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Mine Communications

Proceedings: Bureau of Mines Technology Transfer Seminar, Bruceton, Pa., March 21 - 22, 1973

UNITED STATES DEPARTMENT OF THE INTERIOR

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By Staff—Mining Research
Bureau of Mines, Washington, D.C., and Pittsburgh, Pa.

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

BUREAU OF MINES
John D. Morgan, Jr., Acting Director

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CONTENTS

MINE COMMUNICATIONS

Proceedings: Bureau of Mines Technology Transfer Seminar,
Bruceton, Pa., March 21-22, 1973

by

Staff—Mining Research[1/]

ABSTRACT

The Technology Transfer Seminar on Mine Communications held on March 21-22, 1973, at the Pittsburgh Mining and Safety Research Center, Bruceton, Pa., presented information about recently developed equipment, instruments, and techniques for use in mine communications systems. All of the basic ideas presented in the fine seminar are operational in the Bureau of Mines Safety Research Mine in Bruceton.

INTRODUCTION

The mine communications research program at the Bureau of Mines, in its present form, was initiated in 1970, and includes research projects encompassing the field of mine communications and monitoring.

The Bureau of Mines initiated in 1972 a program aimed at solving some of the problems associated with transferring technology from the developer to the user. The technology transfer program is an intensive, active, and vital Bureau effort to shorten the lead time required for newly developed or improved technology to make its way from mining laboratory to mining practice. One mechanism by which the Bureau helps speed transfer of technology to users is through the conduct of topics seminars which are attended by mine operators, equipment manufacturers, union representatives, and others interested in new mining technology.

Significant advances in mine communications have been made by the Bureau of Mines and its contractors. Since the inception of the program, new and improved means of communication between men on the surface and underground have resulted. Many of these advances are reported in this publication, which presents the proceedings of a seminar held at the Bureau's Pittsburgh Mining and Safety Research Center on March 21-22, 1973.

1/ Additional information may be obtained by writing the Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, Pa. 15213, Attention: Howard E. Parkinson.

The aim of the seminar was to provide the coal mining industry with detailed information about recently developed equipment, instruments, and techniques for use in mine communications systems; to demonstrate the different systems installed in the Bureau of Mines Safety Research Coal Mine; and to further the transfer of technology between the Bureau and the coal mining industry.

ACKNOWLEDGMENTS

The Office of the Assistant Director-Mining and the Technology Transfer Group wish to express their appreciation to the speakers and the many people who helped with the seminar. Special credit is extended to Howard E. Parkinson, Pittsburgh Mining and Safety Research Center, for his efforts in compiling these proceedings. Appreciation is also extended to John N. Murphy, research supervisor, and Howard R. Grainger, scientific photographer, Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, for planning and implementing the fine set of dual-screen visuals that highlighted the presentations. Throughout these Proceedings, mention of trade names is made to facilitate understanding and does not employ endorsement by the Bureau of Mines.

EMERGENCY/NONEMERGENCY MINE COMMUNICATIONS

by

Howard E. Parkinson[1]

ABSTRACT

The Federal Bureau of Mines has developed new and improved means and methods of communicating from the surface to the underground areas of mines, thereby strengthening and extending existing telephone line and trolley wire communications in those areas where the needs are greatest.

New forms of audio and carrier equipment make use of the mine roof, overburden, power cable pilot wires, and phone lines as means of interconnecting equipment for paging and two-way voice communications. Entries, crosscuts, and special cables are also used to propagate UHF radio. UHF repeater and base station concepts strengthen the system and extend wireless radio operating range.

Emergency communication equipment is intrinsically safe, battery operated, and connected with more than one signal path between the underground and surface. Attention is given to personnel safety, mine monitoring, increased communication effectiveness, trapped miner location, and cost-effective alternative schemes.

New and improved mine communication concepts, extended to satisfy emergency requirements, are being readied for testing in the United States Steel Robena No. 4 mine near Waynesburg, Pa.

INTRODUCTION

Mining is a team effort which depends upon communication for its effectiveness and safety of operation. Members of the team in a mine such as that depicted in figure 1 communicate with each other mostly face-to-face, but communication equipment is required to provide communication channels between the in-mine and surface members of the team. This equipment traditionally consists of mine telephone and trolley wire communication systems. However, the systems in their present configurations are becomming increasingly inadequate under modern mining conditions.

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[1] Supervisory electrical research engineer, Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

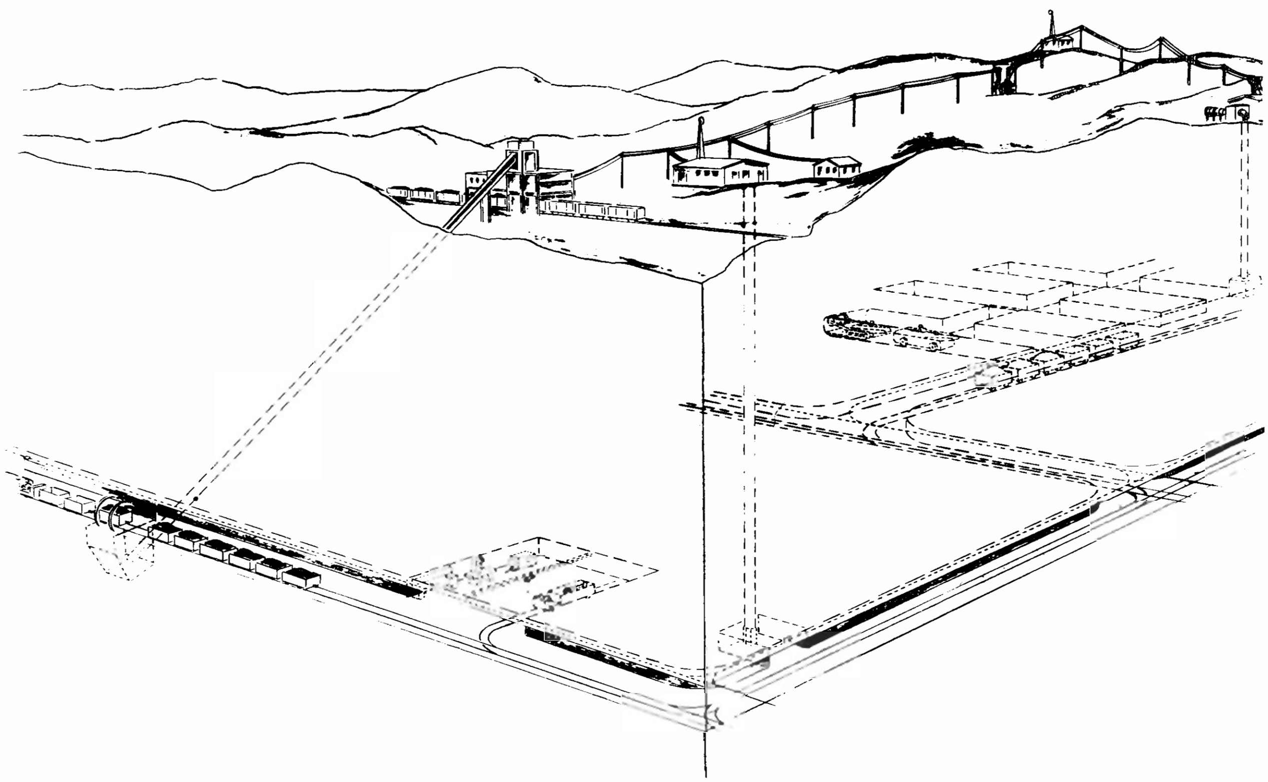

FIGURE 1. - Illustration of a working coal mine.

This paper describes several mine communications problems and needs together with the means developed by the Bureau of Mines for meeting these needs.

BUREAU OF MINES COMMUNICATIONS ACTIVITIES

The Bureau of Mines is actively conducting studies, research, experiments, and demonstrations to develop new or improved means and methods to solve communication problems between the surface and the underground, and within the workings of mines. These efforts have identified solutions to the problems, solutions that can be implemented by modifications to existing communication systems. Our general approach to identifying solutions involves six types of effort.

1. Apply Off-The Shelf Equipment. - We have concerned ourselves with a direct approach. We have procured communications equipment that will solve immediate mine communications problems. This equipment has been installed in the Bruceton Safety Research Mine so that it may be demonstrated to the mining industry.

2. Establish Future Requirements and Equipment. We have begun conducting studies into future requirements of underground communications and the availability of modern communication equipment that will satisfy these requirements.

3. Measure Signals and Noise Properties. - We have begun a series of experiments to measure in-mine electromagnetic noise, to measure the electromagnetic properties of the coal and overburden, and to measure electromagnetic wave propagation in entries, crosscuts, the roof, and through the overburden.

4. Demonstrate Major Systems in Operating Mines. - We have planned for at least three major demonstrations, in operating mines, of whole-mine communication systems designed to provide both operational and emergency communications. These will be cooperative efforts of the mining operators, the Bureau of Mines, and the miners.

5. Establish Groundwork for Equipment Standards. - We have set out to study the technical requirements for mine communications equipment. The results of this study will lead to the development of industry standards that will assure the mining industry that communication equipment suppliers will provide equipment that will satisfy operational requirements, be tough enough to withstand the harsh day-to-day environment, and provide instant communications during an emergency.

6. Develop Special Products. - We have begun a product-development program directed toward special products designed to satisfy particular requirements unique to mine communications. These products will be extensively evaluated in operating mines prior to finalizing designs that can be used by the suppliers to the mining industry.

NEEDS AND ALTERNATIVE SOLUTIONS

The results of the Bureau's work have been many and varied. Here we describe briefly six mine communication needs and the methods that we have found promising for meeting them.

Reduce Traffic Overload Need. - Mines have been expanding, and some now have 20 or more operating sections, all of which work with the same production team on the surface. This frequently leads to heavy communications traffic demands and traffic overload (fig. 2), whereby important messages are delayed or even fail to get through.

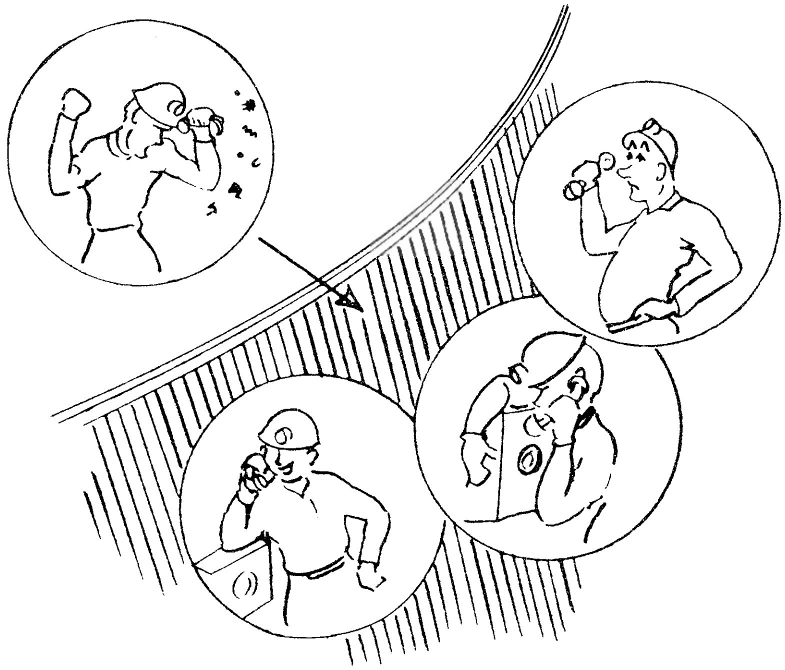

FIGURE 2. - Need: Reduce traffic overload.

Solution: Mine Telephone Grade Carrier. - The electrical characteristics of a phone line are such that communication equipment normally used on the trolley wire can also be used on the phone line. Trolley wire communications do not require any special additional wires. When the phone circuit is busy and the rail dispatcher is engaged in conversation on the trolley wire system, the need for an extra communication circuit (channel) becomes very real. By placing a trolley wire phone with a different carrier frequency onto the telephone line, this extra circuit can be obtained and be used from a section to reach the shift foreman or the shift maintenance foreman on the surface, and vice versa. This extra circuit can be added to each section to provide a private line for use by the section foreman. A battery-operated permissible 61-kHz trolley wire phone is presently in use on a telephone line in the Safety Research Mine to provide additional circuits. Special telephone-grade carrier is now being investigated, and it is anticipated that telephone-grade carrier will be less expensive than the trolley line carrier.

When interconnected with an ultra-high-frequency (UGF) radio centrally located on the section, this carrier telephone placed on the telephone line can provide a private line between the shift foreman on the surface and a roving section foreman equipped with a small two-way handy talkie radio as depicted in figure 3.

Reliable Call Alert for Key Personnel Need. - Incoming pages and calls are frequentlv ignored as a result of past experiences and frustrations with mistakenly answered pages from the loudspeaking phone (fig. 4). The root cause of this situation is that the loudspeaking phone message goes to the phones rather than to the specific individuals.

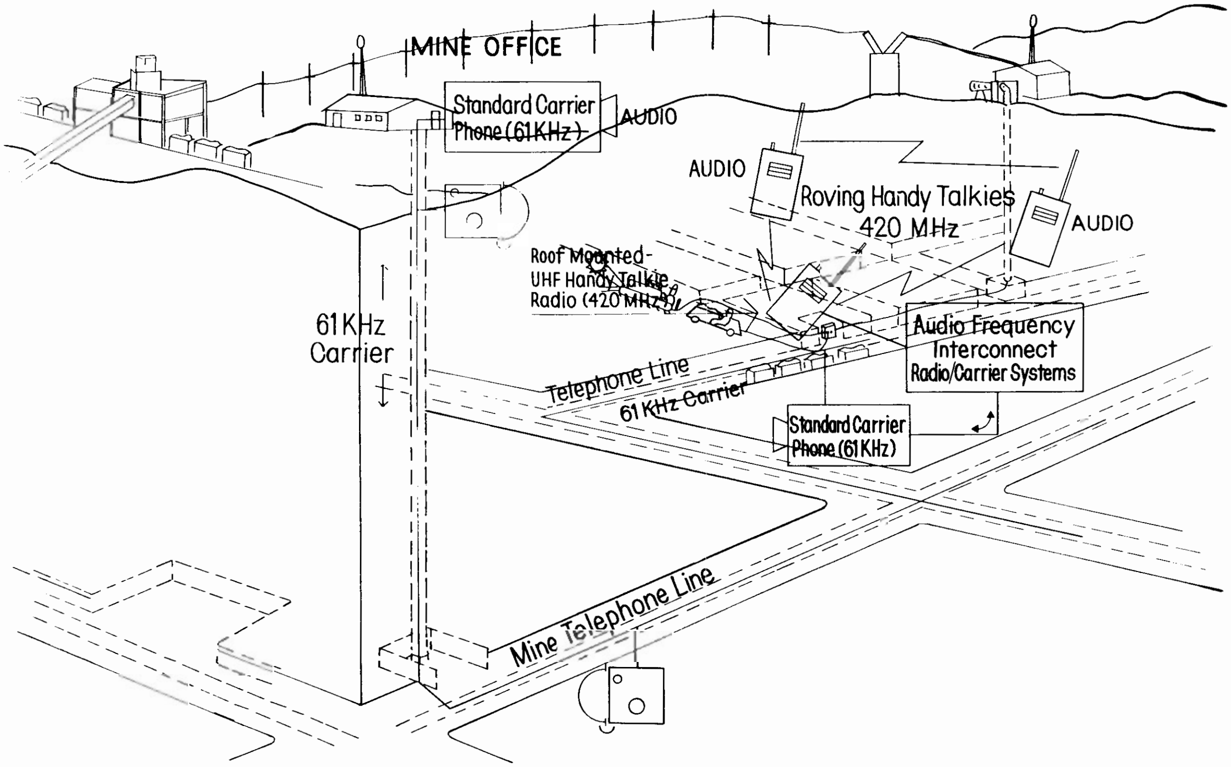

FIGURE 3. - Two-way wireless section radio system.

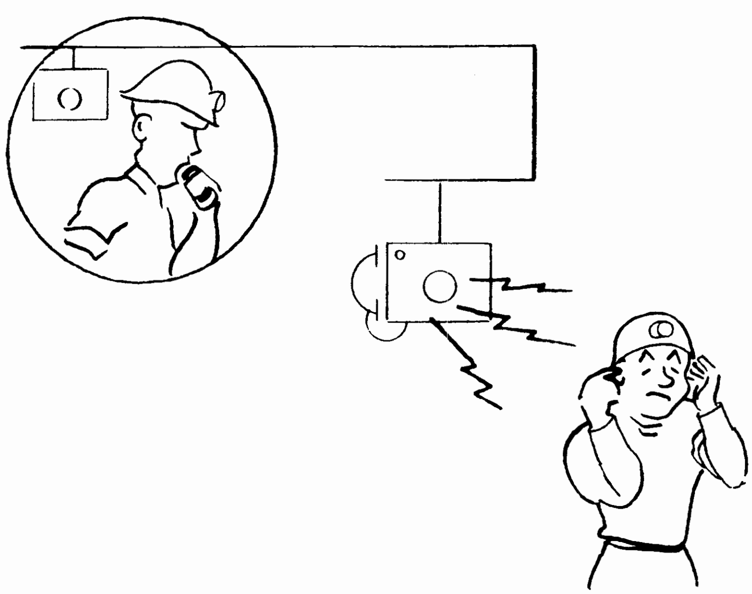

FIGURE 4. - Need: Reliable call alert to key personnel.

Solution: Call Alert Paging. - The ordinary methods of signalling an incoming call are not sufficient in the working section of a mine. The Bureau research team has developed an electromagnetic call alert transmitter that can operate from a cap lamp battery. Incoming section communications over the telephone are interconnected to a stationary call alert transmitter as shown in fig. 5.

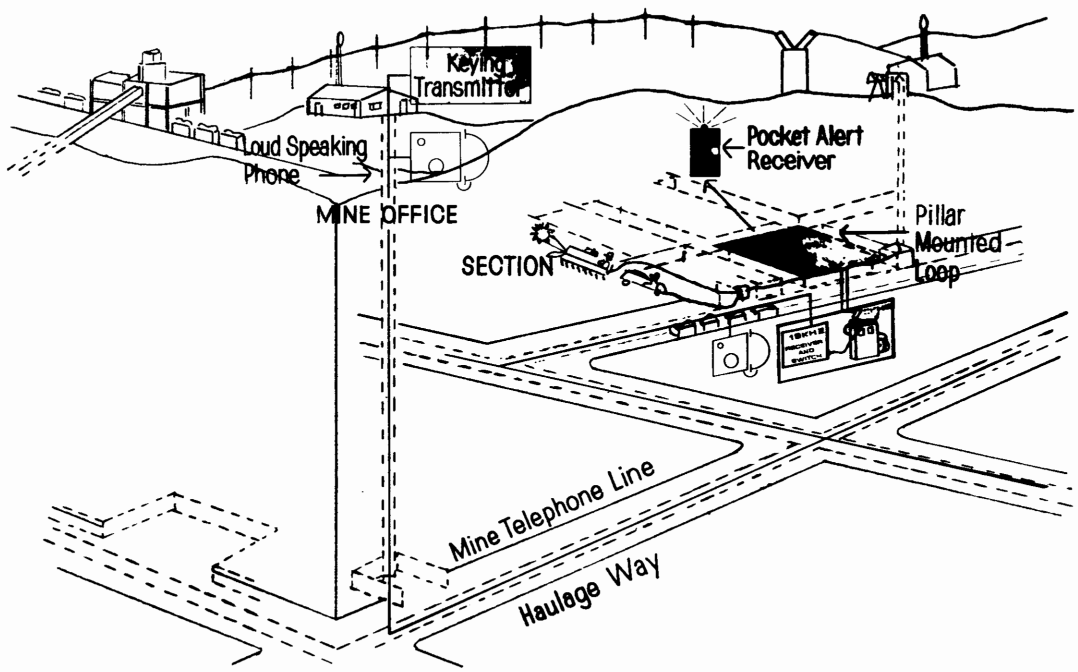

FIGURE 5. - Call alert paging system.

The electromagnetic signal from the call alert transmitter energizes a one-turn loop of wire wrapped around a pillar. The alert signal can cover a typical mine section. The section foreman or maintenance man has a special electromagnetic pocket receiver that receives the call alert. The call alert pocket receiver is energized only when the section foreman or maintenance man is wanted on the phone. To answer the call alert he walks to the phone.

There is also an emergency feature available for this system. In emergencies the call alert signal can be keyed from the sections and will penetrate the mine overburden, thus reaching the surface. Similarly the call alert receiver will receive audio frequency emergency signals transmitted through the earth from a surface transmitter as much as 1, 000 feet above the mine working area.

<u>Trackless-Trolleyless Vehicle Communications-Need</u>. - Safe and efficient operation of trackless-trolleyless vehicles such as face machines is an important objective of the coal industry. Communications between such machines can help realize this objective (fig. 6). In addition, mine haulage ways have been giving way to beltways, and supplies formerly delivered by the return trips are now taken to the sections by trolleyless and sometimes trackless supply vehicles. Trolley wire communication systems are not applicable to these vehicles.

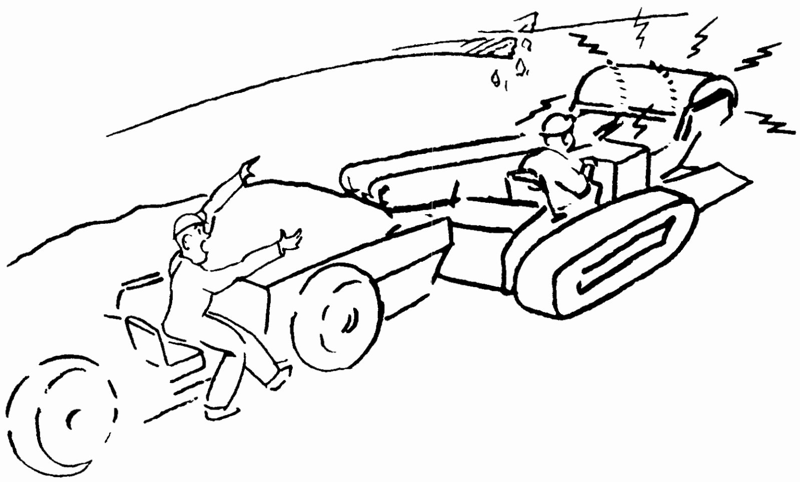

FIGURE 6. - Need: Communications with trolleyless and trackless vehicles.

<u>Solution: Trailing Cable Face Communications</u> - Mine face machines are trolleyless and trackless, but they do have trailing cables. The section telephone can be extended to any face machine via these trailing cables. Permissible equipment is required at the face, and there is a type of mine telephone that is permissable. The Bureau has procured a trailing cable with a shielded phone line so that the pager telephone can be extended to the mine face, or so that private pager telephone communications can be established between the face machine operators on a section as shown in figure 7.

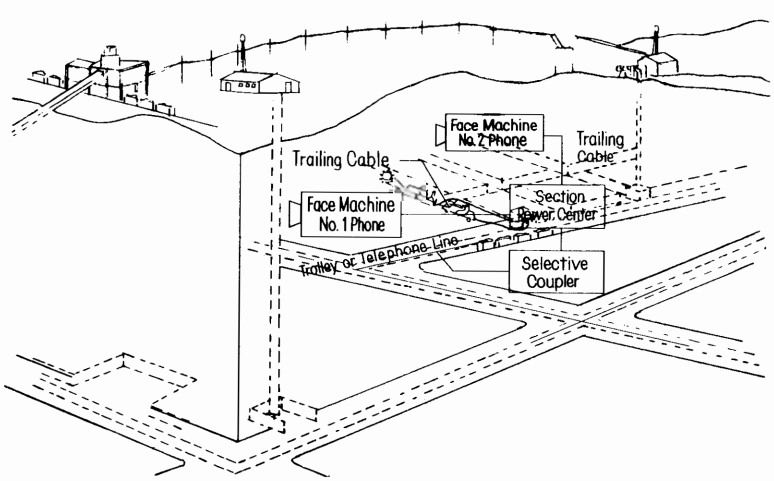

FIGURE 7. - Trailing cable communications systems.

Since the dc shuttle cars are already connected to the trolley wire, a permissible battery-operated mine phone of the trolley wire type can be installed on the shuttle car, thus providing communications with all other trolley phones.

Communication to a diesel rail haulage locomotive has also been achieved with a battery-operated permissible trolley wire phone, loop-coupled to an open-wire phone line installed in a haulage way. A diesel phone system looped back to the surface through a borehole has been installed in the Safety Research Mine. This system is connected to a two-frequency coupler which couples the message to the overland power line back to the foreman's office.

Roving Miner Communications Need. - Presently, communications equipment is mounted in working places or on vehicles. The roving miner can be reached only as he comes within the zone of the vehicle or the working place communications (fig. 8). To get an urgent message to a roving miner, it is frequently necessary to dispatch another miner to serve as a messenger.

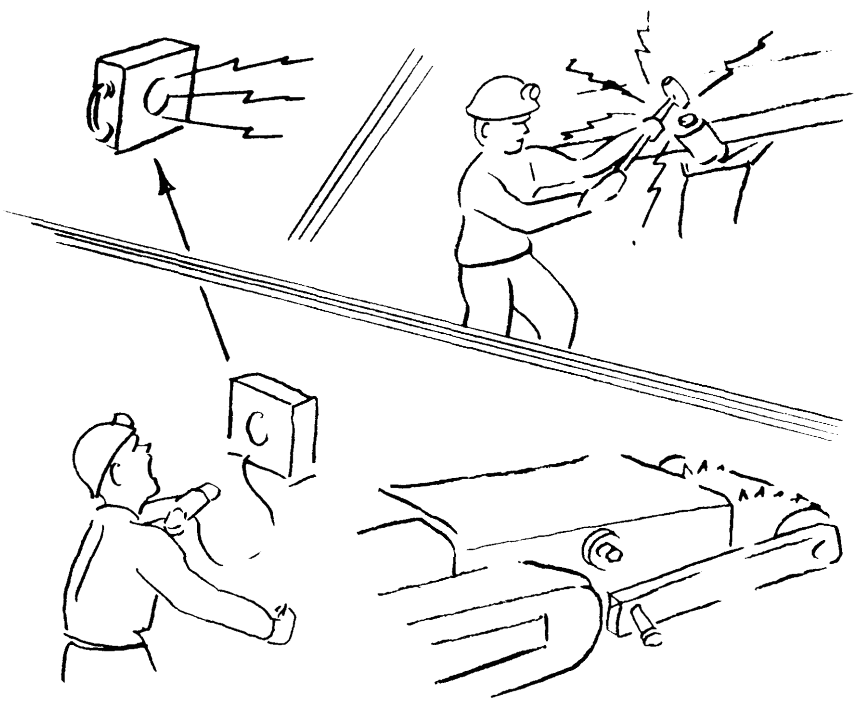

FIGURE 8. - Need: Communications with key roving miners.

Solution A: Paging the Roving Miner. - Trolley wire communications networks make excellent underground broadcasting systems. The Bureau of Mines has located a small pocket pager receiver and had it modified to operate on 88 and 100 kHz, the two standard trolley wire communication frequencies. This system has a selectivity that allows each pager to have its own private receive channel. An audio tone alert signals that a short message will follow. The operating range is in excess of 600 feet from the trolley wire. A special arrangement of this system, shown in figure 9, has been procured by the Bureau. A transmitter and repeater are so connected that a message originating at any surface dial phone is transmitted into the mine over the pilot wire in the power mains, or over the phone line, then connected by a repeater onto two roof bolts. The roving section foreman can receive a page message anywhere in the section, and he can return to the section phone to answer the page.

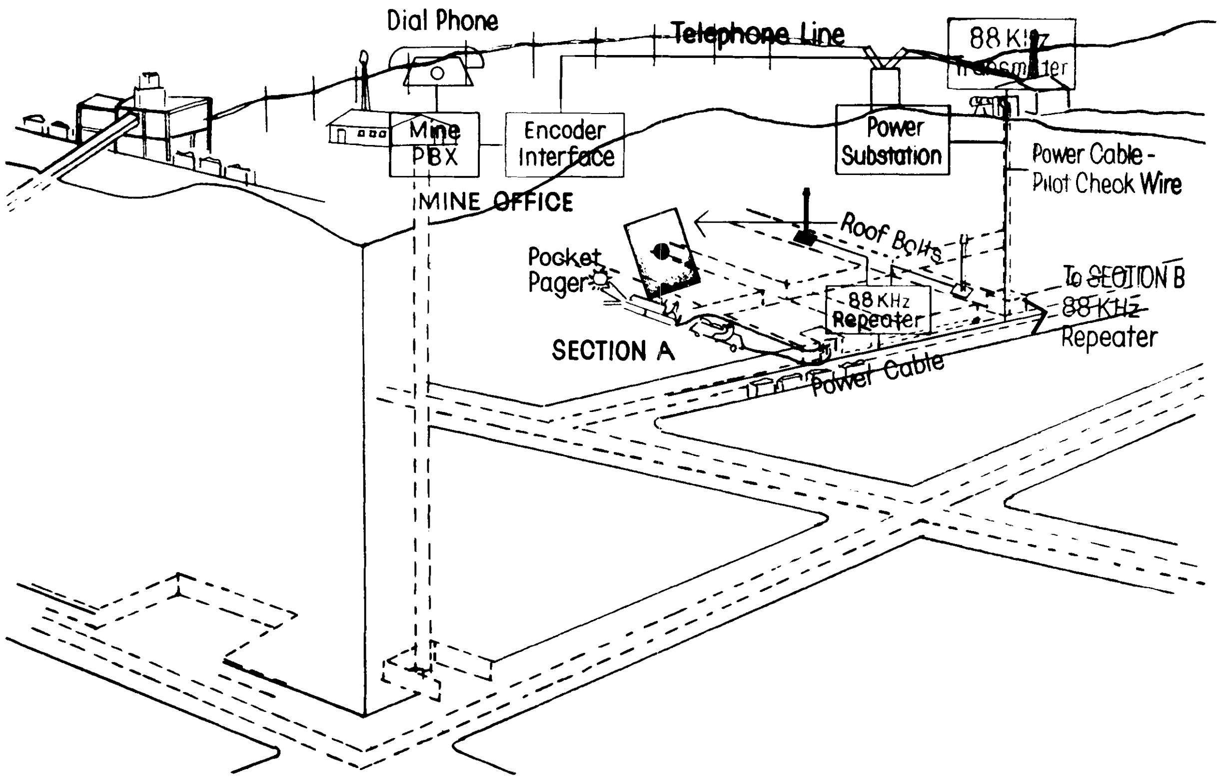

FIGURE 9. - Roof bolt paging system.

