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Underground Mine Communications

(In Four Parts)

4. Section-to-Place Communications

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8745

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Compiled by Staff—Mining Research

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

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UNDERGROUND MINE COMMUNICATIONS

(In Four Parts)

4. Section-to-Place Communications

Compiled by Staff–Mining Research

ABSTRACT

This Bureau of Mines report on underground mine communications addresses methods and equipment to meet the communication requirements of working sections and places of coal and metal-nonmetal mines. A review of the status of trapped miner detection is also presented.

INTRODUCTION

This report focuses on equipment and methods to meet the special communications needs of key individuals in the working sections and places of coal and metal-nonmetal mines. Attention is also directed toward recent developments in and future plans for locating and communicating with trapped miners.

A wide assortment of techniques and ultrahigh-frequency (UHF) radio hardware by which mine operators can increase the safety and productivity of section-place mining operations is now available. Therefore, a comprehensive treatment is given to mine applications and experiences with commercially available, MESA-approved, UHF portable radios, repeaters, and accessory hardware. Applications include two-way radio communications between supervisory, maintenance, and ventilation personnel working in basic room-and-pillar sections; between miners working in sections with special needs, such as longwalls and shortwalls, and in sections with full-dimension continuous haulage; between isolated workers (for example, fan-hole drillers) and supervisory personnel; and between section and off-section personnel communicating via radio interconnects with mine phone systems.

To meet miner-on-the-move communication needs, which are difficult for UHF radio to satisfy, the Bureau of Mines is developing a medium-frequency wireless communication system. The status of the hardware development to date and the associated in-mine medium-frequency radio signal measurement program are described.

Longwall mining is a major component of the Bureau's program for increasing U.S. coal production, and the number of longwall mining sections in the United States continues to increase each year. Therefore, a paper is devoted to the special communication and control needs of section foremen, roof-support advance personnel, machine operators, and workers at the head and tail gates of longwall sections. It covers both U.S. and European practices and equipment experiences, and commercially available, MESA-approved radio and wired equipment for voice communication, signaling, and control.

Developing effective and practical means of locating and communicating with trapped miners continues to be an issue of priority to the Bureau of Mines. A paper on trapped miner location and communication describes the present preproduction ultralow-frequency (ULF) electromagnetic (EM) hardware for use by underground miners and surface rescue teams. Also discussed are test results for a simulated mine disaster, the present measurement program to verify performance of the ULF transmitters through a variety of overburdens, and planned reliability testing of the transmitters in several mines. Lastly, the approach and status of a program to develop a reliable mine refuge shelter communication system based on through-the-earth signaling techniques are described.

Throughout the proceedings, mention of trade names is made to facilitate understanding and does not imply endorsement by the Bureau of Mines unless otherwise stated.

UHF SECTION-TO-PLACE RADIO

by

Robert A. Bradburn[1] and Robert L. Lagace[2]

ABSTRACT

Permissible ultrahigh-frequency (UHF) section radio equipment is available and being successfully used underground in a variety of mine section applications, such as on a longwall face, along a full-dimension haulage unit, and in a magnetite mine. Moreover, recent experiences with UHF radio in several room-and-pillar mine sections have been encouraging.

With a wide assortment of hardware from which the mine operator can choose, section radio systems ranging in complexity from basic portable-to-portable communications to systems interconnected with mine-wide phone networks can be configured to meet varying requirements.

INTRODUCTION

A variety of opportunities for improved safety and management are made possible by the use of portable UHF radios in mine working sections. This can be appreciated by considering the following instances.

Better coordination of section activities can be achieved with portable UHF radios, resulting in a safer operation; for example, during the movement of several mobile machines that must work in concert with each other. In many cases the operators cannot see one another, but with a system of communications they can effectively work together. Another example in which safety is improved by better communication is the contact that can be established with isolated workers to check their status; for example, fan-hole drill operators in iron ore mines.

Improved management can be realized by means of effective section communication. The foreman can exercise better supervisory control, resulting in more efficient utilization of available personnel. Another benefit is the reduction of unnecessary travel, an extreme burden when mining low coal, particularly on longwalls, Additionally, such workers as repairmen, mechanics, and utilitymen can be quickly reached and dispatched to their place of need at the time of need.

Figure 1 shows a machine operator with a UHF walkie-talkie and a special radio headset assembly while at the controls of a continuous miner.

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[2]Electrical engineer, Electronic Systems Section, Arthur D. Little, Inc., Cambridge, Mass.

FIGURE 1. - Machine operator equipped with radio and headset.

Although relatively new to the working crews in underground mine sections, it is reasonable to expect that UHF radio communication will find increasing applications of this type as the quest for expanded productivity intensifies.

UHF RADIO SYSTEMS IN MINES

Basic Building Blocks

The development of a UHF radio system for a mine working section can be approached from the standpoint of a basic "building block" philosophy. In figure 2, the fundamental building block is the UHF walkie-talkie radio. Several of these are sometimes all that is required for an effective section wide communication system. Usually, however, certain portable accessories are helpful to some miners; namely, speaker-microphone headsets, carrying vests, and remote handheld microphones.

In some situations, it is necessary to extend the range of communications beyond that achievable when transmitting directly between portable

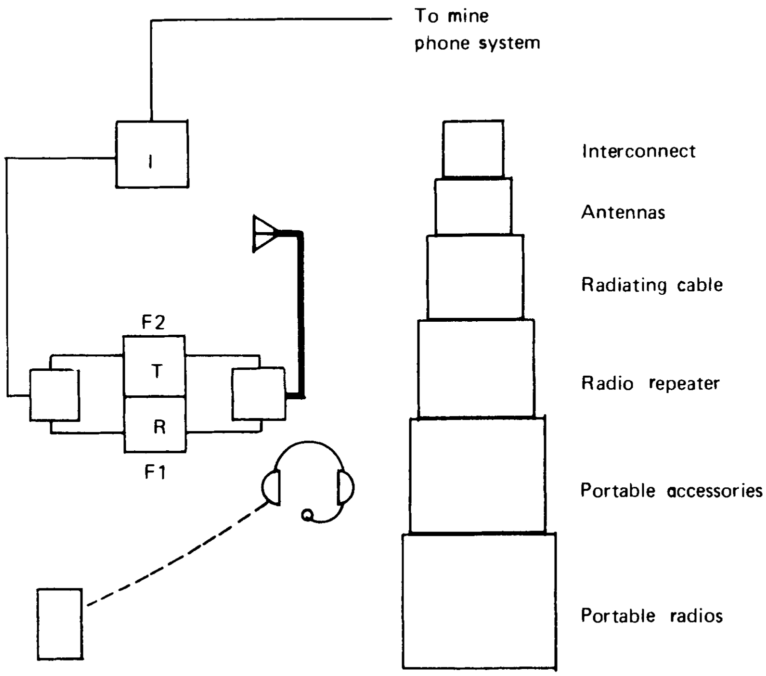

FIGURE 2. - Building blocks for UHF section radio.

units. This can be accomplished by adding a radio repeater to the system. A repeater, which can effectively double the area of coverage, is essentially a signal booster that transforms weak signals received from distant radios into signals retransmitted at full power. Further enhancement is possible by connecting the repeater to its antenna by means of a long length of special "radiating" cable extended into areas of poor coverage, such as the area along a longwall chockway. Radiating cable, also known as leaky coax or leaky feeder, has the characteristic of allowing radio signals to leak out of or into itself at a controlled rate. It effectively behaves as a long antenna with the attendent capability of following corners and bends.

For a comprehensive system, some mines may include an interconnect to allow communication between a section radio system and the surface or other off-section areas by interfacing the radio system with a minewide network, such as a page-phone or trolley-phone system. This would be useful, for example, for paging key personnel in the section who are out of audible range of the section pager phone. However, the interconnect should operate only on a selective basis to avoid interference to, or by, the section radios. Hardware for implementing this idea is commercially available, and additional equipment will be so in the near future.

These are the basic constituents of a section radio communication system; that is, portable radios and accessories, radio repeaters, radiating cable, antennas, and interconnecting hardware. A simple system may consist of only a few walkie-talkies carried by several selected individuals. A more elaborate system might have, additionally, a repeater feeding an antenna-terminated radiating cable, and a selective interconnection between section communication and minewide communication. Figure 3 shows some of the radio hardware that are presently available in MESA-approved versions.

Typical Communication Ranges

Almost anyone who has ridden in an automobile is familiar with the radio fade that occurs when a car enters a tunnel. A mine can be looked upon as a vast network of tunnels going off in various directions. One might expect,

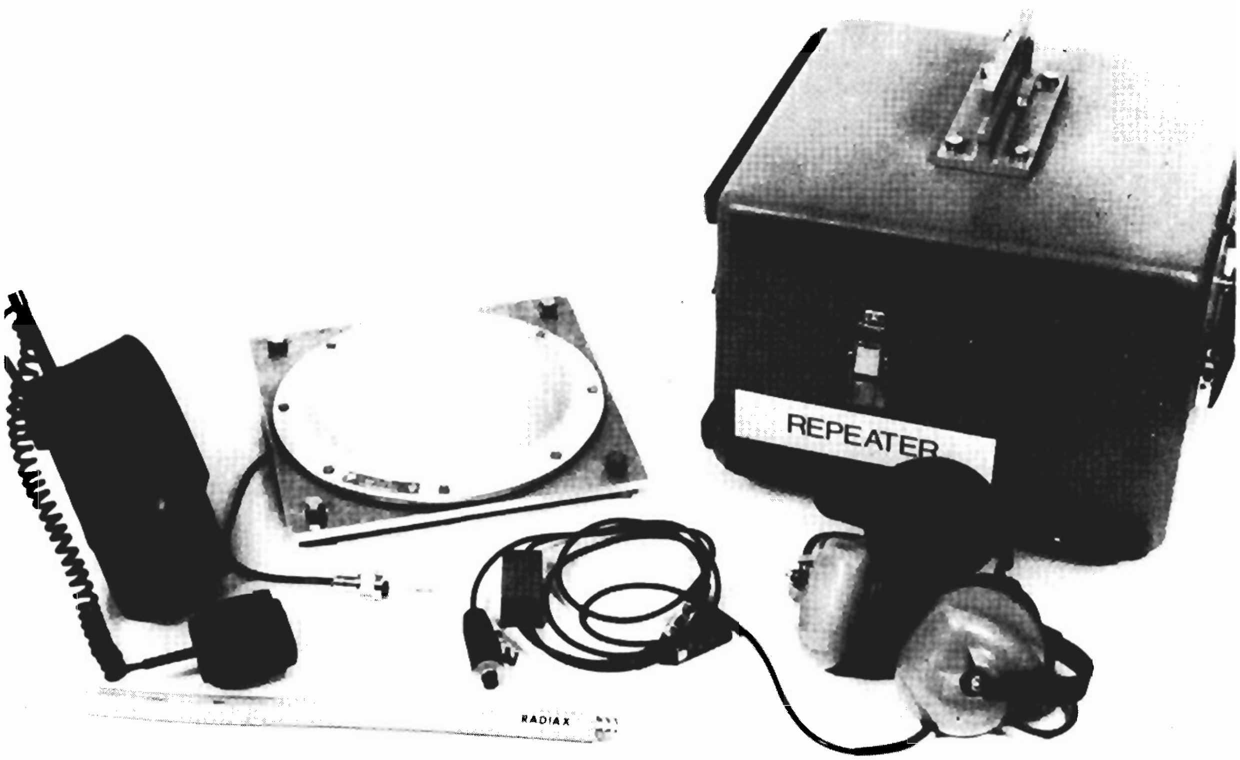

FIGURE 3. - UHF radio hardware.

then, that radio wave propagation would be very poor in mines. This is generally true, and it is not feasible to design practical "wireless" portable radios capable of full mine coverage, except possibly for the smallest mines. However, all is not so pessimistic as the foregoing may suggest. Both theory and experience teaches that the propagation characteristics of radio waves in mine tunnels improve as the frequency increases into the UHF band. This is attributable to a waveguide effect that is prominent when the wavelength of the radio wave becomes small compared with the cross-sectional dimensions of the tunnel. In the UHF band from 400 to 1,500 megahertz, tunnel propagation is suitable enough to provide sectionwide radio coverage.

Probably the most important factor that determines the ability of UHF radio waves to propagate in underground mine tunnels is the cross-sectional dimension of the tunnels. In general, a high, wide opening favors good propagation, whereas a low, narrow opening presents a less favorable medium for radio-wave propagation. Figure 4 shows a comparison in the ability of 450-megahertz UHF radio waves to propagate in high coal (7 feet) as opposed to low coal (3.5 feet), assuming an unobstructed 16-foot-wide entry. The comparison also assumes that 2-watt UHF walkie-talkies are the source of signal. As indicated in figure 4, communication is possible for ranges up to 1,500 feet, along a straight entry in high coal, but the range drops to 400 feet in low coal. Of course the same principles apply to tunnels in noncoal mines.

