagram of MCM-101 telephone system equipped with call-alert paging.

telephone can be equipped with a variety of devices, such as monitors and control units. In addition, each phone can be equipped with a special internal radio transmitter that also can be controlled by the system center. Each phone used in the system has a jack on the bottom to accommodate an antenna. The antenna consists of a single loop of wire around the coal pillar nearest the telephone. The antenna and the associated internal radio transmitter form the basis of the general paging system.

Operational Features

Assume I am near a phone, either in the mine or on the surface, and you are in the mine. As shown in figure 2, I can contact you from any of the telephones in the MCM-101 system. Obviously, if I know you are near a



FIGURE 2. - Operator using a telephone to initiate a page.

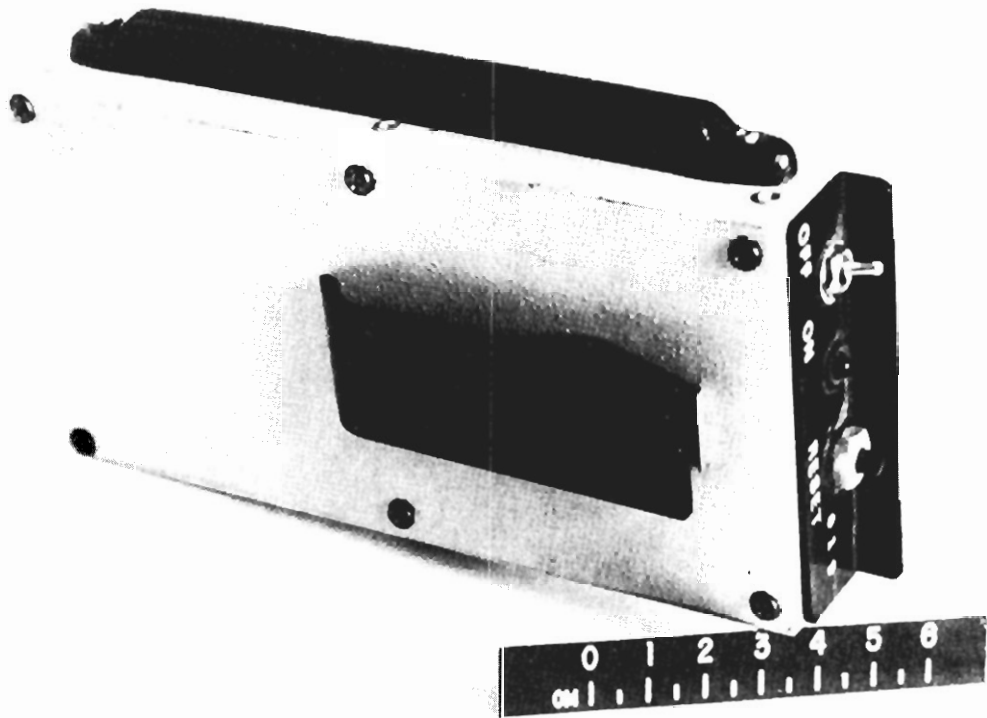


FIGURE 3. - MCM-101 pager unit.

telephone, simple phone-to-phone contact can be made. However, in a mine environment, this is rarely the case; the person being called is usually somewhere in the mine away from a phone. If this is the case, I would then try to page you. To do so, I must know the number of the pocket pager you are wearing (for example, pager No. 019). Then, I just go to any phone, surface or subsurface, and dial "7-019." The seven signals the system center that paging is desired. The system center then instructs each radio transmitter in each underground telephone to transmit a coded message into the mine, using the loop antennas mentioned earlier. Although this coded message may be received by many pocket pagers, only one--yours--is designed for this particular code, and only pager 019 would come on. When it does come on, it buzzes for about 1 second and a small indicator lamp lights, remaining lit until the unit is reset (fig. 3).

Of course, you have no idea who originated the page, or where the originating phone is located. But since the system center is computer-controlled, this information is stored in the computer. To answer my page, you have only to go to any telephone and dial "*-019." The asterisk tells the system center that a page to 019 is being answered. The system center then rings my phone, and we can then carry on a regular telephone conversation. All this is done without me knowing where you were located in the mine, or you knowing where I originated the call.

After a preselected time, usually about 15 minutes, the system center will erase all information from memory. Thus, if a page is not answered within 15 minutes, it cannot be answered. This feature keeps the computer from being overloaded if pages are not answered. An unanswered page usually means that the paged person was so far from a telephone radio transmitter that he did not receive the page.

In addition to selective paging, the system also offers general paging. In this mode, dialing 7-000 results in all pagers in the mine coming on simultaneously--an important feature under emergency conditions. Although this system is sometimes called "whole-mine paging," there is, of course, a limit to how much actual coverage is possible. If the loop antennas are put around coal pillars about 70 feet on a side, the range is about 800 feet from each antenna. Coverage of several thousand feet is possible, but in this case the signals are being complemented by mine wiring, and this is not considered typical.

PROGRESS TO DATE

Experience with the pagers to date has been limited. Systems have been installed at the Robena mine of United States Steel Corp. and the Safety Research Mine of the Bureau of Mines. Tests on these systems showed that the pagers should be modified to reduce their size and improve their stability. However, since these particular units were first-generation prototypes, such modifications are not unusual.

PAGER-PHONE GUIDELINES AND TEST EQUIPMENT

by

Robert L. Chufo¹ and Roger G. Long²

ABSTRACT

Pager phones continue as a widely used communication system in coal mines. Certain limitations, such as the lack of selective calling and the party-line type of operation, are offset by the ease of operation and maintenance, low cost, and proven reliability in the mine environment.

The Bureau has developed technical memoranda to teach operating personnel, maintenance workers, and inspectors how to install and maintain pager-type telephones. These technical memoranda include installation, lightning protection, cable selection, cable splices, and testing. Line drawings illustrate the basic principles of telephone operation, cable splices, protective circuits, and recommended installation and maintenance. The memoranda will be published as a Bureau handbook.

To assist in testing the pager phones, commercial-telephone-testing equipment was modified to suit the unique requirements of these telephones as normally used in coal mines. Additional test equipment was designed to provide a tone-test signal and circuit switching to disconnect the test signal generator during paging.

INTRODUCTION

In large mines, complex communication equipment is used and maintained by appropriately trained personnel. Where traffic loads warrant it, the more complex telephone systems allowing zone and/or selective calling are used. However, in the vast number of smaller mines, the party-line pager phone does the job, and the general maintenance crew is able to service the phone system. Figure 1 shows the pager-phone models now in use in underground coal mines.

To help mine personnel install and maintain a pager-phone system, technical memoranda have been developed, and test equipment has been identified for use within the mine for go no-go testing. Additionally, to assist manufacturers in developing consistent, quality equipment suitable for the environment, and to assist operating personnel in judging the capabilities of a wide choice of pager phones, guidelines were developed for evaluating the acceptability of pager phones.

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²Electronics systems section, Arthur D. Little, Inc., Cambridge, Mass.

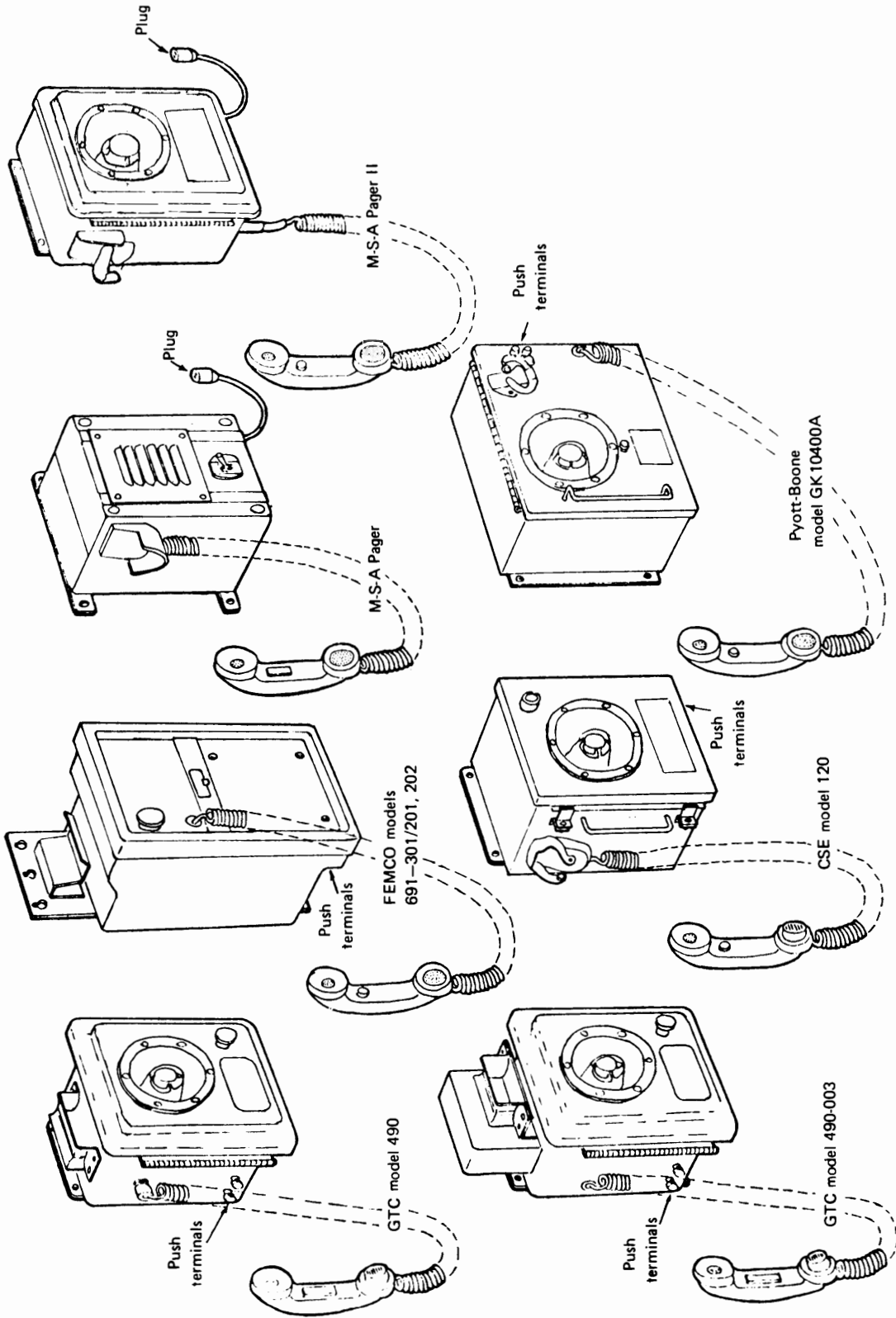


FIGURE 1. - Pager-phone models currently in use. (Terminals or plugs shown are for connection to the lines.)