Solution B: Two-Way Communications With the Roving Miner. Intrinsically safe, vehicle-mounted and personnel radio equipment can provide radio-type communications throughout the main working areas of the Safety Research Mine. Ultra-high frequencies around 420 MHz can provide mobile radio coverage to roving miners equipped with low-power handy talkie radios in the working section without the aid of tranmission line cables. Private communications are established on the working section between the section foreman and the maintenance man using a special UHF section channel, as previously depicted in figure 3. The communications range can be further extended by mounting another handy talkie radio to the roof at a point centrally located in the section, and using it in a repeater mode. To call the surface, the section foreman can use a second UHF channel of the roof-mounted radio which interconnects with the telephone line at a carrier frequency dedicated to mine-to-surface communication.

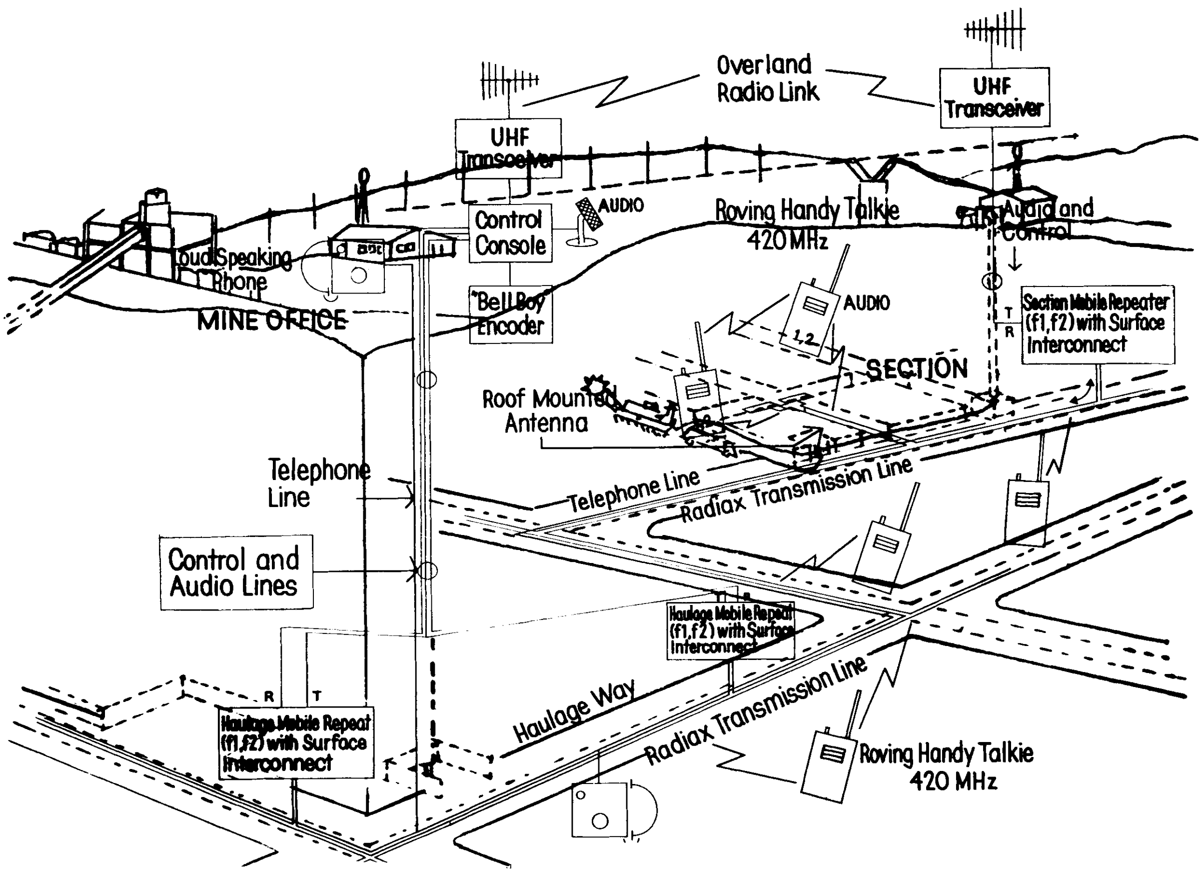

FIGURE 10. - Guided wireless radio system.

The UHF signals can also be transmitted from an in-mine base or repeater station to an antenna on the section via a special Radiax cable transmission line as shown in figure 10, thereby providing two-way communication between the surface and a roving miner carrying a portable UHF radio. The base or repeater stations can also provide communications between the surface and miners in the haulageway because of the continuous radiation from the Radiax cable along the haulageway. In addition, roving miner-to-roving miner communications on the section and in the haulageway can be provided by a two-frequency repeater station connected to the Radiax cable. Such a system can include a paging capability that can be used to reach key personnel carrying less expensive UHF pocket pagers when roving within range of the Radiax transmission line or section antenna. A loop back over an overland radio link also can be provided by UHF transmitter-receiver stations on the surface as shown in figure 10.

Adequate Emergency Communications Need. - Communications are vital to rescue and recovery operations. Some mine operators have selected permissible phone systems that are powered from batteries to provide a two-way communications system in the event that the main electric power source is shut off. However, more is needed to assure an operational system. A phone system requires an intact phone line. Experience has demonstrated that phone lines are often broken during an emergency (fig. 11).

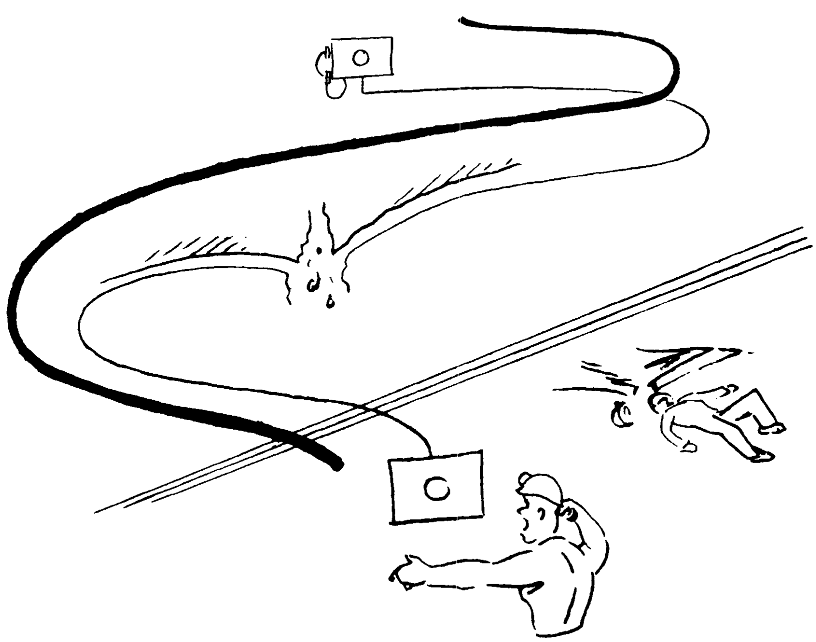

FIGURE 11. - Need: Emergency communications.

Solution A: Strengthening Mine Communications for Disaster-Mode Operation. Most mine communication systems are wire systems. The telephones operate over a twisted pair and the locomotive carrier phones are connected to the trolley wire. These wire systems are unmonitored and open systems. A break in the wire is undetected and communication to the phones inby the break is lost. A simple first cut at solving this problem involves a selective interconnecting of the phone line to the trolley line as shown in figure 12.

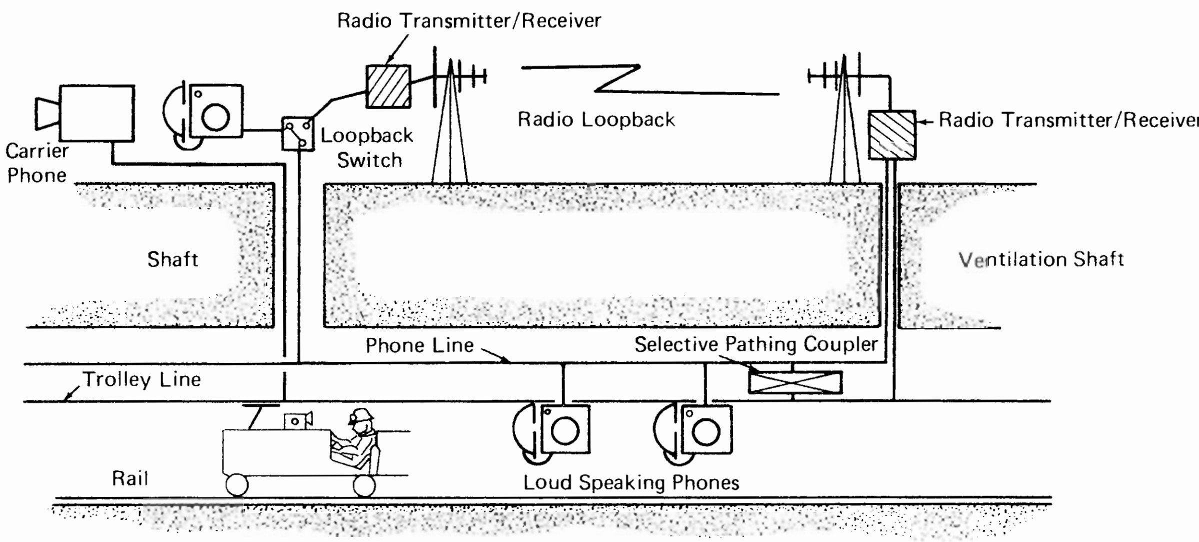

FIGURE 12. - Selective pathing coupler and radio loopback.

These two systems do not have frequency compatibility, since the phone line system operates in the voice frequency band and the trolley wire system operates in the low-frequency radio band. However, mine telephone-to-trolley wire phone interconnect equipment is available. The traffic on each of these systems is heavy, and the resultant interconnect system traffic is the sum of the individual system traffic. Thus, in general, the traffic is too great for good communications in a continuous interconnect system. However, through a selective interconnect placed deep inside the mine, the two systems can be selectively monitored from the surface. A call originating on the mine telephone can be heard on the surface over a trolley phone connected to the trolley wire. If the phone line is down outby the interconnect point, phones inby the phone line break can be reached over the combination of the trolley wire and phone line.

There are many other methods for deriving a loop back to monitor communications and to reach the line break. One such alternative method at the Bureau's experimental mine is an overland radio link. Both haulage way carrier phone and mine telephone signals are returned through a special borehole cable to the surface. Near the borehole a surface two-way radio base station establishes an overland radio link to a second station near the general mine foreman's office similar to that depicted in figure 12. The audio from the trolley wire phone and mine phone are electrically connected to the radio system. The trolley line and phone line are monitored via the radio, and if the voice transmitted from the surface is not heard, the radio link can be used as a means of talking back into the mine to a point inby the line break.

Solution B: Special Mine Emergency Communications. The Bureau has also developed an interconnect coupler depicted in figure 13 that automatically interconnects the in-mine loudspeaking phone to a preselected dialable public phone upon receiving a prearranged audio tone from a pocket tone generator.

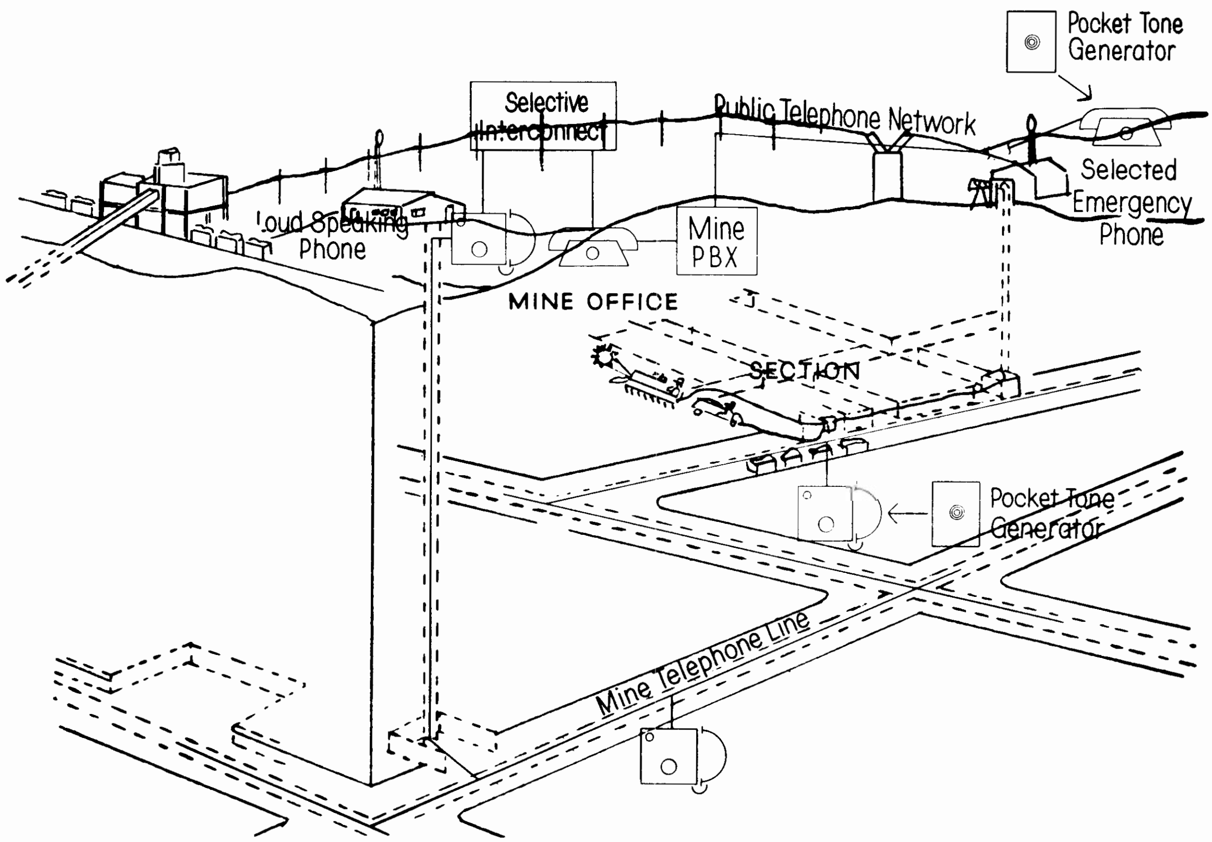

FIGURE 13. - Public-to-mine telephone interconnect system.

The coupler interconnects the mine telephone line directly to the public telephone line, providing access to outside help in the event of an emergency, for example on a weekend. Dialing a preselected number is automatic once the coupler has been activated. The call can also originate at a public phone, by dialing a prearranged telephone number at the mine and using the same pocket tone generator. The caller will then be connected to the mine telephone system and be able to page a person underground. This automatic system does not require a switchboard operator or dispatcher.

CONCLUDING REMARKS

We have given an overall view of the Bureau's communications activities and have presented concepts that can be implemented by you in the mines you operate at this time. Fundamentally, we have treated extensions of the existing communication systems, and the possibility of overlaying or adding wireless radio communications. Those presenting the seminar papers are individuals working at the Bureau or individuals under contract to the Bureau. Many of the suppliers of the communications equipment used in our demonstrations are present. We believe that most of these suppliers could have supplied the special gear that we have built here in the Bureau. The ideas that we present are for use by the industry. If any supplier or any particular mine wishes to use these ideas, the Bureau will be glad to cooperate with them. Similarly, any of our contractors who have built this special interconnecting equipment will be glad to cooperate by supplying information that they have developed under contract to the Bureau.

ROVING MINER PAGING

by

Richard H. Spencer[1] and Howard E. Parkinson[2]

ABSTRACT

Mine paging telephones increase the effectiveness of the mine personnel. The page message reaches the personnel within hearing distance of the phone. Personnel paging extends the page to the individual roving miner wherever he may be.

One system installed at the Bureau of Mines Safety Research Mine is a "dial-in" system. An in-mine page can originate from any mine public phone. The system, exclusive of the Bell System equipment, includes an encoder, a 88-kHz transmitter, a pilot wire signal coupler, a 88-kHz repeater, a roof bolt signal coupler, and pocket receivers.

There are two configurations of the system. One configuration is a whole mine configuration, and the other is a working section configuration. There are two forms of the working section configuration. One form puts the selective page onto the mine phone line and converts the message to 88-kHz at the section, thereby extending the page area to the face.

The second form is a call alert system. This system keys a call alert transmitter on the section. The system has a capacity to handle 24 sections. It is a cost-effective system with an added feature of providing an emergency beacon locator at the time of a mine emergency.

INTRODUCTION

Current Paging Systems

Mine telephones are the backbone of most present mine communications systems. There are two main telephone instruments: the magneto telephone and the mine pager telephone. A large mine may have 40 or more of these phones. Selective calling is attempted on both types of phones.

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[1] Arthur D. Little, Inc., Cambridge, Mass.

[2] Supervisory electrical research engineer, Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

The magneto phone is used to make a selective call by a coded ring that is audible near each phone location. The mine pager phone is used to make a selective call by paging a particular individual by name over loudspeakers at the phone locations. The selective call feature of the mine pager phone is an improvement over that of the magneto phone, and as a result the mine pager phone has gained wide acceptance. These phones can be made permissible and because of their battery operation are ready for use during an emergency.

Additional Paging Needs

The effectiveness of communication with roving miners underground would be significantly improved by meeting the following additional paging needs:

1. Selective page to the desired individual

2. Extensive of paging coverage to individuals in all working places

Currently, there is confusion on the mine phone paging system. Individuals hear pages that are not meant for them, since it is a party line system. Individuals are frequently not within the acoustic range of a page phone loudspeaker, or may be in an area of high acoustic noise near machinery. Thus, many pages are not heard, and even if a page is heard, it is frequently hard to tell who is being paged. As a result, many individuals customarily ignore pages unless a particular call is expected. This makes it difficult to get a reply to an incoming call, resulting in people often having to be dispatched into the mine to locate specific individuals. The root cause of this situation is that the mine pager phone message goes to the pager phones rather than to the specific individuals being paged.

PERSONAL PAGING VIA ROOF BOLTS

Personnel paging extends the page message to the individual. A small pocket pager is carried by the individual. This pager receives a message only when the particular individual is being paged. The selective call feature of the page removes the confusion that is common in the mine page telephone system. Many personal paging systems are in use in a variety of communication applications. These systems are very effective in hospitals, industrial plants, and other large buildings. In their original form they are not satisfactory for mine use; however, relatively straightforward adaptations based on extensions of existing mine communication systems have proved to be fruitful. These adaptations are based on existing trolley wire and mine telephone systems, as described below.

Demonstration of paging capabilities was made by using carrier frequency equipment operating at the 88-kHz trolley wire phone frequency. Signals from the 88-kHz transmitter were connected to the leads of the main power system of the mine. The paging function was incorporated by using a commercial encoder manufactured by Reach Electronics, Inc., to provide an input to the 88-kHz transmitter. This encoder provided 200 selective call numbers. Pocket pagers were given to several individuals to carry with them as they were roving underground. It was possible to reach them in most of the working places.

There were places, however, where the page signal was too weak, thereby requiring the addition of equipment, namely an 88-kHz repeater. This repeater is fed by the 88-kHz signals on the power mains, and the output of the repeater is connected to roof bolts. This addition provided page capability up to the very face of the working sections.

The pocket pagers are selective and are operated only when the page messages are being transmitted. The normal trolley wire communications are not heard by an individual not being paged unless a button on the pager unit is depressed. We have continued to operate the equipment at 88-kHz; however, we recognize that it could be used at some other frequency that would preclude interference with normal 88-kHz transmissions.

Principles of Operation

Figure 1 illustrates the current flow that results when two roof bolts are driven by a source of power. It is noted on this figure that the current flow extends far into the material surrounding the roof bolts.

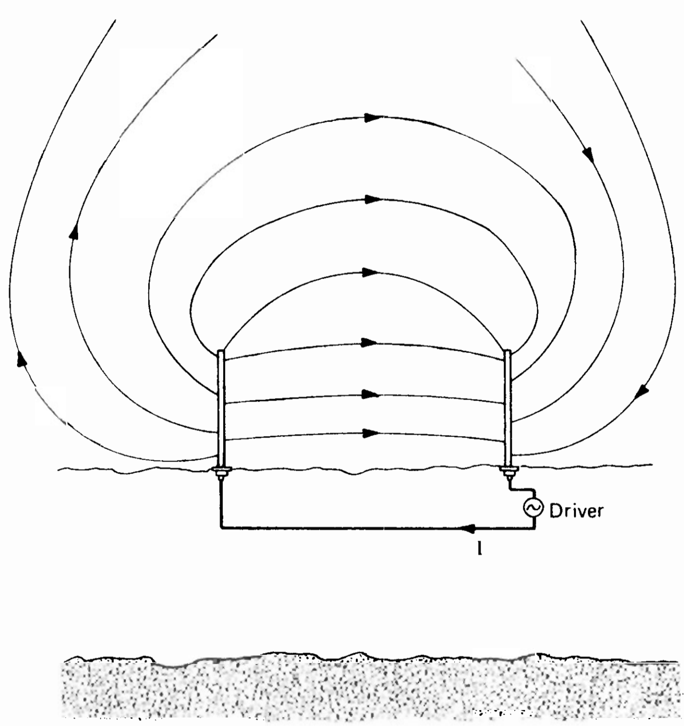

FIGURE 1. - Current flow produced by driving roof bolts.

Indeed, at very great distances there is still current flow; the problem is that the currents are quite small compared to the background noise currents. One can easily see that if a pair of probes is attached to the material surrounding the roof bolts, even at great distances, voltages produced by the current flow will be obtained from these probes. It is also evident that if the current flow is alternating, there will be associated magnetic fields which occur in the material and in the surrounding regions. These fields extend into the open areas of the mine and hence may be picked up by loop antennas throughout the mine region. It is important to know how far from the roof bolts one may obtain usable signals in this fashion.

Expected Coverage

An experiment was conducted in the Bruceton experimental mine as illustrated in figure 2. An 88-kHz repeater of nominal 20-watt capability was attached to two roof bolts separated by a distance of approximately 120 feet. The repeater was driven from a sine-wave source, and a calibrated loop together with a calibrated receiver was used to measure the vertical magnetic field strength throughout all regions of the Bruceton mine. The manner in which roof bolt attachments were made is illustrated in figure 3. A simple, direct electrical connection to roof bolts is illustrated here. The repeater is shown in figure 4. Figure 5 shows the coverage to be expected with a Reach pocket pager receiver using the roof bolt system in the Bruceton mine. Three contours are shown on this plot. The first contour is for a received signal-to-noise ratio of 15 db.

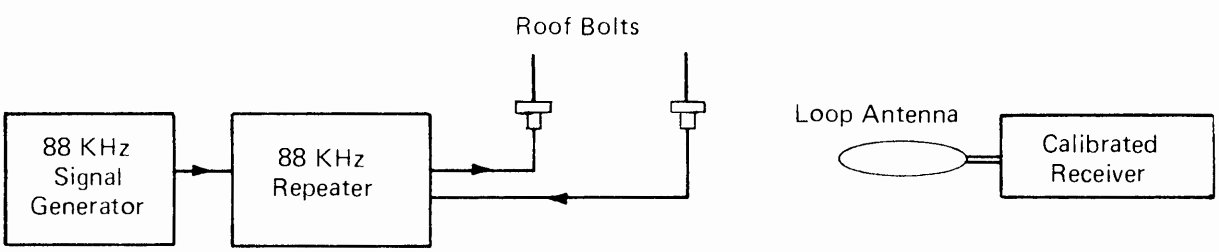

FIGURE 2. - Block diagram of roof bolt experiment.

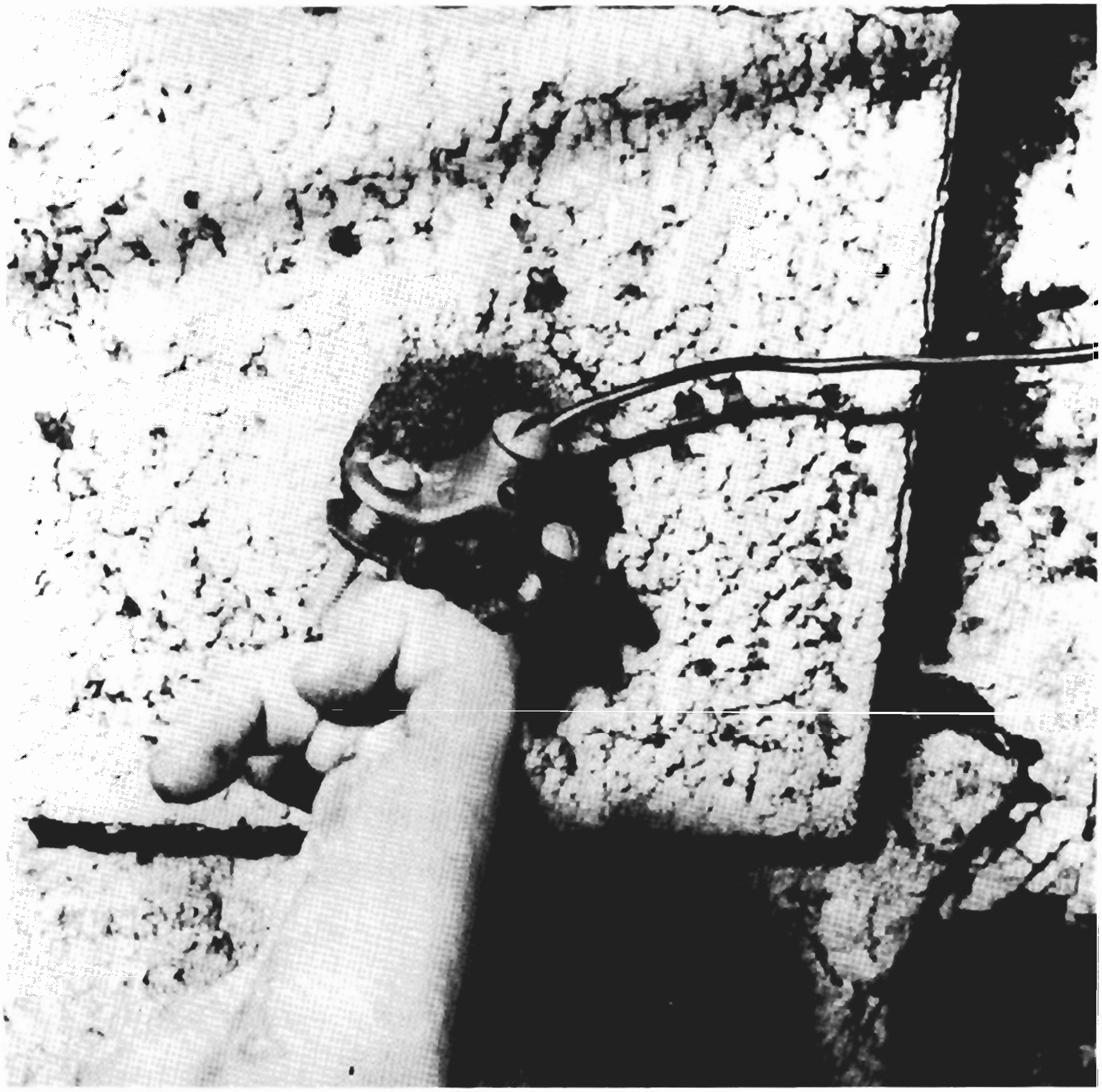

FIGURE 3. - Roof bolt attachment.