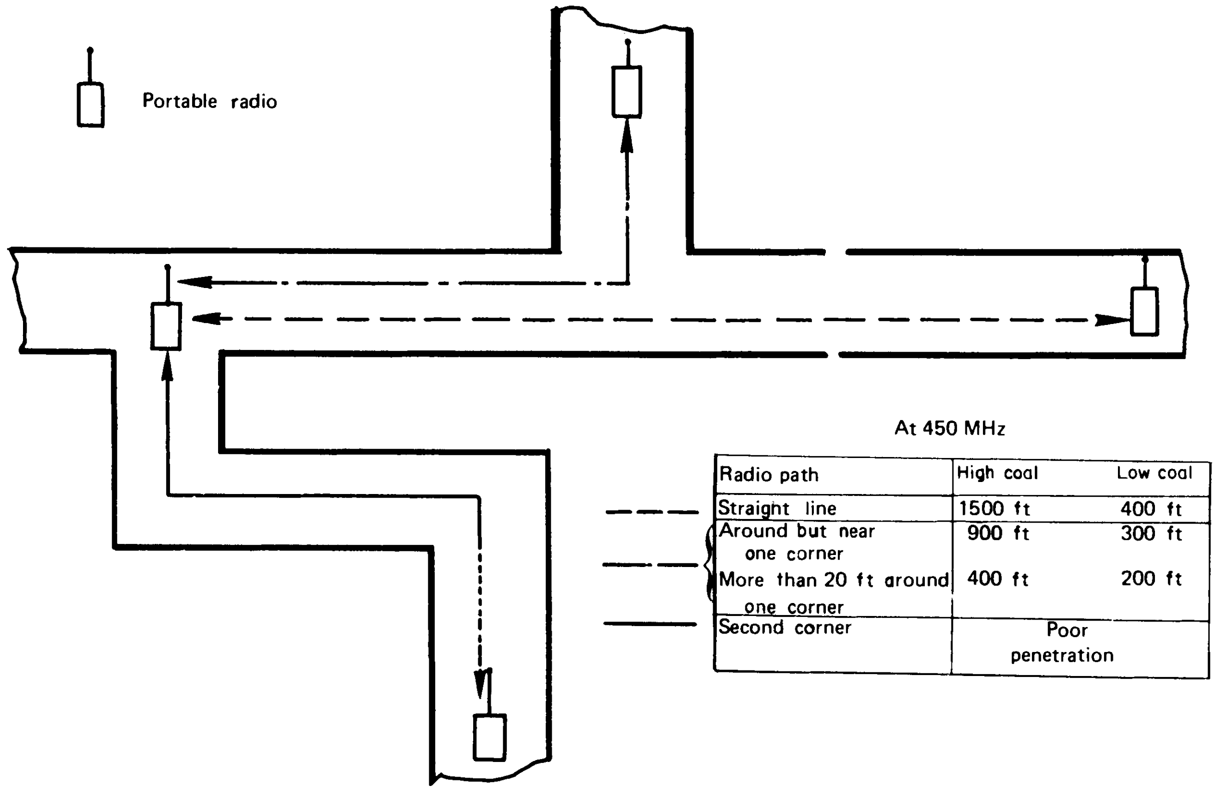

FIGURE 4. - Typical ranges in unobstructed mine tunnels.

Corners present obstacles to the propagation of UHF radio waves down cross tunnels, thereby reducing the communication range as shown. For a path that includes one corner, ranges are reduced but improve if one of the radios can be moved closer to the corner. However, penetration around a second corner is usually poor. To help offset this corner effect, it is good practice to transmit from intersections when possible, thus reducing the number of corners that have to be negotiated. Some other obstacles to radio-wave propagation at ultrahigh frequencies are equipment such as shuttle cars and machines that reduce the channel cross-sectional area of the tunnels or entries, and permanent stoppings. Table 1 shows that when shuttle cars are present, for instance, the range is typically reduced by 200 feet in high coal and by 50 feet in low coal. On the other hand, some types of permanent stoppings can present an almost impenetrable barrier to UHF radio waves. The amount of range reduction due to undulations, curves, and other bends in the tunnel ranges from moderate to severe, depending on the degree of bend.

TABLE 1. - Typical range reduction[1] due to tunnel obstructions at 450 kilohertz

	High coal (7 by 16 ft)	Low coal (3-1/2 by 16 ft)
Shuttle car..........feet..	200	50
Bends......................	Moderate to severe	Moderate to severe
Permanent stoppings........	Moderate to severe	Moderate to severe
Longwalls...........feet..	1,200	250

[1]For range improvement, use radiating cable and/or repeater.

The range of effective communication can be substantially increased by the use, and judicious placement, of a repeater, and in some applications, a radiating cable. When this is done, good communication can be established even under some of the worst conditions encountered on working sections. This is illustrated in figure 5. Referring to figure 5, and ignoring the dashed lines for the moment, suppose the two radios labeled A and B are out of direct radio range of each other. The repeater can function to bring the radios within range in the following manner. When radio A transmits on frequency F1, the signal is picked up by the repeater, which amplifies and converts the signal to a different frequency F2, and retransmits it at a higher power level. Radio B receives the retransmitted signal. In this way, communications from radio A to radio B and B to A are established.

When the tunnels between the portable radios are heavily obstructed by machinery or metal roof-support structures, radiating (leaky coax) cable may also have to be installed in the tunnel to pick up and carry the signals to and from the repeater and portable radios. The dashed lines in figure 5 show a sample cable installation for use with the repeater. In this case, the signals from radio A are picked up either by the antenna connected to the cable, or by the cable itself, carried to the repeater , retransmitted as F2 signals onto the cable, carried along by the cable and leaked into the tunnels where

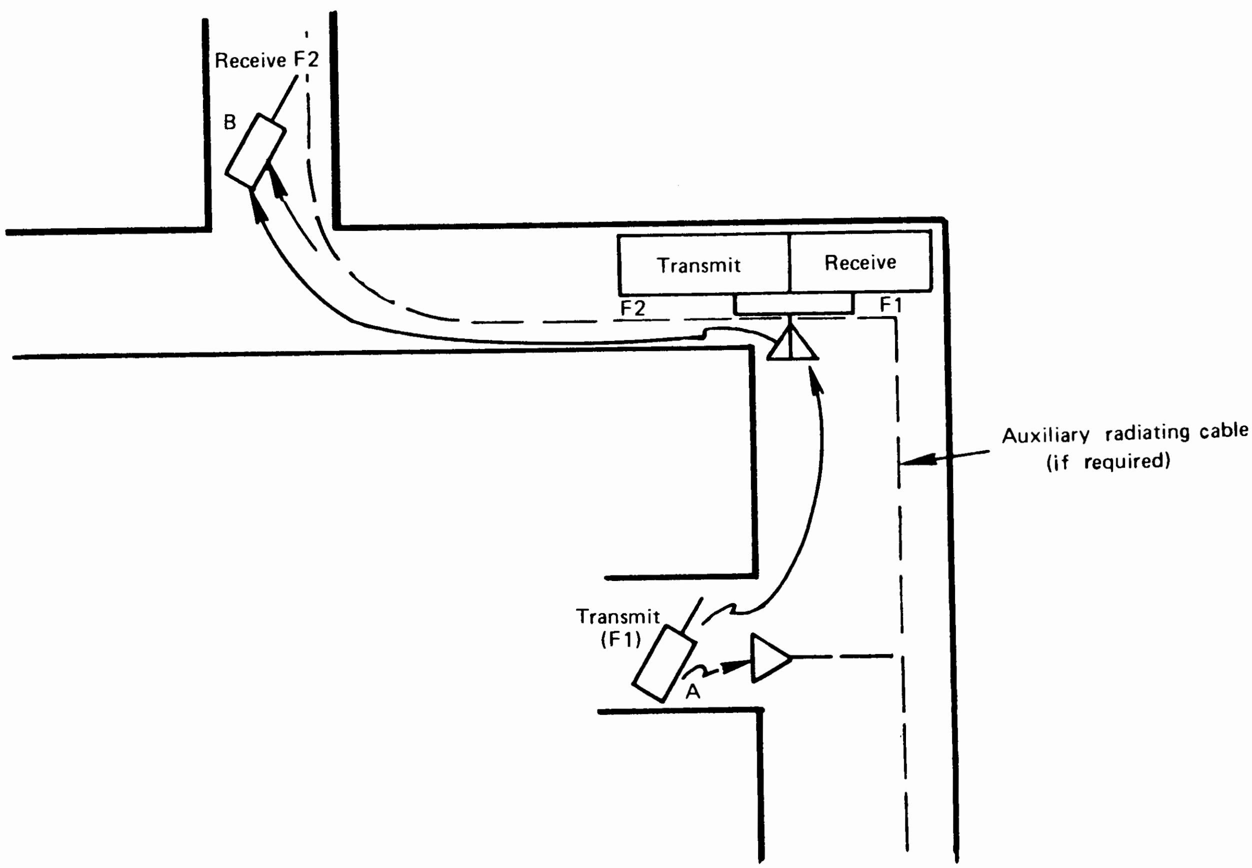

FIGURE 5. - Extending ranges with repeater and radiating cable.

they are received by radio B. The reverse occurs for transmissions from B to A.

UHF RADIO FOR BASIC ROOM-AND-PILLAR SECTIONS

Several individuals working in room-and-pillar sections can be equipped with walkie-talkie radios. Thus equipped, the section foreman can practice better supervision by maintaining instant contact with the various workers. Machine operators can coordinate their activities more efficiently, resulting in a smoother and safer operation. The shot firer can warn other personnel, by radio, when he is about to fire. Unnecessary travel by individuals can be eliminated or, at least, reduced.

The minimum acceptable coverage for a radio system in a room-and-pillar section should be at least one-half the area inby the power center. Under many circumstances this will provide adequate coverage since most workers are usually located in one part of the working section at any one time. However, in some circumstances, some workers are likely to be out of range. To rectify this, a centrally located radio repeater can be employed to extend communication coverage to nearly 100 percent of the section. In some cases, it may be necessary to use radiating cable to extend coverage into weak areas. In other situations, it may be desirable to locate the repeater at a location remote from its antenna; for example, at the section power center. Suitable coaxial cable, such as RG-8, which also has radiating properties can be used for this purpose.

UHF section radio has recently been used successfully on room-and-pillar working sections at several mines. The Bureau of Mines closely monitored the experience gained at two such mines--Jenny mine near Inez, Ky., and Peabody No. 10 mine near Shawnee, Ill. In each mine, one working section was operated as part of the Bureau-sponsored Inherently Safe Mining System (ISMS) project and was provided with UHF radio communication.

Jenny Mine Installation

The Jenny mine had a single conventional room-and-pillar section and was in production 18 months, the duration of the ISMS project. A layout diagram of the working section at that mine is shown in figure 6. The seam height was medium low (42 to 48 inches). The section radio system consisted of walkie-talkie radios carried by various miners and a radio repeater located at a communications center (known as the communication sled), which was placed near the power sled. The foreman, mechanic, shot firer, and a utility cleanup man were equipped with 2-watt walkie-talkies operating on two channels, 454 and 457 megahertz. One transmit channel was used for direct portable-to-portable communications, and the other channel was used for portable-to-portable communications via the repeater. The channel is selected by means of a multiposition switch on the HT 220 walkie-talkies.

The purpose of the repeater at the Jenny mine was twofold: (1) To extend coverage beyond the direct portable-to-portable range, and (2) to provide an interconnect between the radio system and a system of carrier

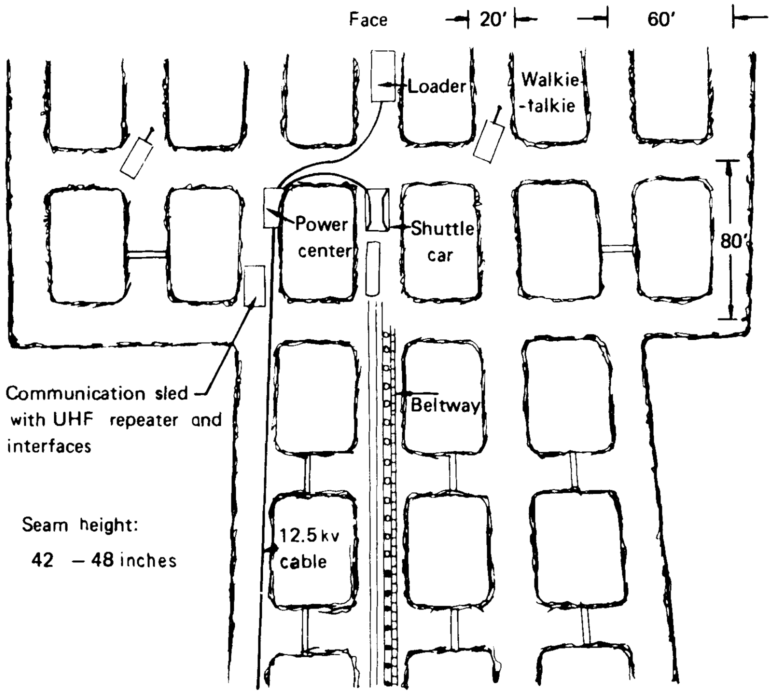

FIGURE 6. - Section layout of Jenny mine.

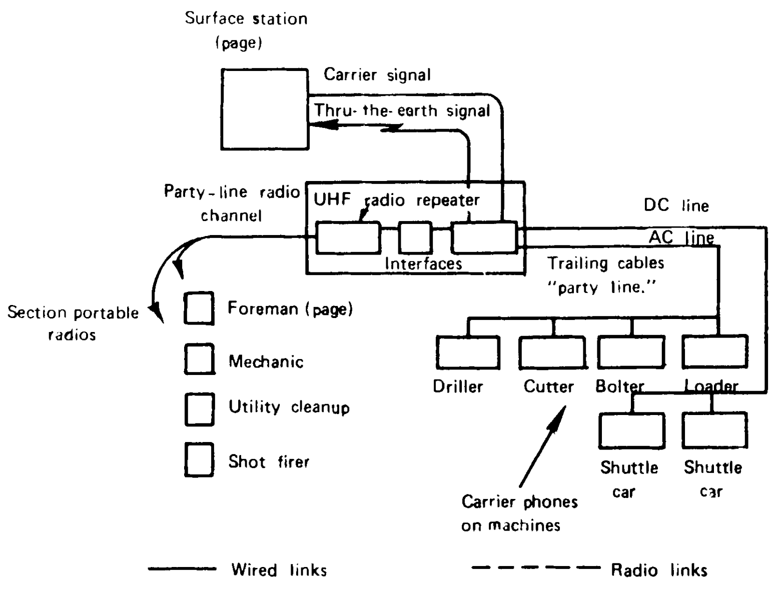

FIGURE 7. - Diagram of section communications at Jenny mine.

phones, which were mounted on mobile machines and interconnected by means of the trailing cable conductors to the machines. It was thus possible to communicate between roving miners equipped with walkie-talkies and machine operators equipped with powerline carrier phones. Paging into the section radio system from a surface point was also possible via a surface-to-section carrier-phone link and a special interface in the communication sled. A low-frequency through-the-earth radio link between the surface and communication sled was also provided. A block diagram of the system is shown in figure 7.