STATUS OF HARDWARE AND ITS INSTALLATION AND MAINTENANCE

Controlling and Monitoring Communication Equipment

Adequate communication within a mine and between the surface and the underground work stations is a vital part of the proper operation of an underground facility. Communication is not only an important safety factor, but also aids in day-to-day operations and the task of moving coal to the surface. In certain classes of coal mines, current regulations require that telephone communication be provided between each working section and the surface. The communication equipment installed in by the last open crosscut must be approved by the Mining Enforcement and Safety Administration (MESA) as either intrinsically safe or permissible. The MESA inspector must verify that all installed equipment functions and meets the safety requirements. By training and current practice, the mine inspector's duties in the area of communication equipment are limited to verifying that acceptable equipment is installed at the minimum required locations, and that the equipment is operational.³

Lack of Training

A major problem in service and maintenance in all but a few of the larger mines seems to be the lack of trained personnel on site, as well as a lack of uniformity in installation standards. Reportedly, only minimum effort is made to ascertain whether the equipment is reliable and suitable for a particular application as long as it is safe to operate. Certain mines experience high rates of communication-equipment downtime, while others with the same or similar equipment have minor problems. The only correlation seems to be in the on-site maintenance practices, which include installation.

Operating personnel are becoming more aware of the necessity for reliable communication. Many of the systems were installed at the insistence of the operating personnel to provide greater reliability, more flexibility in direct communication to isolated work crews, and the capability to interface with a public-service network. In some mines, however, operating personnel have no interest in communication facilities other than using them to assist in controlling vehicle traffic.

Federal, State, and company mine-safety inspectors have training and experience in matters of structural safety and safe mine-operating procedures; in addition, equipment has been developed that enables these personnel to compare these parameters with a common reference. However, the tools and experience required for periodic inspection of communication installations are not universally available. To improve this situation, descriptive guidelines have

³Long, R. G., and J. J. Ginty. Investigation of Communication Standards as Related to Coal Mines. BuMines Open File Rept. 5-75, 1973, 56 pp.; available for reference at Bureau of Mines libraries in Pittsburgh, Pa., Denver, Colo., Twin Cities, Minn., Spokane, Wash., and Morgantown, W. Va., and the Central Library, U.S. Department of the Interior, Washington, D.C.; and from National Technical Information Service, Springfield, Va., PB 240 552.

been developed that define procedures and instruct personnel in their application.

Improvement Possibilities

The suitability of the telephone performance is, to a large degree, a qualitative judgment at present. To change this situation, the following steps should be taken:

- Recognize that good communication contributes to safety and to the economic production of coal. Within a busy mine, the ability to control vehicle traffic improves productivity and promotes safety, as does the ability to call fixed stations easily.
- Examine and define acceptable levels of communication performance. Work that has been done by groups such as the telephone companies on analysis of parameters that limit the transfer of intelligence in alien environments can provide a basis for this examination.
- Provide the inspector and maintenance personnel with simple measurement aids to enable them to evaluate a communication system by comparing it with prescribed performance levels.

The minimum necessary measurements are--

Personal judgment of fidelity or clarity of reproduction.--This can be referenced to standard recordings taken in typical installations to provide a basis of comparison of marginal, acceptable, and nonacceptable conditions. Examination of these standard recordings could be part of the training of the inspectors and maintenance personnel.

Measurement of battery status. This can be done with suitable meters that measure voltage under load and display the status of remaining capacity.

Measurement of the signal-to-noise ratio of the audible transmission.--This can be done with a sound meter, again using training and judgment to determine the relative effect of the background noise.

It is evident that mine communication is becoming a more important factor in mine safety as well as in day-to-day operations. In fact, because communication equipment has become so widely used in day-to-day operations, operating personnel have become dependent upon communication, and this becomes a part of mine-safety considerations.

GUIDELINES AND TEST EQUIPMENT

Instructional Guidelines

Guidelines were developed to provide instruction in some of the fundamental aspects of installation, maintenance, and inspection of underground

coal mine pager telephones. The guidelines will be published as a Bureau of Mines handbook.

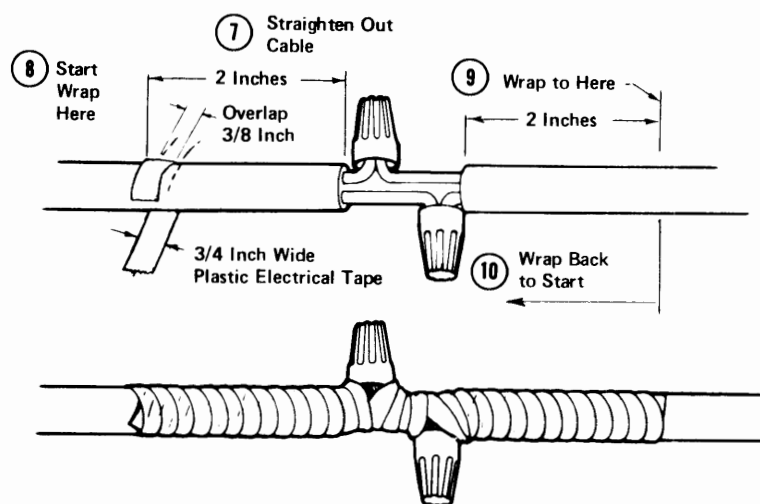


FIGURE 2. - Excerpt from guidelines showing recommended practice for cable splice.

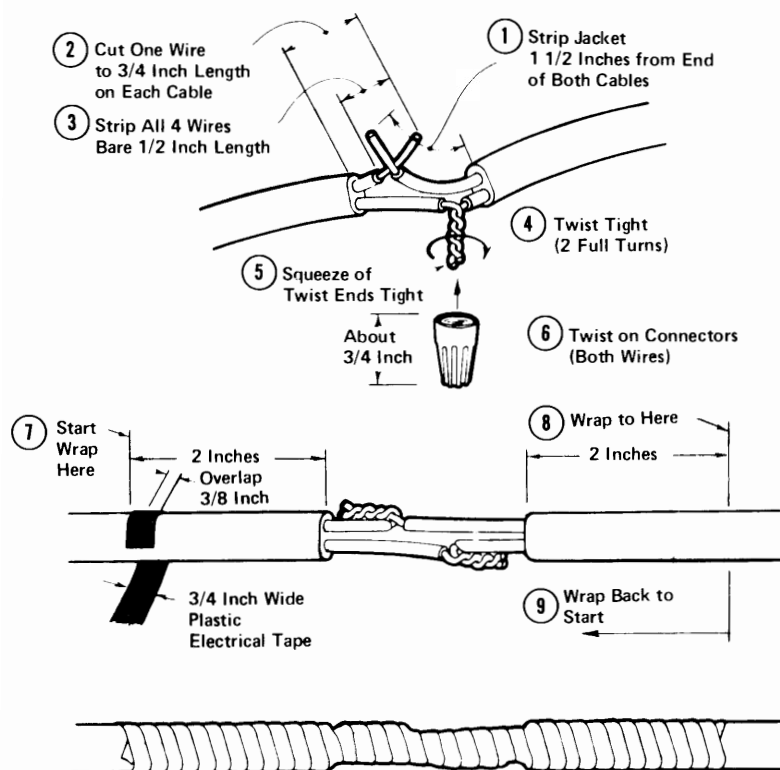


FIGURE 3; - Excerpt from guidelines showing recommended practice for pigtail splice.

Recommended practices were described for cable installation, splicing, and circuit protection. Line drawings are included to demonstrate key principles and methods of performing electrically and mechanically secure splices (figs. 2-3). Representative cable connectors, telephones protective devices, and junction terminals are described.

The operation of the telephone and the telephone system is described and illustrated with line drawings to show the relationship of operating functions, switches, and relays during each of the separate modes of listening, talking, and paging (figs. 4-6).

Methods of testing and inspecting the pager phones are described, including how to test and judge the operational readiness of a pager phone. For a more specific judgment of pager-phone performance, detailed instructions are given on the use of basic test equipment.

A modified subscriber loop test set (fig. 7) was manufactured for the Bureau by Northeast Electronics of Concord, N.H., to measure certain basic phone operations. The set will test direct-current voltages to verify battery level and paging signal, audio-signal levels to measure the audio

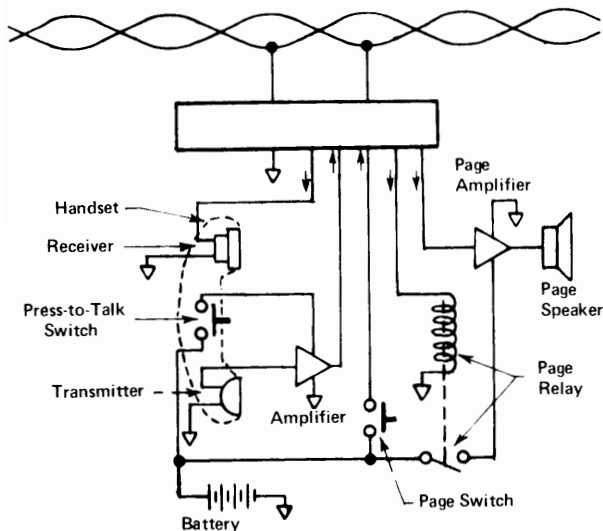


FIGURE 4. - Excerpt from guidelines showing schematic of generalized two-wire system.

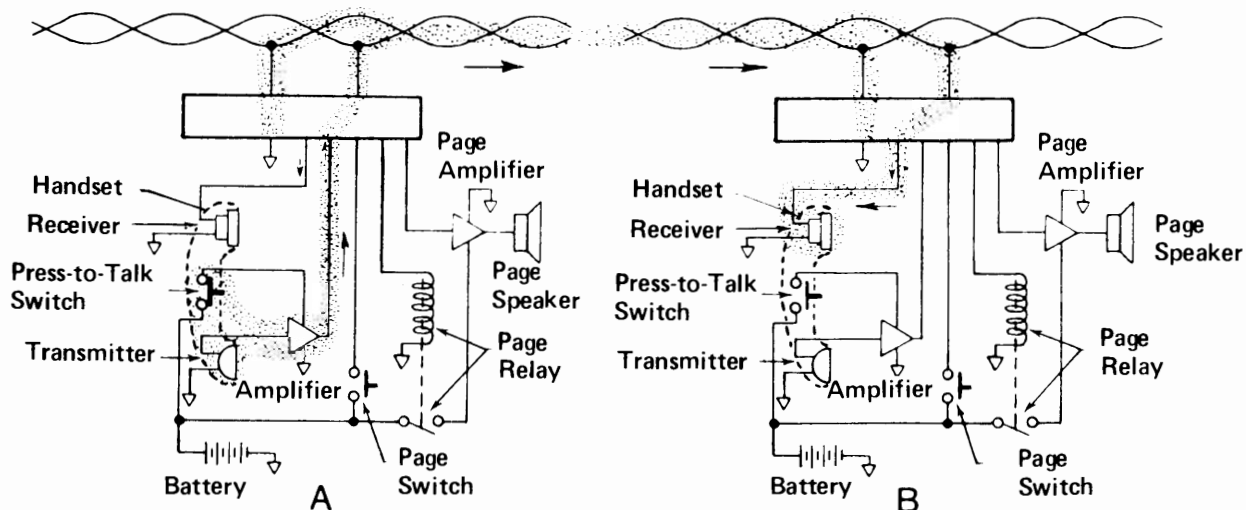


FIGURE 5. - Excerpt from guidelines showing system in talking (A) and listening (B) modes.

output of the transmitter, the audio level on the line, signal losses or attenuation, and line leakage to ground.