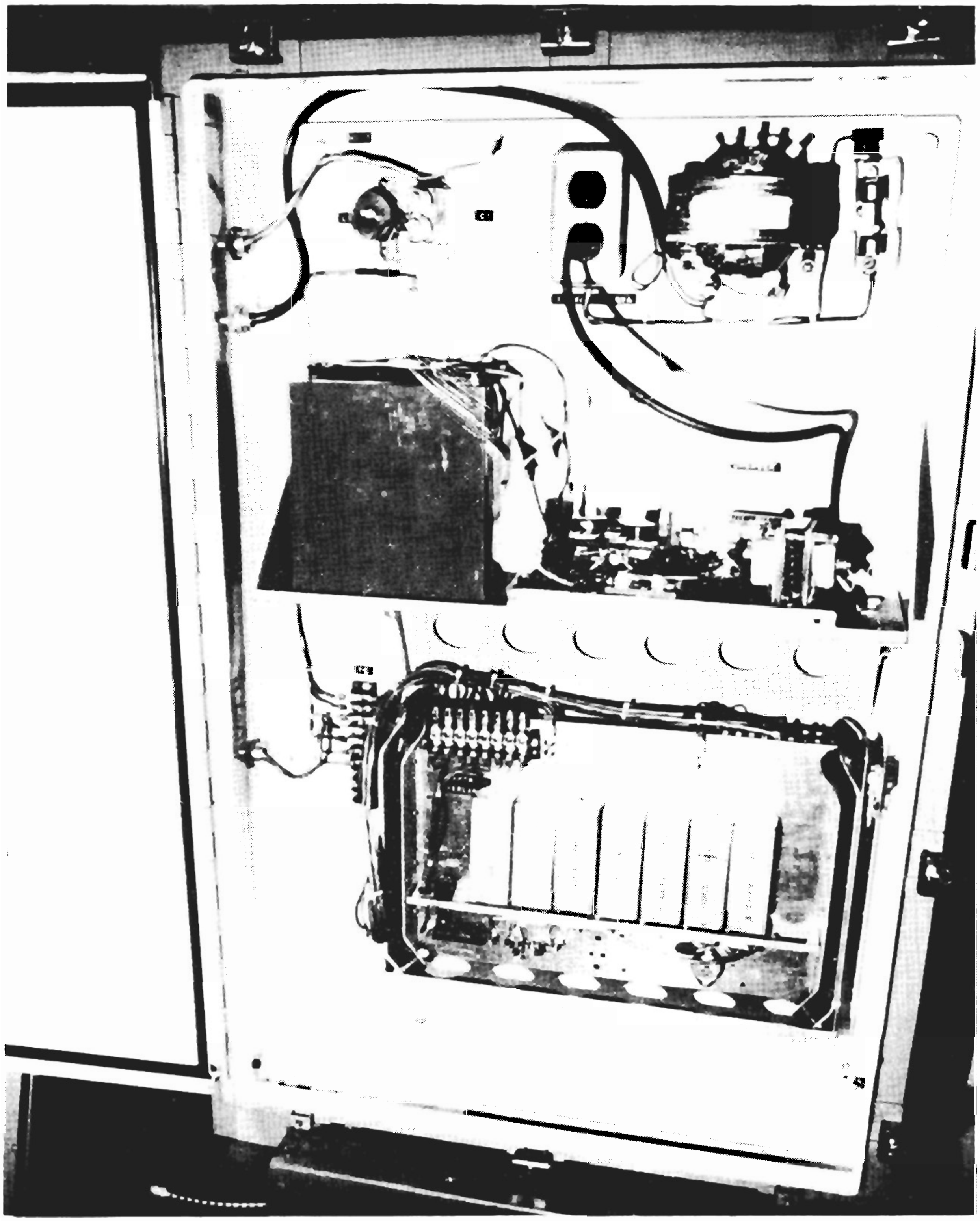

FIGURE 4. - 88-kHz repeater.

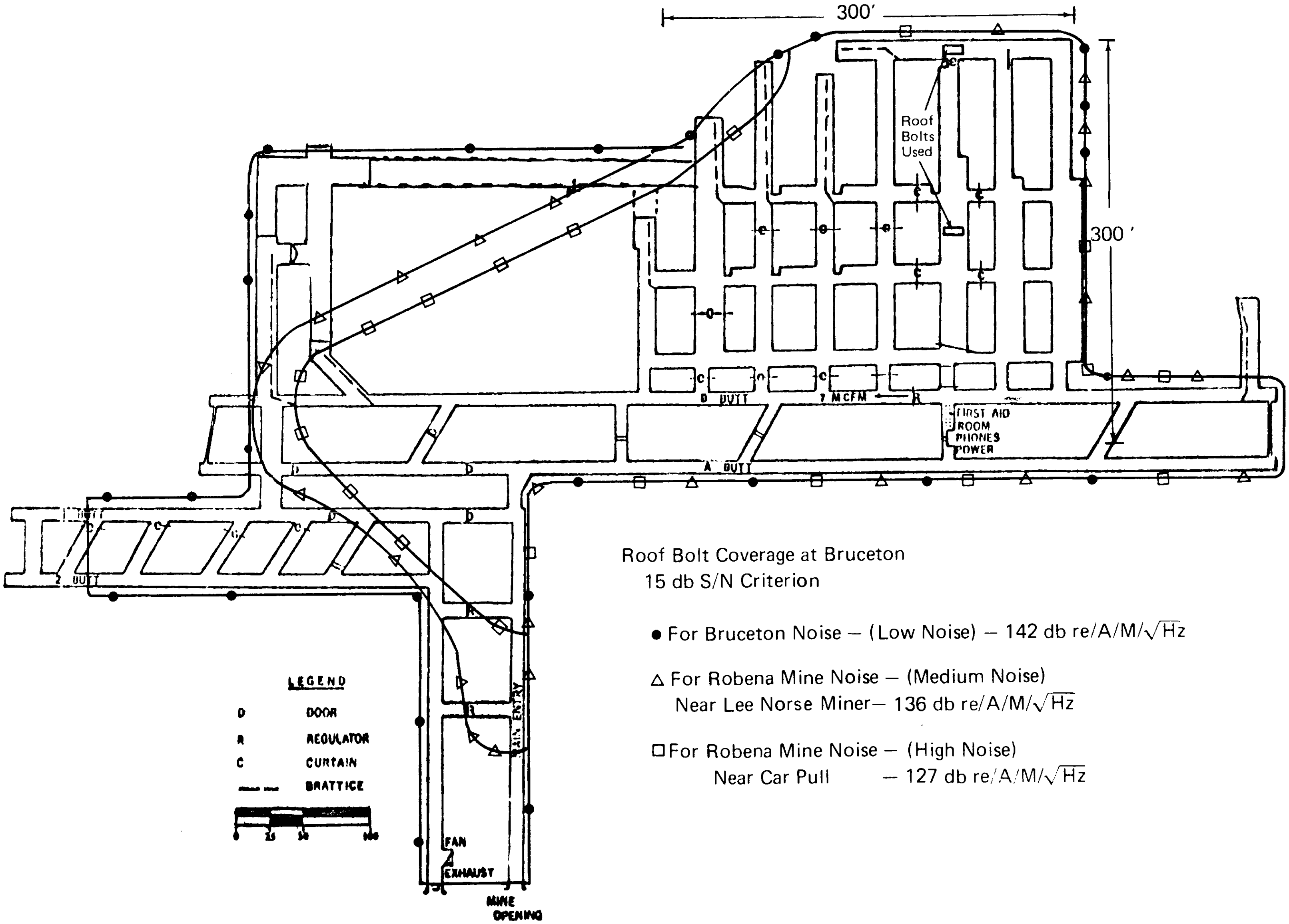

FIGURE 5. - Roof bolt coverage.

This contour was determined by comparing the measured values of vertical magnetic field noise present during the experiment. A 2,000-Hz bandwidth was assumed for these determinations. It is seen that this boundary encloses essentially all of the Bruceton mine except for a region at the far left extremity. Using the measured field strength data and noise obtained by the National Bureau of Standards (NBS) in their mine electromagnetic noise measurement program, two other contours are overlaid on this plot. The first one is the expected limit of coverage were the noise like that in the face area of a working mine near a Lee-Norse miner. It is noted that this coverage is less than that for the Bruceton noise. The third contour represents the expected coverage were the noise like that found in the same working mine near a car pull while the car pull was operating. This machine produced the highest electromagnetic noise levels found by NBS in their mine measurements, and as such probably represent an upper limit of expected noise in mines at the frequencies of interest for mine communications. From these plots, it can be seen that coverage of a typical working section can be expected from roof bolt attachments made near the center of that section.

System Description

The overall block diagram of the system as installed in Bruceton is shown in figure 6. The paging system demonstrated in Bruceton can originate pages from any dial phone within the PBX system at Bruceton. The caller dials 1, followed by a three-digit code.

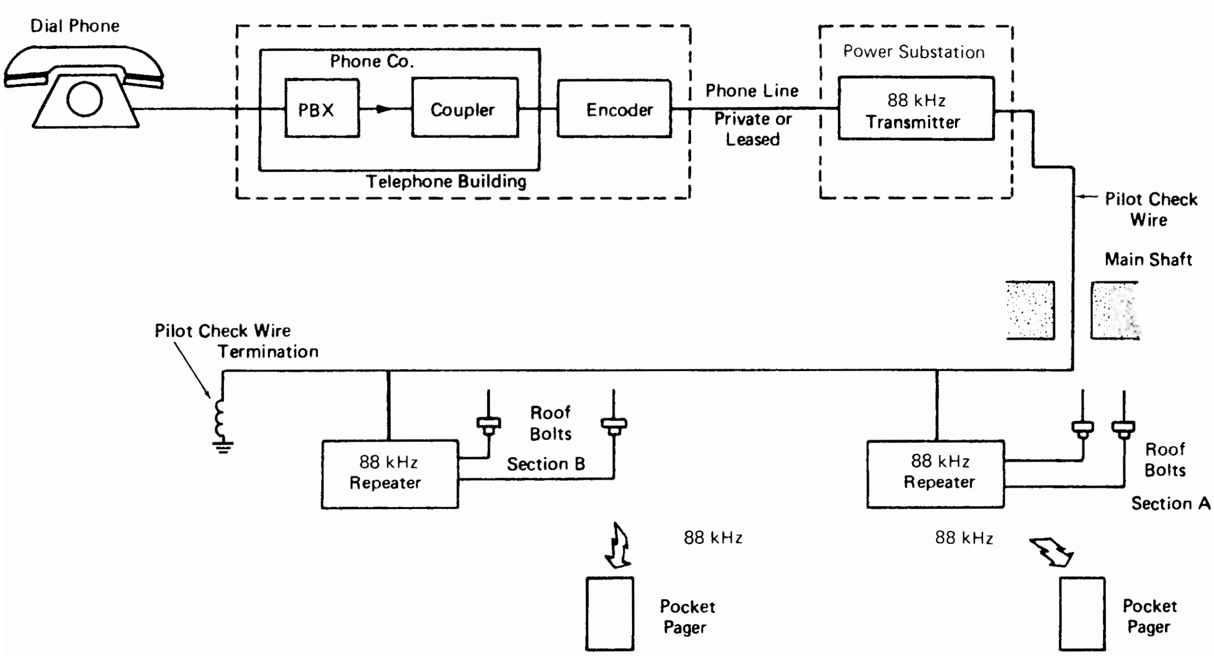

FIGURE 6. - Whole mine paging system.

This connects his phone through the PBX to a Reach encoder which translates his dialed code to the corresponding Reach receiver's code. The signal generated by the encoder is transferred through a pravate line to a 20-watt, 88-kHz transmitter located in the power substation. The 88-kHz transmitter output voltage is connected between the pilot check wire and ground of the power cable that runs down into the mine. In the mine the 88-kHz signal is taken from the pilot check wire and fed through a 20-watt, 88-kHz repeater. The output of this repeater is connected to a pair of roof bolts, and the pocket pagers worn by key personnel in the mine respond to their unique pocket-page code. The person calling the page has an opportunity for 10 seconds of message which can be received by the person carrying the pocket pager. In general, it is intended that the person being paged go to the nearest phone in the mine and respond to the request for communication. Figure 6 illustrates two 88-kHz transmitters used to cover two working sections. This number can be expanded to cover each of the working sections in a mine. The principle of operation is the same.

Figure 7 illustrates the installation of the Reach encoder, and figures 8 shows the 88-kHz transmitter in the mine office. The pilot wire termination is shown in fiture 9, and the underground 88-kHz repeater is shown in figure 4. Figure 10 illustrates the way in which the pocket pager can be worn.

FIGURE 7. - Reach encoder installation.

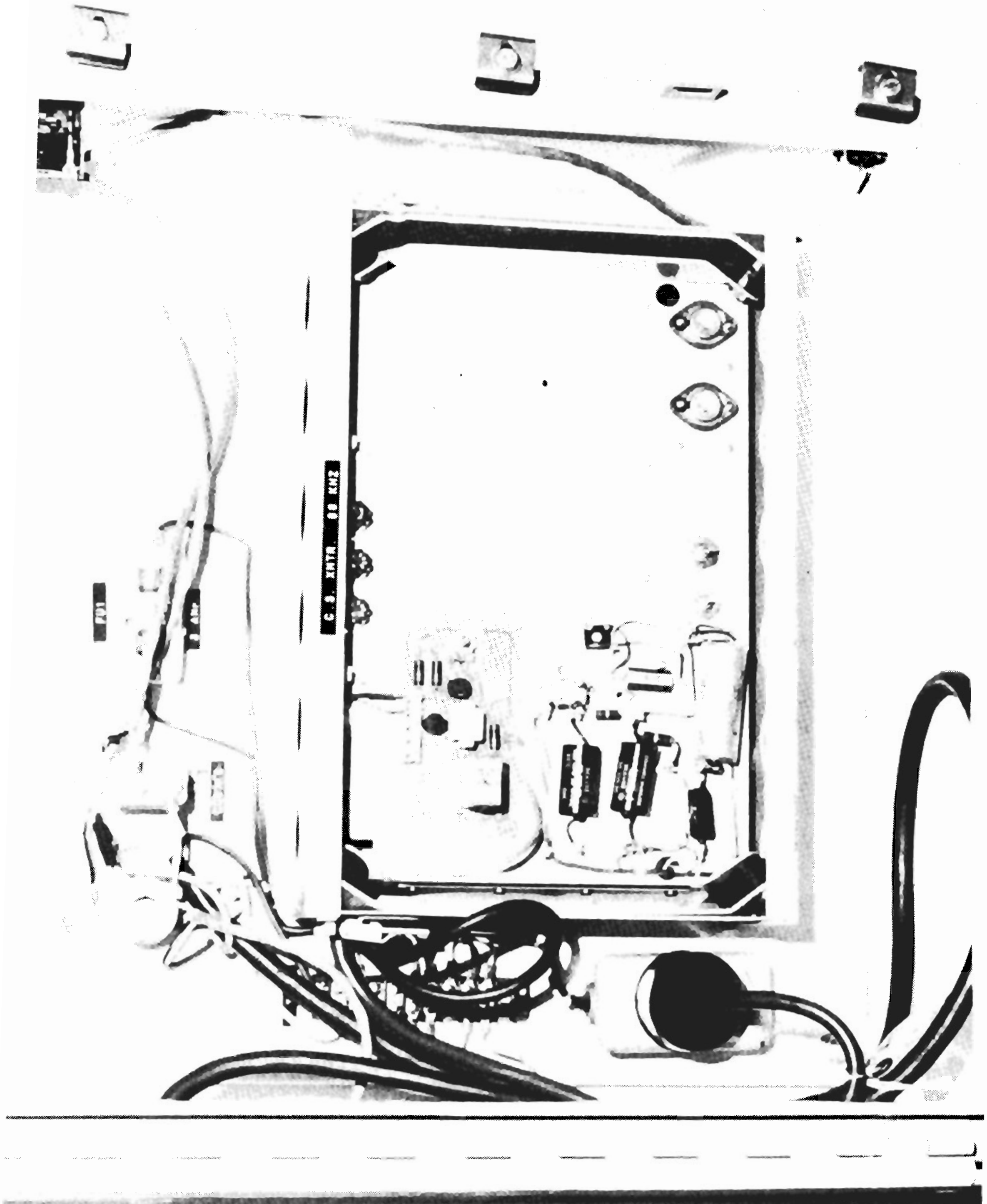

FIGURE 8. - 88-kHz transmitter in mine office.

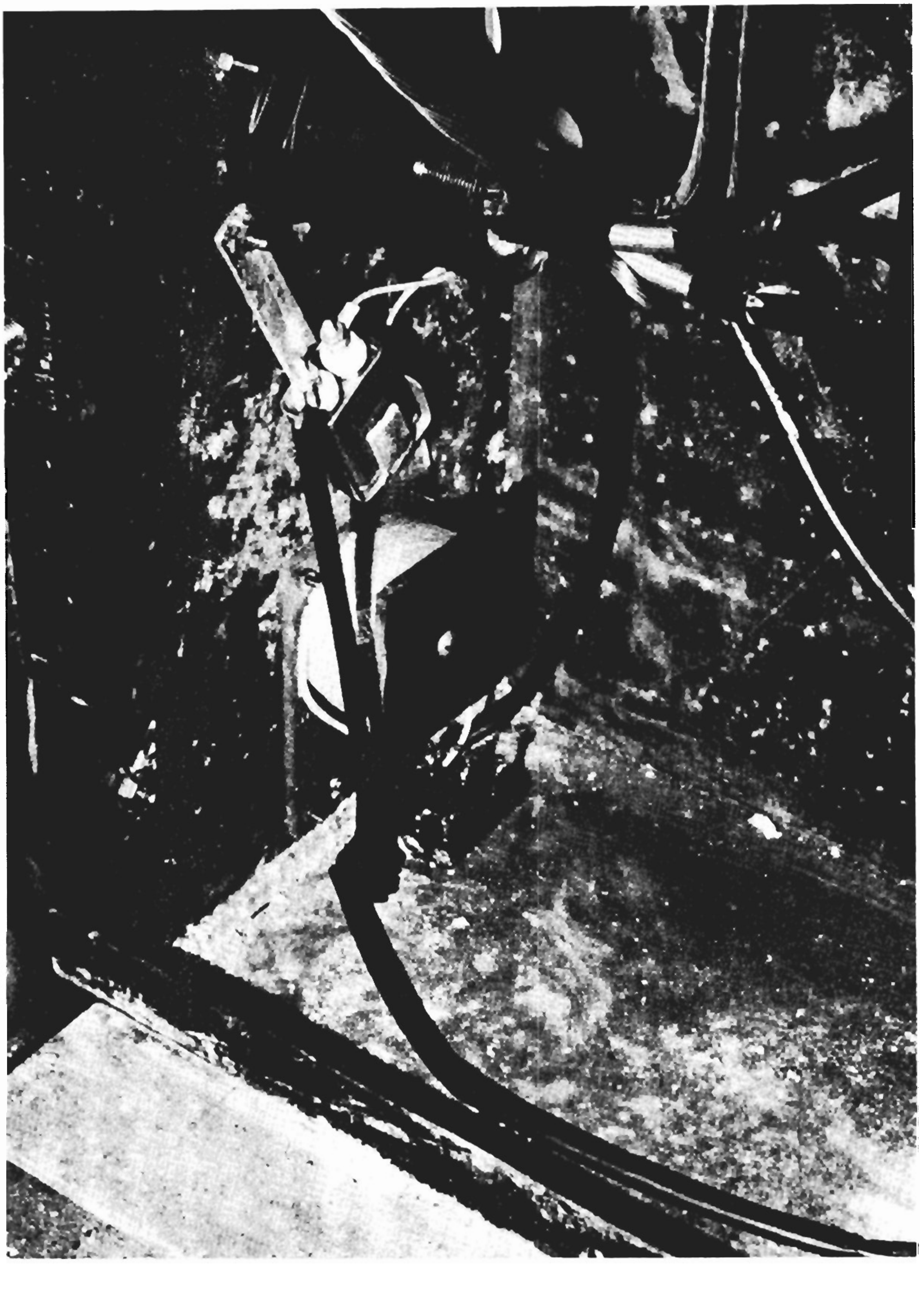

FIGURE 9. - Pilot wire termination.

FIGURE 10. - Miner wearing pocket pager.

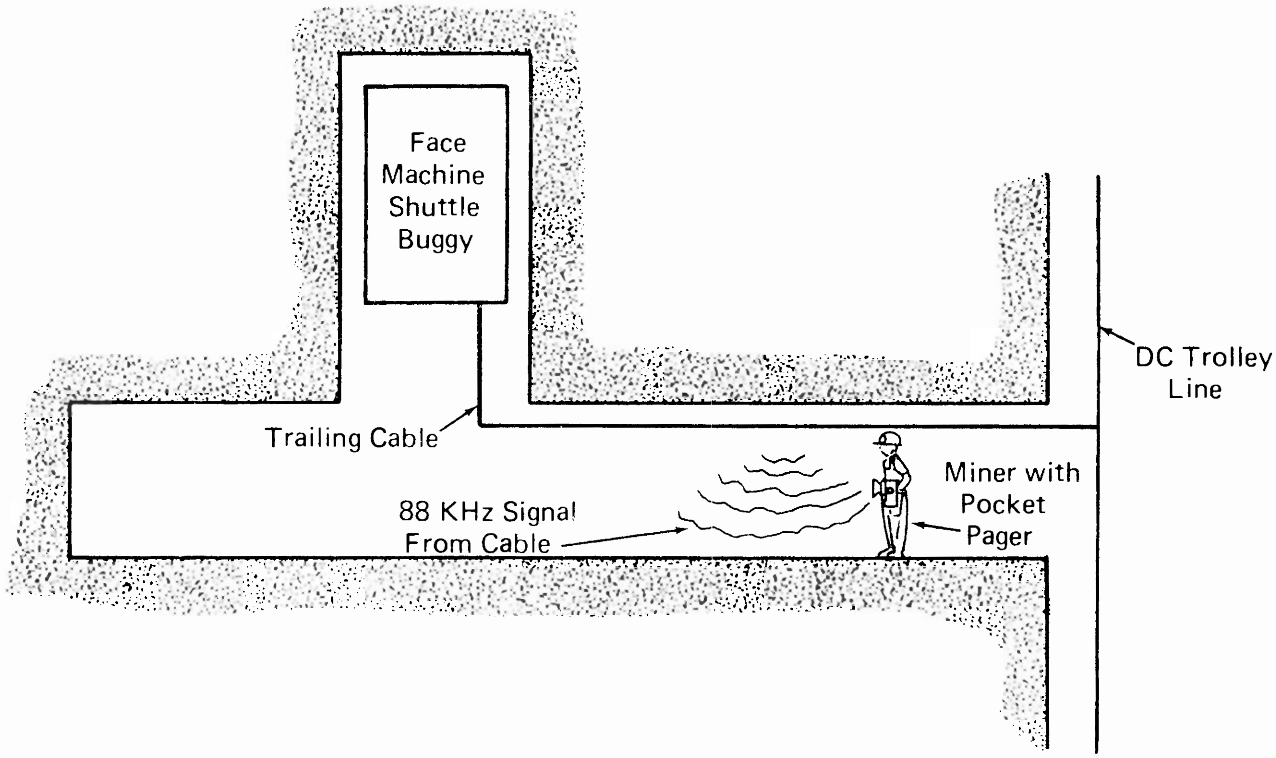

FIGURE 11. - Paging on trailing cable.

There is a second means of employing paging at carrier frequencies inside the mine. The paging transmitter can be connected to the mine telephone wires, connecting the signal between both wires and ground. The phone wires and ground then become the transmission line for the carrier frequency mine paging system. Once again, repeaters feeding roof bolts can be added in the mine working section area to extend the coverage away from the transmission line.

The 88-kHz system described above for whole-mine paging has many similarities with the trolley wire carrier communication systems used to dispatch dc haulage vehicles. As such, paging signals placed on the trolley wire can also be extended into the section via the cables of dc face machines connected to the trolley wire power system. Hence, in the vicinity of a trolley wire or trailing cables, a miner with a pocket pager will be able to pick up the page signals via the magnetic fields in the vicinity of these cables. Such an application is illustrated in figure 11.

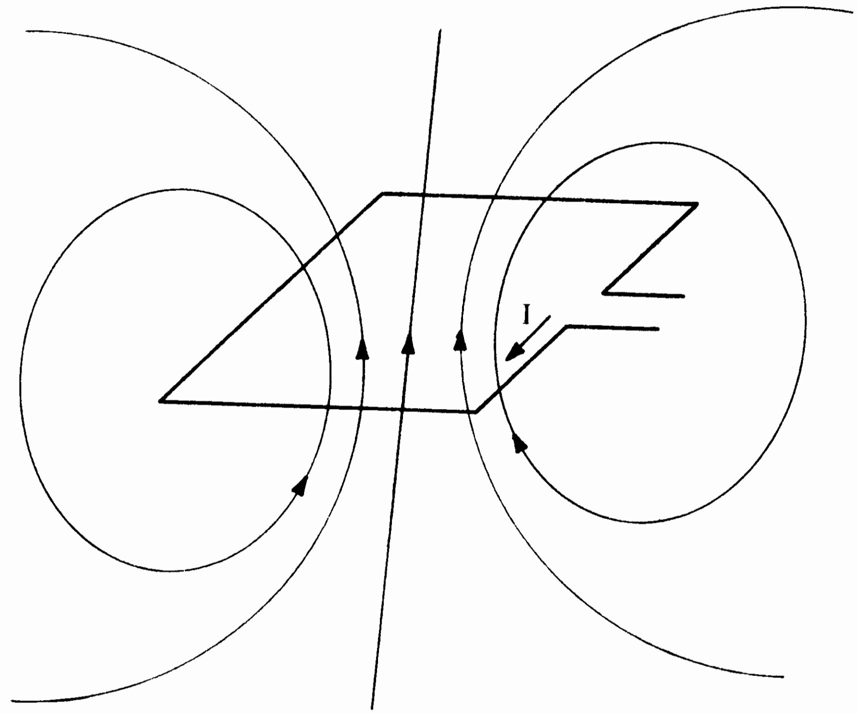

FIGURE 12. - Call alert antenna illustrating magnetic field.

CALL ALERT PAGING

A special form of paging is commonly called "call alert." It differs from the pocket paging system in that it produces a selective call alert signal that notifies an individual when the mine paging telephone is being used to page him. This system is not capable of as wide an area of coverage as the above roof bolt paging system; however, it is very effective in the working section. Once again additional equipment was added to the existing mine communications system. This time the equipment was added to the mine telephone line. A simple transmitter was added in the mine foreman's office, and a receiver and call alert transmitter were added in the mine section. The loop antenna of the call alert transmitter was wrapped around a pillar.

In order to receive a call alert, the individual carries a pocket alert receiver. The receiver has a blinking light to indicate a call. A nonaudible tone is sent over the telephone wires from the surface and is received by a selective filter, which in turn energizes the call alert transmitter on the section being paged. Instead of coming over the mine pager telephone system, the paging is personalized to those section individuals carrying the call alert receivers. When the pocket receiver indicates a call alert, the individual walks to the mine pager phone on the section and replies to the page call. This system was developed from work performed in the Bureau of Mines program on electromagnetic detection of trapped miners.

There is an additional benefit to this system. The signal being transmitted on the section is a low-frequency signal that also penetrates the overburden. It has been possible to receive such signals on the surface some 1,000 feet above the mine section. Miners on the section can use this transmitter for emergency signaling to the surface. Conversely, the miners can also use the call alert receiver to receive similar operational or emergency transmissions from a surface transmitter.

Principle of Operation

Figure 12 illustrates a call alert transmitter antenna and its associated magnetic field. The current flowing in the loop produces a magnetic field which links this loop with a small pickup loop in a call alert receiver carried by a person. The operational range of this system is essentially the distance at which the received signals have become small enough for the background noise to interfere with their reception.

Expected Coverage

Once again, an experiment was done in the Bruceton experimental mine to determine the efficacy of this system in providing paging coverage throughout a working section. A loop antenna was placed around a coal pillar and driven with a transmitter operating at a frequency of 3,030 Hz, and a calibrated receiver tuned to this frequency was carried through the mine to determine the signal strength received at various parts of the mine. The results of these measurements are shown in figure 13, which illustrates the extent of the call alert coverage.

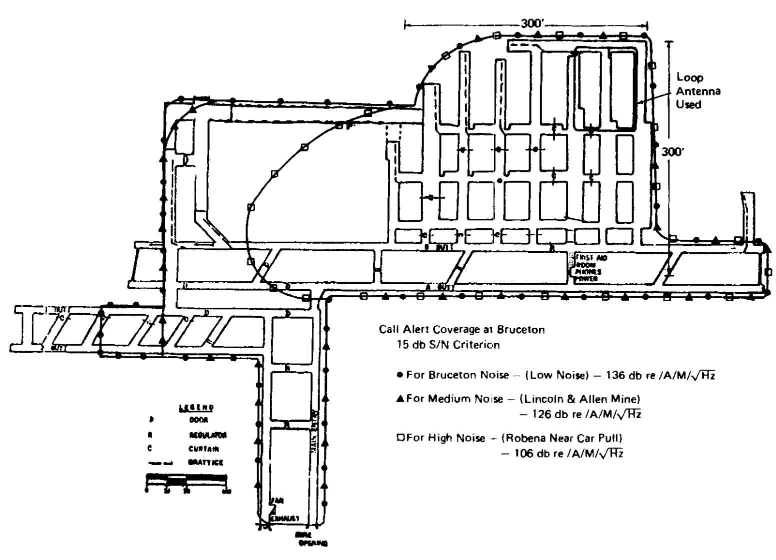

FIGURE 13. - Call alert coverage.