At the Jenny mine, the portable radios were used extensively by the miners on the one daily production shift. The most often used mode of operation was direct portable-to-portable without the repeater. However, this was largely because the repeater and interconnect to the machine-mounted carrier phones were made operational only late in the program. The walkie-talkie portables by themselves were usable over an area encompassing more than half of the working section. With the repeater, section-wide radio coverage was possible. The carrier phones were installed mainly to demonstrate an alternative communication method for the machine operators. At the termination of the project, the portable units showed much evidence of in-mine use, but they were all in good working order, except for one defective battery.

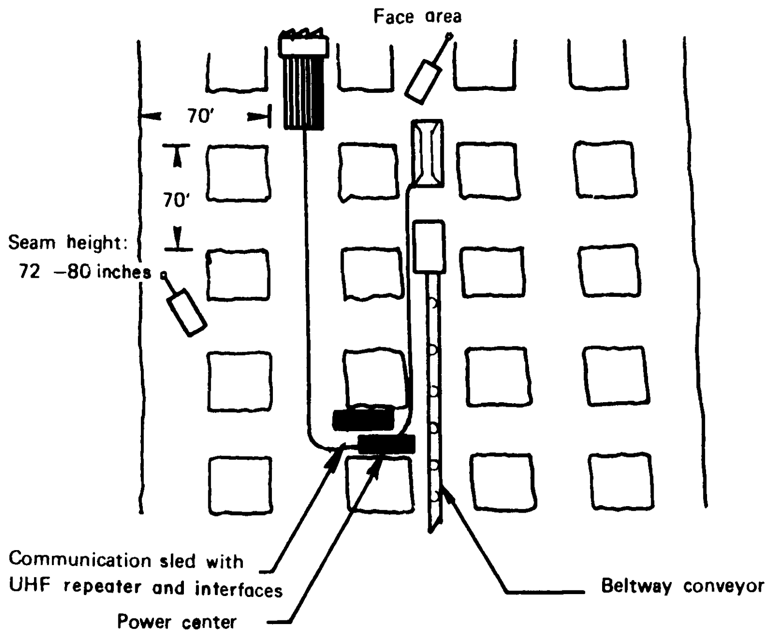

FIGURE 8. - Section layout of Peabody No. 10 mine.

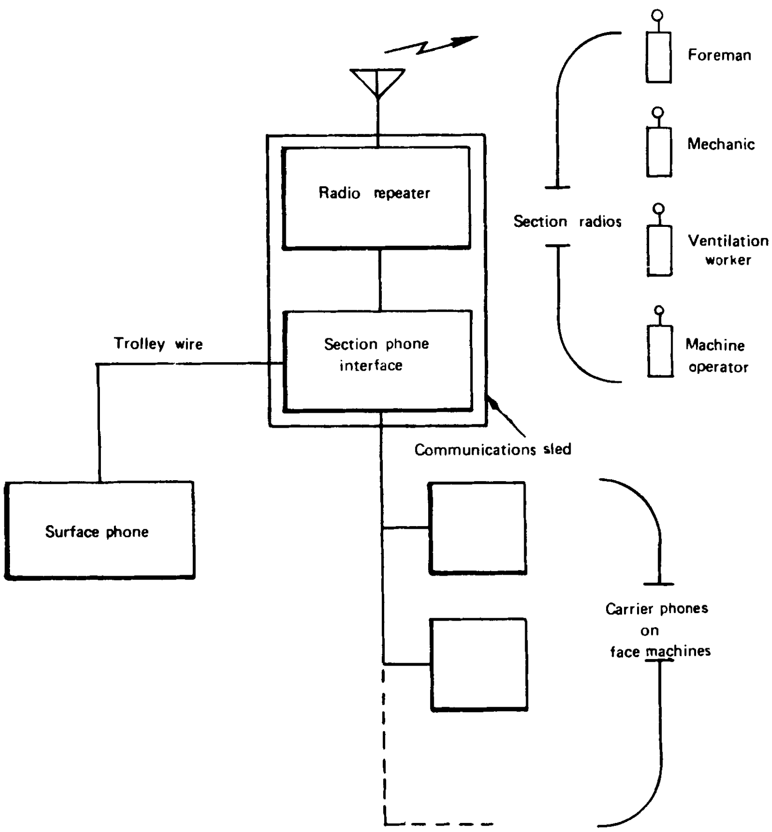

FIGURE 9. - Diagram of section communications at Peabody No. 10 mine.

Peabody No. 10 Mine Installation

At the Peabody No. 10 mine, one continuous room-and-pillar section was devoted to the ISMS demonstration program. This section remained in operation for about 1 year. The section radio communication system was very similar to that at the Jenny mine, including the machine carrier phones and a surface-to-section interface at a communication sled. A layout diagram of the working section is shown in figure 8, and a block diagram of the communication system is shown in figure 9.

Conditions at Peabody No. 10 were much more favorable for radio communication than at the Jenny mine, mainly because the seam height was 6 to 7 feet. Direct portable-to-portable communication was generally good over an area encompassing up to three-quarters of the working section, although some dead zones were encountered where several corners had to be traversed. When the face was at maximum advance from the power center, the repeater located in the communication sled near the power center was out of reach of some portable radios. This could have been rectified by extending the repeater antenna in toward the face area by means of a coaxial cable.

The foreman, mechanic, ventilation man, and the operator of a stationary drive storage unit all used walkie-talkie portables. The portable radios, which were identical to those used at Jenny, were used daily during the daytime working shift. When returned to the Bureau of Mines at the conclusion of the ISMS demonstration, one out of four radios was found to be inoperative, requiring repair.

Although of fairly modern design, the HT 220-type radios used at the Jenny and Peabody No. 10 mines have been superseded by a more compact, lighter weight unit, the Motorola MX 300 series, which also has MESA approval. Because of their smaller size and improved circuit design, the MX series radios are now recommended over the HT type for most underground mine applications.

UHF RADIO FOR FULL-DIMENSION HAULAGE SYSTEMS

The Bureau of Mines entered into a cooperative agreement with Clinchfield Coal Co. in 1976 for the development of a communication system for use on mine sections with full-dimension haulage equipment.[3] In a mine section of that type, an articulated mobile conveyor system extends to the continuous miner for removal of produced coal to an outby haulage conveyor. Shuttle cars are not used. The Bureau of Mines has developed a useful UHF radio system for this application, and it is in operation at Clinchfield's Splashdam mine near Haysi, Va.

The full-dimension haulage unit at Splashdam mine consists of three mobile bridge conveyors connected as one unit by two mobile bridge carriers. The unit empties coal onto an extendable Long John[4] belt. The bridge carriers each require one operator as does the continuous miner. The continuous miner is operated at a location several feet from the machine by means of a wired remote control box. A layout diagram of the working section is shown in figure 10 which also shows the radio system. The seam height ranges from about 30 to 48 inches.

System Objectives and Equipment for Splashdam Mine

Early in the program, Bureau personnel and officials of both the Splashdam mine and Clinchfield Coal Co. established the following objectives for the system:

1. Primary need.--The operators of three machines (the continuous miner and two mobile bridge carriers) should be able to communicate with each other.

2. Secondary need.--Two roving miners (the foreman and repairman) should be able to communicate with the three machine operators and with each other.

These objectives, together with the results of range tests using UHF portable radios on the working section, led to a radio system configuration that has a

[3] Also known as continuous conveyor systems.
[4] Trade name of West Virginia Armature Co.

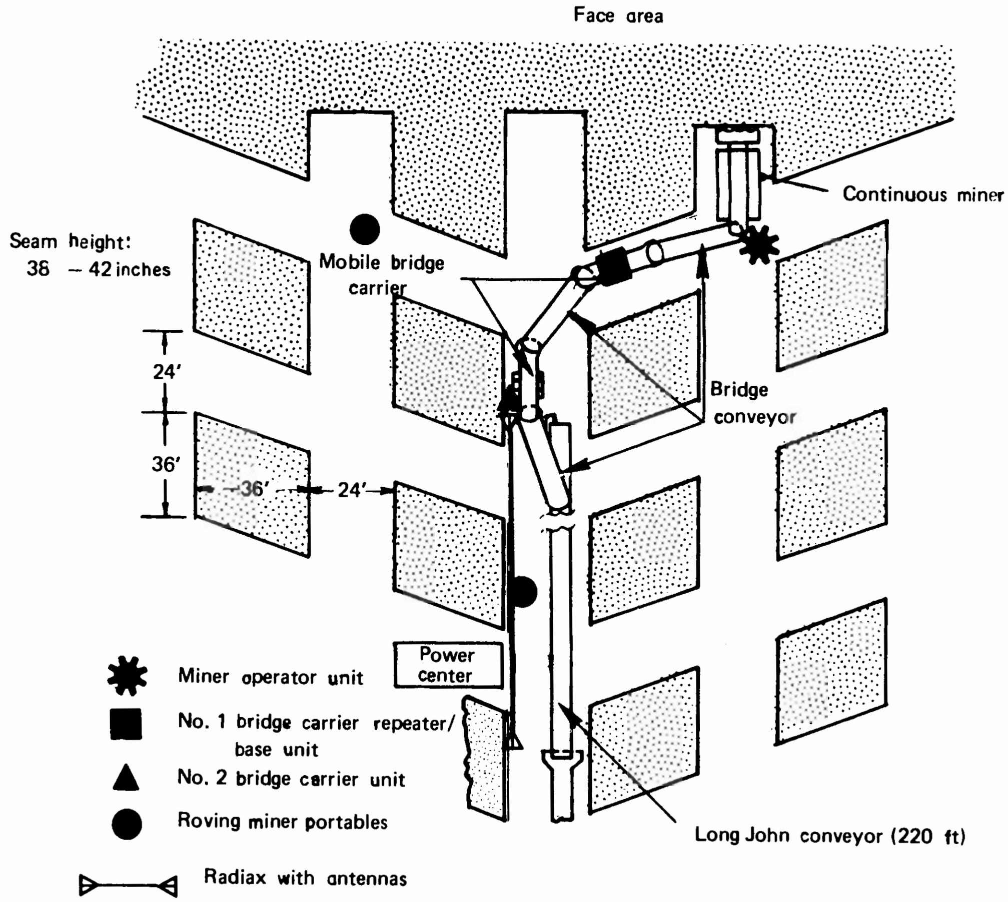

FIGURE 10. - Section layout of Splashdam mine showing UHF radio system.

radio repeater mounted on the No. 1 bridge carrier as depicted in figure 10. Although not crucial, it was also decided to include a length of cable terminated at each end by an antenna, and extending from the power center inby toward the face area paralleling the Long John belt, to improve coverage along the center heading of the section. A picture of the cable with the antenna connected at each end is shown in figure 11.

The decision to mount the radio repeater on the No. 1 bridge carrier presented a problem, since permissibility is required of any electrical equipment installed there, and no approved repeater hardware was available at that time. To overcome this problem, the Bureau of Mines repackaged an existing portable radio repeater into a certified explosion-proof enclosure and obtained a permit from MESA to install it on the machine. Figure 12 shows an in-mine picture of the repeater main enclosure installed on the No. 1 bridge carrier. The repeater obtains 120-vac operating power from the machine, but also has a standby nickel-cadmium storage battery located inside the main enclosure.

Several control adjustments are accessible on a separate repeater control box located on the operator's side of the machine. This control box also has

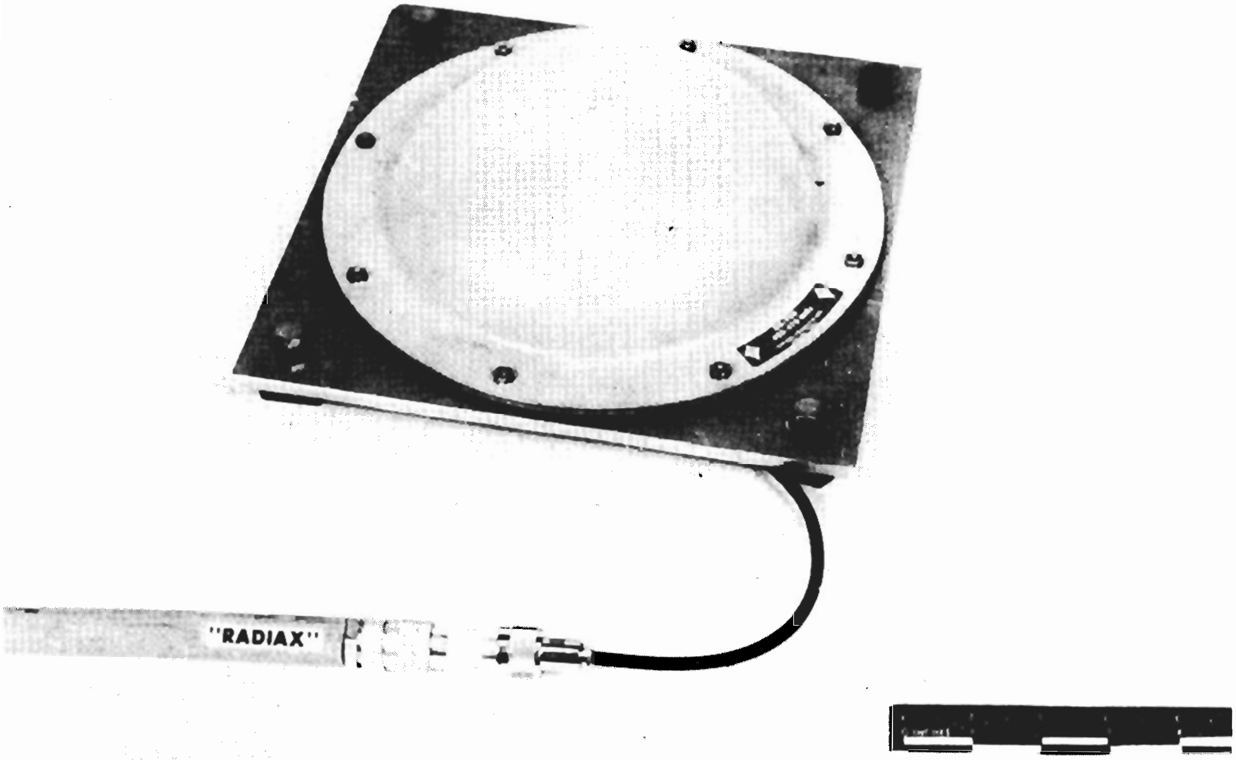

FIGURE 11. - Radiax[R] radiating leaky feeder cable with antenna.

provisions for plugging in a speaker and microphone, which allows the machine operator to use the repeater as a fixed radio for communicating with other crew members. This precludes his need to carry a separate portable radio. Figure 13 shows a miner at the controls of the No. 1 bridge carrier, and speaking into the repeater microphone.