An audio test tone can be applied to the line by a specially designed tone generator developed for the Bureau by Arthur D. Little, Inc. (fig. 8) to provide a standard audio-signal reference for telephone and system diagnoses. A standard tone signal is useful in system diagnoses and in evaluating system losses. To avoid interference of normal operation of the pager phone during testing, this tone generator produces tone bursts for 10 seconds every 30 seconds. An additional circuit was added to shut off the tone during paging so that the tone would not be broadcast by the paging speakers. The tone source and switching circuit are included in a self-contained, battery-operated test set.

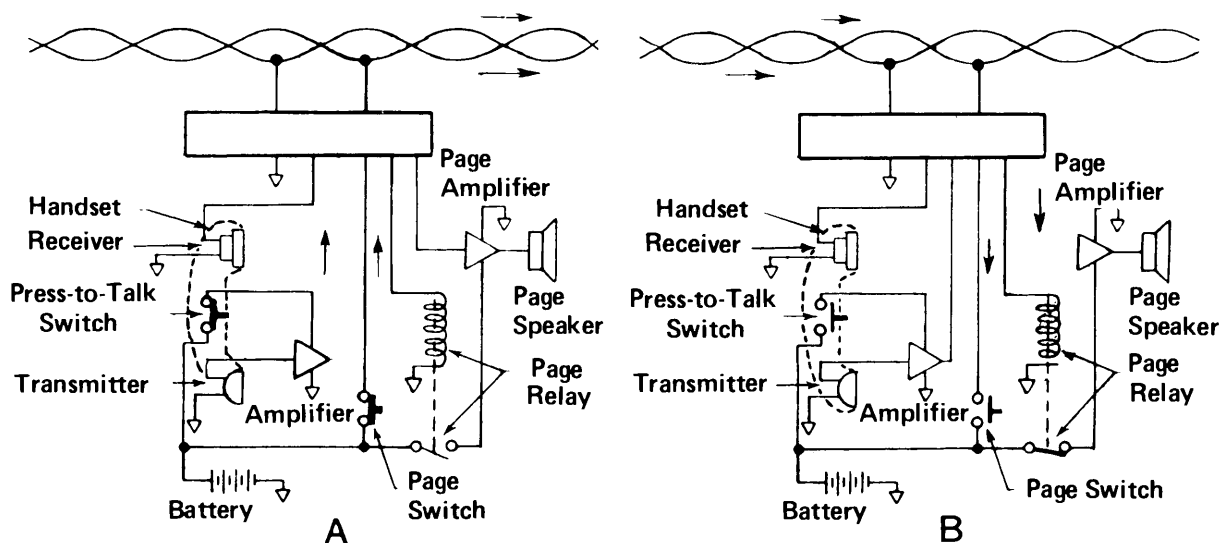


FIGURE 6. - Excerpt from guidelines showing system in paging mode.

Acceptability Guidelines

Continuing in this program of developing instructional information on pager-phone systems for the use of operating personnel, a set of guidelines was developed to establish a common reference for manufacturers, inspectors, equipment-certification personnel, and mine operating personnel to judge the acceptability of a pager phone for underground coal mines. The guidelines cover recommended design, construction, and performance. With this common reference, manufacturers can design and fabricate pager phones to meet a known standard, and the users can judge acceptability by the same reference. The guidelines include recommendations on electrical parameters, construction practices, compatibility with other equipment, intrinsic safety, and permissibility.

Electrical parameters included are the paging function, audio transmission and reception, loudspeaker volume, the ability of the telephone to function with typical electrical-noise levels, and the relative impact of power drain on battery selection, life, and replacement.

Construction practices applicable to the underground coal mine environment include recommendations for materials selection, packaging methods, serviceability requirements, and selection criteria for components suitable for reliable operation underground.

The telephone must function in the presence of other signals in such a manner that it will not interfere with the transmission of these signals on the telephone lines. Recommendations are made to guard against interference or degradation of the telephone signal or of the other signals on the telephone line.

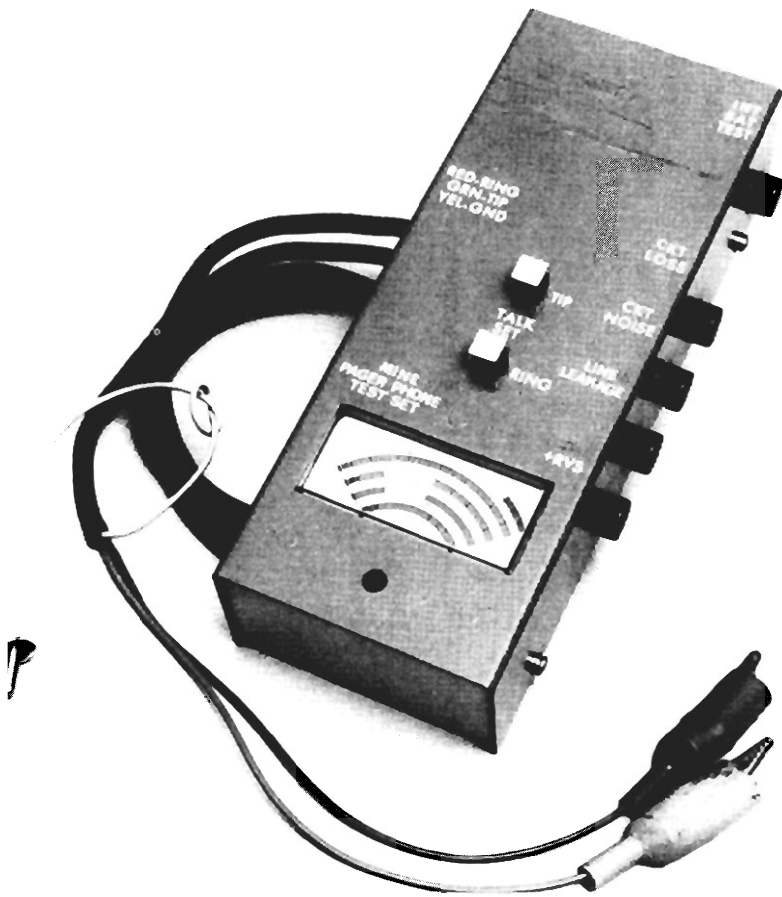


FIGURE 7. - Modified subscriber loop test set.

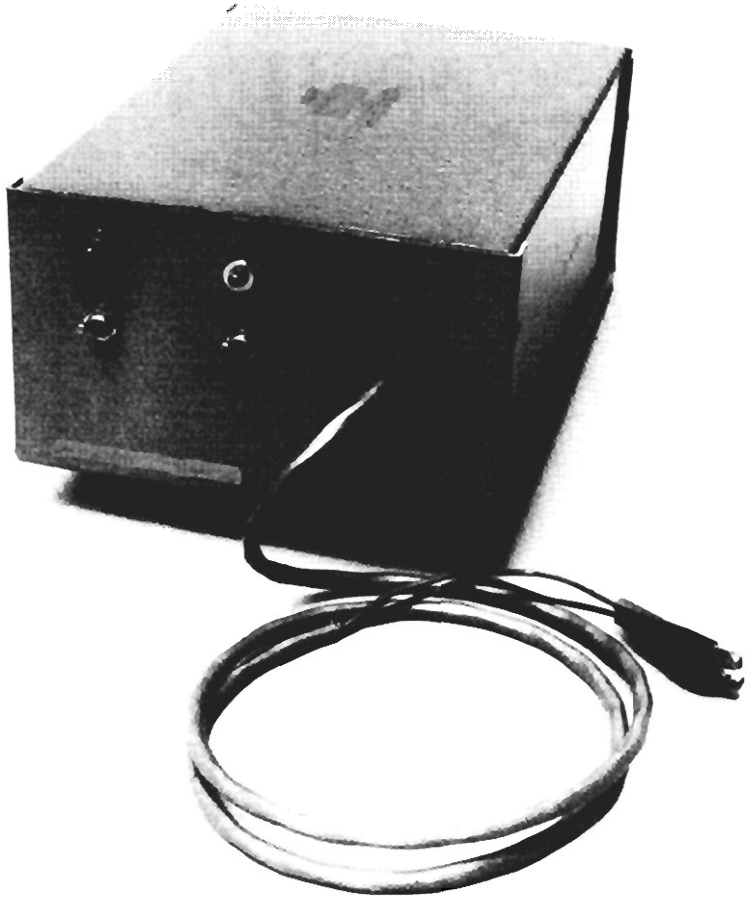


FIGURE 8. - Specially designed tone generator used to test audio tones.

Practices and procedures are prescribed to insure that a telephone can operate safely within an underground coal mine or in a gassy area. These procedures are described in applicable regulations, and they are discussed in the guidelines with alternative procedures for conforming to the regulations.

PROGRESS TO DATE

These guidelines are currently being reviewed by key industry personnel in addition to review by the Bureau of Mines and MESA. They should be available from the National Technical Information Service (NTIS) during the second quarter of 1977.

VISUAL PAGING SYSTEM

by

Harry Dobroski, Jr.,¹ and John E. Trombly²

ABSTRACT

Pager phones are the primary method of communication in many mines. When an audio page message is transmitted, the person called may be out of audible range, or the paged message may not be understood because of ambient noise. A system has been developed under a Bureau of Mines contract that presents a visual indication that a call is being held for a specific person working in the mine. This signal can be left on view for a prolonged period without additional power drain. Power drain occurs only during the actual time of signaling, and this power is supplied by internal batteries. The visual paging system operates over the two-wire system of the pager phone.