These coverages are for a 5-Hz bandwidth receiver. Three contours are shown. The first is for the background noise level found at the Bruceton mine, which we call low noise. It is seen that the coverage provided at a 15-db signal-to-noise ratio extends through most of the mine area, excluding the far extreme left corner. Measured noise from operating mines has been used to determine the contours of coverage that would result were such noise levels present in the Bruceton mine. In the medium-noise case, a small region of the above coverage is eliminated, while in the high-noise case, a further shrinkage of coverage is observed. The high-noise case represents noise levels measured by NBS at an operating mine near a car pull, and has been identified as the maximum noise condition. Figure 14 shows a photograph of the call alert transmitter, and figure 15 shows a photograph of the call alert receiver. Much like the roof bolt system, coverage over a typical working section can be expected with appropriate positioning of the transmitting loop.

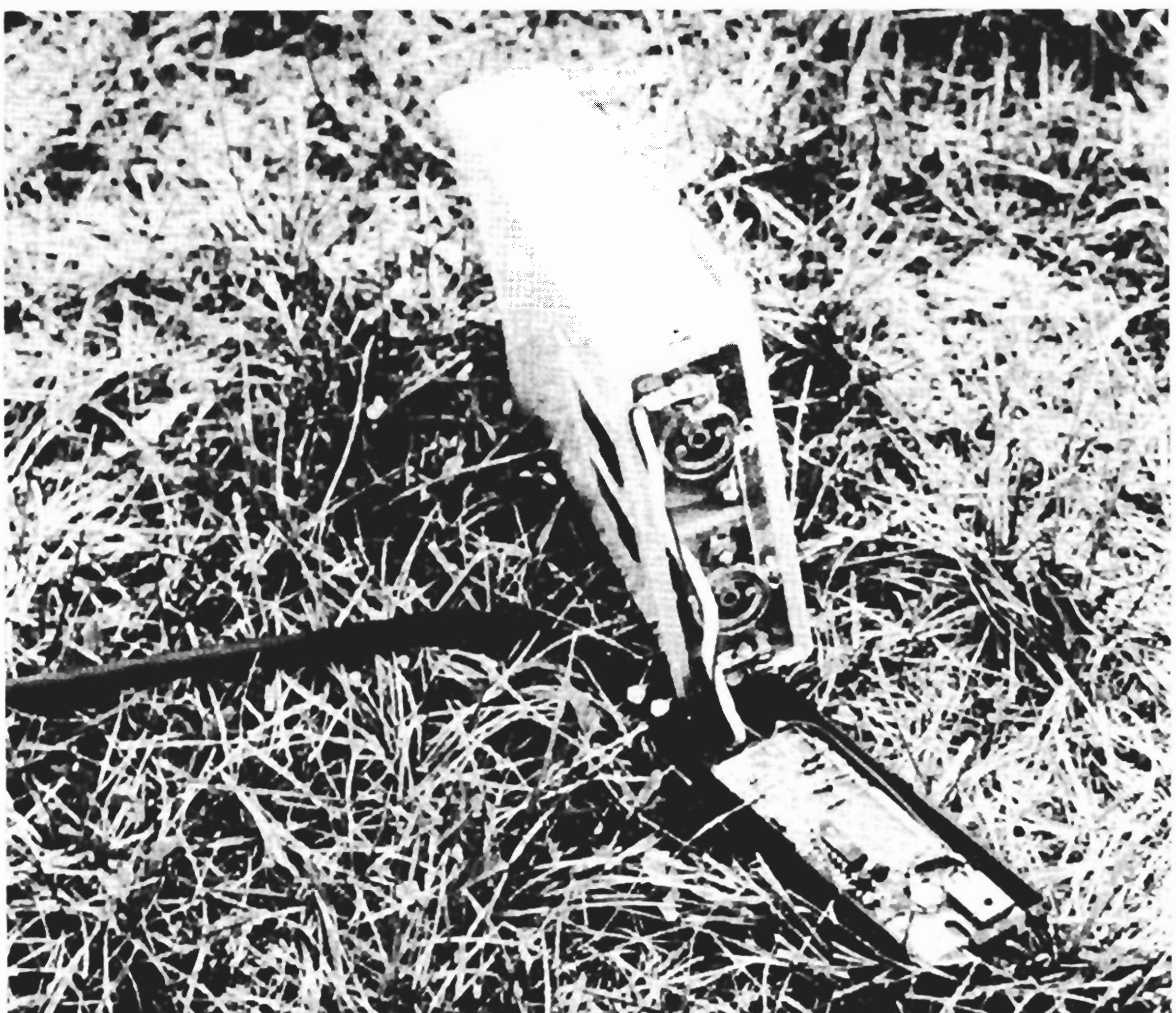

FIGURE 14. - Call alert transmitter.

FIGURE 15. - Call alert receiver worn by miner.

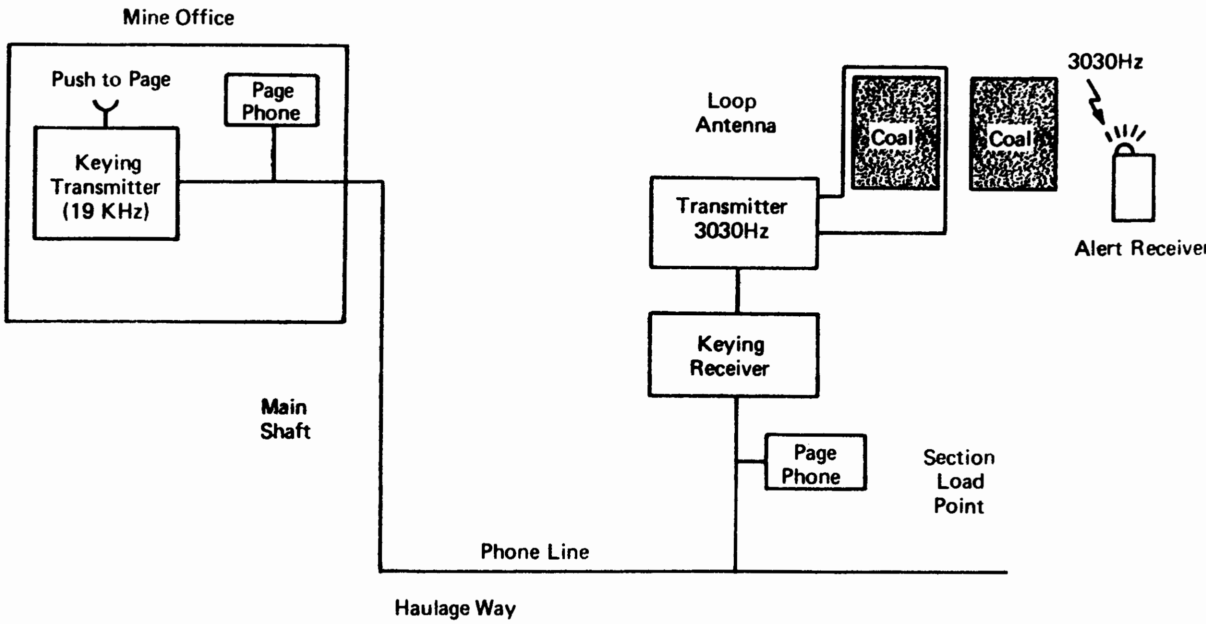

FIGURE 16. - Call alert paging system.

System Description

The block diagram of figure 16 illustrates the entire system configuration. A keying transmitter is located in the mine office. To initiate a page, an individual pushes the "press to page" button on this transmitter. This action causes a 19-kHz carrier (other selected inaudible tones can also be used) to be impressed on the mine phone line. This tone enters the mine on the phone line. The keying receiver, attached to the phone line located at a keypoint in a section, responds to this tone. These two units are illustrated in figure 17. As long as the tone is present,

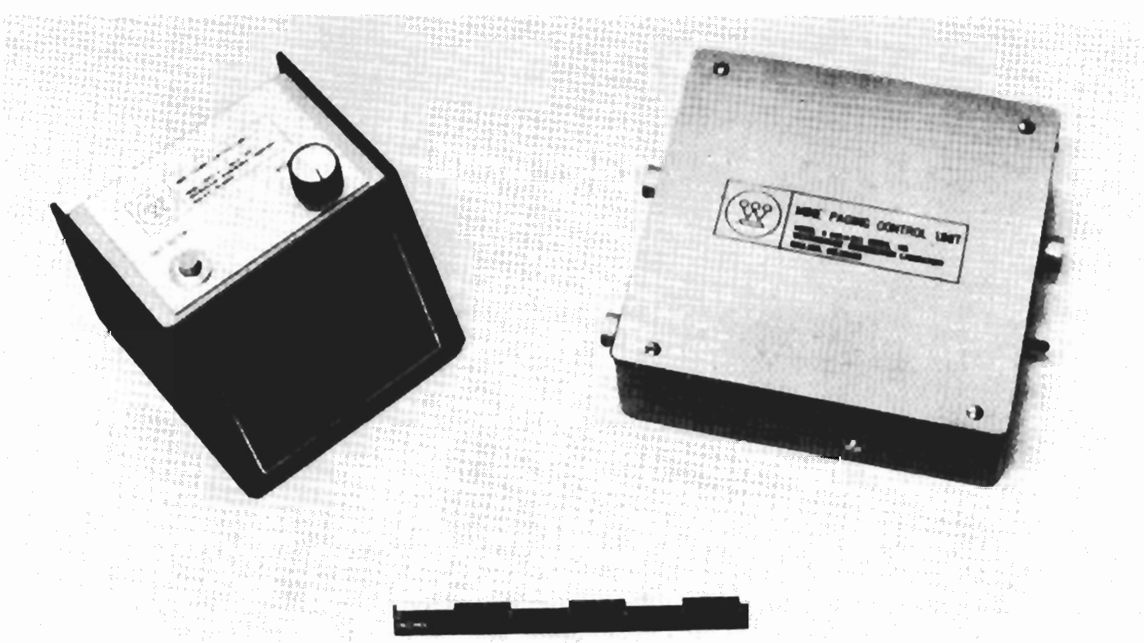

FIGURE 17. - Keying transmitter and keying receiver (control unit).

the keying receiver connects operating power to the call alert transmitter connected to the pillar-mounted loop. In the present system this call alert transmitter drives a 3,030-Hz signal current into the loop antenna of the system, thereby producing a 3,030-Hz signal that penetrates to all regions of the section. A pocket-sized call alert receiver incorporating a small pickup loop is carried by a person roving through the section. This receiver responds to the presence of the 3,030-Hz signal by flashing a light on the receiver or by generating an audio alert signal. The person paged is thus notified to call the mine office.

A word of caution: Call alert systems use carrier signals over the telephone wires. A preliminary examination of several of the mine pager telephones indicates that these phones are not fully compatible with the normal range of telephone grade carriers. We are now investigating this problem and anticipate that a simple add-on device (applique) can be made for installation on existing mine pager phones to make them compatible with carrier applications. At this time, it is possible that some carrier frequency systems will require excessive amounts of power if utilized on present mine telephone installations.

CONCLUDING REMARKS

The emphasis of our paging efforts has been placed on the extension of existing mine communications to improve their utility under operational and emergency conditions. Primarily we have been concerned with extending the page message from the equipment that receives the page to the person who is being paged. Paging can also be added to wireless radio communication system; however, very few mines currently use wireless radio. The objective in paging is to alert a person that he is wanted on the telephone. The person replying to the page will generally not reply over the same channel by which he was paged. The paging system and the call alert system discussed here meet different needs. The general features of these two systems are summarized in table 1.

TABLE 1. - Roving miner paging

	Roof bolt system	Call alert system
Coverage	Part or whole mine	By section
Voice Page	Yes	No
Selectivity	To individual	To section
Emergency use	Not practical	Yes
Equipment available	Current	60 days

TWO-WAY COMMUNICATIONS WITH FACE MACHINE OPERATORS

by

Robert A. Bradburn[1] and Howard E. Parkinson[2]

ABSTRACT

Mine communications have been extended to the face machinery in the U.S. Bureau of Mines Safety Research Mine. Simplex two-way communications have been established using commercial products approved for use in coal mines. Two approaches have been taken.

A mine pager phone has been mounted on a roof bolter. This phone is connected to an extra pair or wires in the power trailing cable by means of a special cable reel, thereby establishing communications with phones at the power center or on another face machine. The pager is a permissible unit. These phones can also be selectively interconnected with the surface.

Carrier current over the pilot check wire establishes communications between two face machines or between a face machine and the surface. Attention has been directed toward permissible equipment.

The equipment is battery powered, so that the phone is operational when the machine is down for maintenance.

Franklin Institute is determining whether sufficient radio frequency energy at 88/100 kHz can be transferred to accidentally fire an electric detonating cap.

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[1] Electrical engineer

[2] Supervisory electrical research engineer

Both authors are with Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

INTRODUCTION

Existing mine communication systems stop at the last open crosscut of the section. Present mine communication systems are aimed at satisfying the need that the mine section foreman be able to communicate with the mine shift foreman. However, in some mines there are additional communication needs <u>within</u> the mine section, needs which are not adequately met as follows:

Between the continuous miner operator and the shuttle buggy operators.

Between the shuttle buggy operators and the "gathering" locomotive operator.

Between the general maintenance foreman and the section maintenance man repairing a machine.

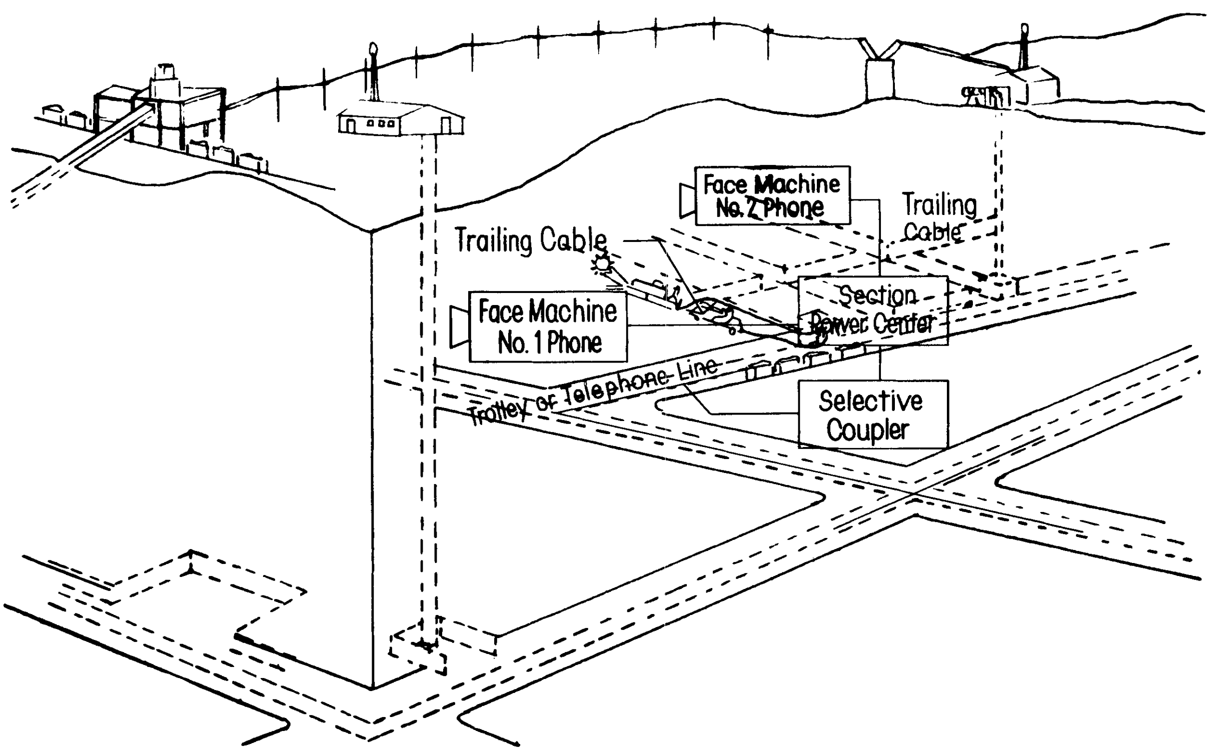

FIGURE 1. - Trailing cable communications system.

FIGURE 2. - Loudspeaking phone on roof bolter.

By satisfying these needs, both the safety and efficiency of mining operations can be improved. The existing power trailing cables to the face machines provide the means to achieve these communications capabilities in a reliable and economic manner. Figure 1 provides an overview of the communications systems to be discussed below.

The operational and safety advantages of the aforementioned communication capabilities are several and diverse. The shuttle buggy operator will be able to alert the continuous mining machine operator of an impending roof fall. The shuttle buggy operators will be better able to coordinate their activities as they go in to dump on the belt or into the cars. The maintenance mechanic will be able to communicate with the surface while working at a face machine. When maintenance on a face machine is required, the maintenance mechanic can be called directly from the trobled machine. This paper describes some of the trailing cable techniques that we have developed to fulfill the above communication needs.

Adaptations of existing mine communication hardware have been used to the fullest extent possible, subject to the following requirements:

1. Hardware must be permissible.
2. Hardware must be battery-operated.
3. System must provide intermachine communications.
4. System must selectively interconnect to a surface system.

APPLICATION OF EXISTING TECHNIQUES

Loudspeaking Telephones

Loudspeaking telephones can be used on mine face machinery. Figure 2 shows an experimental installation on a roof bolter. This phone is battery operated, and the newer versions are not only designed for rugged mine usage, but also are intrinsically safe. An overall diagram of a loudspeaking phone trailing cable communications system for face machines is presented in figure 3. The system depicted in figure 3 allows a shuttle buggy operator (face machine No. 1) to communicate with the continuous miner operator (face machine No. 2) on standard loudspeaking (pager) mine telephone apparatus. The fact that continuous miners are powered from ac and shuttle buggies from dc does not jeopardize or hinder this form of communication.

To facilitate the use of these phones on face machinery, it is necessary that telephone wires be provided in the trailing cables. Figures 4 shows a cross-sectional view of a trailing cable that the Bureau procured with a shielded telephone pair of No. 22 wire.

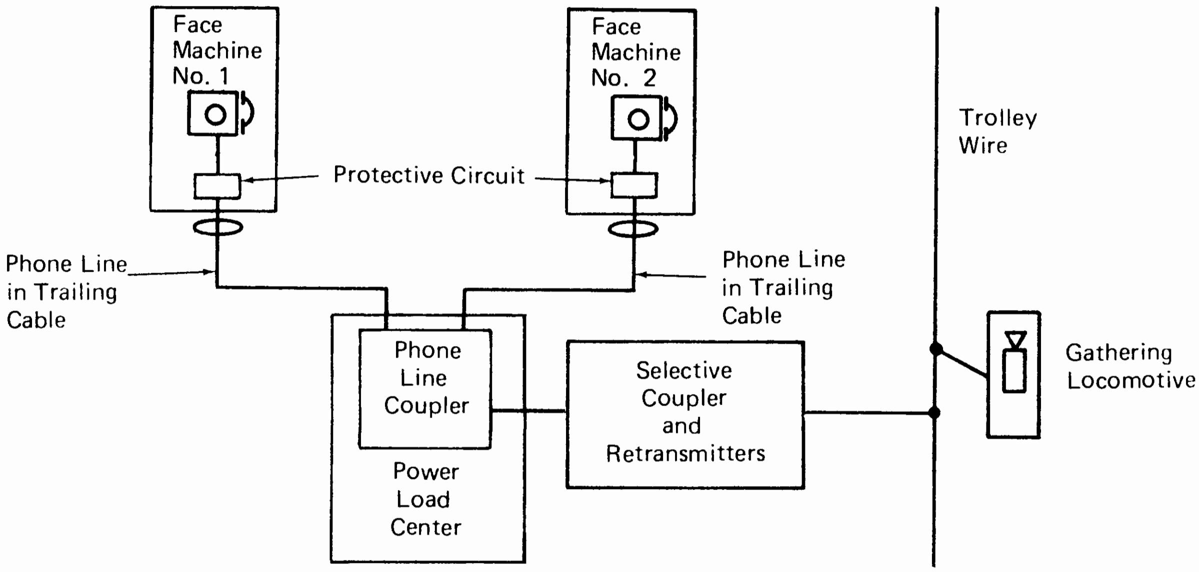

FIGURE 3. - Face-machine to face-machine loudspeaking phones showing interconnection to gathering locomotive.

This particular cable was readily available for our experimental installations. For operating-mine applications, a larger wire size is recommended to increase the strength of the telephone pair.

To insure safety in the connection of the machine-mounted phones to the telephone pair inside the power cable, the phones have protective circuits as illustrated in figure 5. To ensure that there is no danger of any power accidentally interfeeding between one cable and another, a transformer coupler located at the power center provides isolation between the trailing cables as depicted in figure 6. As on the machines, protective circuits are also used at the power center, as shown in figure 6.

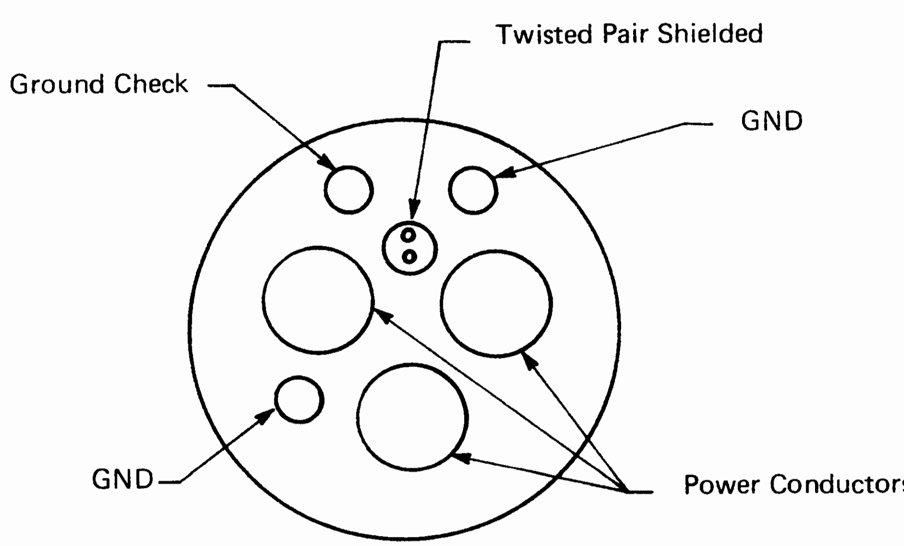

FIGURE 4. - Trailing power cable with a shielded telephone pair.

To allow the face machine operators to occasionally communicate with the "gathering" locomotive operator, it is necessary that a loudspeaking telephone-to-trolley wire telephone selective interconnect coupler be placed in the mine section as indicated in figure 3. We have modified a standard, Femco loudspeaking phone-to-trolley phone coupler to provide this selective coupling. The coupling is selective in order not to burden the trolley system with routine face machine communication traffic and vice versa. Either the shuttle buggy operator or the "gathering" locomotive operator can initiate the interconnect by simply applying an audio tone to the mouthpiece of his phone using a pocket-sized tone generator.

The advantages and disadvantages of this trailing cable communication system are summarized as follows:

Advantages	Disadvantages
1. Permissible.	1. Extra wires in trailing cable.
2. Rugged.	2. Isolation required between interconnected phones.
3. Battery powered.	3. Special coupler required for providing paging voltage.
4. Reliable.	4. Extra terminals at plug.
5. Simple.	5. Extra slip rings in cable reel.

Carrier Type Telephones

We have also examined a second approach to meeting face machine communication needs. Carriertype telephones normally used on the trolley wire system have been placed on face machinery as shown in figure 7. One difficulty with this approach is that permissible trolley wire phones are not yet commercially available, although one of the manufacturers of trolley wire phones isnow considering submitting its equipment for approval. Therefore for this experimental installation, we modified a trolley wire phone and obtained a permit to operate it in a gaseous mine. These section trolley wire telephones are also battery operated, which permits them to be used when machine power is shut off, such as during maintenance operations.

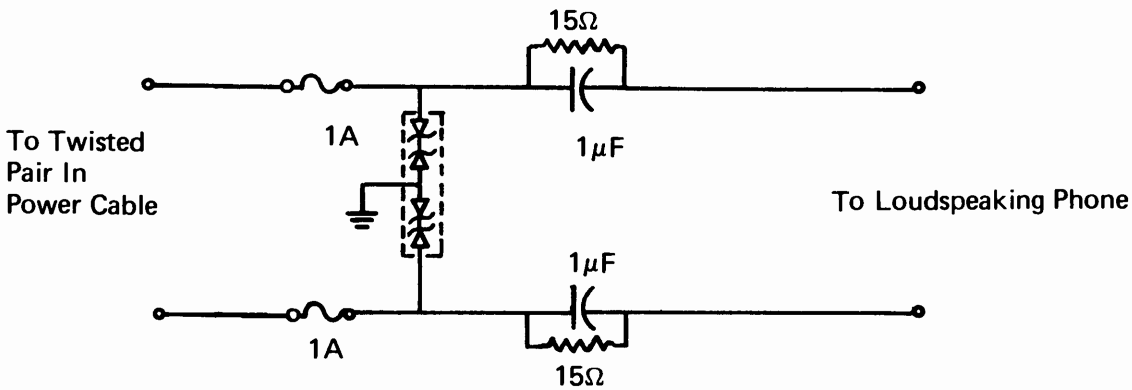

FIGURE 5. - Protective circuit installed on face machine.

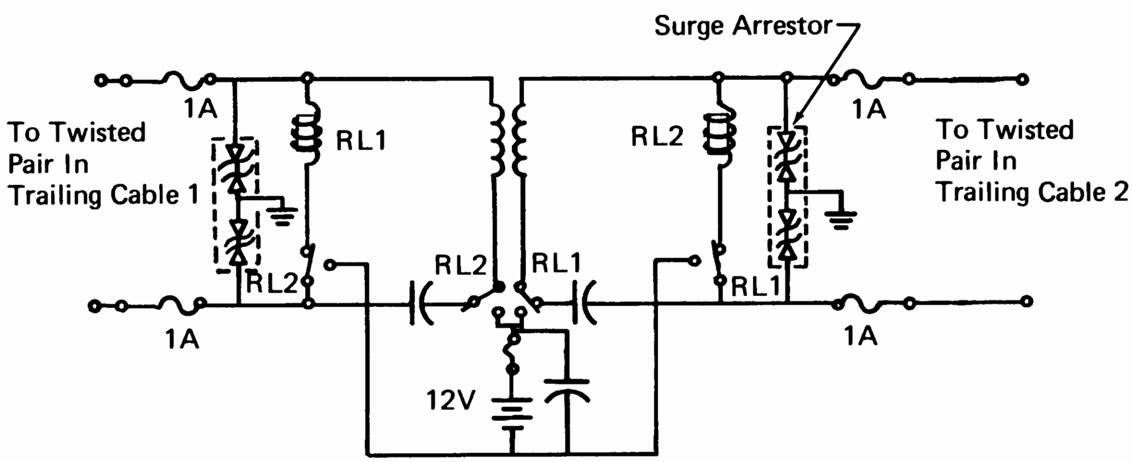

FIGURE 6. - Phone line transformer coupler installed in powerload center.

Trolley wire phones on face machinery can best be used over the power wire in the trailing cable as shown in figure 8. In a situation where the cintinuous miner is on ac and the shuttle buggies on dc, it will be necessary to use a special safety coupler that ties one of the phase wires of the ac system to the positive wire of the dc system. This safety coupler must provide a means of fuse separation for the circuits in case of failure.

As in the loudspeaking phone system, the "gathering" locomotive of the trolley wire system can also be selectively interconnected to the face machinery carrier phones by means of a selective coupler. This selective coupler prevents the normal traffic on the trolley wire system from interfering with the traffic on the face machinery equipment and vice versa. Figure 9 presents an overall system diagram, including this selective interconnect feature. Separate frequencies are used for the trolley wire and face machine systems.

FIGURE 7. - Carrier phone on face machine.

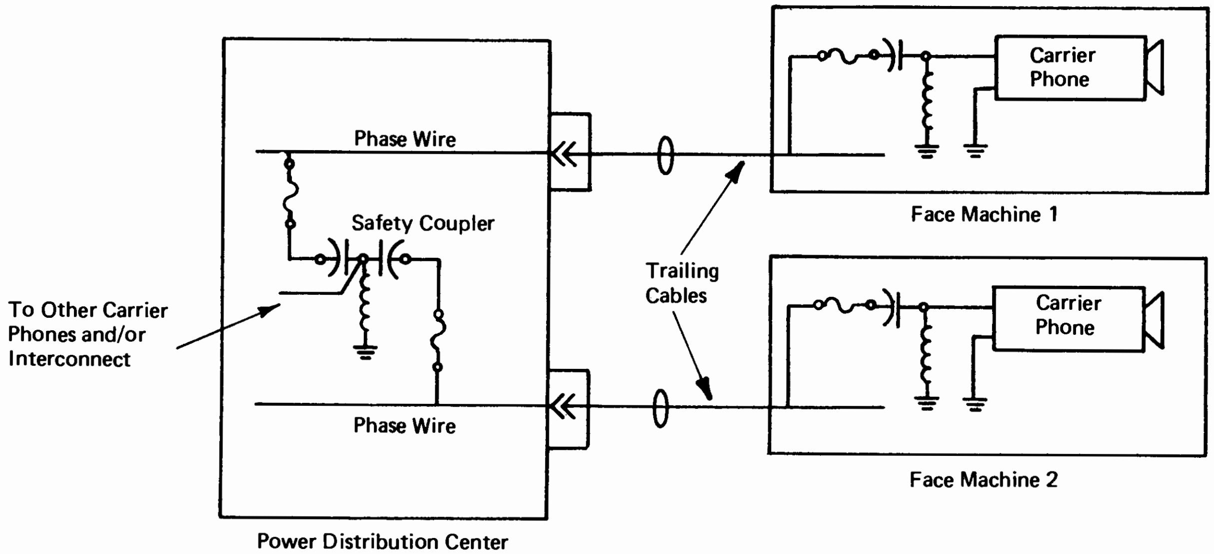

FIGURE 8. - Phase wire as signal carrier between face machines.