The portable radios used on this system are 2-watt Motorola HT 220 units with two transmit frequencies (464.7 and 469.7 megahertz) manually selectable by the user. One frequency is used for direct communication between portable units, and the other is used for communicating via the repeater. A MESA-approved, battery-operated radio repeater not requiring an explosion-proof enclosure is now commercially available from Motorola for section radio applications.

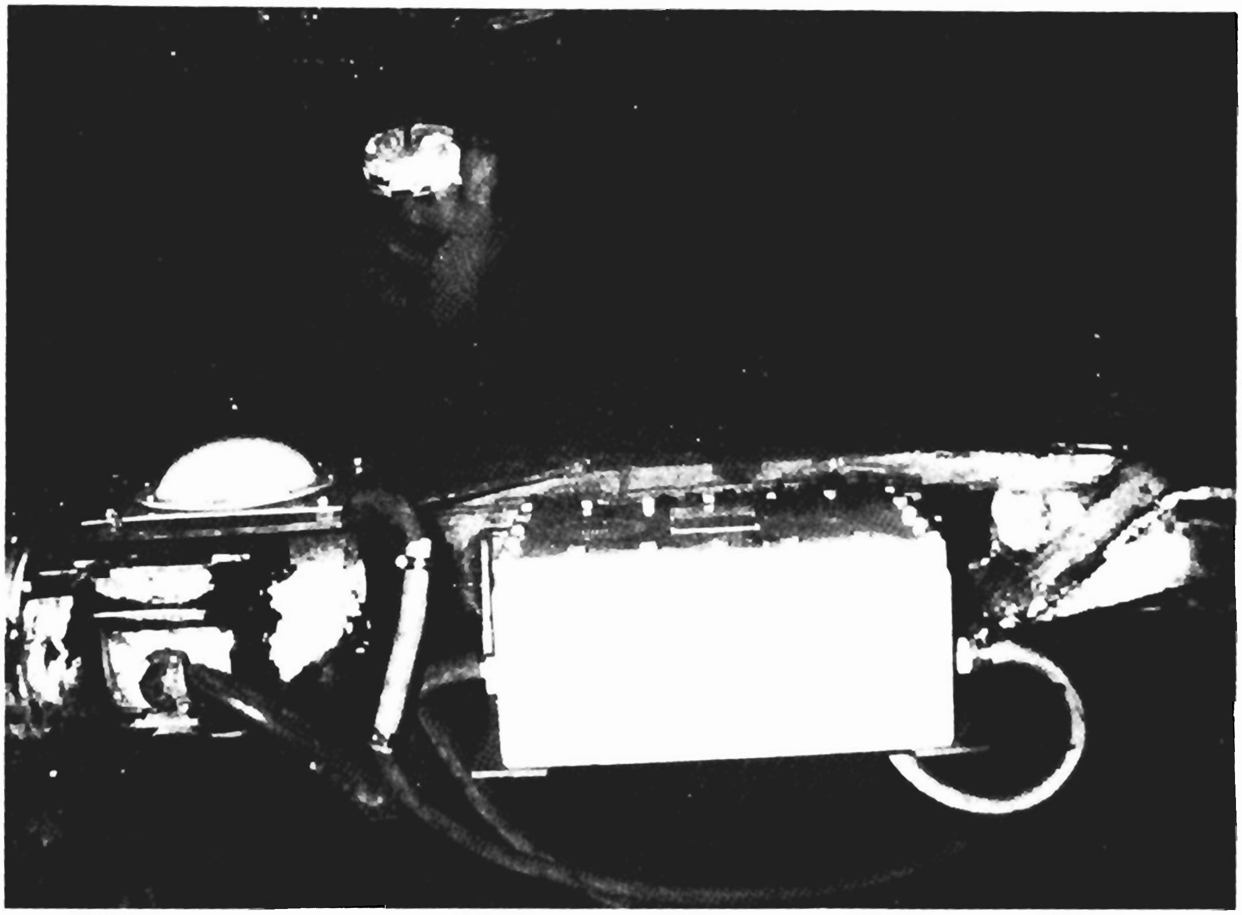

FIGURE 12. - Repeater and antenna installation on No. 1 bridge carrier.

<u>Methods for "Hands-Free" Operation</u>

To facilitate use of the portable radios by machine operators who require both hands to operate their machines, three special interfaces were developed using commercially available components:

1. Headset with earmuff-speaker and head-contact microphone:

   Arm-actuated control

   Used at continuous miner

2. Hardhat-mounted speaker and boom microphone:

   Arm-actuated control

   Used at dust-free location

FIGURE 13. - Miner speaking into repeater microphone on No. 1 bridge carrier.

3. Machine-mounted loudspeaker and extended microphone:

Lever-actuated control

Equipment off operator

Used at outby bridge carrier

The method for hands-free control developed for the continuous-miner operator employs an earmuff-speaker assembly with a head-contact bone-conductance microphone. Figure 14 shows a man wearing the assembly. The microphone, rather than protruding in front of the miner's face, makes contact with the top of the head. The miner is, therefore, able to wear a dust respirator over his mouth. The standard press-to-talk control supplied with the equipment utilizes a pushbutton situated at the end of a small extension cord. For hands-free control, the Bureau has incorporated certain modifications and substituted a miniature leather-encased switch situated so that the transmitter can be keyed by movement of the user's upper arm. This

FIGURE 14. - Miner wearing accessory headset with ear-muff speaker and head-contact microphone.

assembly, which allows either standard or hands-free operation, must be appropriately fitted to the miner before use.

Another hands-free accessory, for use in locations where respirators are not required, is shown in figure 15. Transmitter keying is done in identical fashion as in the case with the assembly of figure 14, with either the standard or hands-free option available to the user. The headset assembly, which consists of a miniature boom-type microphone and either one or two miniature speakers, attaches to the user's hard-hat. The speaker(s) hangs alongside the user's ear(s). The microphone is suspended from the left-side speaker and can be adjusted for proximity to the user's lips.

The third method for hands-free operation of a portable radio (fig. 16) was developed for use at No. 2 bridge carrier to free the operator of the burden of carrying a radio on his person. An interface box, into which a portable radio can be plugged, has provisions for attaching a trolley-phone loudspeaker, a microphone, and an external press-to-talk switch. The press-to-talk switch has a sensitive 6-inch-long lever-actuator that can be operated by a bump of the knee or other body part. A strong permanent magnet is attached to the base of the switch housing and allows positioning in a location convenient to the operator. A section of flexible "gooseneck" tubing, with a hook on one end for hanging the microphone, extends from the speaker housing. By this arrangement, the microphone position can be adjusted for convenience.

FIGURE 15. - Miner wearing hands-free hardhat accessory for dust-free location.

Another feature of the foregoing interface was incorporated to compensate for the wide changes in ambient noise level. By means of a two-position toggle switch on the speaker housing, either the full volume output of the speaker or a reduced and adjustable volume can be selected by the operator.

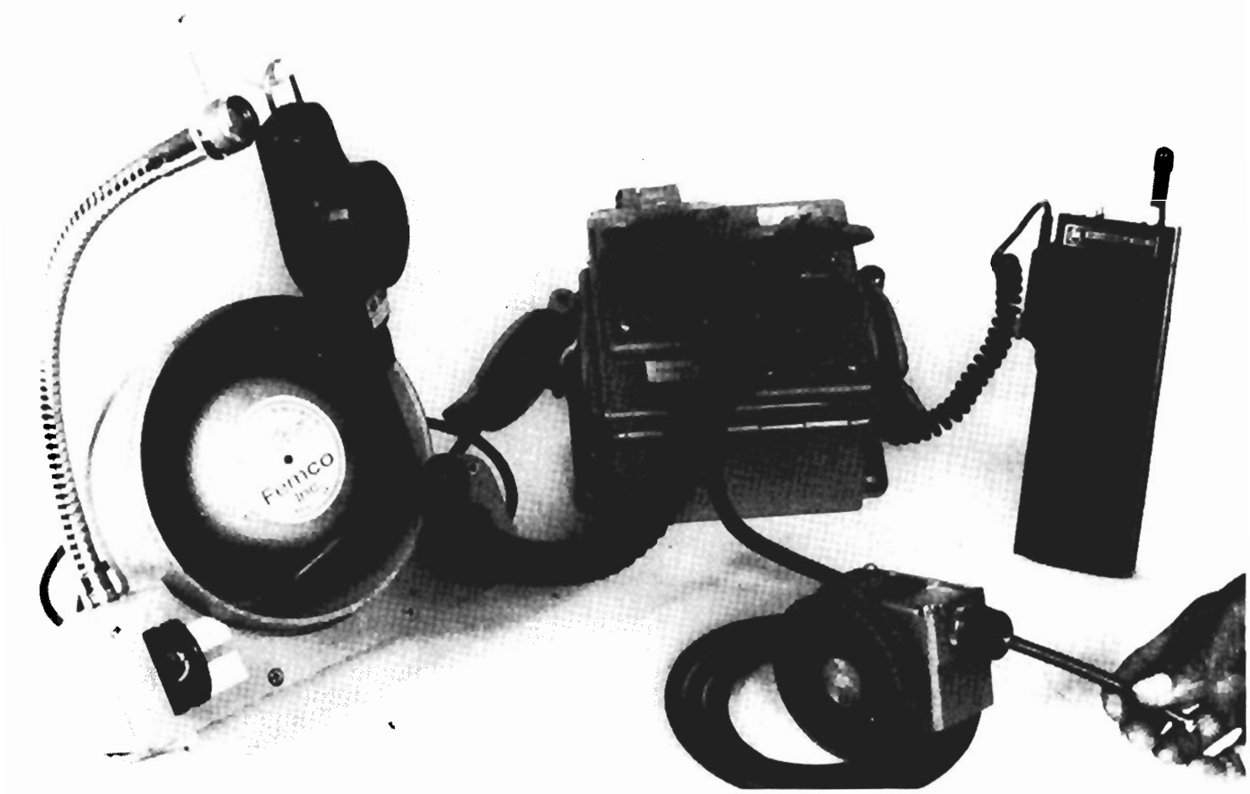

FIGURE 16. - Interface with loudspeaker/extended microphone for No. 2 bridge carrier.

When the special accessories are not needed, the radios can be carried on the miner's belt in a leather holster, which is a standard accessory. An extension speaker-microphone with a flexible cord that plugs into the radio can be used for initiating or receiving a communication. A miner using a radio in this fashion is shown in figure 17.

The Splashdam mine experience thus far has yielded some valuable information regarding the use of portable radio equipment on a low-coal mine section. The Bureau plans to continue to monitor this program closely, to participate actively in it, and make necessary or desirable system improvements as well.

FIGURE 17. - Miner using portable radio with speaker-to-microphone extension accessory.

UHF RADIO FOR LONGWALLS AND SHORTWALLS

Longwalls

On longwall sections, a communication requirement not generally being met is personal communication for miners on the face; that is, portable walkie-talkie-type communication. With some exceptions, truly wireless radio for longwalls is not feasible at ultrahigh frequencies. However, cable-aided UHF radio is feasible, and is presently the best choice for obtaining the linear tunnel coverage required on a longwall section.

The environment on a longwall is usually harsh. Figure 18, which shows a shearer machine and operator under the protective canopy of roof-support chocks, illustrate this clearly. Certain individuals should be able to communicate from any location along the chockway without the fatiguing ordeal of crawling a distance to a page phone. A cable-aided UHF radio system provides that capability. Table 2 summarizes the important points regarding the design and implementation of a longwall UHF radio system.