Experimental units have been tested at the Bureau of Mines Safety Research Mine in Bruceton, Pa., and smaller, more advanced units have been built and are scheduled for testing.

INTRODUCTION

Experience with pager phones has clearly indicated the need for additional methods of summoning mine personnel to a telephone. Loudspeaking pager phones are ineffective in a working area where the ambient noise level is high, and when personnel are simply out of reach of a telephone. For this reason, a visual paging system, with a stored message capability, has been developed to alert mine personnel to contact the dispatcher.

DISCUSSION OF SYSTEM

To alert personnel to a call, the visual pager uses an easily recognized pattern of signals (fig. 1) that can be read from as far away as 100 feet or more by the light from a miner's cap lamp. The pattern can be of any type, but the work to date has focused on a matrix of letters and numerals presented so that selected symbols appear in a predetermined position on the grid. The code called is identified by its position within the matrix as well as by the imprinted symbol on the displayed disk.

The visual display unit (fig. 2) is about the size of a pager phone, is controlled by the dispatcher, and can be operated over the existing pager-phone line. The system can be put into service by simple two-wire connections on the pager-phone line. The self-contained visual display unit is powered by

¹Electrical engineer, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

²Electronic systems section, Arthur D. Little, Inc., Cambridge, Mass.

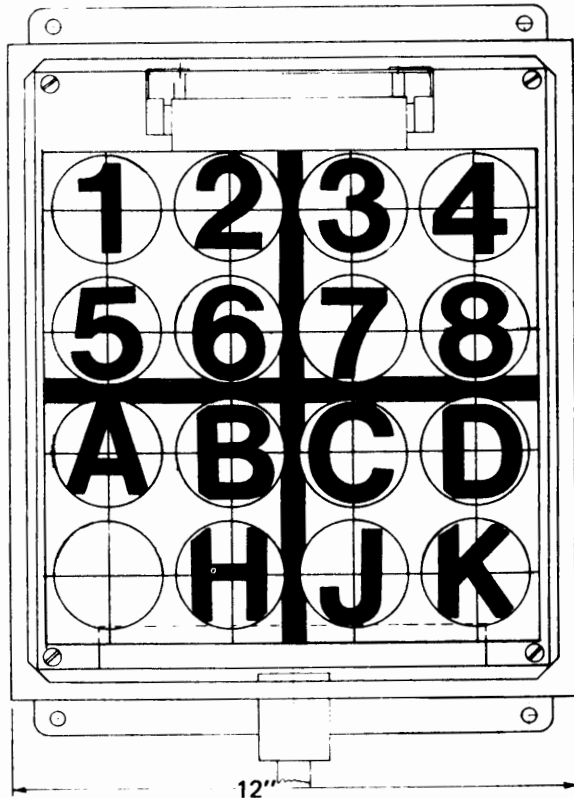


FIGURE 1. - Visual pager display.

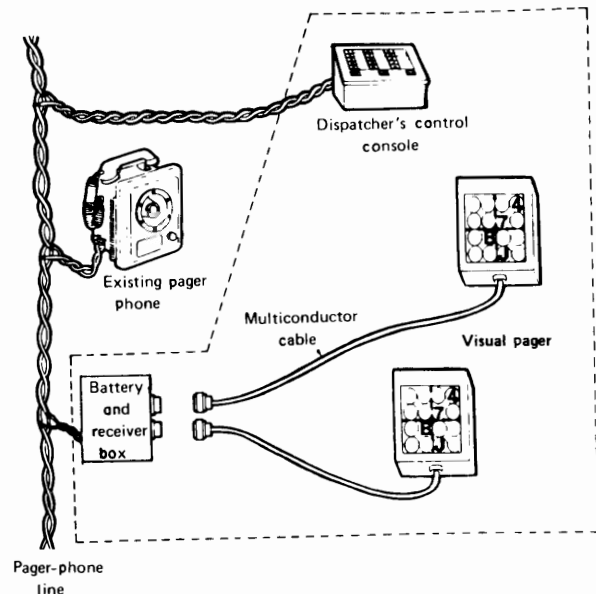


FIGURE 2. - Visual pager system network.

a 12-volt lantern battery of the type normally used in a pager phone. Power consumption is low and the service life of the battery exceeds that of one installed in a typical pager phone.

In operation, a coded signal is generated at the dispatcher's location by depressing a series of pushbuttons or keys on the console (fig. 3). To place a page, the dispatcher first presses the "Post" button. This action puts a direct-current voltage on the line, which activates the visual display circuit and energizes the page circuit at each pager phone. He/she next depresses the key (or keys) to identify the person(s) being called. The console sends a coded signal to all visual pagers to display the appropriate symbol. The displayed symbol remains in view until the dispatcher presses a "Clear" button.

The signal transmitted to the visual pager by the console is a two-tone pair of the type used in touch-tone telephones. Just prior to sending the signal tones, the direct-current voltage is put on the pager-phone lines. This voltage activates all pager phones for a few seconds and also activates the visual-pager circuitry. When the tones that select the visual-display symbols are transmitted, the pager phones broadcast the tone signal. This signal alerts personnel within hearing distance that a call is being made. A quick look at a nearby visual pager shows the viewer who is being contacted. When a signal has been displayed for about 10 minutes, a lamp on the

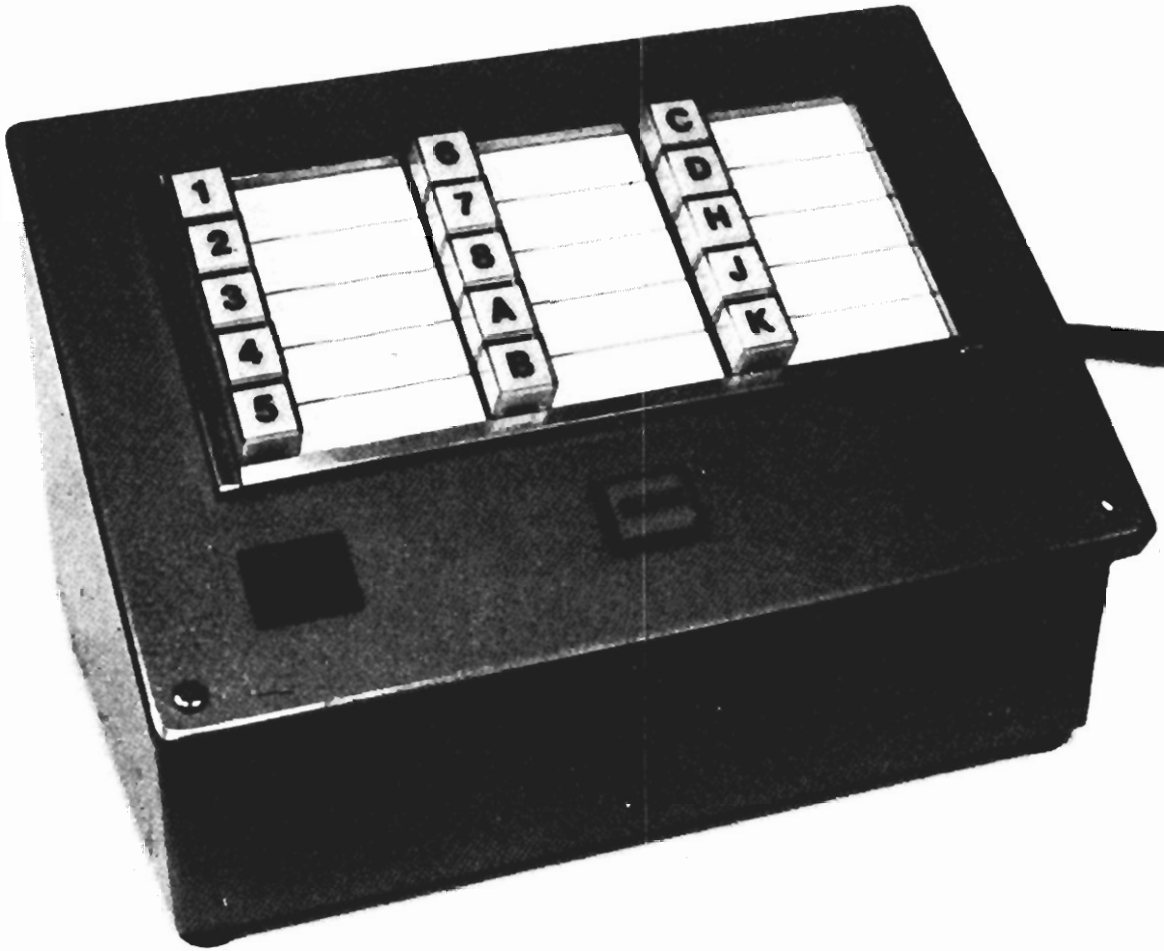


FIGURE 3. - Dispatcher's console.

dispatcher's panel flashes to remind him/her that the call has not been answered and that he/she should try to contact the desired person by other means.

The display unit (fig. 4) activated by the console consists of disks on which the code numbers and letters are imprinted, and the electronics required to receive and decode the number or letter for display. These disks can be grouped into four quadrants, which are divided by reflective axes. The side of the disk normally in view is blank; the other side is brought into view only on command and is imprinted with a number or letter of a reflective material. When a page is posted, the disk rotates so that the side with the symbol is displayed. When the page is cleared, the disk rotates to its normal position with the blank side in view.

The reflective material (fig. 5) is well suited for use in a mine. Since light is reflected in the direction of its source, the display can be read over a broad viewing angle by the beam from a cap lamp without additional illumination. The letters or numbers may be individually assigned to

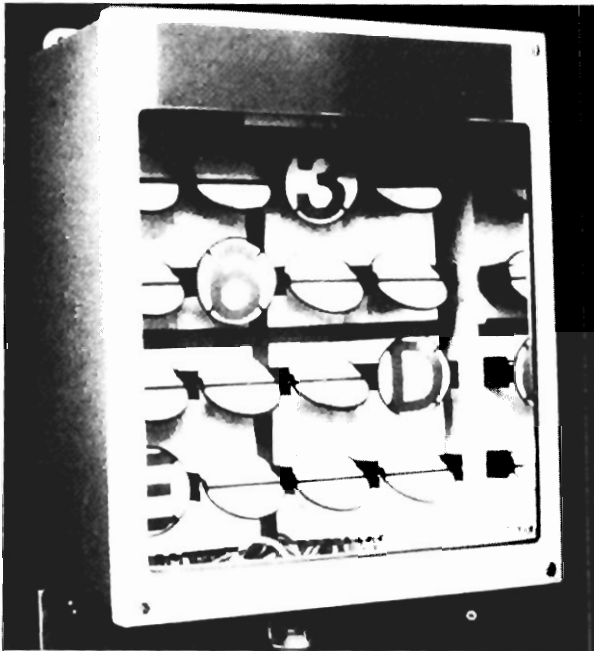


FIGURE 4. - Visual-pager display system showing reflective disks.