The 88-kHz (typical) signal used on the trolley wire is connected via the selective coupler to a 133-kHz transmitter, 133-kHz being the carrier frequency for the face machines on the section. When the "gathering" locomotive operator wishes to talk to the face machinery operator, he sends a selective coupling signal (audio tone) that causes the coupler to interconnect and retransmit his message via a 133-kHz carrier to the face machinery on the section. In the opposite direction, when a person on the section wishes to talk to the trolley wire system or locomotive operator, he sends the selective coupling signal (audio tone) to the coupler which interconnects the section equipment to the trolley wire system and locomotive.

The advantages and disadvantages of this trailing cable communication system are summarized as follows:

Advantages

1. No extra wires or contacts.
2. Couple onto phase wire.
3. Battery power option.
4. Rugged.
5. Reliable.

Disadvantages

1. Presently nonpermissible.
2. Isolation required between machines.

Surface Interconnect

Both of the above face machine communication systems can also be connected to the surface via the mine trolley wire or phone line. If the dispatcher, mine foreman, or any other surface personnel wish to contact the section, the section can be selectively coupled into the trolley wire system or the phone line system. Each section can be assigned a special selective audio tone for coupling purposes. This permits the sections to be isolated one from another and to be paged selectively. Therefore, the selective page for any particular section will not be heard on any other section.

CONCLUSIONS

Two-way communication between face machine operators and between face machine operators and surface personnel on a selected call basis is possible with existing communication hardware or modification of existing hardware. These communications can help mining personnel improve safety and efficiency of mine operations.

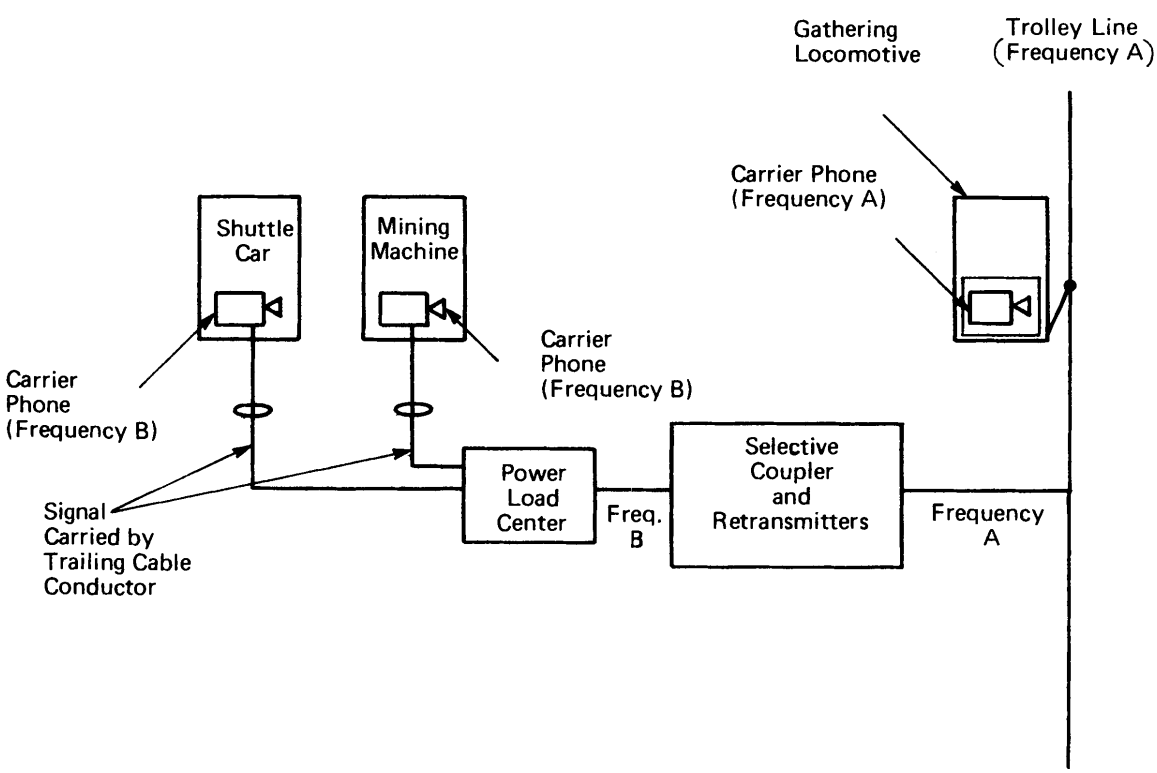

FIGURE 9. - Face-machine to face-machine carrier phones showing interconnection to gathering locomotive.

TWO-WAY COMMUNICATIONS WITH ROVING MINERS

BY

Robert L. Lagace[1] and Howard E. Parkinson[2]

ABSTRACT

UHF wireless and guided wireless radio systems are operational in the Bureau of Mines Safety Research Mine in Bruceton, Pa. The systems satisfy the need for instant personal two-way communications between key individuals roving in working sections and haulageways, and between these indiciduals and the surface. The individuals are equipped with portable handy talkie radios that are Bureau-approved for operation in a gassy mine. The Bureau's systems operate at 420 MHz, a frequency allocated to Government users. Systems belonging to industrial users such as mines can utilize the 450 to 470-MHz UHF band allocated to industrial land mobile applications. The UHF band is more effective than the VHF (very high frequency) band for unaided propagation in the sections and haulageways of mines.

The UHF wireless radio system does not need any special guiding cables and is particularly attractive for mine section applications, as well as haulageways. The UHF guided wireless radio system is based on the use of a special radiating coaxial cable installed along main entries, and is suitable for haulageway applications. This paper treats the principles of operation, expected communication ranges, and the key features and limitations of both systems.

---

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[2] Supervisory electrical research engineer, Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

INTRODUCTION

Need for Two-Way Communications With Roving Miners

Historically, communication equipment for underground mine use has been based on "wired" systems, namely, the loudspeaking mine telephone system and the trolley wire carrier phone system. The mine telephone system includes both magnetophones and loudspeaking telephones, while the trolley wire carrier phone system utilizes carrier current transmitters and receivers. In both cases all the transmitting and receiving equipment is "hard wired" to the telephone line or to the trolley wire, respectively. As such, this equipment is not portable. Therefore, it is inadequate for paging or communicating with key induviduals, such as foremen and maintenance men, when they are not in the immediate vicinity of the communication equipment.

The roving miner paging systems recently developed by the Bureau of Mines and discussed in a companion seminar paper meet the need to deliver one-way paging messages and call alerts to key individuals on the move in the mine. These are messages or alerts that the paged individual must either act upon, or acknowledge via another communications channel in the mine. However, situations also arise in which an instantaneous and continuing response from key roving miners is either essential or extremely desirable from an operational or safety point of view. The ability to reach and talk with an individual where he happens to be, and not only at a limited number of fixed stations, is particularly beneficial when-

1. Downtime can be reduced by permitting individuals working on machinery to communicate with surface supervisors without leaving the machinery; or

2. The message is urgent and the individual is on the move underground.

Two-way wireless and guided wireless radio systems recently investigated by the Bureau can provide this personalized instantaneous communication to individuals over important parts of the mine.

Two-Way Wireless Radio in Mines

The thrust of our two-way wireless radio communication work has been to extend two-way communications to key miners roving within the section and in the haulageway. The principal objective has been to find ways in which commercially available, portable radio equipment can be adapted for practical use in operational coal mines.

Electromagnetic waves at radio frequencies are not capable of penetrating the overburdens of typical mines because of the severe attenuation suffered in the overburden by the waves at these frequencies. To utilize radio waves in mine entries and crosscuts, the radio signal sources must be brought into the mines and to the areas of interest, either directly or via guiding cables or wires.

The operating frequency is a key factor that significantly influences the communication range of any wireless radio system in mines. U. S. coal mining methods require area coverage, as opposed to the linear haulageway coverage that is typically needed for European longwall mining. By area coverage we mean communications throughout a working section that may typically encompass an area 600 feet by 600 feet, and communications down crosscuts to several hundred feet away from the main haulageways.

We have found that frequencies in the UHF band offer the best area coverage for completely wireless two-way voice communications between portable handy talkie radios. This we have determined from theoretical considerations backed up by in-mine experiments. Two-way wireless communication ranges between handheld units in mine entries are limited to approximately tens of feet at citizens' band frequencies near 30 MHz, are extended to several hundreds of feet at VHF band frequencies around 150 MHz, and are further extended to over 1500 feet for UHF band frequencies around 450 MHz. These ranges apply to straight line communications along an entry, and are reduced if corners are present in the transmission path. In addition to offering the greatest promise for extending two-way communications to roving individuals, the 450-MHz UHF frequency band is presently the upper limit for commercially available portable radio transceivers. This frequency band has also been receiving much publicity and interest in the underground mining industry.

Two specific UHF radio communication systems are treated in this paper. The first is truly wireless and particularly attractive for section applications, so it has been named <u>UHF wireless section radio</u>. The second makes use of a special coaxial cable for guiding and radiating UHF radio waves along mine entries, so it has been named <u>UHF guided wireless radio.</u>

UHF WIRELESS SECTION RADIO SYSTEM

Two-way wireless section radio systems can provide communications between key individuals who may be working at different locations within a section, and between these individuals and the surface. These systems can also be applied to haulageway communications. Figure 1 gives an overall view of such a system for a section application. It is described in detail under "System Description," after discussion of the system's principles of operation and expected communications coverage.

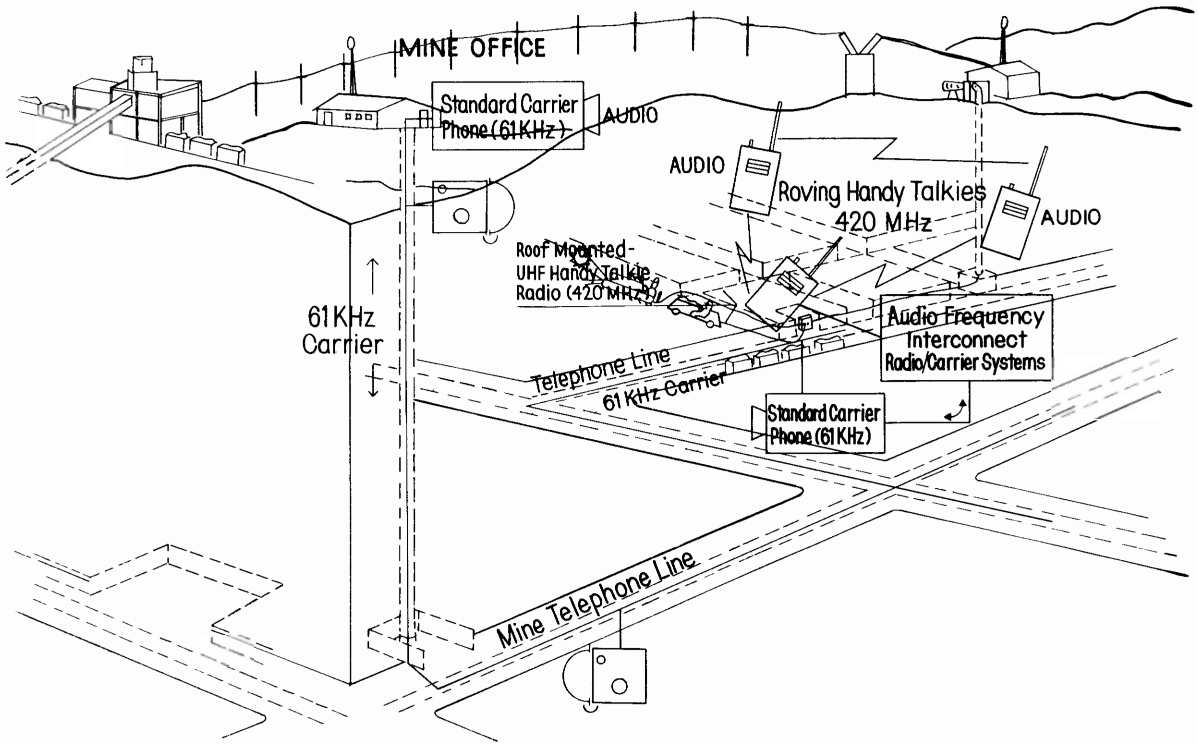

FIGURE 1. - Two-way wireless section radio system.

Principles of Operation

Figure 2 depicts in schematic form a UHF radio wave propagating down a coal mine entry (tunnel) without the assistance of any metallic guiding wires or cables. At VHF or UHF frequencies, the entries themselves behave like "leaky" waveguides, guiding the signal energy along the length of the entry, while also losing part of the energy to the surrounding medium. By analogy, the roof, floor, and walls of a mine entry can be considered as imperfect mirrors and the radio waves as light beams. As the light beam, or radio wave, travels down the mine entry, bouncing off the walls, roof and floor, part of its energy is reflected at each bounce and therefore retained in the entry, while part of its energy is transmitted into the coal or rock by refraction and therefore lost.

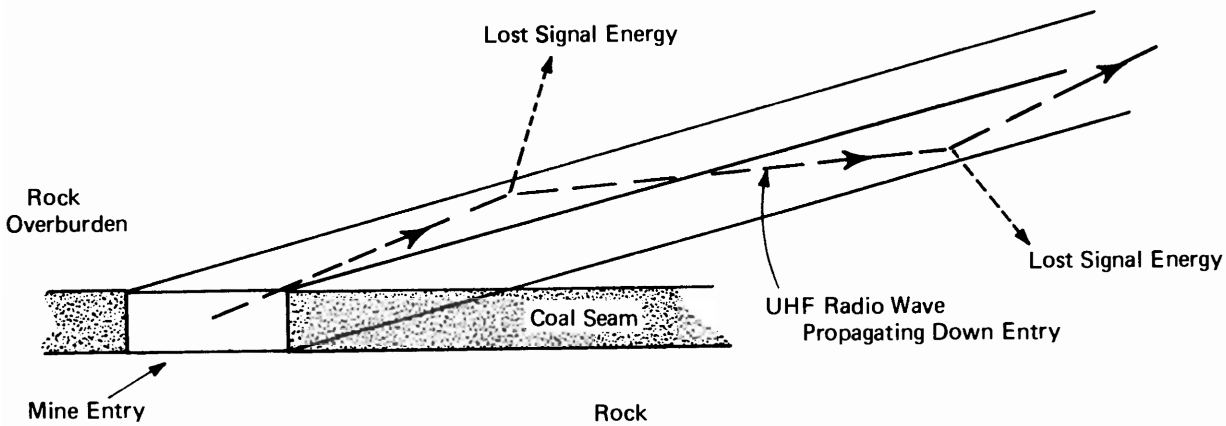

FIGURE 2. - UHF wireless radio in coal mines—principle of operation.

Figure 3 illustrates how the signal attenuation loss for mine entries varies with operating frequency for the dominant propagating mode. This loss represents the fractional decrease in strength, expressed in decibels (dB), suffered by the signal for each 100 feet it propagates down the entry. The curves in figure 3 are based on data from propagation experiments performed in an operating high coal mine, and on values calculated from theoretical equations. As shown, both theory and experiment indicate that in high coal entries, wireless radio signals are attenuated severely below the UHF frequency range, experience a broad favorable minimum in attenuation between 500 MHz and 2,500 MHz in the UHF band, and finally suffer a gradual increase in attenuation as the frequency is increased beyond the UHF frequency band. In low coal the attenuation loss is shown to be more severe, particularly below 1,000 MHz. This low coal behavior has only been partially confirmed by the routine use of 420-MHz handy talkies during field trips to mines.

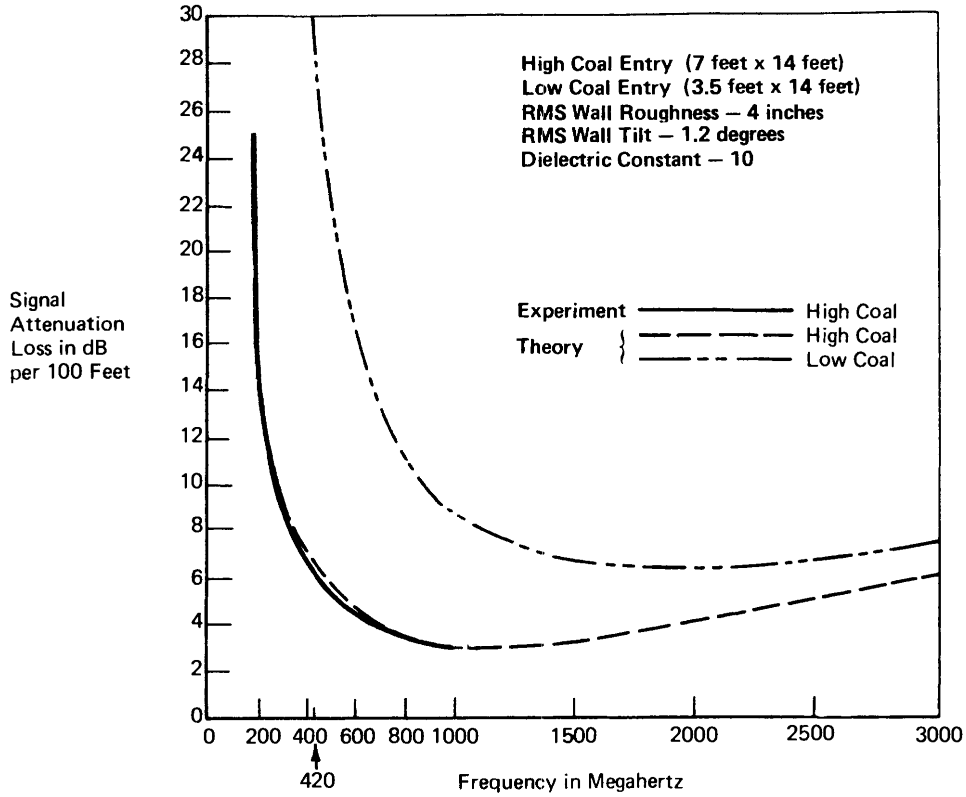

FIGURE 3. - UHF wireless radio signal attenuation loss in coal mine entries.

The other major frequency dependent losses are antenna coupling loss and corner loss. When they are added to the attenuation loss, the appearance of an optimum operating frequency band becomes more pronounced. In high coal, the optimum band is 400 to 1000 MHz. Within this band, the best frequency for a particular application will depend on the desired communication distance and whether the signal must travel around a corner to reach the receiver. For example, operating frequencies near 400 MHz are favored for transmission paths about 500 feet long that include one corner. Such paths are typical for section applications. Frequencies near 1,000 MHz are favored for long straight-line transmission paths along haulage ways.

The Bureau has tested portable mobile radio equipment up to the present frequency limit of equipment availability, the 450-MHz band, the band which also offers the most favorable performance for section applications in high coal. Allocation of a new band of frequencies around 960 MHz for land mobile industrial applications is presently under consideration by the Federal Communications Commission. However, portable and fixed station 960-MHz equipment for haulageway applications will still not be commercially available for several years. Therefore our present investigations and range predictions were concentrated on the 450-MHz band.

Expected Coverage

Communication can be maintained between two separated individuals or stations until the separation distance increases to a point where the signal strength is not sufficient to overcome the background electrical noise. At UHF frequencies, measurements have shown that the levels of this background noise will be governed by the intrinsic electrical noise of the UHF receivers rather than by externally generated electrical noise in the mine. The wireless radio coverage of a typical section in high coal has been estimated for Motorola HT220 FM handy talkie units operating at a frequency of 420 MHz. These portable units have a transmitter power of 2 watts and receiver sensitivity of 0.5 microvolt for 20 dB of quieting.

Since communication on a working section requires coverage down crosscuts, one must add to the straight-line attenuation the loss incurred by the signal in going around at least one 90° corner. At 420 MHz, theory and experiment support the use of a corner loss of about 58 dB for the dominant propagating mode. To these losses must be added a total antenna coupling loss of about 46 dB to account for the insertion, polarization, and efficiency losses expected for two portable handy talkies. A nominal signal fade margin of 12 dB should also be included. These values lead to the conservative section coverage prediction shown in figure 4.

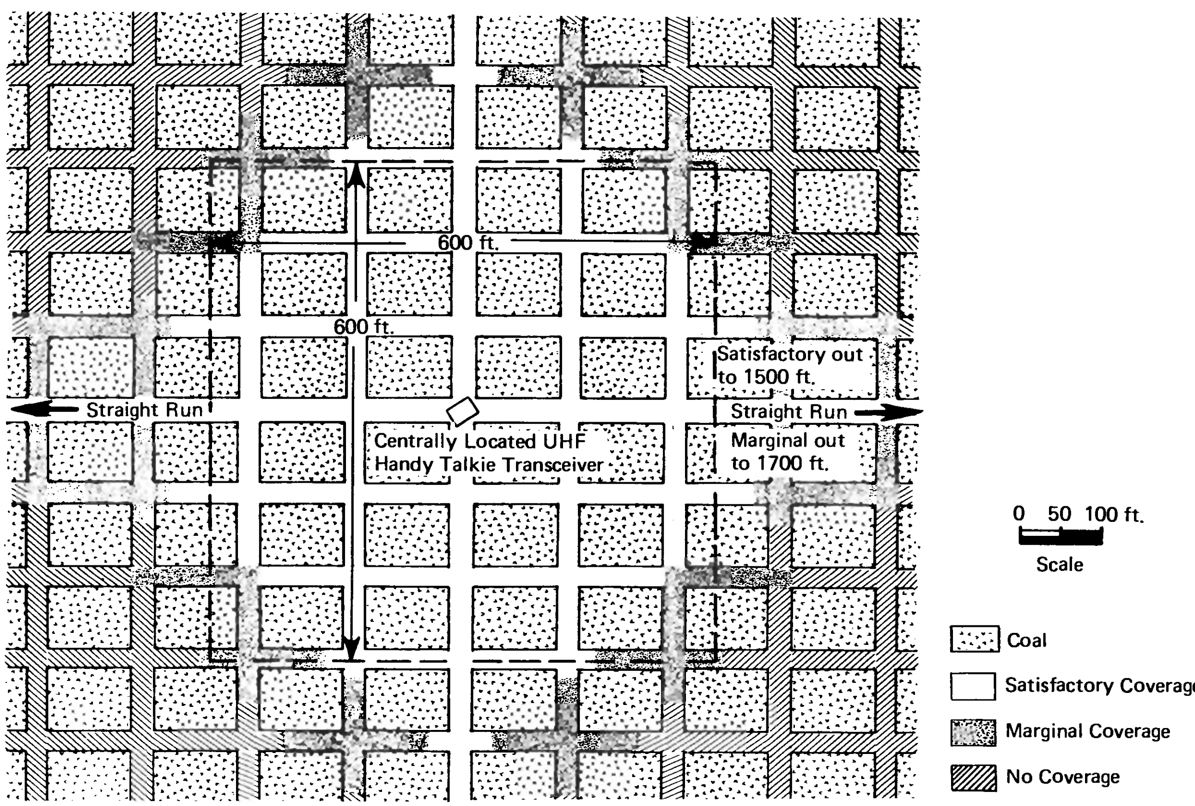

FIGURE 4. - Predicted UHF wireless radio coverage.

Figure 4 illustrates the coverage expected in a high coal mine between a centrally located miner with a handy talkie unit and a second miner roving throughout the section with another unit. Miner-to-miner separation of more than half a section is possible, unaided by any transmission lines or other guiding cables. This separation can be doubled to cover the whole section by placing a repeater unit at the central location in the section.

Note that when the signal must go around only one corner, satisfactory communication can be expected over a linear distance of approximately 500 feet down an entry and crosscut. When no corners are encountered, as in a haulageway transmission path, satisfactory straight-line communication can be expected over distances in excess of 1,500 feet. These range limits can usually be somewhat extended if the handy talkies are rotated into the horizontal plane and pointed across the entry, thereby taking full advantage of the dominant horizontal field component. Practical ways to further extend section coverage, by reducing the relatively high corner loss, are presently under investigation.

Figure 5 represents a coverage diagram obtained for a portion of the Bureau's Safety Research Mine at Bruceton. The coverage experienced in the Safety Research Mine supports the coverage predictions of figure 4. In figure 5 the transmitter is located in the upper right-hand corner, and the coverage represents roughly one quadrant of a working section as indicated by the dimensions. The other three quadrants will experience the same coverage. Note that when the signal has to go around one corner, the coverage is as predicted, but that two corners produce a quick transition to unsatisfactory performance. The coverage to the left of figure 5 does not extend beyond 200 feet because of the absence of a connecting crosscut. Also depicted in figure 5 are the main elements of wireless section radio system installed in the Safety Research Mine. This system will be described in the next part of this paper.

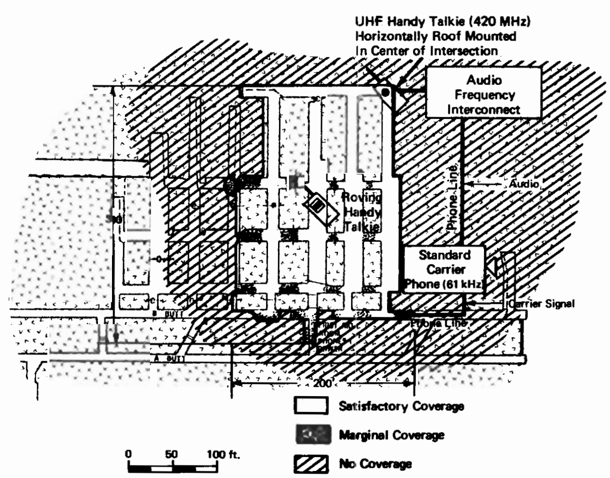

FIGURE 5. - UHF two-way wireless section radio coverage in the Safety Research Mine.

System Description

An overall block diagram of a wireless section radio system is shown in figure 6. Roving miner-to-miner direct wireless communication within the section is obtained by using channel 2 on the portable handy talkie units. In this direct mode of operation, the portable units transmit and receive on channel 2. The system also provides roving miner communication with the surface on this same channel. This is accomplished by the use of a special interconnect unit which is roof-mounted wiht another handy talkie in an intersection at a centrally located position in the section. This radio-to-carrier system interconnect unit couples the audiofrequency portion of the roof-mounted UHF handy talkie to the audiofrequency portion of a 61-kHz standard miner carrier phone that is attached to the mine telephone line. In the mine office at the other end of the mine telephone line is a corresponding carrier phone unit which completes the mine-to-surface communication link. A conversation can be initiated from either the mine office or the roving miner on the section by simply using the mine office carrier phone or the portable handy talkies in their standard modes of operation. The system described provides an instantaneous direct private line to key roving miners on a section, even when the mine telephone line is busy with normal audiofrequency communication traffic.

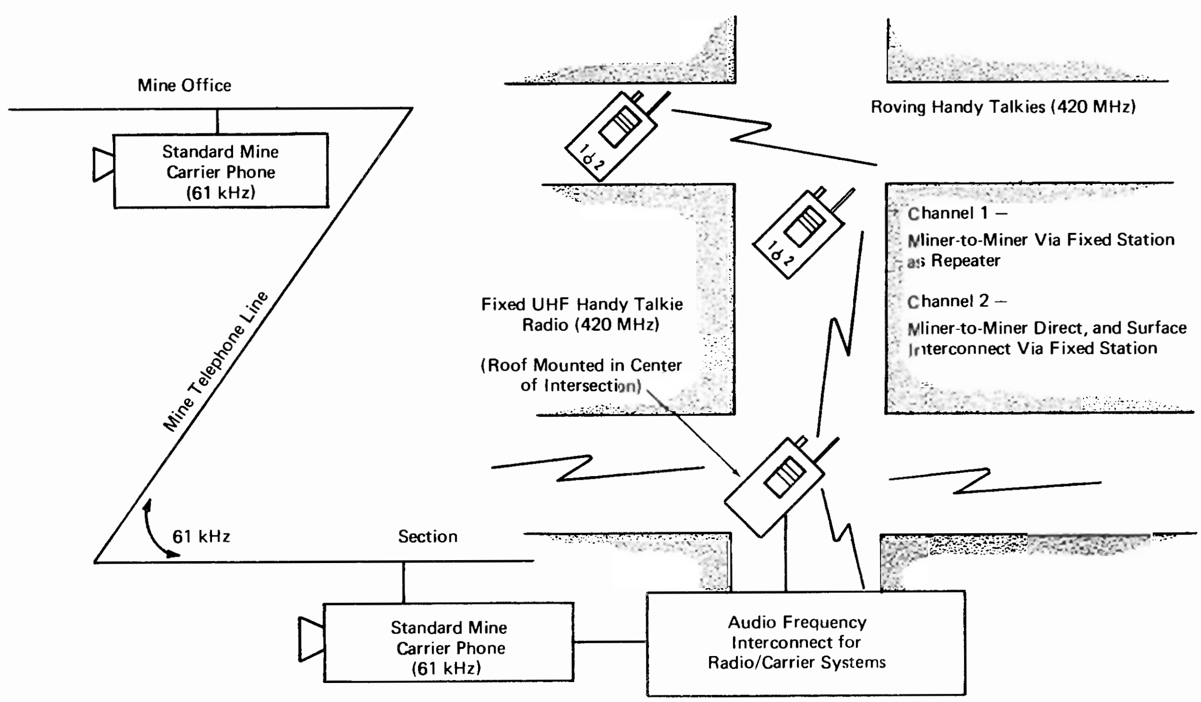

FIGURE 6. - Two-way wireless section radio system block diagram.