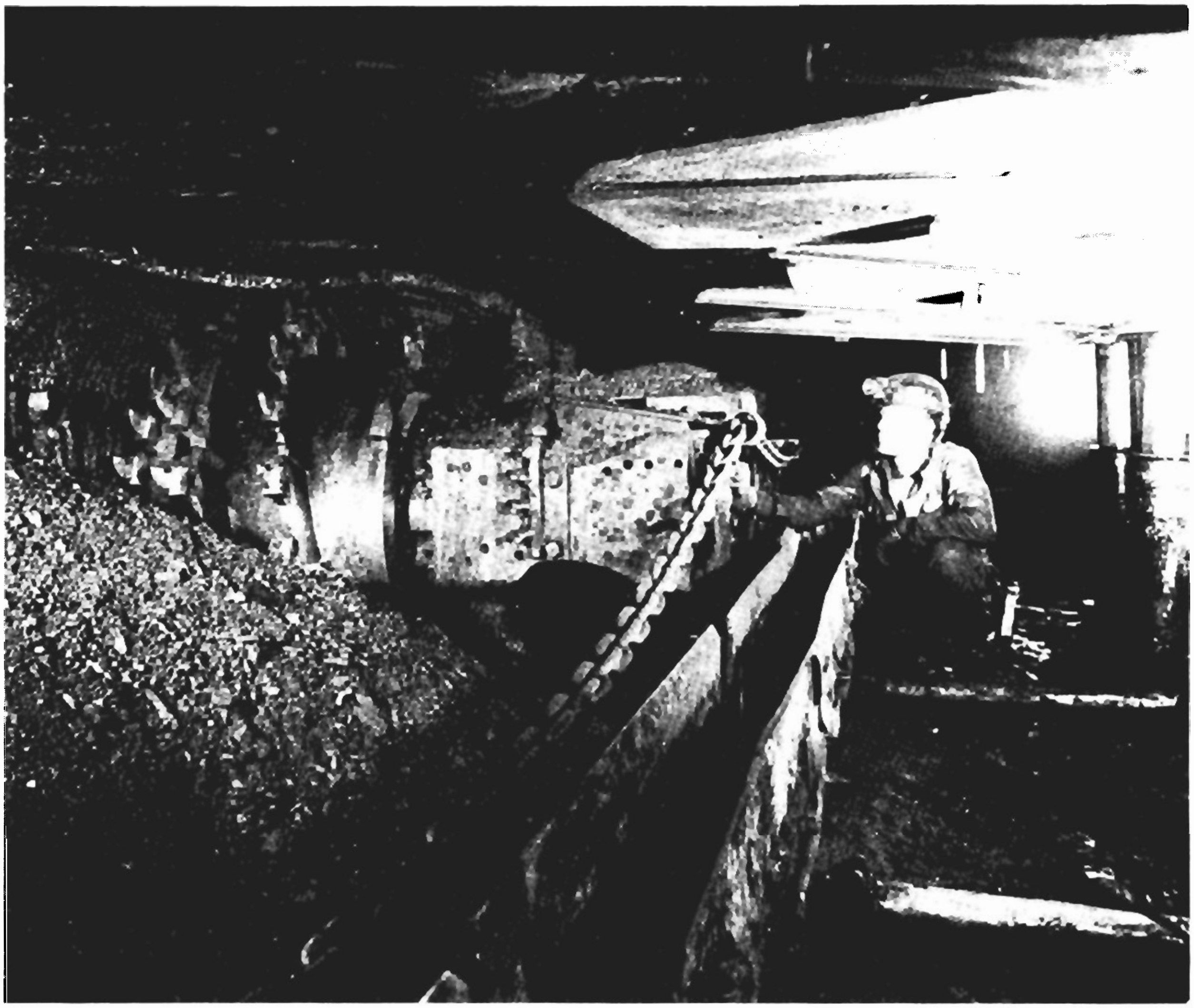

FIGURE 18. - Illustration of longwall working environment.

TABLE 2. - Ranges of completely wireless communication system for longwalls at 450 megahertz

Type of roof support	Range with no machine, feet		Range reduction caused by shearer machine, feet	
	High coal	Low coal	High coal	Low coal
Chocks...........	300	150	100	50
Shield...........	1,000	150	300	50

Truly wireless communications is not feasible except under some special and favorable conditions such as a shield-type roof support system in high coal or on the shorter faced high-coal longwalls. This is due to the substantial range reduction that results from the presence of both the chock roof-support and conveyor systems and the cutting machine. Therefore, the best choice usually is to employ a radiating leaky feeder cable extending along the chockway area. On shorter faces, a radiating cable extending along the length of the longwall and passively terminated at each end with a suitable antenna can provide face coverage without a repeater. A radio repeater, connected to the cable at one end, is needed on longer faces, or when coverage to the head entry outby the headgate is required. Presently, a passive system using Andrews Corp. Radiax slotted-type radiating cable is in operation on a short-face longwall section at Clinchfield Coal Co.'s Moss No. 2 mine near Dante, Va.

A repeater-based configuration for a longwall UHF radio system is shown in figure 19. In this system, good radio coverage can be expected along the face area and into the head entry for several hundred feet. If the repeater should fail, direct communication between portable radios is still possible at reduced range. This system can be implemented using commercially available battery-operated hardware that is also MESA-approved (fig. 20). The tone remote adapter (fig. 19) provides a surface-to-section link, and will be available in the near future. The Bureau of Mines has performed a number of experiments with radiating cable on a number of longwall sections, and has also established that inexpensive RG-8 flexible coaxial cable can be used in place of the more expensive, rigid Radiax radiating cable for repeater-based, cable-aided UHF radio installations on longwalls. However, there has not yet been enough in-mine experience to determine whether the RG-8 cable is sufficiently rugged for this kind of application.

Shortwalls

A shortwall section has characteristics of both a longwall and a full-dimension section. Roof-support equipment, for example, is similar to that used on longwalls. On the other hand, the coal is mined by a continuous miner which, in some cases, feeds onto an articulated mobile conveyor system similar to the equipment used on full-dimension sections. The congested situation in the areas between the chocks and coal face presents an unfavorable condition for radio-wave propagation, but the distance along the face is typically only about 150 feet.

For a radio system to be effective on a shortwall, communication should be possible in the face area, along the chockway, and for several hundred feet into the head entry. Many radio system configurations are possible, but a logical choice would be to place a repeater at the end of the chockway by the head entry. The repeater should operate into two remotely located antennas, one for coverage in the face and chockway areas, and the other for coverage in the head entry area.

A more detailed coverage of longwall mining communications is presented in the paper on Longwall Mining Communications.

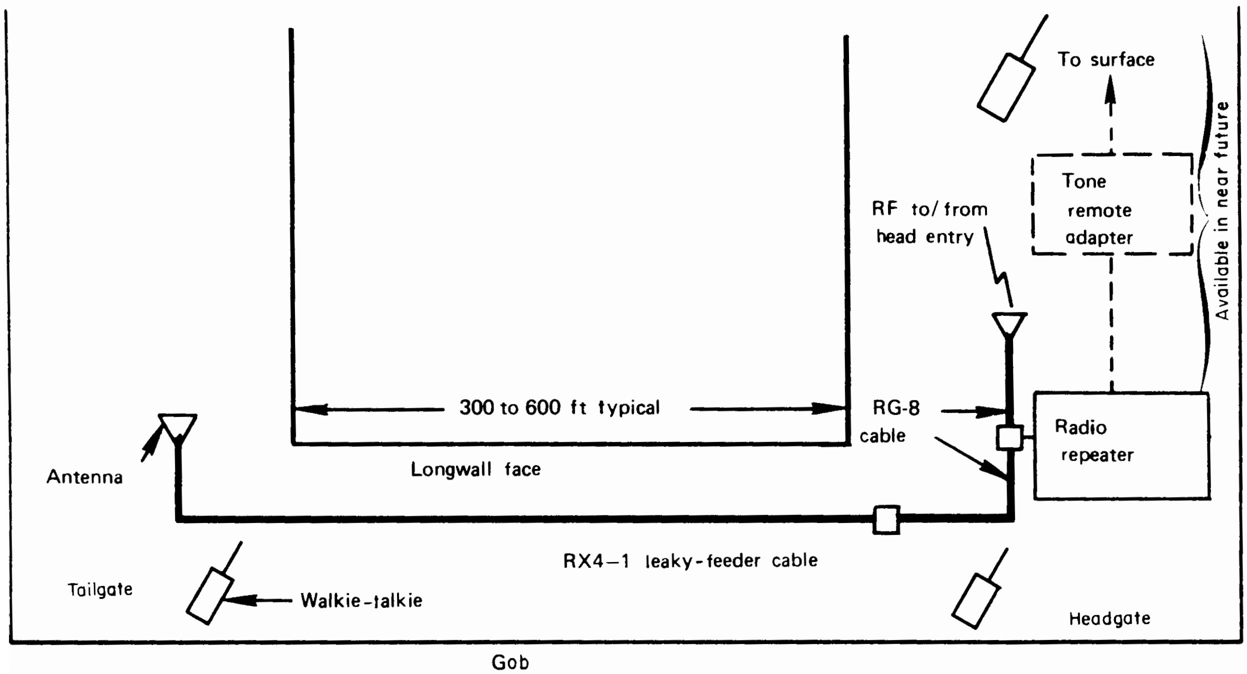

FIGURE 19. - A repeater-based UHF radio system layout for longwalls.

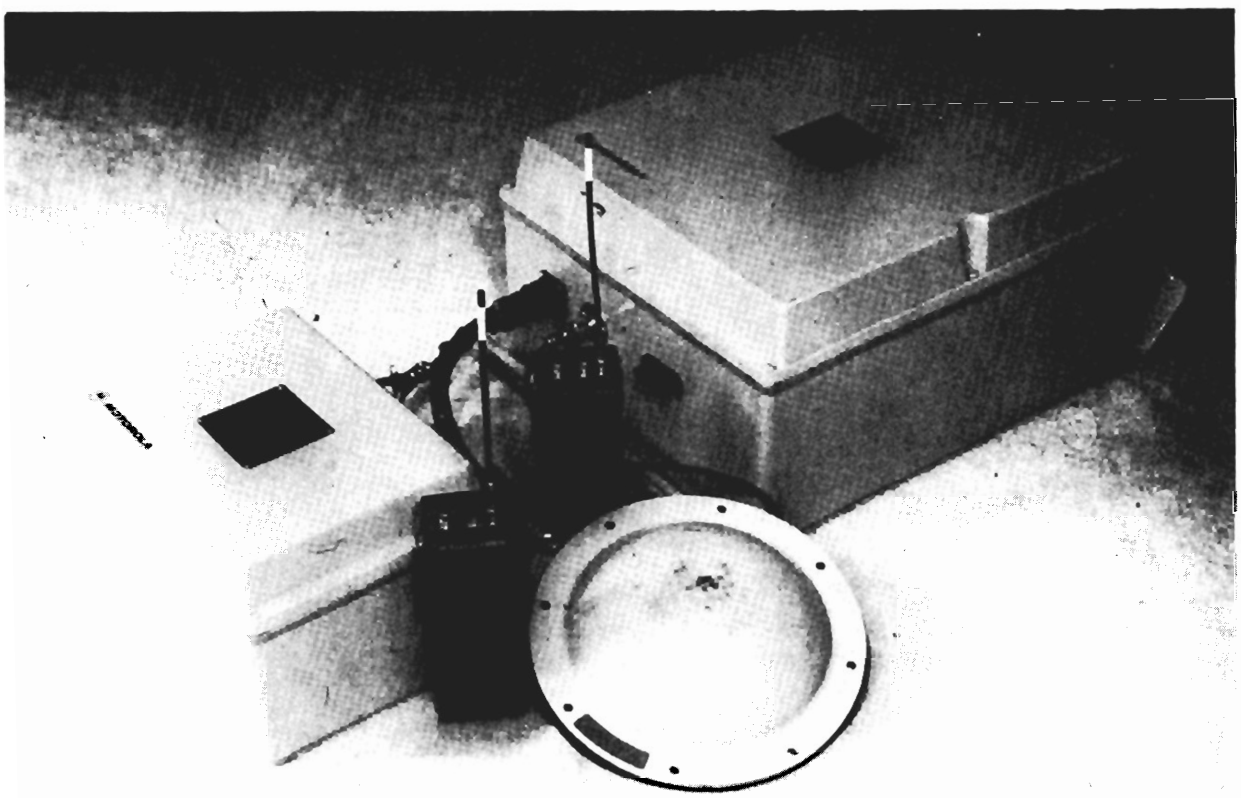

FIGURE 20. - A MESA-approved UHF Motorola repeater and battery unit, with "hardhat" antenna and HT 220 walkie-talkies.

UHF RADIO IN METAL AND NONMETAL MINES

UHF radio is finding application in metal and nonmetal mines in both the United States and Canada. Most common are minewide systems having repeaters operating into expanses of radiating cable. Communication restricted to within a working place is usually achievable without a repeater or cable. One example of an effective UHF radio system in a metal mine is that installed in the Grace mine near Morgantown, Pa. The system there provides radio communication throughout the mine by means of repeaters connected to Radiax leaky feeder cable. The system allows the status of certain isolated workers, such as fan-hole drill operators, to be checked periodically by a central dispatcher, thereby allowing the use of single-man, fan-hole drill teams. A fan-hole drill operator with a portable radio and wearing a noise-reducing earmuff is shown at the Grace mine in figure 21.

The subject of metal-nonmetal mine communication is covered more thoroughly in the paper on Leaky Feeder UHF Radio Systems in the third part of this seminar series (Haulage Systems, IC 8744).

FIGURE 21. - Fan-hole drill operator wearing portable radio and special accessories in metal mine.

INTERCONNECTS TO MINE PHONE SYSTEMS

An interconnect between a section radio system and a minewide phone system is an extremely useful concept. For example, the ability to reach key section personnel from the surface is facilitated if the individual can be paged by radio. Because section page phones are often inaudible due to high ambient noise, it can take up to a half hour, or more, to contact a paged individual from the surface. Conversely, the ability to initiate a call to the surface or at least, answer a page with one's radio, would eliminate the distractive necessity of walking (or crawling) to the section phone.

An interconnected communication system can also introduce a factor of safety. In time of emergency, for example, quick communication means faster evacuation or first aid. Another example is the ability to maintain contact with certain isolated workers who, for practical reasons, cannot have a phone near them.