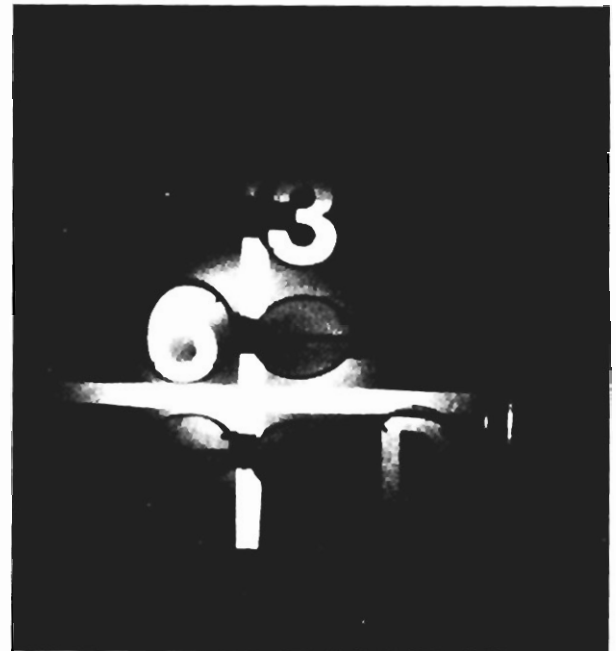


FIGURE 5: - Reflective disk material is well suited for mine use.

personnel by name or by job function, or the symbols may designate a specific preassigned message.

PROGRESS TO DATE

The present display unit prototype is totally self-contained, and has integral decoder and driver electronics, in addition to a power supply and dry-cell battery. This assembly evolved from a previous engineering model, housed in two interconnected assemblies (fig. 2). Additional space was needed in the original unit to accommodate rechargeable batteries, power supplies, and fixtures provided for display illumination. Experience with the display during mine tests (fig. 6) has proven that the best visibility is obtained by employing the miner's own cap lamp as the light source to illuminate the reflective display symbols, without added illumination. The prototype weighs less, is much more compact, and is as simple to install as a pager phone (fig. 7).



FIGURE 6: - Visual pager being tested in mine.

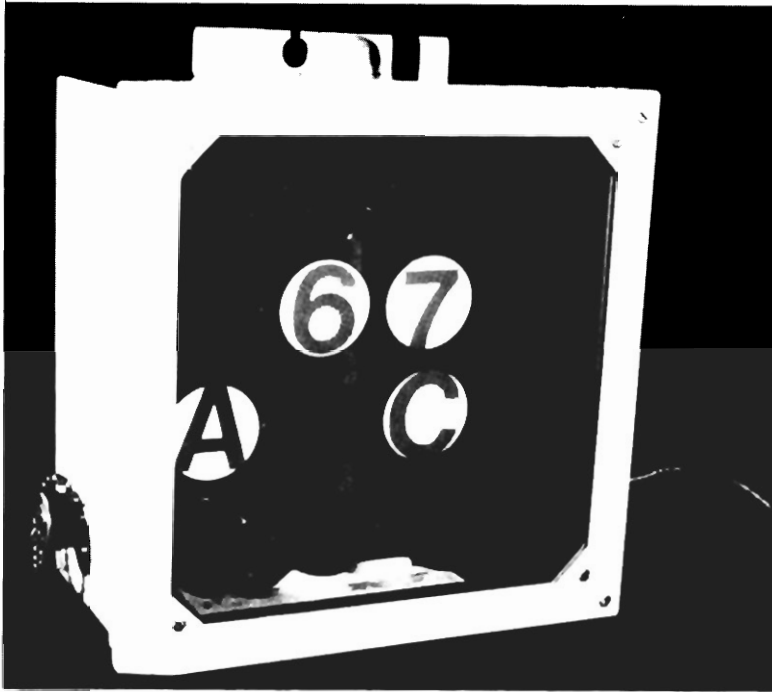


FIGURE 7: - Current model of self-contained visual display, receiver, and battery.

The display prototype was designed to be large enough to accommodate an entire mine roster, with the exact number of display elements selected as a tradeoff between display visibility and physical size (fig. 8). Displays can be deployed at random along a pager line because they operate in unison. The disadvantage of this approach is that the roster size usually provides more information than is necessary in any one location. A roster of eight or perhaps four disks, or even a single disk, would permit a relatively small, compact display (figs. 9-10). However, to serve more than a single working section, the dispatcher's console must have a selective zone-paging capability. Selective zone

paging would give the dispatcher individual control over each display, rather than simultaneous control of all displays operating in unison. The Bureau of Mines is currently considering a program that would add zone paging to the visual pager system.



FIGURE 8. - Visual pager viewed from a distance.

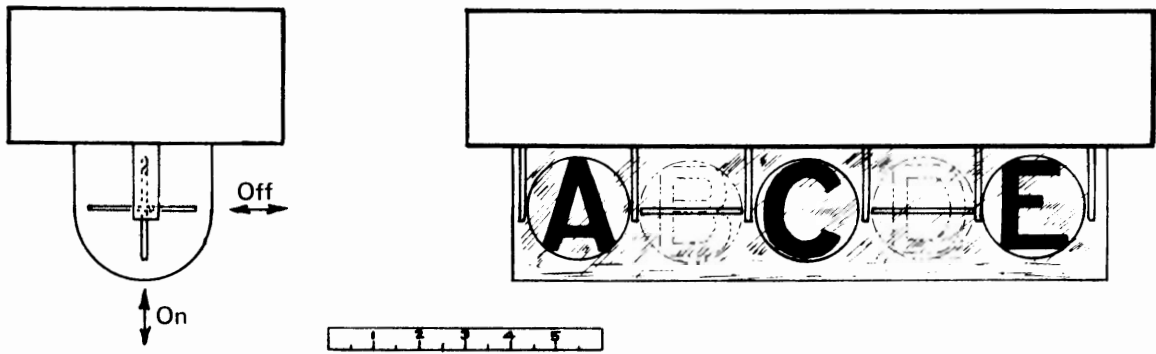


FIGURE 9. - Single-line zone-pager display.

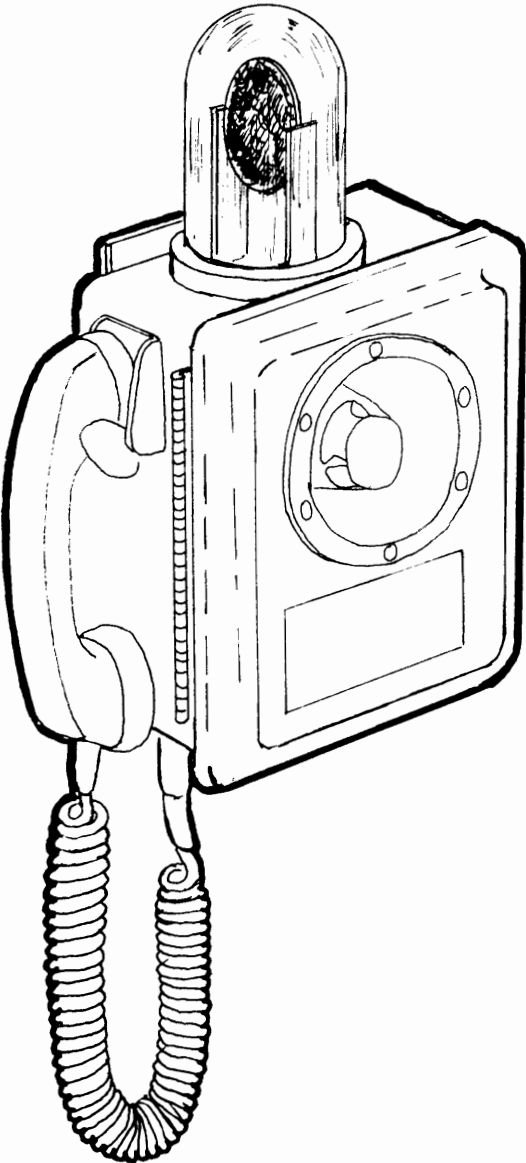


FIGURE 10. - Single-unit zone-pager display.

CALL-ALERT PAGING FOR PAGER-PHONE SYSTEMS

by

Harry Dobroski, Jr.,¹ Stuart J. Lipoff,² and John E. Trombly²

ABSTRACT

The pager-phone system can be upgraded or expanded by adding a visual paging system. To further expand the capability of this system, a radio link for selective paging to key personnel is under development by the Bureau of Mines. In one version, an ultralow-frequency radio transmitter and antenna are added to each visual pager unit. Key personnel carry a small radio receiver that will provide both visible and audible indication of a page signal. When the dispatcher enters a page signal into the visual paging system, the transmitter broadcasts a signal to the called party in addition to the visual display. This system is currently under development and is scheduled to be demonstrated during 1977. A further refinement of this system will allow operation of the radio call alert as part of the basic pager-phone system without the visual pager.

INTRODUCTION

Individual radio receivers with selective-code-calling features are available in a variety of applications. As noted in earlier papers, certain of these systems have been adopted for use in underground coal mines. The call-alert paging associated with the computer-controlled MCM-101 telephone system is designed to provide selective calling of key personnel in remote locations. By adding small radio transmitters to recently developed visual pagers, remote selective radio calling can also be implemented reliably over two-wire mine pager-phone systems. A 3-kHz, differential-phase, shift-keyed signal is used with a parity bit to minimize false alarms. The codes used are the same signals used to operate the visual-pager system.

DISCUSSION OF SYSTEM

Arthur D. Little, Inc., is developing a self-contained, call-alert radio paging system. This system is designed as a low-cost modular addition to the visual pager equipment in underground coal mines that have a two-wire audio paging telephone system. Another system that will operate independently of the visual pager system is also under consideration. A diagram of the visual pager system is shown in figure 1. The call-alert system can be added to the visual pager (fig. 2), or it can be installed as a completely separate system.