As stated in the coverage discussion, the roving miner-to-miner communication range can be doubled, thereby extending roving miner coverage to the whole section by using a roof-mounted repeater at the central location. To operate in the repeater mode, miners would switch to channel 1. In this repeater mode of operation, the portable units transmit on channel 1 but still receive on channel 2. This allows a centrally located repeater station to pick up the channel 1 transmissions of the miners and rebroadcast them on channel 2 for subsequent reception by the other handy talkies, thereby doubling the miner-to-miner range of the system.

Another benefit is obtained when in the repeater mode, namely, roving miner-to-miner communications traffic will not clutter the section-to-surface interconnect channel, but messages from the surface will still be receivable by the roving miners.

Figure 7 shows a Motorola HT220 intrinsically safe handy talkie unit attached to a miner's belt. Operation can be via a push-to-talk switch and speaker-microphone that are integral parts of the handy talkie unit. Alternatively, the switch and speaker-microphone can be in the form of a handheld accessory, as shown in figure 7. This accessory can be conveniently clipped to a pocket or lapel. Operation is also possible by means of a bone conductance microphone and ear speakers attached to the miner's hardhat as shown in figure 8. The bone conductance microphone is situated in the middle of the hardhat webbing so that it can pick up the skull vibrations created when a person speaks. The ear speakers are put close enough to the ears to hear the received audio while still leaving the ears open to the normal sounds in the mine. This hardhat unit can be operated by a belt-mounted pushbutton as shown in figure 8, or by means of a voice-operated switch which keys the transmitter on whenever the person speaks. This allows completely hands-free operation. Figure 9 depicts a handy talkie unit installed in a roof-mounted radio-to-carrier surface interconnect unit fabricated by Collins Radio Co. This station is typically mounted horizontally at a 45° angle in an intersection centrally located in the section. The cabling on the left goes to a standard mine carrier phone attached to the mine telephone line.

FIGURE 7. - Miner using intrinsically safe handy talkie unit.

FIGURE 8. - Handy talkie operation using hardhat with ear speakers and bone conductance microphone.

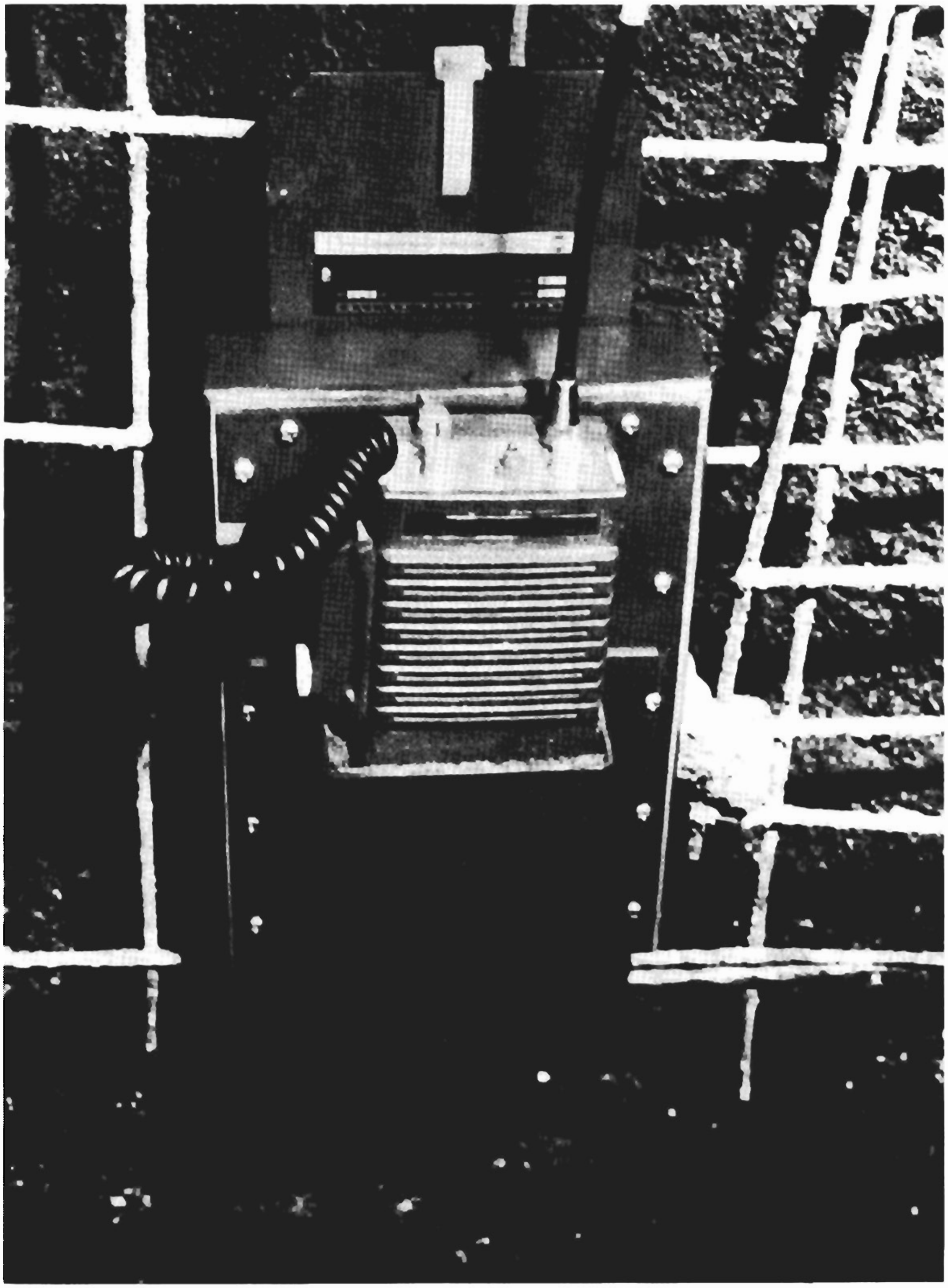

FIGURE 9. - Roof-mounted radio-to-carrier surface interconnect unit and handy talkie unit.

The basic system depicted in figure 6 can be used in a variety of ways and circumstances. It can be used to extend two-way communications between key roving miners within a section, and between these miners and the surface. The system can be used to communicate with roving miners along any haulageway having a mine telephone line by placing interconnect and repeater stations similar to those for sections at approximately 0.6== miles intervals along the haulageway. The system with the surface interconnect also lends itself to installation and use as a temporary surface-to-roving-miner communication link during maintenance or rescue operations. Finally, this particular system can be modified for use with less expensive pocket pagers, instead of handy talkies, to provide a more limited call alert or paging mode of operation.

UHF GUIDED WIRELESS RADIO SYSTEM

The second UHF radio system treated in this paper is the guided wireless radio system. This system can provide communications between key individuals who may be roving at different locations along or near haulageways, and between these same individuals and the surface. As in the wireless section radio application, the key roving individuals carry portable handy talkie radio transceivers. However, unlike wireless section radio, guided wireless radio uses a special cable to pick up, transport (guide), and radiate the radio frequency energy along haulageways and main entries to communicate with the portable handy talkies. Figure 10 gives an overall conceptual view of a roving miner two-way haulageway communication system based on the guided wireless radio concept at UHF frequencies. As illustrated, such a system operating at UHF requires that a special cable (Radiax in this case) and auxiliary lines be hung along the walls of the haulageways and selected section entries, together with periodically spaced repeater or base stations. The system will be described in detail under "System Description."

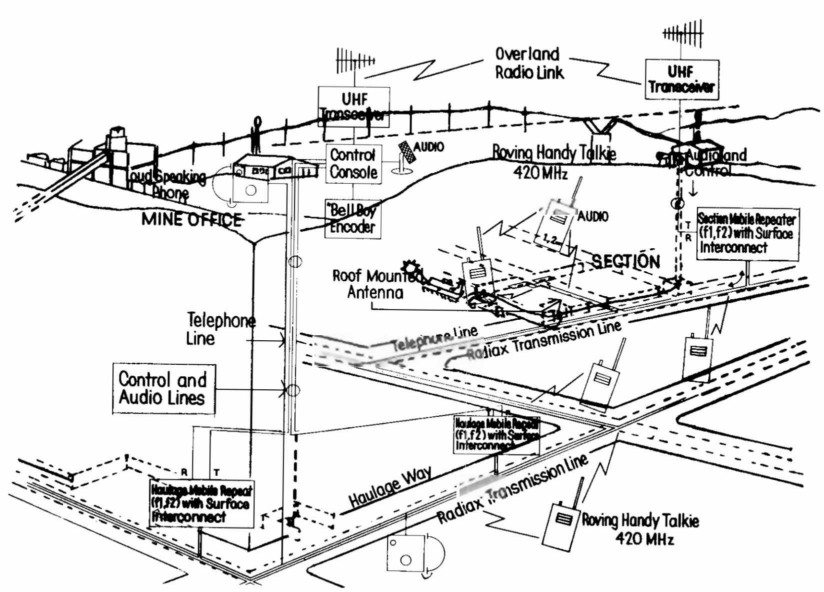

FIGURE 10. - Guided wireless radio system.

The UHF Radiax cable system was investigated because it has been receiving increased publicity and attention by the equipment suppliers and mine operators, and because of the favorable propagation characteristics at UHF for the area coverage desired in U. S. coal mines. However, our investigations indicate that the desired area coverage is not achievable in an economical manner with Radiax cable. Furthermore, much lower frequencies can be effectively used with more economical guiding cables if the desired communications can be restricted primarily to the haulageways as in Europe.

Principles of Operation

Figure 11 depicts in schematic form a cross-section view of a coaxial cable and the lateral variation of its associated fields. In such cables the bulk of the radiofrequency electromagnetic energy is transported down the cable between the center conductor and the shield. However, the shields of most practical cables do not provide perfect containment of the internal electromagnetic fields nor isolation from external fields. As shown, a small fraction of the cable's internal field is usually coupled to the external space. External fields are coupled into the cable in a similar manner. The existence of this weak coupling between internal and external fields forms the basis for several guided wireless systems for communicating with roving miners. Cables which transport most of the signal energy inside the cable have an added advantage; namely, performance is essentially not affected by normal accumulations of dirt and moisture, nor by installing the cable directly against the rib of a haulageway.

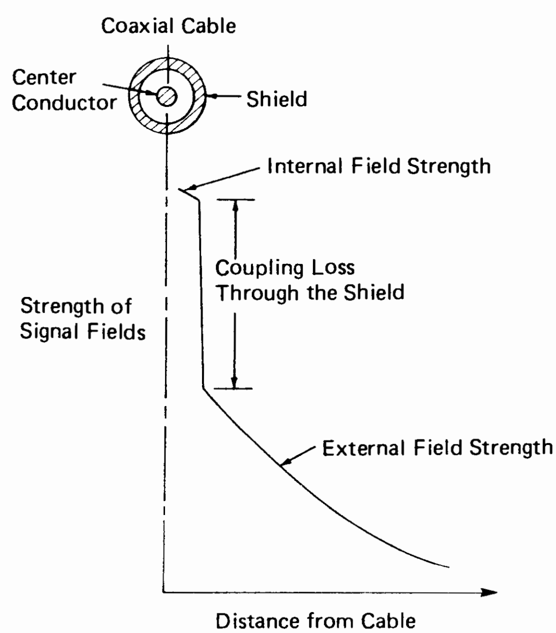

FIGURE 11. - Guided wireless radio with coaxial cable—principle of operation.

As shown in Figure 11, the fields coupled to the external space will continue to decrease in strength with increasing distance from the cable. In addition, the internal and external fields will be attenuated, primarily because of the cable's resistance, as they travel along the cable to and from the fixed and portable communication stations. The amount of coupling loss and longitudinal attenuation loss experienced depends on the material and construction of the cable and on the operating frequency.

The UHF guided wireless system treated in this discussion is one based on the use of special semiflexible RX4-1 Radiax coaxial cable of ½-inch diameter and 50-ohm characteristic impedance. The cable has a solid copper shield in which holes have been machined to increase the amount of coupling to the external space, as opposed to the braided-type shield used in conventional flexible cables for lower frequency applications. A cutaway view of the Radiax cable is shown in figure 12. Its cost is more than ten times that of conventional braided cable used for cable television home installations. According to the cable manufacturer, Andrew Corp., a lateral coupling loss of 85± 10 dB is experienced when the external signal strength is measured at a distance of 20 feet from RX-1 Radiax cable. This loss includes the shield coupling loss and the radial spreading loss for this distance and applies for both incoming and outgoing signals. The longitudinal attenuation loss is 2.1 dB/100 feet.

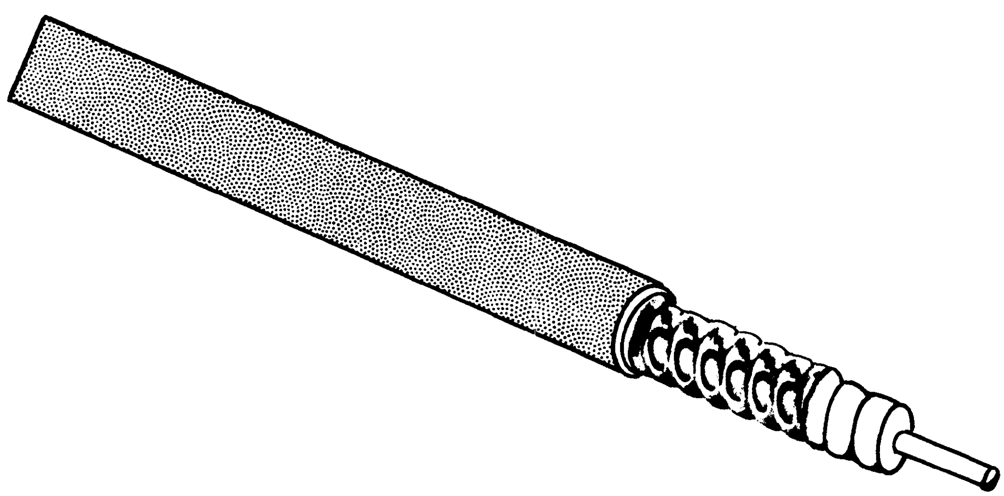

FIGURE 12. - Radiax coaxial cable, cutaway view.

Figure 13 is a sketch illustrating how signals both in the cable and in the haulageway decrease in strength as the distance along the cable from a repeater station is increased. Signal voltages and external fields are reduced in strength by a factor of 10 to 1 (20 dB) for every 950 feet of cable traveled, due to the 2.1 dB/100 feet longitudinal atenuation rate. Figure 13 depicts the decrease in signal strength for transmissions by the repeater. A similar signal strength decrease occurs for transmissions from a handy talkie, but with the signal strength now being largest at the handy talkie location and decreasing as the signal travels in the cable towards the repeater.

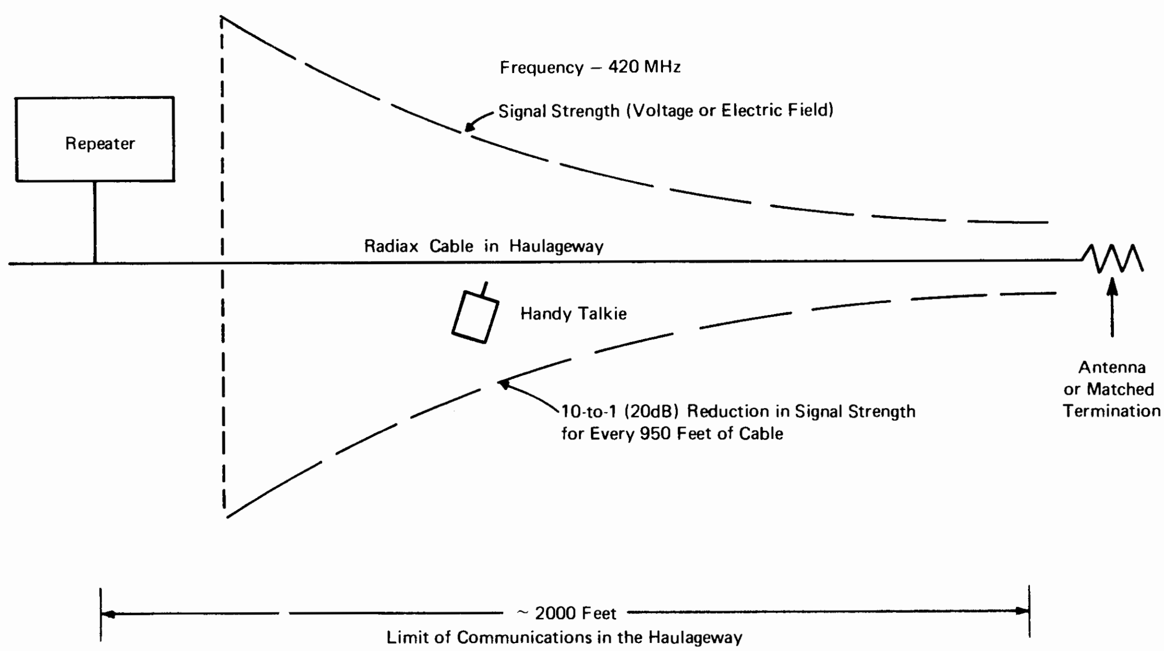

FIGURE 13. - Two-way communication range for Radiax guided wireless radio system.

In spite of the holes, the coupling loss imposed by the shield is high and requires the use of repeaters (to amplify and retransmit incoming signals) to allow communication via this cable between roving miners carrying portable handy talkie radios. The spacing of these repeaters along the cable (base stations if only a surface-to-mine channel is desired) will be governed primarily by the lateral range desired from the cable, the longitudinal attenuation rate of the cable, and the transmitter power of the portable units. Since the transmitter power available for portable units is generally lower than that available for fixed repeater or base stations, the portable units set the coverage limits for two-way communications.

Expected Coverage

The two-way coverage obtainable with a guided wireless radio system has been estimated for a haulageway installation consisting of the Andrew RX-1 Radiax coaxial cable, 2 watt base stations and repeaters, and the same Motorola HT220 2 watt handy talkies used for the wireless section radio system. As in the case of wireless section radio, communication range will be limited by intrinsic receiver noise as opposed to external electrical noise. The coverage estimates are based on lateral coupling loss and longitudinal attenuation data supplied by the cable manufacturer, preliminary experimental data obtained for the Radiax installation in the Bureau's Safety Research Mine, and some of the theoretical and experimental results discussed under wireless section radio. Of particular interest are the ranges expected along haulageways and down entries crossing haulageways.

When an entry crossing the haulageway is close to a repeater station, two-way lateral coverage should be possible to handy talkie radios located 300 to 500 feet down the cross entry. Figure 14 illustrates the expected signal behavior and coverage down such a cross entry. Once the UHF signal field becomes well established in the cross entry, its propagation down the entry and around subsequent corners will be governed by the same principles and attenuation rates discussed under wireless section radio.

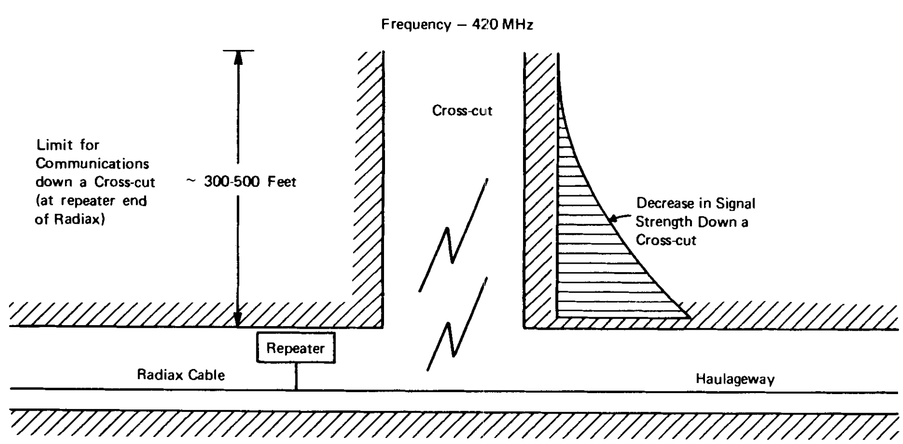

FIGURE 14. - Guided wireless radio system, propagation down crosscuts off haulage ways.

As the distance between the cross entry and the haulageway repeater station becomes larger, the signal available at the mouth of the entry will become weaker, so the lateral coverage down the cross entry will be correspondingly reduced. Eventually the two-way coverage will be restricted to the confines of the haulageway cross section. The manufacturers of the cable and portable handy talkies, Andrew and Motorola respectively, have found that coverage becomes confined to the haulageway at a distance of approximately 2,000 feet down the cable from the repeater station as indicated in figure 13. This 2,000-foot distance limit dictates that a UHF Radiax cable system, if designed to give two-way coverage primarily in the haulageway, will require a repeater placed at the center of each 4,000-foot run of cable. If coverage is also desired down cross entries, the spacing between the repeaters will have to be reduced to meet the minimum two-way lateral coverage required in the cross entry located midway between repeater stations.

In sum, the UHF Radiax-based guided wireless system does provide some lateral two-way coverage down entries crossing haulageways, but this lateral coverage does not remain constant or large over a substantial length of a cable run. This decreases the attractiveness of the Radiax system from the standpoints of cost and practicality for providing area coverage in a U. S. mine environment. If, on the other hand, the coverage requirement canbe limited to the haulageway, this requirement can be more economically satisfied in a practical manner by using much lower frequencies together with less expensive coaxial cables, the mine power cables, or the trolley wire/track transmission line.

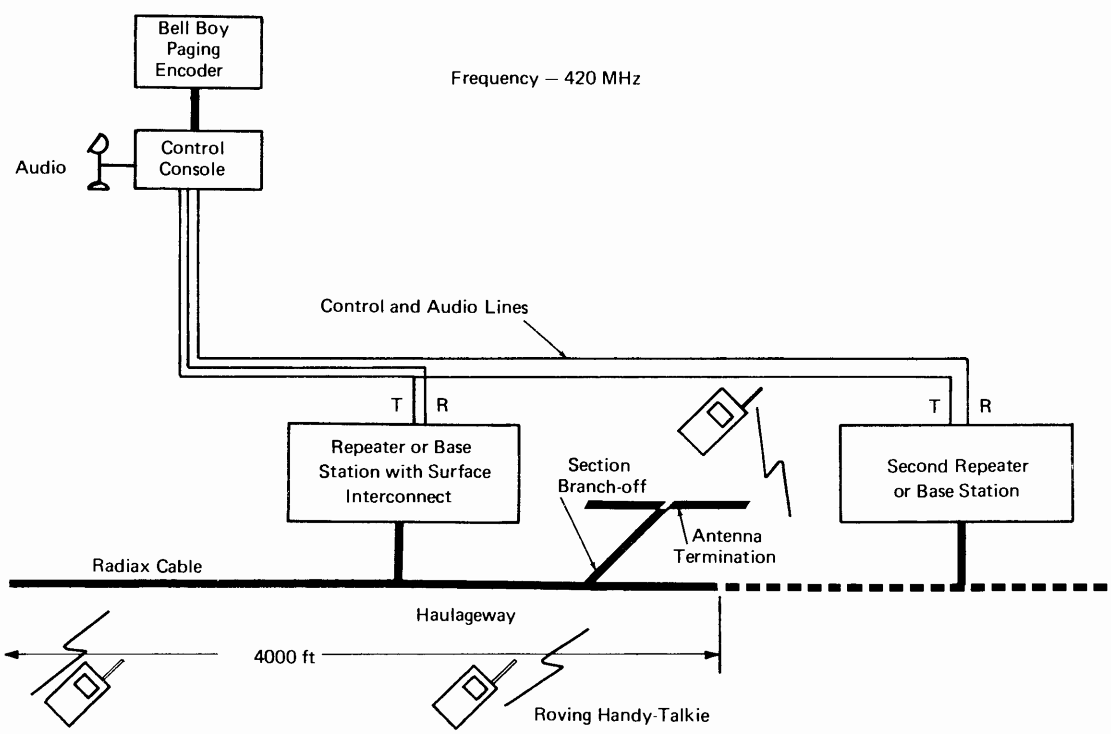

FIGURE 15. - UHF guided wireless radio system using Radiax cable.

System Description

Figure 15 is a block diagram of a basic UHF guided wireless radio system using Radiax cable. It represents the kind of equipment needed for a UHF haulageway application. The system also has a branch-off and associated antenna termination to allow communication with roving miners on a section. Communications from the surface to a roving miner are established by means of audio and control lines that go from the control console on the surface to repeaters (or base stations) at fixed locations in the haulageway. The transmitters of these fixed stations send UHF radio signals down the Radiax cable to roving miners equipped with portable handy talkies. These handy talkies pick up a portion of the signal energy coupled into the haulageway by the holes in the shield of the cable. Conversely, radio transmissions from the roving miners are picked up via the holes in the cable and carried inside the cable to a repeater or base station, where the audio output is sent via the audio and control lines to the control console on the surface.

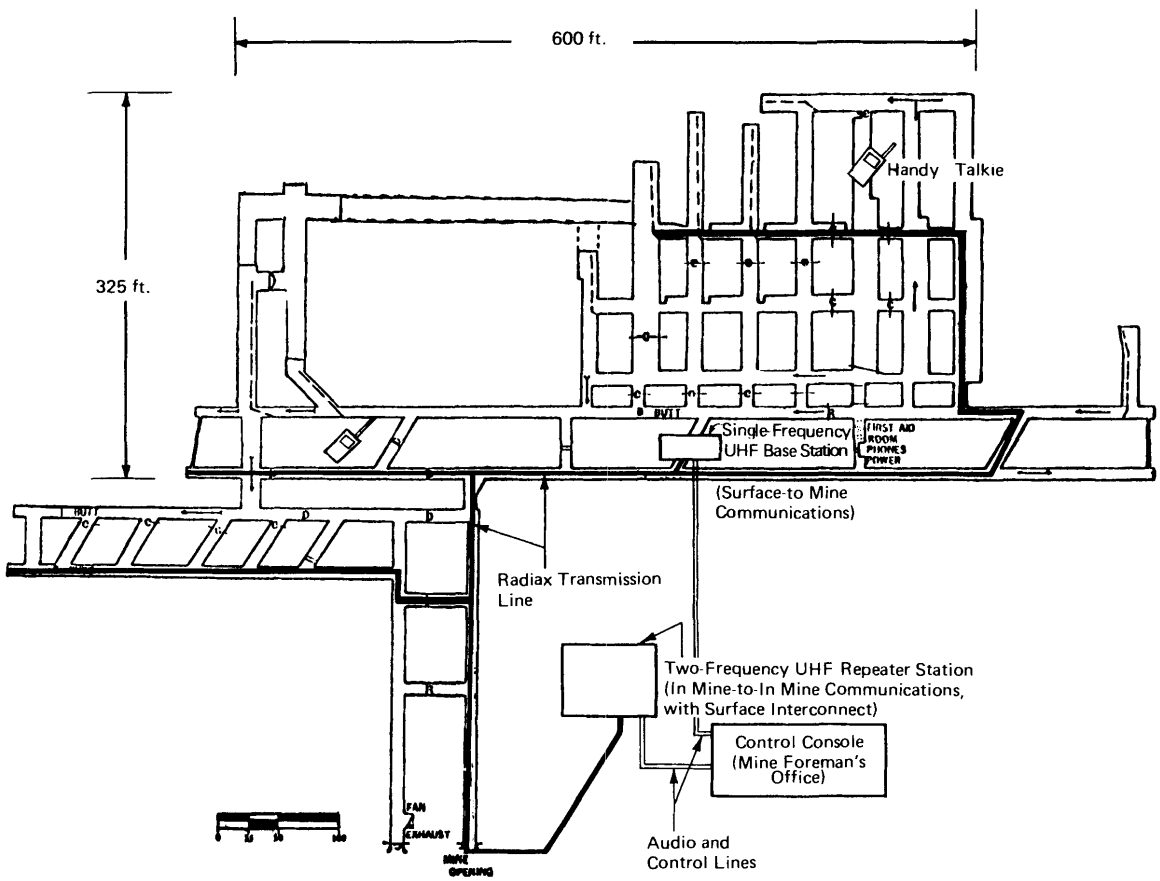

FIGURE 16. - UHF 420-MHz guided wireless radio system installed in the Safety Research Mine.

If only roving miner-to-surface communication is required, base stations instead of repeaters can be used, with only a single frequency (channel 2) for transmit and receive being required for both the base stations and portable units. If roving miner-to-roving miner communication is required, in addition to communication with the surface, repeater stations that receive, amplify, and retransmit signals from the portables must be used, together with two frequencies. (In this case, channels 1 and 2 will be needed for transmit and receive by the portables, respectively, and vice versa for the repeater stations.) Adequate two-way coverage in the haulageway is obtained by spacing the repeaters or base stations 4,000 feet apart.