An important consideration when planning to interconnect section radio systems and minewide communication is that the interconnection should be made to function on a selective basis. The two systems should be isolated, except when actual communication to or from the section is desired. Otherwise, intolerable interference may result.

Some interconnecting hardware that incorporates the desirable features mentioned has been developed (table 3). Some of this equipment was built for experimental use and is not sold commercially. Other equipment, being of recent development, has not yet been released for commercial sale, but will be available in the near future.

TABLE 3. - Interconnecting hardware

Type	Interconnects from section radio system to--	Manufacturer	Availability
MCM (telephone to radio).	MCM telephone system......	Collins Radio...	Soon.
Tone remote-control adapter.	Dedicated phone line......	Motorola........	Do.
Trolley phone/radio coupler.	Trolley-phone system......	Collins Radio...	Prototype.
Carrier phone/UHF repeater interface	Face machine carrier phones.	FMC/Gaitronics/ Motorola.	Special design.

For mines that have a Collins MCM telephone system, an interconnect will soon be available, allowing selective interfacing between section radios and the wired phone system. Figure 22 shows a diagram of a section radio system interconnected with a minewide MCM communication system by means of a Collins interconnect. Calling the section radios from an off-section phone is accomplished by dialing an assigned number. Initiating calls from a section portable radio can be accomplished in either of two ways: by transmitting carrier bursts from a radio three times in quick succession, or by transmitting a switched-on tone from a radio having that capability.

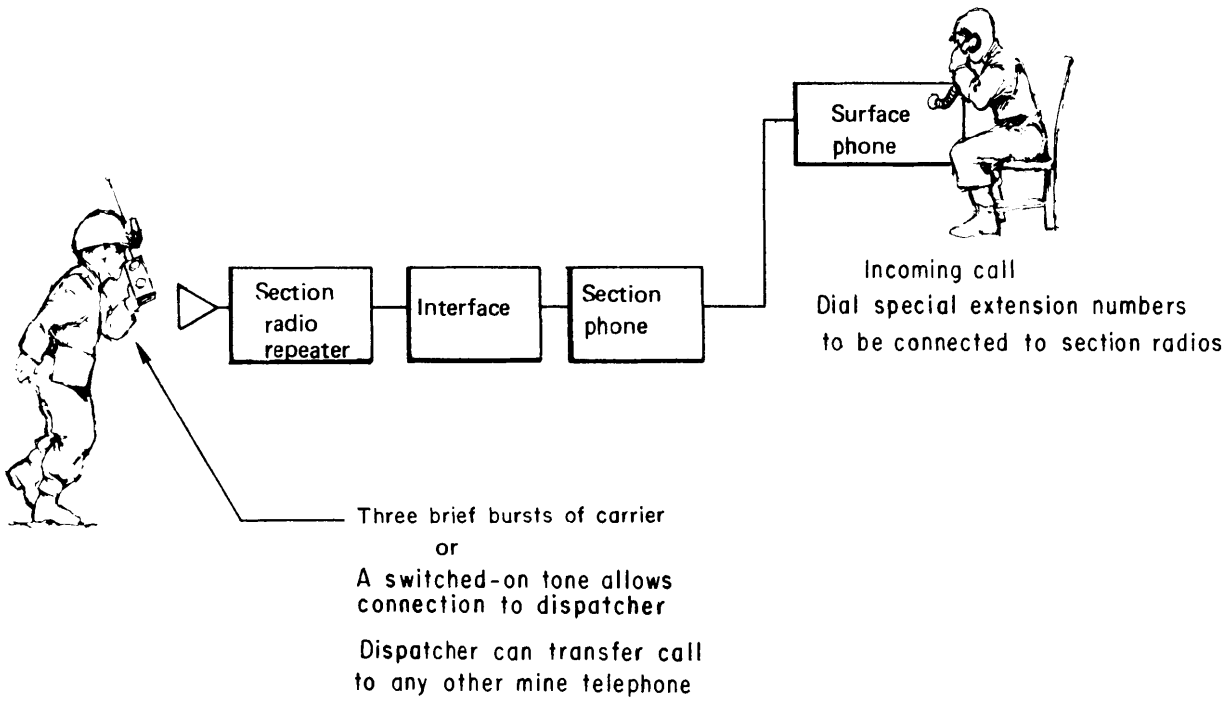

FIGURE 22. - Interconnect between section radio and MCM telephone system.

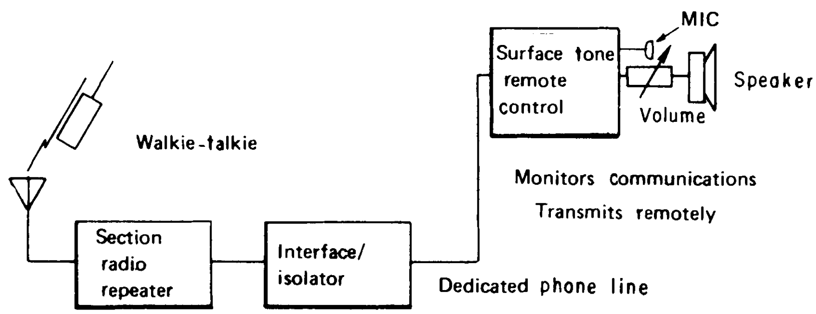

FIGURE 23. - Interconnect between surface station and section radio.

MESA approval is pending on a tone remote-control interface made by Motorola that allows operation of a section radio repeater from a remote location such as a mine office. Figure 23 is a block diagram showing a surface station-to-section radio interconnect. In this system, which requires a dedicated (single-purpose) phone line, section radio communication can be continuously monitored over the remote speaker. If someone wants to call into the section from the surface, the repeater transmitter can be keyed remotely from the surface station, and messages spoken into the remote microphone will be heard on the section radios. The system is expandable using the single dedicated phone line.

LICENSES AND APPROVALS

Federal law requires a license to operate radio equipment of the type reported herein. It is issued for a period of 5 years by the Federal Communications Commission (FCC). The ultrahigh-frequency spectrum is relatively uncrowded, and frequency allocation is no problem, except possibly in heavily populated urban areas. Nevertheless, one can expect that it may take up to 9 months to obtain a license from FCC. Radio equipment suppliers assist their customers in filing the necessary forms, and they can also furnish important information regarding this matter.

Portable two-way radio equipment, bearing MESA approval for use in mines, is available from several manufacturers as listed in table 4. Competent repair facilities, both factory authorized and independent, are located in larger towns. Most mines in the United States are located within at least 50 miles of such facilities.

TABLE 4. - Manufacturers of MESA-approved portable two-way radios

Manufacturer	Frequency range	Type of battery[1]	Portable repeater hardware available
Harris RF Communications Rochester, N.Y.	VHF, UHF	R, N	Yes
Motorola Communications and Electronics Ft. Lauderdale, Fla.	VHF, UHF	R, N	Yes[2]
RCA Corp. (Communication Systems) Meadowlands, Pa.	VHF, UHF	N	No
Standard Communications Wilmington, Calif.	VHF, UHF	R, N	Yes

[1]R--Rechargeable; N--Nonrechargeable.
[2]MESA-approved version.

The State of Pennsylvania, Department of Environmental Resources, Office of Deep Mine Safety, requires special approval on electrical equipment used in Pennsylvania mines. For this reason, mine operators in Pennsylvania should determine, before purchasing, that any radio equipment destined for use underground is approved both by MESA and the State.

DISCUSSION AND RECOMMENDATIONS

Initial resistance to the use of radios by section workers can be expected. A gradual phasing-in period is suggested. When full implementation is in effect, using the radios will be second nature to them.

When communicating with a machine operator, it is usually preferable to keep the radio gear off the man when possible. This constraint spurred the development of the special interface and the repeater control box for the bridge carriers at Splashdam mine.

It is difficult to equip a continuous-miner operator. He not only works in a dusty environment and has to wear a respirator, but he also requires both hands to operate his machine. The special accessory developed for the continuous-miner operator at Splashdam mine is satisfactory for this application, but other avenues are being explored with the expectation that an improved accessory will soon be developed.

Hardhat and headset accessories are generally not comfortable for a miner to wear. However, when a miner is required to communicate in a noisy environment, these accessories are the only choice, unless a machine-mounted loud speaker interface can be provided.

Although the HT 220-type radios used at some of the reported installations are fairly rugged and appear to require minimal maintenance, newer, MESA-approved portable radios (the MX 300 type), which are smaller and lighter, are now available and recommended over the HT type.

If a radio system is installed at a mine, it is imperative that a responsible individual be designated to take care of the radios. His responsibilities should include simple maintenance chores such as cleaning and basic testing to determine operational status of individual units. He would issue the radios on a checkout basis and see that they are returned. He would also send radios to authorized shops when necessary for repair or periodic performance tests.

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TRAPPED-MINER LOCATION AND COMMUNICATION SYSTEMS

by

H. Kenneth Sacks[1]

ABSTRACT

The history of coal mine disasters has established a need for a simple, reliable system for locating and communicating with miners trapped underground. Such a system will not only increase the chances of success rescue, but will also reduce the risks to the rescue team. The Bureau has developed such a system by using several principles of electromagnetic theory. The Bureau is presently testing the system for performance (transmission capability through a variety of overburdens) and reliability (ruggedness of use in mine environments).

INTRODUCTION

The most feared occurrence in underground coal mining is an explosion of gas or coal dust. In the period 1911-69, about 6,000 miners have been killed in 290 major disasters involving explosions. The immediate concern after each such incident is whether there are survivors and, if so, how they can be rescued. To this end, both mining companies and Government agencies have encouraged and financed the development of rescue teams and equipment. Specifically, as a result of a study performed by the National Academy of Engineers, the Bureau of Mines has been developing systems for locating and communicating with workers trapped underground. Such systems will contribute to the overall safety of the underground coal miner.

The Need To Locate

The problems facing rescue teams have been well documented in a number of historical surveys of mine disasters. Searching a mine after a fire or explosion is a slow and often dangerous job. The 13-man rescue party killed following the Scotia mine disaster is an example. Besides the inherent dangers involved, the rescue team must first decide where to begin its search. The area to be searched may be large. After an explosion, miners who manage to escape can direct rescue teams to those parts of the mine where others may remain trapped. The nature of the mine workings and the circumstances of the explosion can also be used in locating survivors, but all of these techniques are based on guess work. Accurate knowledge of the location of trapped men cannot only increase their chances for survival, but can reduce the hazards to the rescue team that might conduct an unnecessary, futile search in dangerous areas.

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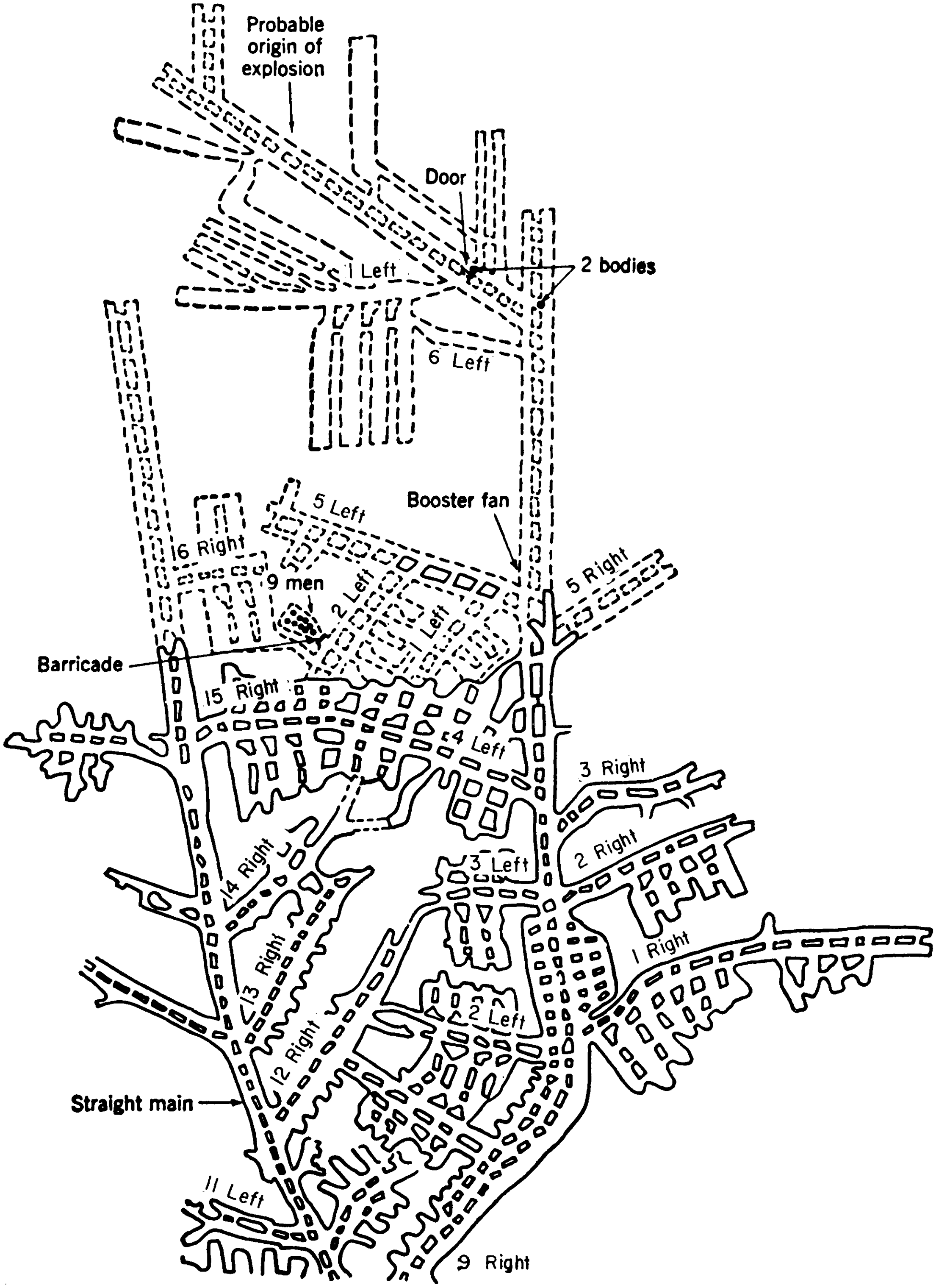

FIGURE 1. - Part of Belva mine showing area to which miners retreated and erected imperfect barricade.