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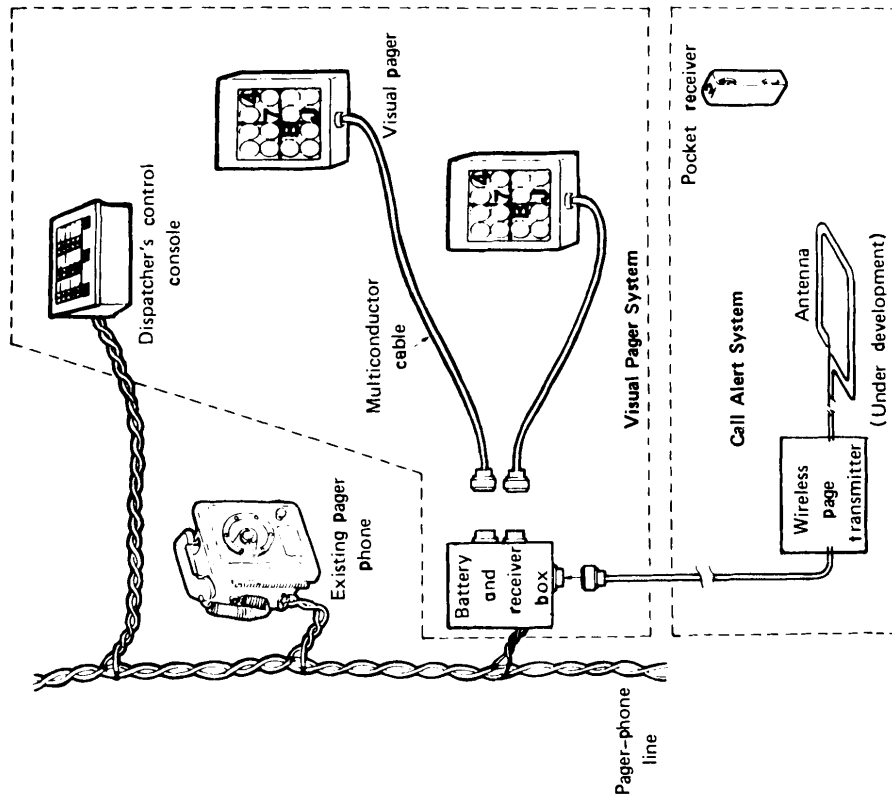


FIGURE 2. - Block diagram of call-alert visual pager.

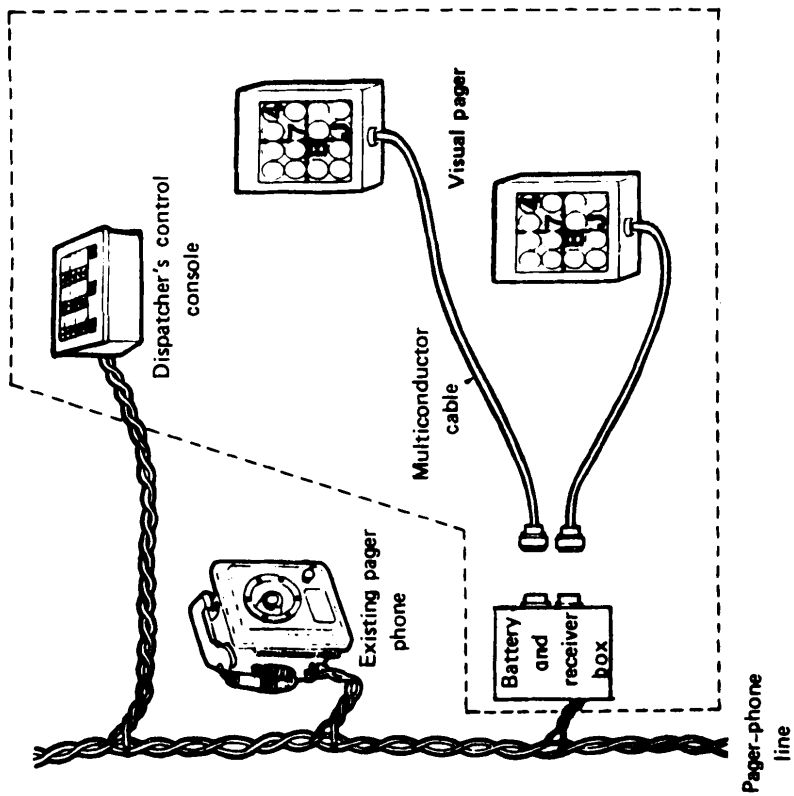


FIGURE 1. - Block diagram of visual-pager system.

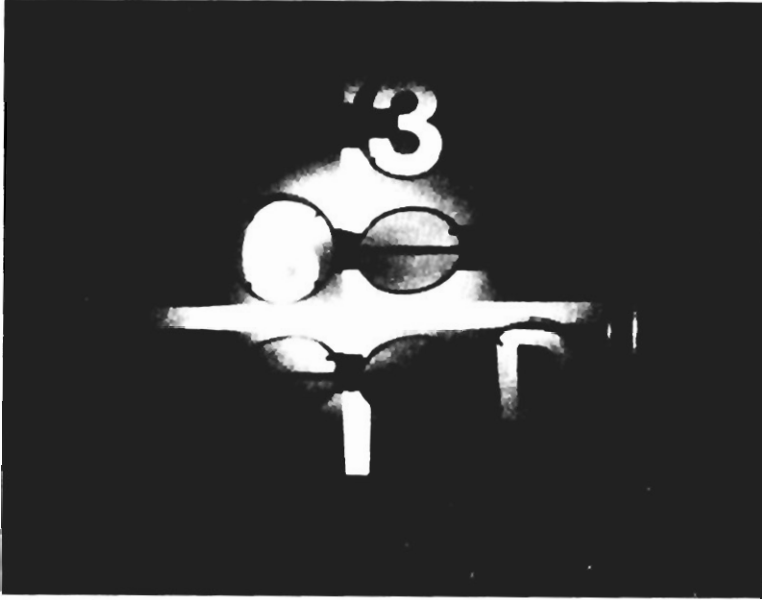


FIGURE 3. - Visual-pager display.

Visual Pager and Pager- Phone Operations

The visual pager is designed as a low-cost, modular supplement to alert mine personnel in high-noise mining operations where a normal audio page cannot be heard. The dispatcher on the surface chooses 1 of 15 key sequences on the visual pager console to alert a specific miner. The console puts an audio tone pair on the pager-phone lines. Wherever a visual-pager module has been clipped to the pager-phone lines, the audio tone pair triggers the desired alphanumeric character in the visual pager

display (fig. 3). The characters appear as highly reflective letters or numbers on the disk, and any miner can read the symbols by the light from his cap lamp.

Fixed-wire paging systems are limited in some underground mine applications because of fixed pager-phone locations. Audio paging must be intelligible to convey information, so the area within which a call can be understood can be limited by gallery acoustics, noise levels, available amplifier power, and speaker distortion. Although visual paging systems are well suited to high-noise environments, they can be limited by poor visibility and must be within a miner's line of sight. To improve underground communication systems with a minimum of added cost and equipment, an ultralow-frequency (ULF) radio paging system has been designed.

Call-Alert System

The call-alert system is compatible with present two-wire underground pager-phone systems and the new visual pager system. It can alert any one or all of the radio-receiver-equipped personnel in a particular mine area. Each receiver is capable of decoding two signals: One signal is unique to each receiver; the other pages all receivers simultaneously.

To trigger the ULF 3-kHz radio transmitter at the dispatcher's console, the call-alert system is designed to use the same audio tone pairs for signaling over the pager-phone line as used by the visual paging system. The transmitter antenna consists of a single loop of wire wrapped around the nearest pillar. The system is designed for use where mine personnel may be working outside the range of both the audio and visual paging systems. Any personnel who must work in such areas can carry a small, lightweight, battery-operated

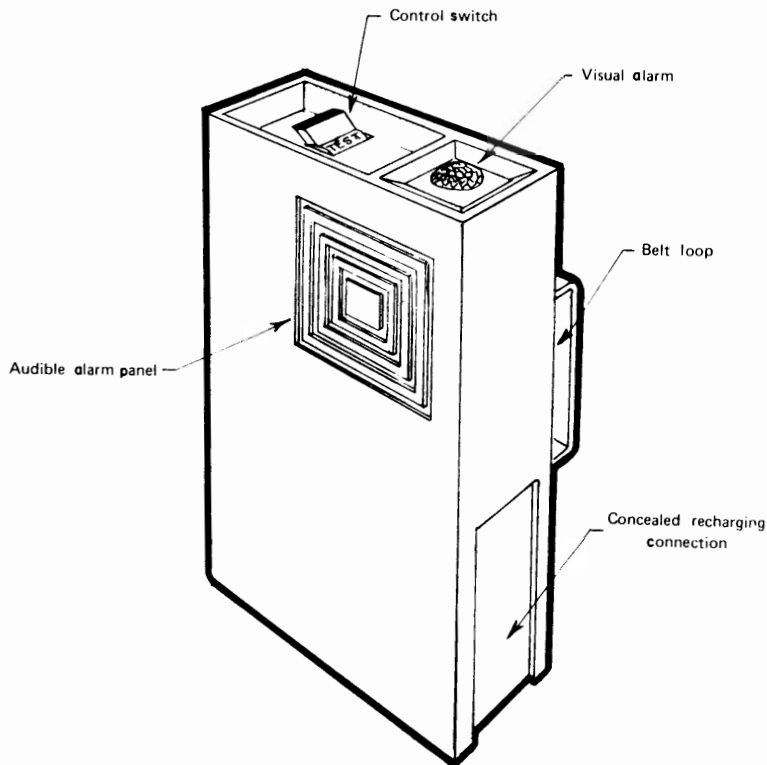


FIGURE 4. - Call-alert receiver, showing controls.

radio paging receiver (fig. 4) that will produce both audible beeps and visible lighted signals in response to the keyed two-tone code sent from the surface console by the dispatcher.

The ULF radio transmitters use differential phase-shift keying modulation to maximize the sensitivity of the pocket receivers, and include a parity check bit in each transmitted code to minimize false alarms. The basic call-alert system was designed as a low-cost, modular addition to a visual pager system. No additional hardware is required at the dispatcher's console, and the in-mine ULF transmitter units are easy to install. The radio transmitter-

receiver units are designed so that the same 15 paging codes needed for the visual pager may be used without interference or conflict in other sections of the same mine. For independent installations, the same dispatcher's console used for the visual pager is required on the surface. Underground, the battery-operated call-alert transmitters can be connected to the two-wire pager-phone line at convenient locations, and the associated antennas installed around nearby coal pillars.

In operation, the dispatcher keys a particular page button, which sends a two-tone audio pair along the pager-phone's two-wire circuit. The two audio tones cause any visual pagers on the line to display an alphanumeric character and cause the call-alert radio transmitter to send a coded signal five times. The receiver responds to its unique code (or the general signal) with both an audio alarm (buzzer) and visual signal (light). Each time a receiver is turned on, both the audible and visible alarms go on, as a check of both battery condition and alarm operation. The on-off test switch can be recycled at any time to test the alarms. A reset button is provided to turn off the alarms.