As shown in Figure 15, each fixed station has an independent audio line for relaying received messages to the surface. However, a common audio line is used to activate all fixed stations along the haulageway for transmitting messages from the surface. This allows the surface to cover the entire haulageway with a single transmission, and to receive noninterfering replies from miners located along different 4,000-foot sections of the cable. To provide roving-miner-to-roving-miner communication between miners located along different 4,000-foot sections of cable, additional audio and control lines must be run between each of the repeater stations, to allow each message from a portable to be automatically retransmitted by all repeater stations along the haulage way.

Figure 16 depicts a UHF guided wireless radio Radiax cable system installed in the Bureau's Safety Research Mine. The dimensions of this small mine approach those of a 600"by 600 foot mine section, so the cable layout is somewhat representative for a section application without an antenna termination. A two-frequency 12-watt Motorola repeater station located outside the mine is used for miner-to-miner and miner-to-surface communications. A single-frequency 40-watt Motorola base station located in the mine is used as an alternative miner-to-surface communication path. The system is also equipped with a paging encoder as indicated in Figure 15. This encoder provides a more limited call alert or paging mode of operation with less expensive pocket pagers instead of handy talkies.

Figure 17 shows the system control console which would normally be located on the surface. Figure 18 is a photograph of the two-frequency 12-watt repeater station, while figure 19 shows the 40-watt base station and special power supply unit. The 2-watt handy talkies are the same one discussed under wireless section radio and are shown in figure 7.

FIGURE 17. - System control console.

The installation shown in figure 16 did not meet our performance expectations despite the use of approximately 2,000 feet of Radiax cable. Complete two-way coverage of the mine was not obtained. The worst areas were largely located in the left half of the mine, particularly in the vertical crosscut with the 45^0 corner on the map in figure 16, but pockets of weak performance were also present in other parts of the mine. Means of improving this performance by adding antenna terminations at selected locations are currently under investigation.

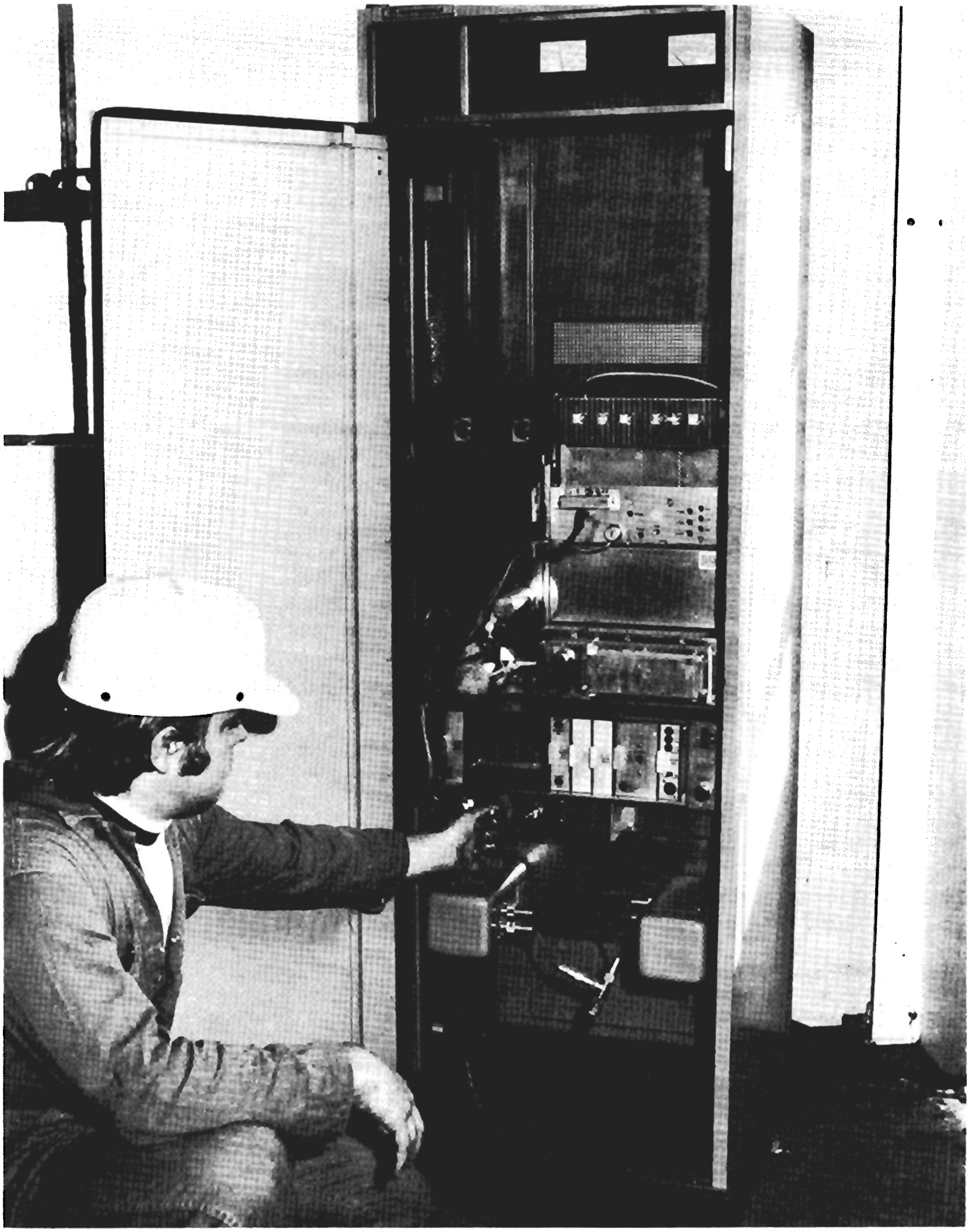

FIGURE 18. - Two-frequency 12-watt repeater station.

UHF OVERLAND LOOPBACK

The Bureau has also investigated means of looping underground communication channels back to their points of origin on the surface. An example of a typical overland radio loopback channel is shown as part of figure 10. In this illustration it is used to loopback a Radiax guided wireless radio communications channel. As shown in figure 10, the audio output of an in-mine fixed station is brought, via audio and control lines in a power borehole or ventilation shaft, to a surface loopback station consisting of a 12-watt, six-channel UHF transmitter receiver and associated antenna. Figure 20 is a photograph of such a surface loopback station located near a borehole. The UHF radio loopback system can also loopback the outputs of the underground mine phone and carrier phone communication channels, and those of mine environment monitoring channels. This is done by running independent sets of wires up the same borehole to the UHF loopback station on the surface and occupying more of its UHF channels. On the surface, all messages are transmitted overland to a similar transmit receive station located near the mine foreman's office, and subsequently to appropriate minitoring or control stations.

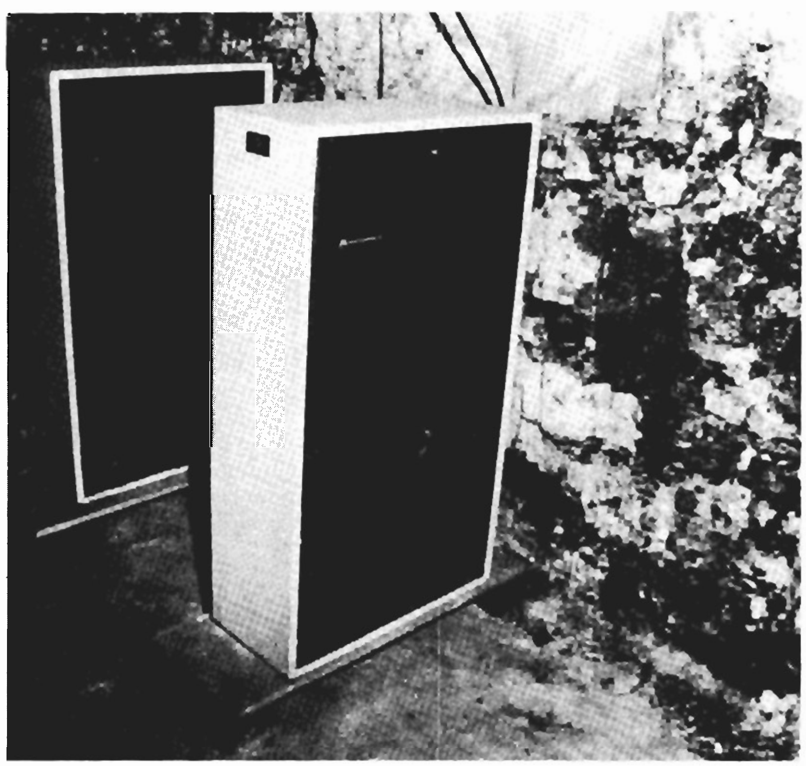

FIGURE 19. - Single-frequency 40-watt base station and special power supply unit.

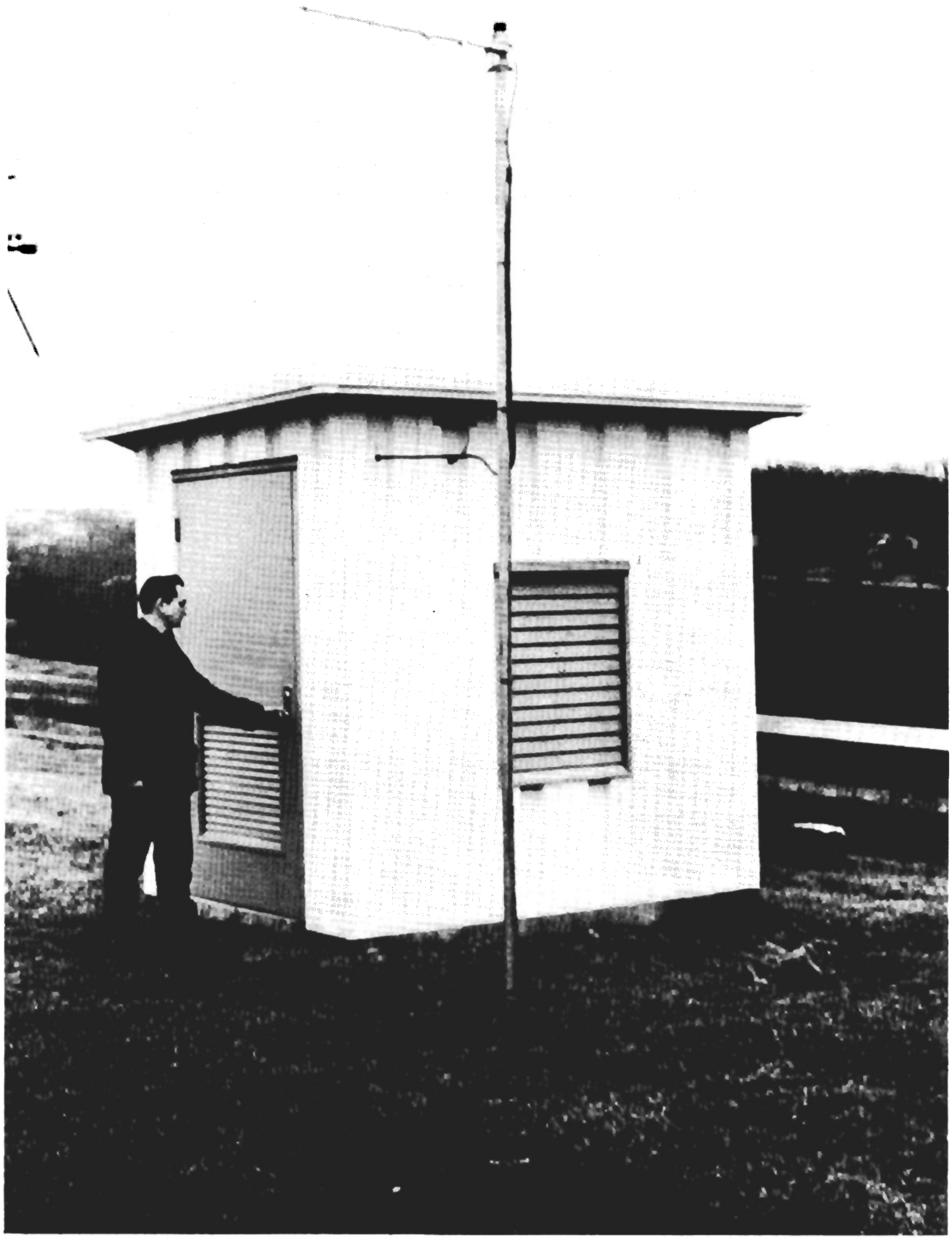

FIGURE 20. - Surface transmitter-receiver-antenna station for overland radio loopback.

By placing the surface stations at strategic locations, the mine phone line, trolley wire, and environment monitoring channels as well as wireless and guided wireless channels can be looped back together. In this manner every transmission that goes into the mine via a primary route can be sent out again via the overland loopback. If a break should occur in any one of the communication channels and a miner inby the break cannot be reached by the primary route, the loopback route can be used to reach him. Surface power lines and telephone lines are also suitable for looping back in-mine communication channels.

CONCLUDING REMARKS

The general features of the methods discussed in this paper for establishing two-way wireless and guided wireless radio communications between underground roving miners at UHF are summarized in table 1.

Table 1. - UHF Radio In Mines for Roving Miner-to-Miner Communications

Method	Units of coverage	Equipment (per unit of coverage)
Direct wireless	Half section, or 0.3 mile of haulage way.	Handy talkies
Wireless via repeater.	Whole section, or 0.6 mile of haulage way.	Handy talkies, plus central low-power repeater.
Guided wireless via repeater and Radiax cable.	Whole section, or 0.8 mile of haulage way.	Handy talkies, plus central high-power standard repeater, plus Radiax cable along haulageway or distributed in section.

Furthermore, roving miner communications can be established with the surface, and between separate coverage units along haulageways or different sections, by adding interconnect equipment appropriate to each method. The wireless-via-repeater method can use a radio-to-carrier interconnect to the existing mine phone line at each repeater location, together with a standard carrier phone at the surface end of the mine phone line. The guided wireless method can use interconnect equipment similar to that for the wireless method, or install a set of audio and control lines connecting all the repeater stations with each other and with a surface console station. The latter approach is the current practice for Radiax-based guided wireless systems.

In sum, our investigations reveal that UHF wireless section radio is more effective, practical and economical than Radiax-based UHF guided wireless radio for both section and haulageway roving miner applications. Wireless section radio also provides superior flexibility for establishing two-way communications at locations that may temporarily require wireless coverage because of an emergency or maintenance problem. For strictly haulageway applications, much lower frequencies and lower cost transmission lines appear to offer other advantages and are presently being investigated.

INTERCONNECTING NEW COMMUNICATIONS TO EXISTING SYSTEMS

by

Dean Anderson,[1] William Stout,[1] and Howard E. Parkinson[2]

ABSTRACT

The Bureau of Mines has developed a number of interfaces devised to extend mine communications.

A selective interface loops back the mine telephone over the mine haulage carrier phone and vice versa. The interface is connected and disconnected upon remote command from within the mine or from the surface.

A unique coupler interfaces the mine telephone to the public phone. A preassigned number is dialed upon command from the in-mine pager telephone, and the two-way communications are established with the selected public phone. In addition any public phone can be used by an individual who has a special pocket-carried tone generator to establish an into-the-mine telephone connection to the mine pager telephone system. The individual in the mine is paged, and two-way communications can be established with any in-mine pager telephone.

Mine pager communications are selectively coupled into portable two-way radio on the section, thus extending mine telephone paging to the working face. The coupler also mounts one of the portable two-way radios to serve as the centrally located fixed end of the radio link.

A novel call alert system selectively interfaces with the mine telephone line. The call alert is activated upon command when a page is intended for a key individual on a particular section. Each section is commanded separately.

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2/ Supervisory electrical research engineer, Industrial Hazards and Communications, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

INTRODUCTION

U. S. coal mining industry experience has demonstrated that the communication requirements of a mine are best met by a combination of different communications systems. The industry has wisely selected the best solution for each major communication link. The most important and least expensive communication system is the hard-wired mine pager type telephone used throughout the mine in fixed locations. The other major communications system is the trolley wire phone used between the locomotives and the fixed dispatcher stations.

As coal mines have grown and mining technology has improved, needs have arisen for new and improved communication capabilities which cannot adequately be provided by the traditional mine telephones or trolley wire carrier phones. These include the following communication needs:

1. Ability to communicate when the phone line or the trolley wire breaks.

2. Ability to communicate with personnel not in the vicinity of a telephone.

3. Ability to communicate over private channels.

4. Ability to deliver important messages during periods of heavy communications traffic.

5. Ability to communicate with surface public phones.

Several new techniques for mine communications have been under investigation and trial by the Bureau of Mines to meet these needs:

1. Underground phones with manual trunking or automatic exchanges.

2. Low-frequency induction radio for section communications.

3. Medium-frequency induction radio for whole-mine communications.

4. Very-high-frequency radio for whole-mine communications.

5. Ultra-high-frequency radio for wireless section communications.

The following techniques are capable of satisfying the foregoing needs for improved mine communications:

1. Underground phones with manual trunking or automatic switching can provide privacy and an interconnection to the public telephone system on the surface. Also, a larger number of simultaneous communications can take place.

2. Low-frequency induction radio offers a means of paging and communicating directly through the mine structure within a working section, and through the mine overburden in times of emergency.

3. Medium-frequency induction radio can be used with power cables, trolley wires, and roof bolts to provide haulageway and section paging throughout the mine to key mining personnel carrying pocket pagers.

4. Very-high-frequency radio can be used with leaky, radiating coaxial cable or coaxial cable with integral passive antennas, as a technique for guiding radio waves throughout the mine haulageways and entries. This technique can be used to provide whole mine communications via radio handy talkies carried by key mining personnel.

5. Ultra-high-frequency (UHF) radio can provide wireless communication between key roving miners carrying radio handy talkies within a working section, without the aid of additional metallic guiding structures.

HYBRID SYSTEMS

An objective of the Bureau's development work has been to exploit the added capabilities of these new communication techniques by incorporating them into existing mine communication systems. The approach adopted is a hybrid one, whereby two or more communication systems are interconnected to take advantage of the benefits of each system. Several hybrid arrangements have been investigated:

1. Selective path between trolley wire and telephone pair.

2. Personal selective paging via telephone and low-to-medium frequency induction radio.

3. Personal two-way communications to the section via the mine phone line and ultra-high-frequency radio.

4. Multichannel carrier telephones interconnected to existing mine phone system.

5. Interconnection of the mine phone to selected public phones.

Interconnection of equipment is required in order to realize these hybrid communication systems. The concepts of interconnection are well known. However, it has been necessary to devise new equipment so that existing mine communication systems and the new communications equipment can be formed into an integrated communication network capable of meeting all the demands placed on it by an operational mine environment. The hybrid systems developed are described below in terms of the communication needs they fulfill.

Need: Ability To Communicate When Phone Line or Trolley Wire Breaks

Solution: Selective Path Between Trolley Wire and Telephone Pair

If a trolley wire or phone line should break, it would be desirable to selectively connect the phone wire to the trolley wire inby the break. Then a new selective communications path would exist, entering the mine on either the phone line or the trolley line, advancing to the point where the two systems were connected together, and thereby establishing communications beyond the break. The best way to accomplish this capability is to go inside the mine to an extreme inby point, and at that point install an interconnect between the phone line and the trolley wire. To avoid the situation of having all the traffic on the trolley wire system superimposed on the phone line, the interconnect should be a selective one, activated only when communications are not possible on one of the lines. An example of this type of hybrid system is seen in figure 1. Femco's trolley phone to loudspeaking phone coupler, together with a special tone-actuated latch, make up the selective coupler. A functional diagram of the tone-actuated latch is shown in figure 2.

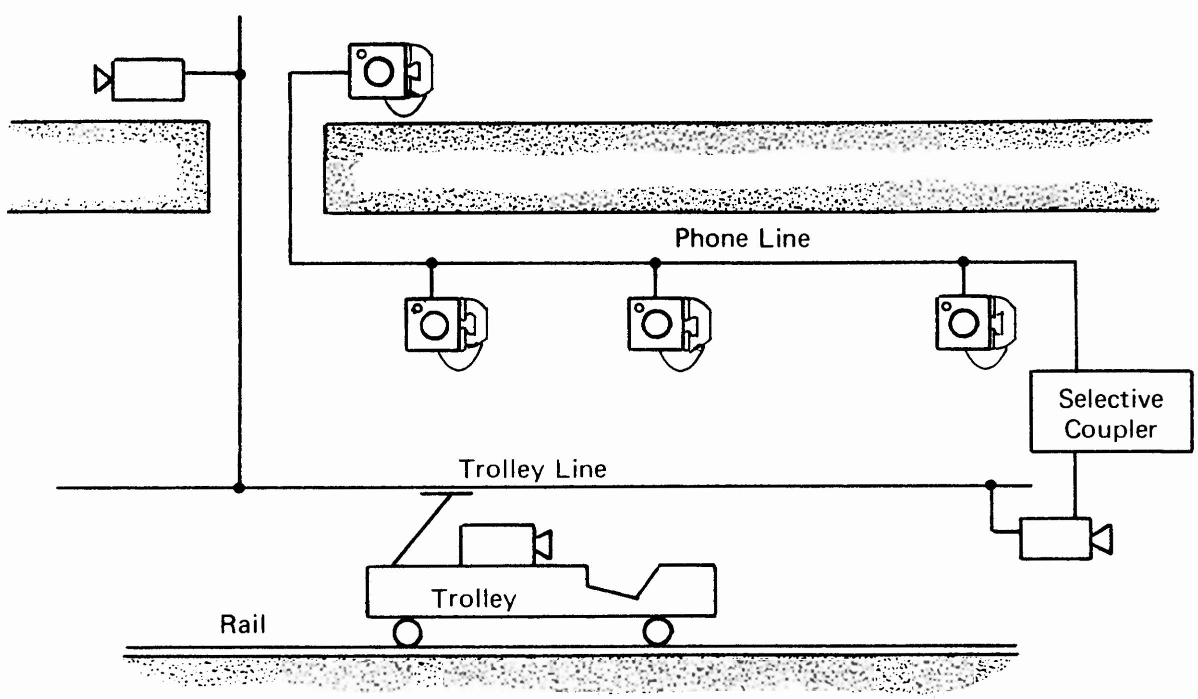

FIGURE 1. - Trolley to mine phone hybrid.

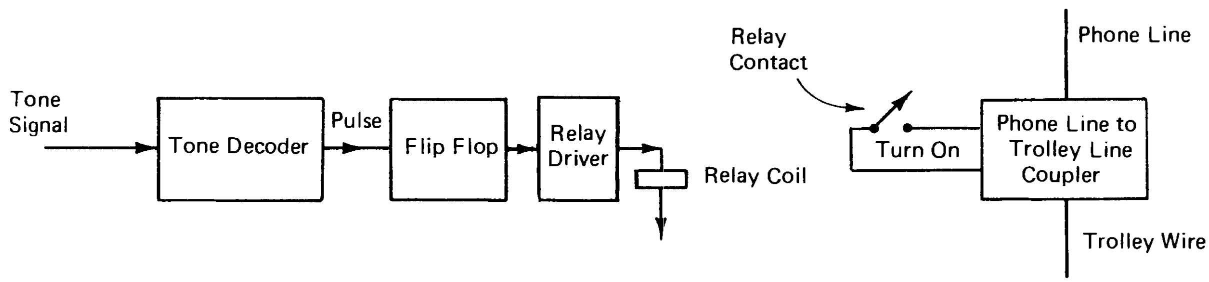

FIGURE 2. - Functional diagram of tone-actuated latch.

The tone-actuated latch is the heart of the interconnect and is activated from any trolley phone or mine phone in the system by key personnel equipped with pocket-sized audio tone generators. Once power is applied to the coupler, the trolley phone system and the mine telephone system are tied together through the coupler. Two-way simplex conversation is then possible between a mine phone and a trolley phone. To disconnect the systems, the audio tone is sent again. This activates the tone-actuated latch and unlatches the power from the selective coupler.

Suspected breaks in communications lines may be tested for as follows:

A selective turn-on signal is sent into the mine over the trolley wire. An attempt at communication is made with the signal going in on the trolley wire and coming back out on the phone line to the surface. If the signal is heard on the surface, then one can assume that there is no break in the lines. If the signal is not heard, the assumption is that a break exists in one of the lines. In the latter event the signal would return only as far as the break in the line, so that if the individual being paged was inby the break on the phone line, he could now be reached via the trolley wire system and the inby section of the phone line. Thus, all fixed locations on the phone line system inby the break would be reached. The same reasoning would apply if the phone line were intact and the trolley line broken, provided the equipment on the locomotives were battery operated. Then even if the dc trolley power were not present, it would be possible to reach inby the break of the trolley wire by going in on the phone line to the innermost interconnect point, thereby providing access to the inby section of the trolley wire.

Need: Ability To Communicate With Personnel Not in the Vicinity of a Telephone

Solutions: (1) Paging via Roof Bolts
(2) Paging via Trolley Line
(3) Paging via Call Alert
(4) Two-Way Wireless Section Radio

These solutions are described in the following paragraphs.

Roof Bolt Paging System. - Mine paging telephones show a drawback in that the individual to be reached frequently is not in close proximity to a loudspeaking phone. Also, it is a common page system on which many individuals are normally being paged, so that there is a tendency for individuals to ignore the page. Figure 3 shows a block diagram of a whole-mine roof bolt paging system that can reach key personnel roving in the working sections.

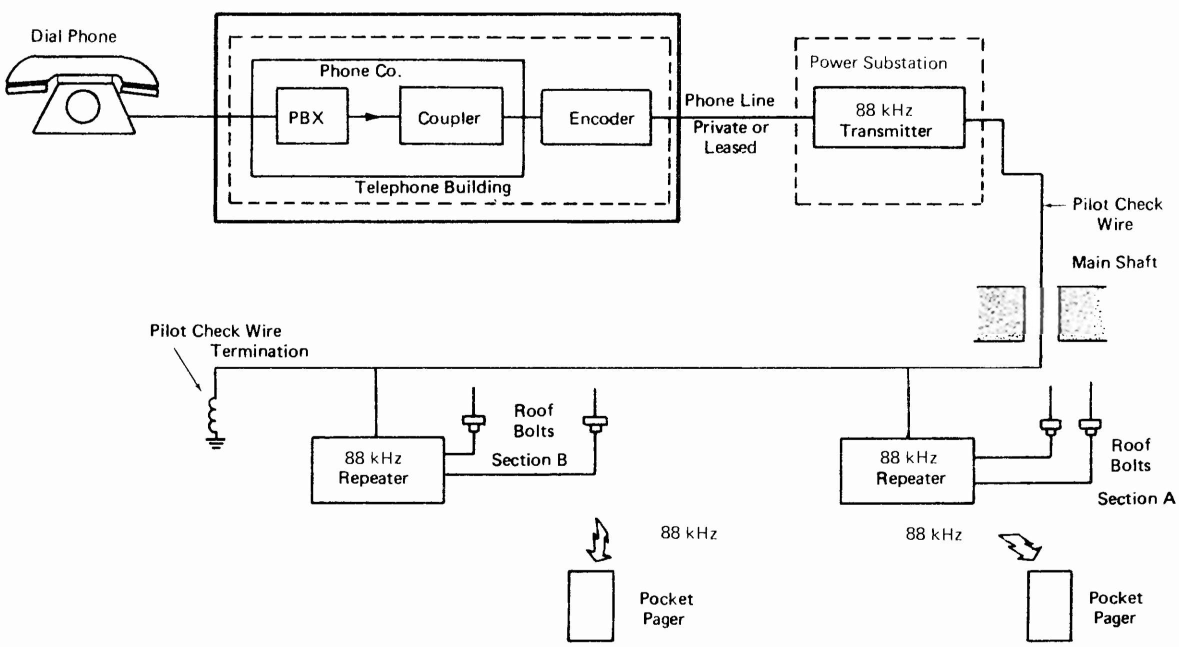

FIGURE 3. - Whole mine paging system interconnects.

Two such regions are shown. The first is a call alert keying transmitter. A functional diagram of this transmitter is shown in figure 5. A push-to-page push button connects power to a 19-kHz oscillator, the output of which is amplified in a driver stage and then fed via a transformer and isolating capacitor to the phone line. (Operation of the oscillator is verified by causing a 2-kHz audio tone to be generated when the oscillator is functioning.) In this way the keying signal is sent into the mine. At an area near the load point of the section, the signal is fed to a call alert keying receiver. A functional diagram of the receiver is shown in figure 6. When this receiver detects the keying signal, a relay connects power to a call alert transmitter. As may be recalled, this transmitter feeds an audio frequency signal to a loop antenna wrapped around a pillar in the section. Signals from this loop are picked up by pocket call alert receivers, and the person carrying the call alert receiver is notified by means of a blinking light or tone that he is being paged. Prototype equipment for this call alert system was designed and fabricated by Westinghouse Georesearch Laboratory.