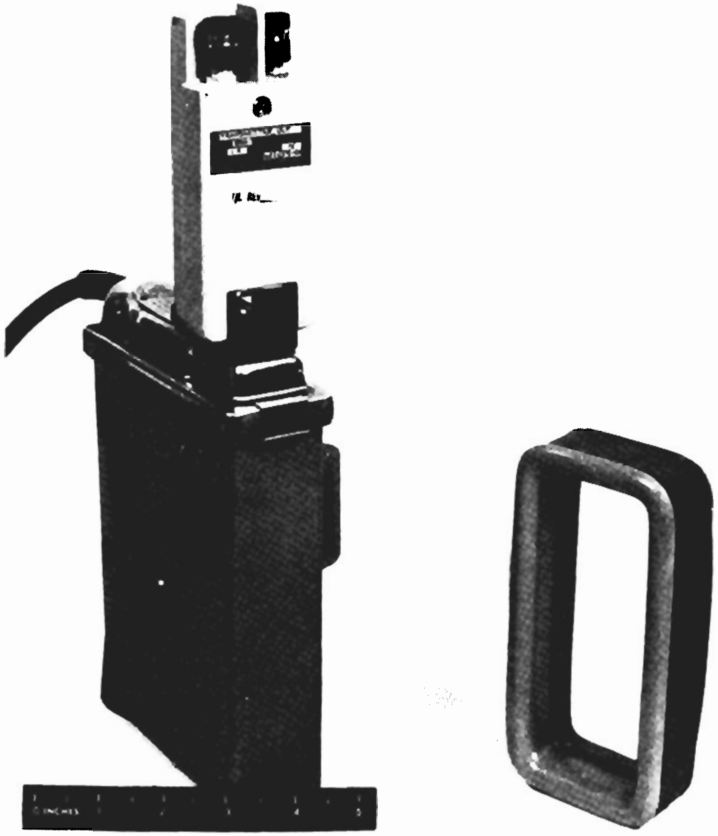

FIGURE 2. - Underground miner-carried ultralow-frequency (ULF) EM transmitter for signaling surface rescue crew.

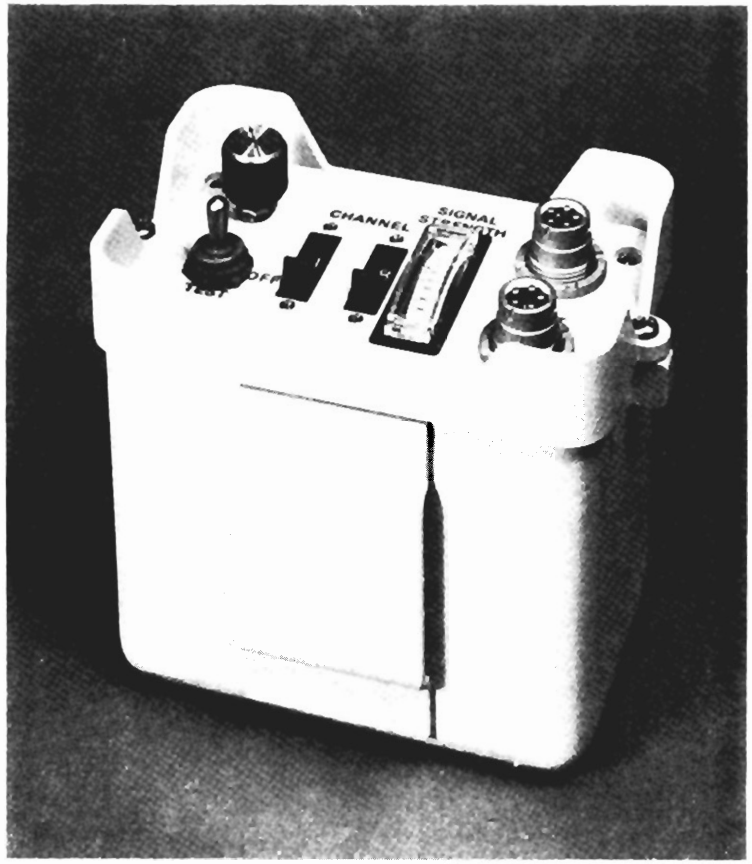

FIGURE 3. - ULF EM receiver used to detect and locate ULF EM transmitter.

The electromagnetic system relies on a small transmitter (fig. 2) that can be carried by the miner, and surface receivers (fig. 3) that "listen" for the signals broadcast through-the-earth or through-the-mine workings by the miner's transmitter. Basic development is completed, and prototype hardware is in the testing phase.

The EM system offers numerous advantages over the seismic equipment. For example,

1. The EM transmitter operates continuously once deployed and will function for at least 24 hours from one caplamp battery. Besides operating continuously, its electrical signal is a known rhythmic "beep," which is much easier to detect than the random thumps of a miner pounding on the ribs or roof.

2. The detection receiver, which can be readily carried by one miner (fig. 4) and can be used to cover a reasonably large area. It can also be used by underground rescue teams since it is permissible. A version of the surface receiver has been adapted for use in helicopters (fig. 5). With this unit, large areas can be scanned quickly. Once a signal is detected, miner-carried units can obtain an exact fix.

FIGURE 4. - Portable ULF EM receiver and loop antenna in use at a simulated mine disaster.

The surface gear of the seismic system, on the other hand, is complex and stationary. Its deployment site must be carefully selected. If it is not within 2,000 feet of the signal source, it probably will not work. In a large mine, this limitation is a serious handicap. In mountainous terrain, setting up the seismic geophones can present difficult problems as well.

3. A prototype model of the original underground miner-carried transmitter has been converted to receive voice messages from the surface (fig. 6). This capability is not available with the seismic system.

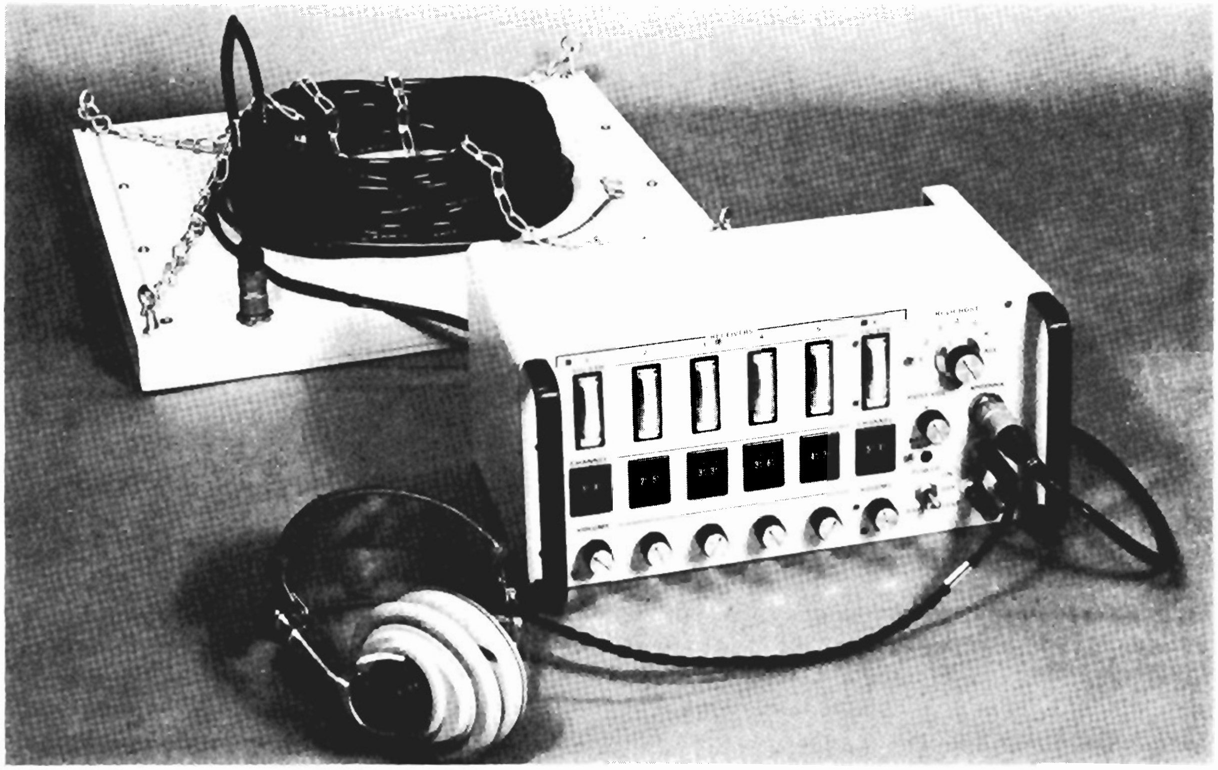

FIGURE 5. - ULF EM receiver and antenna for use by helicopter to scan large area rapidly.

Operation of Underground EM Equipment

The trapped-miner transmitter (fig. 2) weighs one-half pound and can be worn by a miner; a second version has been built (fig. 7) that is encased with a caplamp battery. In an emergency, and when it is decided that all routes of escape are closed, the transmitter unit is opened up. It contains 90 feet of 16-gage wire. This is uncoiled, laid out in as large a loop as possible, and connected to the transmitter. The transmitter is then attached to the battery (fig. 8). The transmitter and loop antenna produce a magnetic field (fig. 9) much like a bar magnet. The direction of these signal-field lines can be used to pinpoint the location of the underground loop antenna. By measurements taken on the surface, the surface location above the antenna can be determined within 50 feet. The signal is a short 1,000-hertz tone transmitted once a second to make it readily distinguishable from the background electrical noise. The unit will continue to transmit for at least 24 hours. When operating, the signal can penetrate as much as 1,000 feet of overburden and be detected on the surface.

Several prototype transmitter units being tested also contain a voice receiver, which allows rescue crew voice transmissions to be heard, and a special button for sending a continuous tone rather than an intermittent beep. In this manner, once contact with the surface is made, the miner can relay information to the surface using a simple code, like one long for NO, and two longs for YES. However, even if this feature is not used, the transmitted

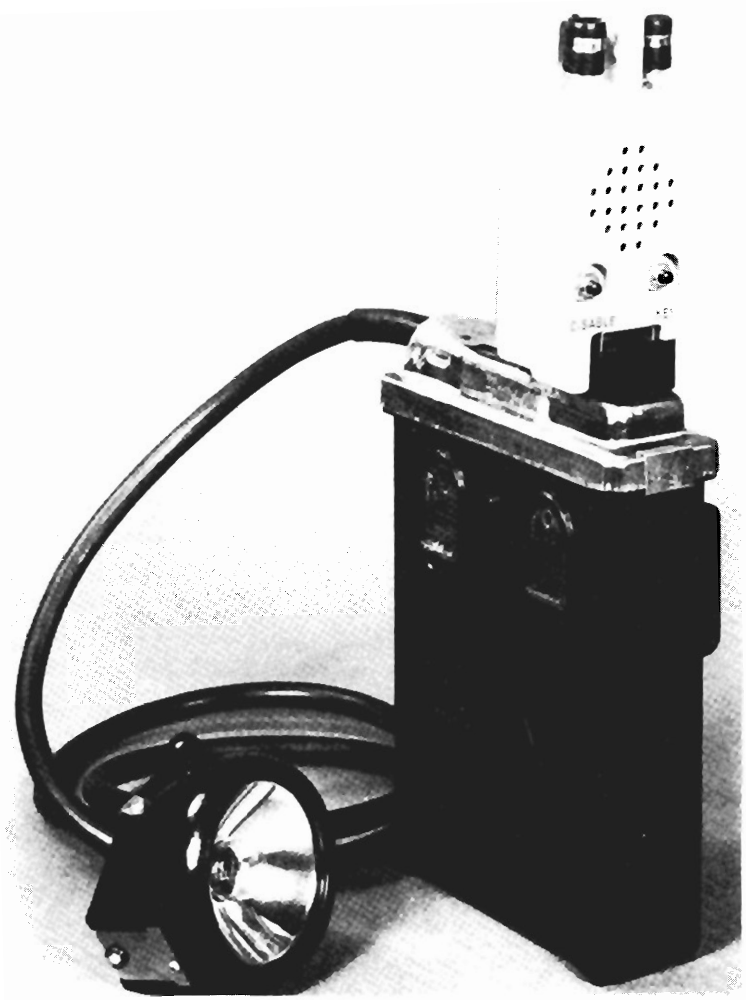

FIGURE 6. - Prototype miner-carried ULF EM transceiver for receiving voice from surface.