The pocket-sized receiver is powered by rechargeable batteries that can operate the receiver continuously for up to 16 hours (two shifts) before requiring an 8-hour recharging cycle. The radio transmitters are powered by self-contained batteries.

By supplementing audio and visual paging systems with a radio-transmitted call alert, personnel response to pages should be greatly improved, and mine safety should be enhanced by the ability of aboveground dispatchers to provide rapid and early warning of safety hazards or broadcast evacuation alerts to all underground personnel.

PROGRESS TO DATE

The visual pager is currently undergoing field trials. The electronic components of the call-alert system are undergoing laboratory tests, and field trials are expected to begin in mid-1977. The complete call-alert design package should be available early in 1978.

RADIO PAGING

by

Harry Dobroski, Jr.¹

ABSTRACT

It is necessary to page key operations personnel in underground coal mines reliably and selectively. A system of commercially available hardware developed by the Bureau allows a dispatcher to voice-page selected individuals, deliver short messages, or inform them where to go to receive detailed instructions.

INTRODUCTION

A modern coal mine is a vast underground complex of working sections, haulageways, and repair shops, which extends for several square miles underground. Key personnel may not work in fixed locations; for instance, a section foreman may be assigned to a single section, but that section could embrace a vast area, or maintenance personnel or electricians could be anywhere in the mine at any time. Because such personnel are important to the smooth operation and high productivity of a mine, considerable production losses could occur if they cannot be located when they are needed.

The communication system in most mines consists of pager phones, carrier phones, or both. Although these systems are reliable, they do not provide for communicating with roving personnel. In fact, they are simply station-to-station devices. If a person being paged is not within hearing range of the speakers on these phones, he/she will not get the message. Thus, considerable time may be lost in trying to locate an individual just out of range of a phone, or maybe thousands of feet from a phone. Clearly, a system is needed that can page selected individuals wherever they may be in an underground complex.

DISCUSSION OF SYSTEM

System Characteristics

In a mine that uses rail haulage, there is usually a carrier phone in each locomotive or jeep. These carrier phones allow the vehicle operators to communicate with each other and with a dispatcher who controls the flow of traffic. The trolley line itself is the communication link between all the vehicles and the dispatcher.

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However, communication is not limited to phones connected to the trolley line. If one carrier phone were connected to a trolley line and another to the phone line, good communication would be possible even if there were no connection between the two lines; this is known as carrier-current communication. Even a single wire strung down an entry and connected to a carrier phone would make it possible for the carrier phone to communicate with other phones on the trolley line, such as one located in a locomotive. The point is that if a carrier-current signal is impressed on any mine wiring--trolley line, phone line, 7,200-volt, alternating-current line, or single purpose ("dedicated") line--that line will function as a long-line antenna, broadcasting the signal into the mine where it can be received by special pocket radio pagers (fig. 1). The signal can also be received by other wires in the mine and rebroadcast such that wherever there is any sort of mine wiring, there is a signal.

This property of carrier-current signals--that they can be aided by any sort of mine wiring--made it possible to develop a general radio paging system for the entire mine. Figure 2 is a block diagram of a general radio paging system based on carrier-current techniques. A carrier phone, located at some central location such as a dispatcher's room, is equipped with a small pushbutton-encoder unit. This unit causes the carrier phone to transmit short



FIGURE 1. - Miner equipped with pocket radio pager.

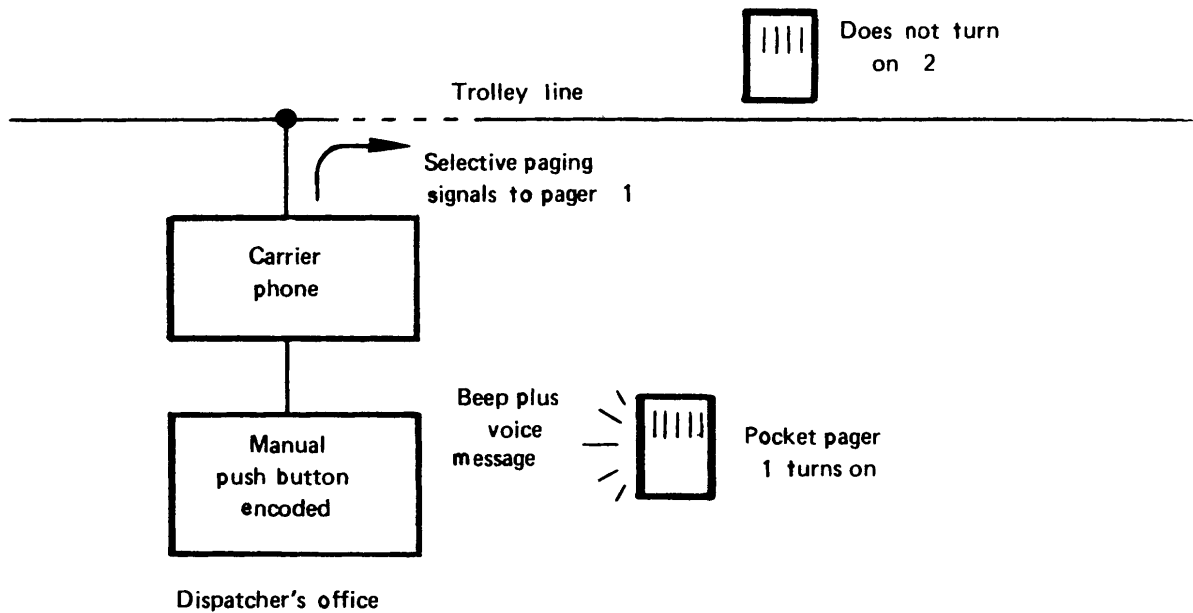


FIGURE 2. - Block diagram of general radio-paging system.

tone bursts whose frequency depends on which pushbutton was activated. These tone bursts are transmitted from the carrier phone in exactly the same way that a voice signal would be sent out. As explained before, all the mine wiring acts as an antenna, allowing these tones to be broadcast throughout the mine.

The pocket receivers that have been developed to respond to these tones are really small FM radio receivers.² They are activated by the tones, and remain on for about 15 seconds.

Once the tones have been sent, the dispatcher then talks into his carrier phone in the usual manner. Only the pocket pager activated by the tones will receive the message. Hence, the dispatcher can radio-page any individual, no matter where that individual is in the mine. In an emergency, a special tone activates all pagers at once. Of course, the radio pager is a receiver only and cannot be used to talk back to the dispatcher. Therefore, the system should be used only for paging, not for giving instructions.

Operation of System

The current system (fig. 2) is designed so that only the dispatcher can initiate a page, because he/she is the only one who has a carrier phone equipped with an encoder. However, other encoders could be used with other carrier phones, if necessary. Figure 3 shows a system in which the encoder is remotely accessed by a dial telephone line. Thus, any dial telephone

² Spencer, R. H., and H. E. Parkinson. Roving Miner Pager. Proceedings of Bureau of Mines Technology Transfer Seminar on Mine Communications, Bruce-
ton, Pa., Mar. 21-22, 1973, BuMines IC 8635, 1974, pp. 17-35.

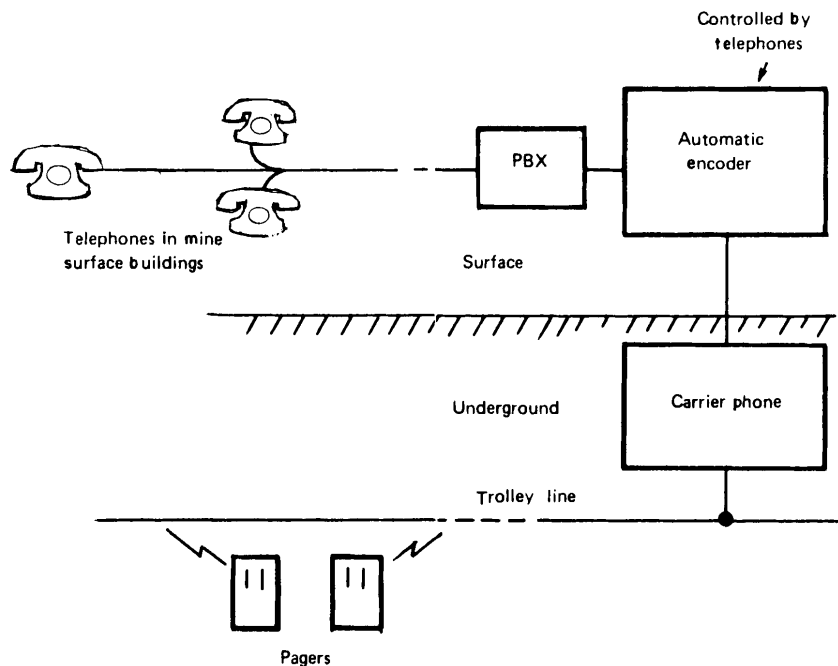


FIGURE 3. - Block diagram of system with remotely accessed encoder.

associated with the mine switchboard (PBX) could be used to initiate a page without ever being near the encoder. Such a system offers an advantage should many people have to page into the mine from several surface locations. To operate the system, a user goes to a telephone and dials the number assigned to the pager he/she wishes to call. Then, the encoder converts the telephone dial pulses into tones and transmits them via the carrier phone. The tones turn on the desired pager, at which time the user can speak into the mouthpiece to deliver the voice message.

Existing pager receivers are equipped with a small internal timer that turns the device off after a preselected time, usually 15 seconds. Any voice message lasting longer than this is cut off unless an override button on the pager is depressed to hold the call.

A continuous "On" mode is not desirable because it wastes battery power. That is why the pagers are equipped with the automatic timing device. In this mode, batteries last for months. However, there are times when the continuous "On" mode is useful; for example, when continuous monitoring of the radio paging system is important to certain maintenance personnel.

The radio paging system can be operated on a special channel, or on the regular channel used by the locomotives. The only difference is that if everything is included on the same regular channel, all the carrier phones will hear the paging traffic, but the pagers will hear only what is sent to them directly.

In spite of the large amount of mine wiring that aids paging-signal propagation, it may still be impossible to transmit a paging signal to certain areas in the mine. When this occurs, the mine overburden can often be used as a large antenna to aid the signal in reaching these areas (fig. 4). However, this scheme is somewhat complicated compared with the other paging schemes, although it provides good local coverage.