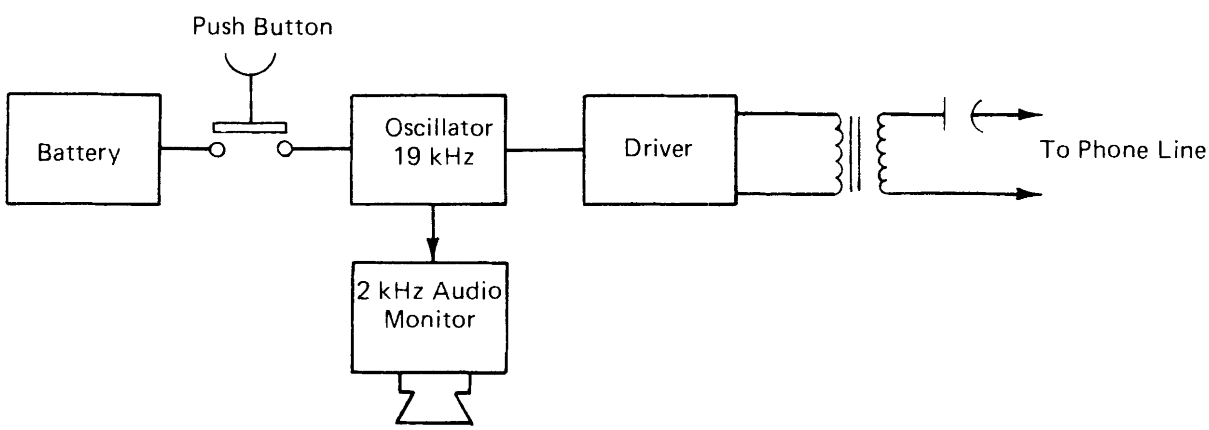

FIGURE 5. - Call alert keying transmitter.

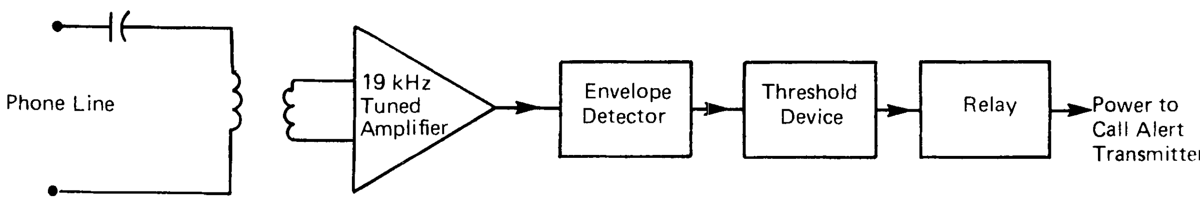

FIGURE 6. - Call alert keying receiver.

This system has been described in the "Roving Miner Paging" seminar paper and the discussion here pertains only to the interconnects. These interconnects are outlined with bold lines on the block diagram. The first interconnect is partially provided by telephone company equipment of a generally available nature. The purpose of the telephone company equipment is to direct all local (inside) calls with a prefix 1 to a Reach encoder. The Reach encoder immediately becomes connected to the calling phone line and stores the next three digits. These digits are the code identification of pocket page receivers also manufactured by Reach, and cover 200 possible codes (000 to 199). Upon reception of these three digits, the encoder generates the corresponding tone code and feeds this tone code to an 88-kHz Femco transmitter. The encoder also serves to pass along any voice page message that the caller wishes to communicate to the paged person. In addition to these functions, the encoder output signals serve to actuate the 88-kHz transmitter. It will be recalled that the 88-kHz transmitter signal enters the mine on a pilot check wire, is amplified by an 88-kHz Femco repeater or repeaters in the mine, and then is applied to roof bolts and received by the pocket pager receivers carried by key individuals on the section.

Trolley Line Paging System. - A second paging system makes use of the concepts and parts of the 88-kHz roof bolt system discussed above. Rather than feeding the output of the 88-kHz transmitter to the power cable pilot check wire and thence through repeaters to the roof bolts, the 88-kHz transmitter is fed directly to the trolley line. Persons carrying 88-kHz Reach pocket pagers can then be paged by such a system when they are near the trolley line or near trailing cables going to face machines. In this way coverage of the haulageways can be provided for mines using trolley wires.

Call Alert Paging System. - The call alert paging system is shown in figure 4. Again, we treat here only the areas outlined in bold lines.

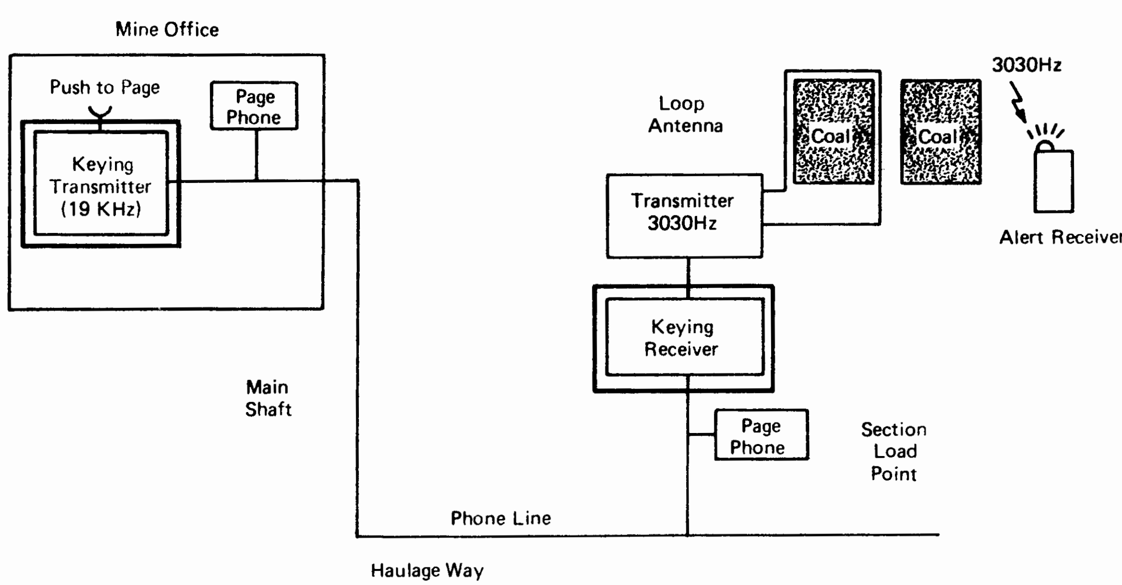

FIGURE 4. - Call alert paging system interconnects.

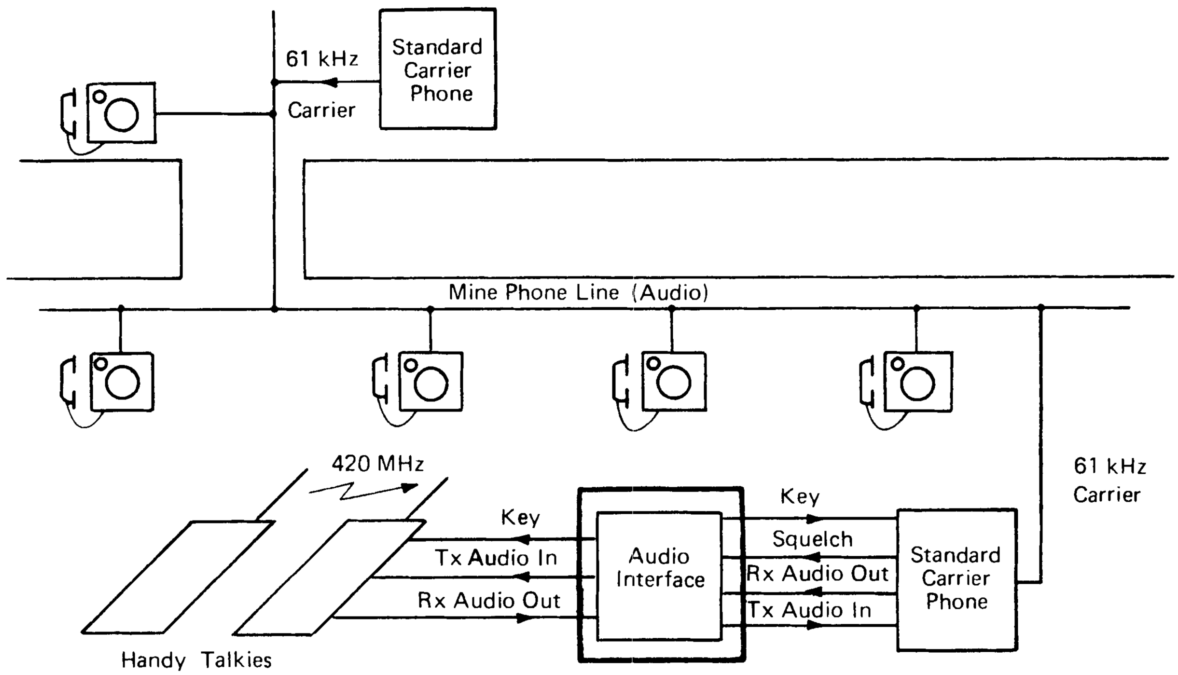

FIGURE 7. - UHF-to-carrier-phone interface.

<u>Two-Way Wireless Section Radio System</u>. - Two-way communication is possible today in the mine using UHF handy talkies. These units can be interfaced to a carrier phone which is coupled to the surface either via the trolley wire or multiplexed onto the normal mine telephone line. The frequency of the carrier phone will be different from the mine's normal trolley phone frequency to prevent interference with normal trolley phone communications. Communication between the surface and a roving miner on the section will then be possible via a surface carrier phone coupled to either the mine phone line or the trolley wire, which is in turn coupled to a matching carrier phone and a special interface unit on the section. The interface unit couples the section carrier phone to a stationary UHF radio handy talkie that can communicate to a portable UHF radio handy talkie carried by a key miner. A prototype system designed for use by the Bureau of Mines uses two MSA 1601P carrier phones, one Collins Radio Co., UHF to carrier phone interface unit, and two Motorola HT220 UHF handy talkies as shown in figure 7. A block diagram of the system is shown in figure 8. A photo of the interface unit with a HT220 transceiver mounted in it is shown in figure 9.

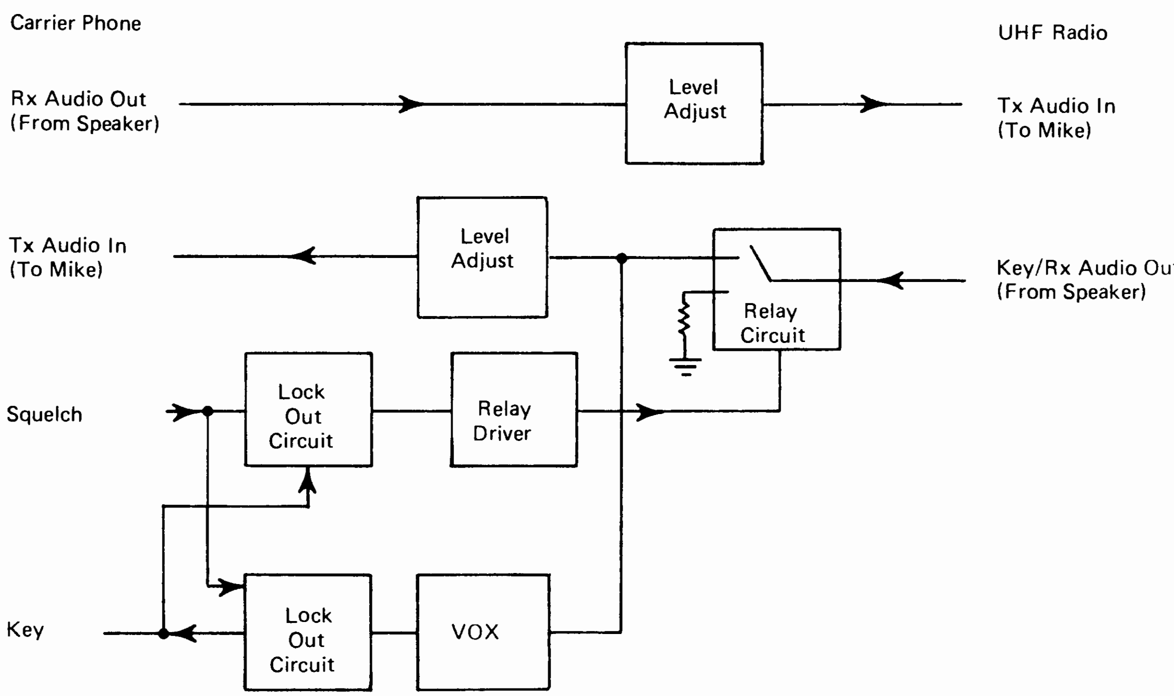

FIGURE 8. - UHF-to-carrier-phone interface block diagram.

The interface unit can be installed either in the vertical or horizontal position. However, based on recent UHF propagation data taken in coal mines, the orientation for best section coverage is horizontal.

Need: Ability To Communicate Over Private Channels, and Deliver Important Messages During Periods of Heavy Communications Traffic

Solution: Multichannel Carrier Telephone Interconnected to Existing Mine Phone System

Sometimes a mine phone system becomes tied up, for example when a maintenance man is working out a complicated repair problem with his foreman on the surface. Carrier telephone systems can overcome this tie-up by establishing private channels over the present mine phone line. To interconnect this equipment, it is necessary that the mine phone line equipment be compatible with the carrier equipment. New mine communications carrier equipment called Mine Telephone Grade Carrier will be developed by the Bureau of Mines. This equipment will be readily connectable to the mine phone line to provide a private channel.

Carrier over the mine phone line can provide not only a private channel, but also additional channels. This multichannel concept is

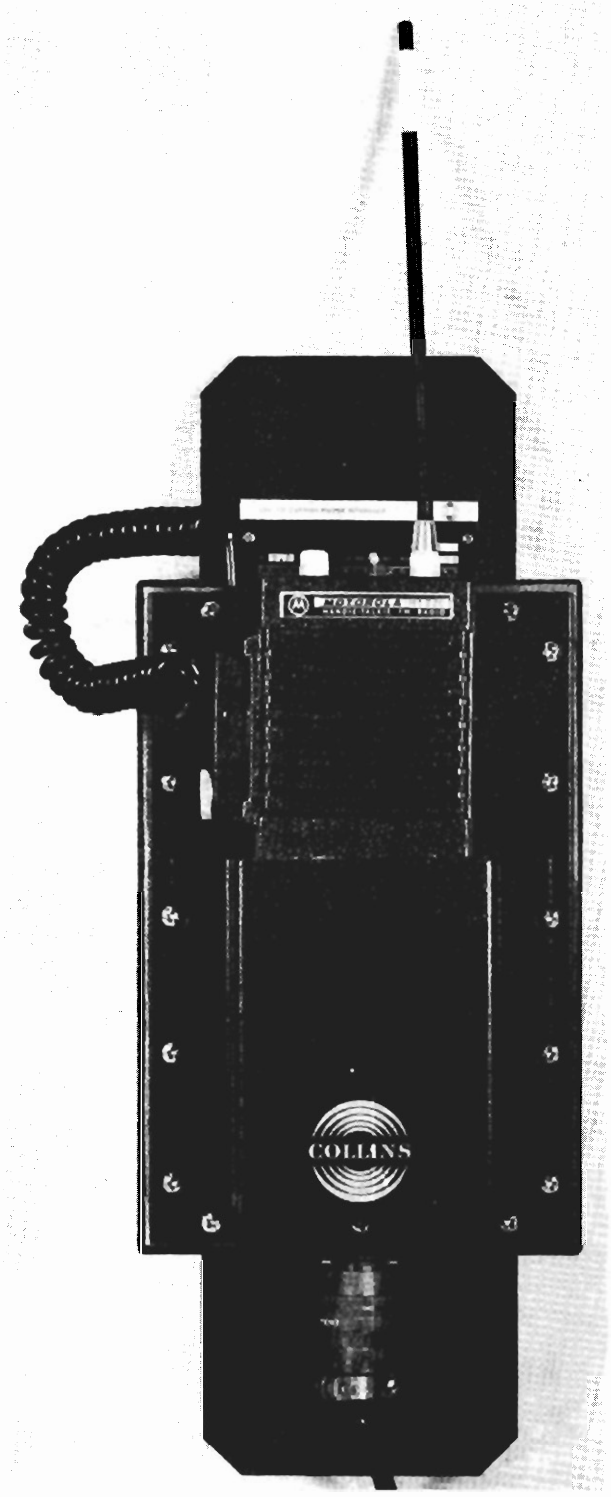

FIGURE 9. - UHF-to-carrier interface with
UHF portable transceiver.

often called trunking, whereby the phone line can be used by selecting at each carrier phone, one of the carrier channels that is not busy. The mine telephone line is thereby not dedicated to single conversations nor to any one particular purpose such as communication with the dispatcher or with the section foreman. To accommodate the necessary communications traffic, a group of extra carrier channels can be supplied on each section phone and each of the main surface phones. A total of five channels could easily be achieved in this way.

Need: Ability To Communicate With Surface Public Telephones

Solution: Interconnection of Mine Paging Telephone to Selected Public Telephones

An interconnect device is now available that permits mine paging telephones to be interconnected with the public phone system on a selective basis. The intent of this system, illustrated in figure 10, is to provide greater off-hours or emergency communication capability. The system enables a person at a mine pager phone to gain access to the public phone system and call one or more preselected phone numbers. Likewise it permits access to the mine pager phone system from any public phone that can dial a selected telephone number at the mine, subject only to the condition that the caller have the required audio tone generator to initiate the interconnect between the public phone and the mine pager phone system. Similarly, a person calling from inside the mine must also have an audio tone generator to initiate the outgoing interconnect to the public phone system.

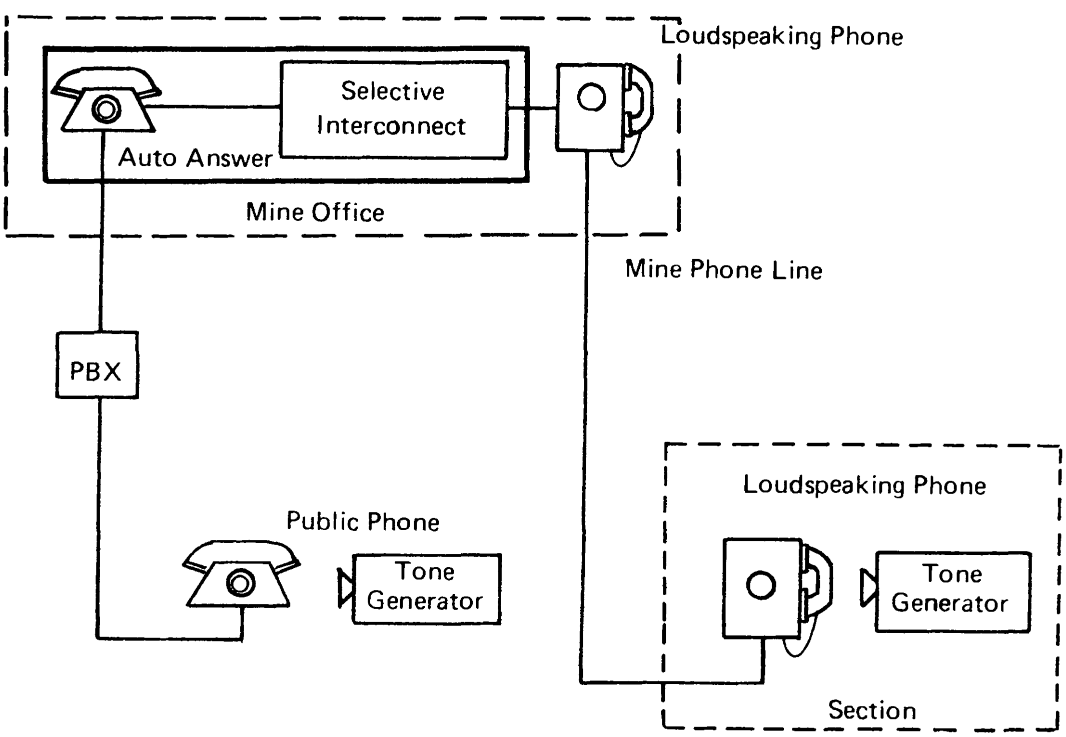

FIGURE 10. - Public-to-mine-phone interconnect.

If a person in the mine is equipped with the small hand held tone generator and wants to reach a prearranged public telephone number from his mine phone, he sends the tone via the mine phone to a telephone interconnect unit on the surface. At this surface interconnect, the tone is detected and activates a relay which in turn dials the preset telephone number. System operation is illustrated by the flow diagram of figure 11. Once the public telephone is answered and the conversation is concluded, the telephone must be disconnected from the mine phone line.

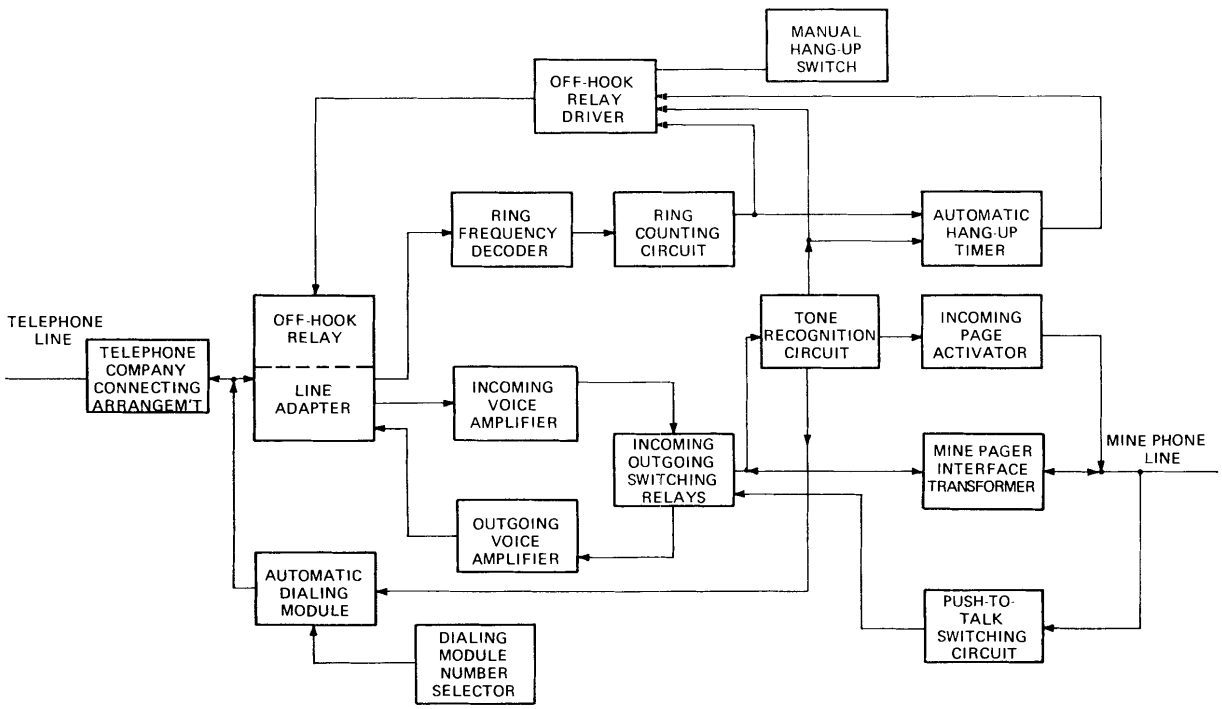

FIGURE 11. - Operational flow diagram public telephone-to-mine pager phone interconnect system.

This is also accomplished by the sending of the audio tone, or by an automatic time-out circuit. When a person calls the selected mine public telephone number from the outside, the interconnect unit answers the phone, and upon reception of the audio tone from the outside party, connects the incoming call directly to the mine pager phone line, thereby enabling the calling person to page and talk to the desired person in the mine.

This telephone interconnect unit is a small desk-top or wall-mounted unit that connects directly to both the public telephone line and the mine pager phone line, and requires no modifications to either the public dial telephone or mine pager phones. The interconnect unit and a hand held audio tone generator are shown in figure 12. This type of telephone interconnect was first conceived and demonstrated by the Bureau of Mines, Pittsburgh Mining and Safety Research Center. The present third-generation prototype units were designed and fabricated by Arthur D. Little, Inc., under contract to the Bureau.

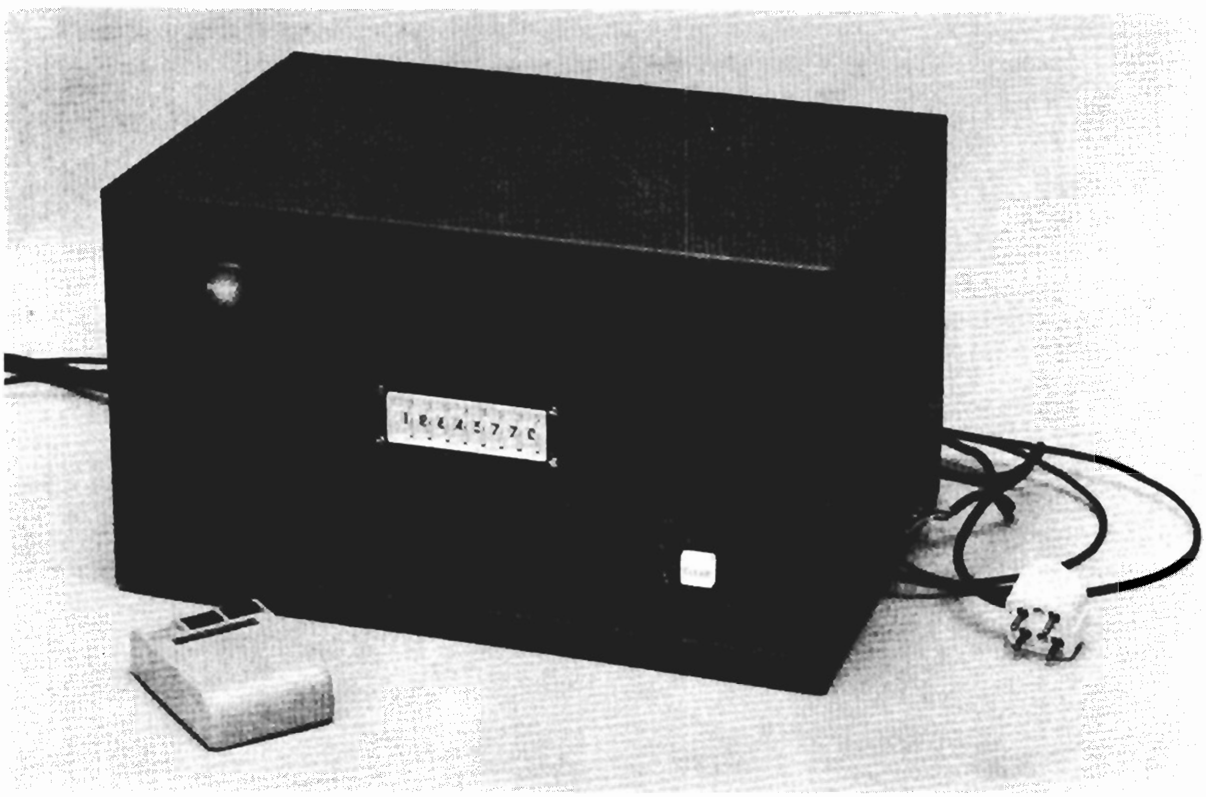

FIGURE 12. - Public telephone-to-mine pager phone interconnect unit and handheld audio tone generator.

SUMMARY

Today's mine phone and trolley or carrier phone system can be greatly expanded with the use of currently available communication equipment and the appropriate interfaces developed by the Bureau of Mines. Not only can operational communications be improved for greater productivity, but also emergency communications can be provided to increase mine safety. Table 1 shows a selection of new communications and interface equipment that is either currently available to the mining industry or will be in the near future.

Table 1. New Mine Communications and Interfacing Capabilities

	Function	System with Hybrid Interface	Manufacturer	Availability
1.	Selective Couple Trolley Phone to Mine Phone	Trolley Phone Interface to Mine Phone Through Use of Pocket Tone Generator	Interface Coupler - Femco, Tone Decoder - Signetics, Dictaphone Pocket Tone Generator-Code-a-Phone, Dictaphone	Yes
2.	Selective Surface Page To Working Section via Dial Telephone	Surface Dial Telephone Interface to Reach Encoder through	Telephone Interface to Encoder-Telephone Company, Encoder, Pocket Pager - Reach, Transmitter-Femco	Yes
3.	Selective Surface Page to Haulageway via Dial Telephone	Surface Dial Telephone Interface to Reach Encoder to Femco Transmitter Tied to Trolley Line to Reach Pocket Pager	Telephone Interface to Encoder-Telephone Company, Encoder, Pocket Pager - Reach, Transmitter-Femco	Yes
4.	Selective Surface Page to Total Mine via Dial Telephone	Combine both 2 and 3 above	Combine both 2 and 3 above	Yes
5.	Selective Call Alert to Working Section with Emergency through-the-Earth Capability	Future Equipment that can be used on Mine Phone Line or with Modified Mine Phones	Transmitter, Receiver, Pocket Alerter - Westinghouse Georesearch Laboratory	Near Future
6.	Two Way Communications to Roving Miner on Working Section	Surface Carrier Phone Tied Into Mine Phone Line to Working Section Carrier Phone Tied Via Coupler to Stationary UHF Transceiver to Portable UHF Transceiver	Carrier or Trolley Phone - MSA, Coupler - Collins Radio Co., UHF Transceiver - Motorola	Yes
7.	Private Mine Phone Communication Channels using Mine Telephone Grade Carrier	Future Equipment that Can Be Used on Mine Phone Line		Future
8.	Mine Phone Coupled to Select Public Telephones	Surface Outside Public Telephones Interfaced With Mine Phones Through Use of Pocket-Tone-Generator	Interface Unit - Prototypes - Arthur D. Little, Inc., Production Unit - Mine Suppliers, Pocket Tone Generator-Code-a-Phone, Dictaphone	Yes