PROGRESS TO DATE

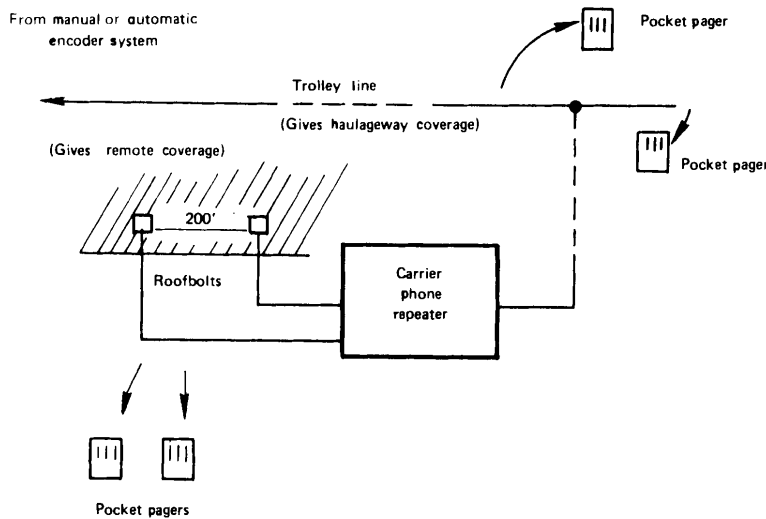


FIGURE 4. - Block diagram of system using roof-bolt-type antenna.

All hardware is commercially available from the National Mine Service Co.

A radio paging system that incorporates the automatic encoder system (fig. 3) and the roof-bolt system (fig. 4) is in operation in the Bureau of Mines Safety Research Mine near Bruceton, Pa. The automatic encoder and carrier phone are located on the surface; all else is underground. The in-mine roof bolts are separated by about 300 feet and connected to the carrier phone by No. 12 wire. With this system, paging can be effected from as far away as 500 feet from a roof bolt.

Several pagers (fig. 5) were loaned to the Robena mine of United States Steel Corp. for informal evaluation. Although no encoder was provided, the mine made excellent use of the pagers. By taping the "On" button down, the mine superintendent used the pager to monitor all carrier-phone traffic from dispatcher to locomotives and jeeps, and excellent pager coverage resulted in all areas of the mine of reasonable distance. It appears that if a mine contained only a single wire (say, the trolley line with no branches), pages could be received several hundred feet from this line. Other lines, such as phone lines, control lines, and the like, either parallel to or across the trolley line, would simply improve the coverage that much more.

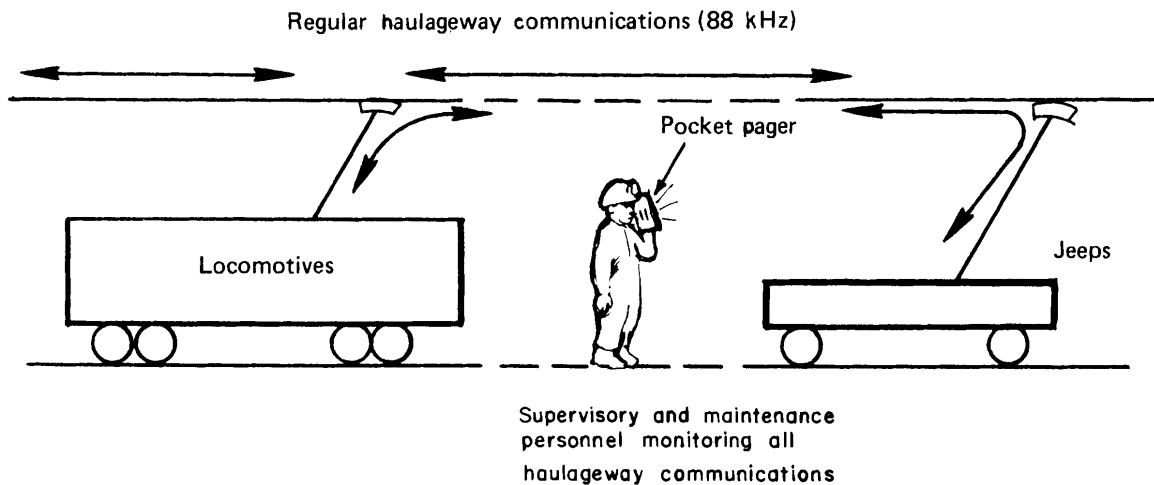


FIGURE 5. - Robena experiment.

APPENDIX.--COMMUNICATION REPORTS

The following is a list of reports available in the area of communications. These reports may be obtained from the National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, Va. 22161. Microfiche copies are \$2.25 each, and paper copies are available at the prices indicated.

<u>Company name</u>	<u>NTIS No.</u>	<u>NTIS price</u>	<u>Title</u>
Westinghouse	PB 208 266	\$5.50	Coal Mine Rescue and Survival V. 1--Survival Subsystem
	PB 208 267	9.00	V. 2--Communications/Location Subsystem
	PB 208 268	9.00	V. 3--Rescue Subsystem
J. H. Crary	PB 213 204	9.00	Determination of the Electromag- netic Environment
A. D. Little	PB 218 688	4.00	A Field Program and Instrumentation System for EM Noise Measurements
A. D. Little	PB 218 658	4.50	Assessment of EM Noise Measurements Taken by Bureau of Mines Contractors
Westinghouse Georesearch	PB 226 600/AS	5.50	EM Location System Prototype and Communication Station Modification
West Virginia University	PB 225 862/AS	6.00	Analysis of Communication Systems
National Bureau of Standards	PB 226 773/AS	4.00	Survey Report of the USBM EM Noise Measurement Program
National Bureau of Standards	PB 226 781/AS	3.50	Applicability of Speech Bandwidth Compression Techniques in Mine EM Communications
Colorado School of Mines	PB 231 154/AS	7.75	Thru-the-Earth Electromagnetics Workshop
Mine Safety Appliances			Develop, Assemble, and Install a Permissible Surveillance and Com- munication System in the Bureau of Mines Mining and Safety Research Center Coal Mine, at Bruceton, Pa.
	PB 231 574	4.00	V. 1--System Description
	PB 231 575	4.50	V. 2--Circuit and Installation

<u>Company name</u>	<u>NTIS No.</u>	<u>NTIS price</u>	<u>Title</u>
Westinghouse Georesearch	PB 232 880/AS	\$4.50	Electromagnetic Location Experiments in a Deep Hardrock Mine
Continental Oil Company	PB 232 887/AS	5.50	Seismic Miner Detection and Location System; Phase I--Final Report
A. D. Little			Survey of EM and Seismic Noise Related to Mine Rescue Communications
	PB 235 069/AS	6.00	V. 1--Emergency and Operational Mine Communications
	PB 235 070/AS	10.50	V. 2--Seismic Detection and Location of Isolated Miners
Westinghouse	PB 235 604 (set)	21.50	Trapped Miner Location and Communication System Development Program
	PB 235 605/AS	7.50	V. 1--Development and Testing of an EM Location System
	PB 235 606/AS	4.50	V. 2--Detection and Location of Entrapped Miners by Seismic Means (by Dr. S. J. Duda)
	PB 235 607/AS	5.00	V. 3--Monitoring, Locating, and Communication System for Normal Mine Operation and Post-Disaster Rescue Operations
	PB 235 608/AS	4.50	V. 4--Performance Test and Evaluation of a Full Wave Location Transmitter
Collins Radio	PB 237 218/AS	4.00	System Study of Coal Mine Communications
Colorado School of Mines	PB 237 852/AS	5.50	Research on the Transmission of EM Signals Between Mine Workings and the Surface
A. D. Little	PB 240 552/AS	4.50	Investigation of Communication Standards as Related to Coal Mines
Collins Radio	PB 240 481/AS	3.50	Waveform Generator for EM Location of Trapped Miners
National Bureau of Standards	COM 741 1688/AS	4.00	Surface Magnetic Field Noise Measurements of Geneva Mine
National Bureau of Standards	COM 741 1687/AS	6.00	Electromagnetic Noise in Grace Mine

<u>Company name</u>	<u>NTIS No.</u>	<u>NTIS price</u>	<u>Title</u>
National Bureau of Standards	COM 741 1717/AS	\$6.75	Electromagnetic Noise in McElroy Mine
National Bureau of Standards	COM 741 1718/AS	5.50	Electromagnetic Noise in Itmann Mine
National Bureau of Standards	COM 741 1450/AS	4.50	Time and Amplitude Statistics for Electromagnetic Noise in Mines
National Bureau of Standards	COM 751 0258	6.00	Electromagnetic Noise in Lucky Friday Mine
Continental Oil Company	PB 243 068/AS	5.00	Seismic Mine Monitor System--Phase IV report
Continental Oil Company	PB 241 504/AS	4.00	Seismic Mine Monitor System--Phase II report
A. D. Little			Technical Services for Mine Communications Research
	PB 249 829/AS	5.00	Task D--Applicability of Available Frequency Multiplexed Carrier Equipment
	PB 249 830/AS	5.00	Task B--Applicability of State-of-the-Art Repeaters for Wireless Mine Communications
	PB 249 831/AS	5.00	Task A--Applicability of State-of-the-Art Voice Bandwidth Compression Techniques for Wireless Mine Communications
Collins Radio	PB 244 896/AS (set)	20.00	Research and Development Contract for Coal Mine Communication Systems
	PB 244 897/AS	4.50	V. 1--Summary and Results of System Study
	PB 244 898/AS	5.50	V. 2--Mine Visits
	PB 244 899/AS	7.50	V. 3--Theoretical Data Base
	PB 244 900/AS	4.50	V. 4--Environmental Measurements
Continental Oil Company	PB 251 705/AS	4.00	Seismic Mine Monitor System

The following publications are available without charge from the Publications Department, U.S. Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, Pa. 15213:

Lamonica, J. A., R. L. Mundell, and T. L. Muldoon. Noise in Underground Coal Mines. BuMines RI 7550, 1971, 11 pp.

Lee, F. R. Permissible Mine Equipment Approved by the Bureau of Mines During 1967-68. A Supplement to Bulletin 543 and Information Circulars 8220, 8299, and 8372. BuMines IC 8463, 1970, 25 pp.

Lepper, C. M., and J. H. Scott. An Improved Electrical Resistivity Field System for Shallow Earth Measurements. BuMines RI 7942, 1974, 20 pp.

Parkinson, H. E. Mine Pager to Public Telephone Interconnect System. BuMines RI 7976, 1974, 14 pp.

U.S. Bureau of Mines (Staff--Mining Research). Mine Communications. Proceedings: Bureau of Mines Technology Transfer Seminar, Bruceton, Pa., Mar. 21-22, 1973. BuMines IC 8635, 1974, 86 pp.

In addition, Preprint No. 76-F-133, entitled "A Review of Research on Underground Mining Communications," by John N. Murphy and Howard E. Parkinson is available from the Society of Mining Engineers of AIME, 540 Arapen Drive, Salt Lake City, Utah 84108.