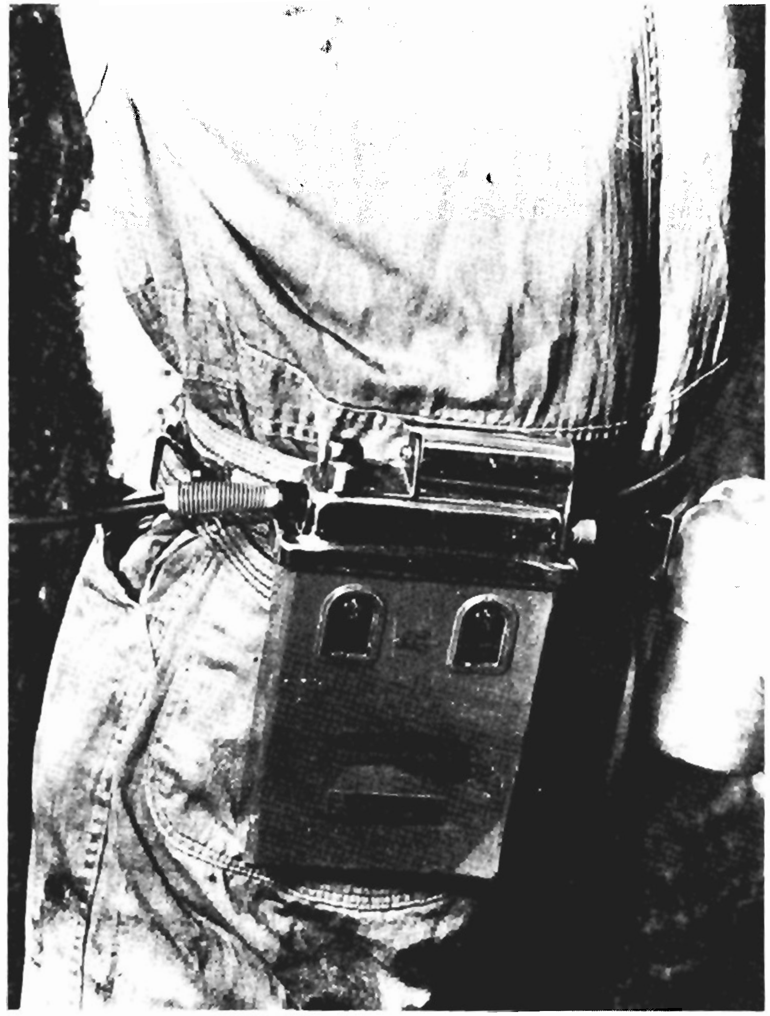

FIGURE 7. - ULF EM transmitter packaged in top of miner's cap-lamp battery.

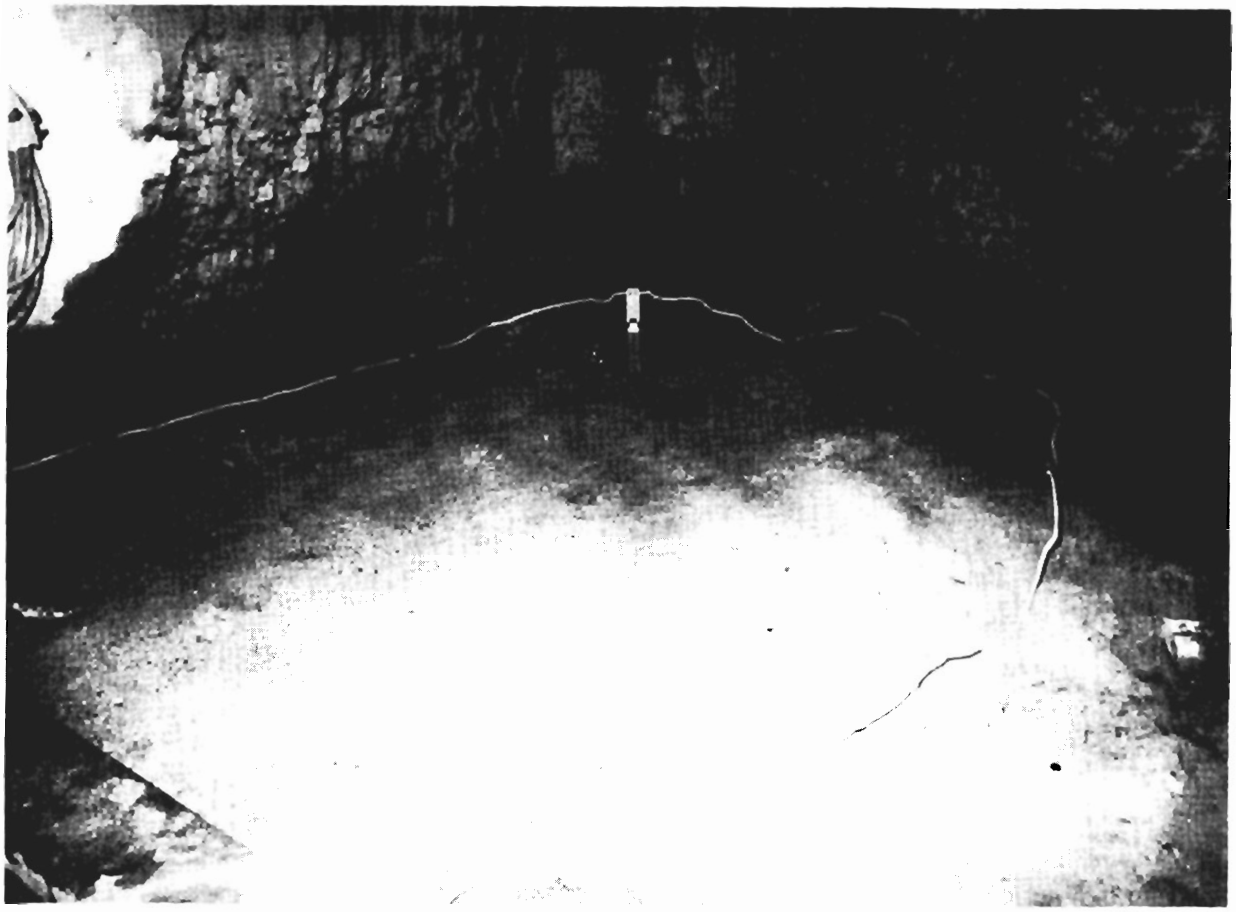

FIGURE 8. - ULF EM transmitter connected to cap-lamp battery and loop antenna.

signal will allow the surface crew to fix the transmitter location as previously discussed.

Operation of Surface EM Equipment

The surface equipment consists of

1. A helicopter receiver (figs. 3, 10) for surveying a large area rapidly.

2. Miner-carried receivers (fig. 4) for accurately locating the underground transmitter unit.

3. Voice transmission equipment (fig. 11) for establishing two-way communications with the trapped miners.

For a large mine, a helicopter would be used to scan the large surface search area above the mine workings. The helicopter-based equipment is not designed to pinpoint the exact location of an underground transmitter, but rather to

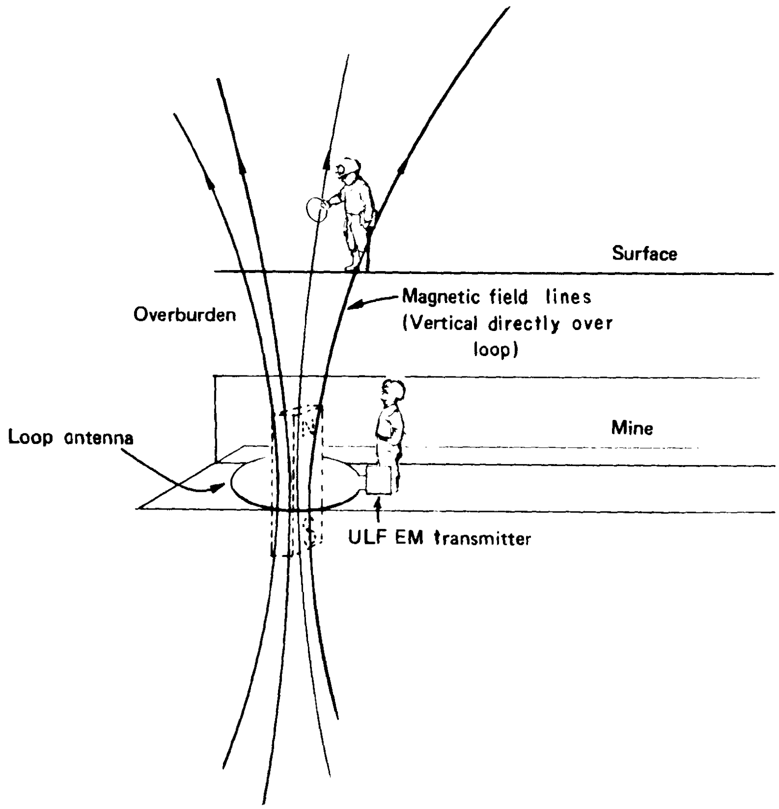

FIGURE 9. - Magnetic field produced by the ULF EM transmitter. As shown, the field lines resemble those of a simple bar magnet so that directly over the antenna, the field is vertical.

detect whether any trapped miner EM signal is present. Each underground transmitter is designed to operate on one of several fixed-frequency channels to prevent nearby transmitters from interfering with one another. Therefore, the helicopter receiver has been designed to listen simultaneously to six different "channels." Once a signal is detected, the pilot can radio his approximate position and indicate the channel detected to the surface rescue crew.

The surface crew miner-carried receiver uses a simple loop antenna (fig. 4). Pinpointing the location of the trapped miner EM signal is similar to radio direction finding. The received signal is heard as a chirp every second, and is also shown as a meter reading. If the loop is turned to give the lowest signal, the plane of the loop will point in the direction of the signal source. By repeating this procedure at several positions around the approximate transmitter location, the true location of the underground transmitter can be found. Using this information in conjunction with a mine map, the rescue team can then determine the best approach.

When a signal is detected by the surface crew, the voice transmitter can be set up. This is really a large version of the underground transmitter consisting of a loop of wire 300 feet in diameter and a powerful audio amplifier. This equipment would only be used if the miners were known to have units containing voice receivers.

Detailed information on the performance, construction, and theory of this equipment can be found in the bibliography.

FIGURE 10. - Operation of the helicopter ULF EM receiver during field trials.

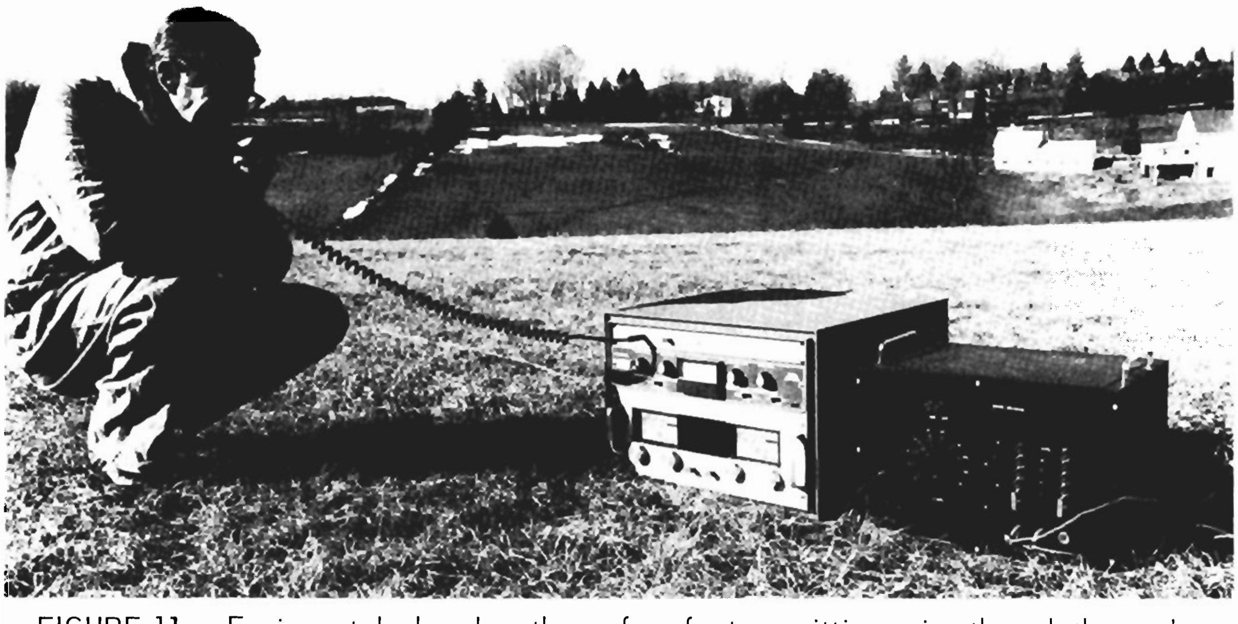

FIGURE 11. - Equipment deployed on the surface for transmitting voice through the earth to trapped miners.

EXPERIMENTAL RESULTS

The Bureau has tested the hardware previously described at a number of mines having different overburden depths. In a simulated disaster at United States Steel's Robena mine (fig. 12) near Waynesburg, Pa., three transmitters were hidden from the searchers. Within 4 hours, an area of several square miles was scanned and the three transmitters were located. A voice transmission was also successfully received by the "trapped miners" through the 480 feet of overburden.

Other location experiments have been successfully carried out in coal mines as deep as 1,500 feet, and voice transmissions have also been received through 700 feet of overburden. Refinements in equipment should improve this performance.

FIGURE 12. - Airborne helicopter ULF EM receiver searching area over Robena No. 1 mine for trapped-miner EM signals.

OUTLOOK FOR THE FUTURE

The success of the EM system depends on a number of factors, including the local electrical resistivity of the earth, overburden depth, manmade and natural electrical noise at the site, and the presence of metal cables or buildings. To better understand how these factors vary for U.S. coal mines, the Bureau is presently conducting an EM survey at 100 coal mines. This survey will give a good picture of the likely performance of our present system for the wide variety of overburdens found in U.S. coalfields. The hardware will also be tested in several mines over a long period of time to see if it meets the necessary requirements of ruggedness and reliability. The outcome of these programs will clearly determine the strengths and weaknesses of the present system and indicate the future course of the trapped-miner program.

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[2] Open File Reports are available for consultation at the Bureau of Mines libraries in Pittsburgh, Pa., Denver, Colo., Twin Cities, Minn., and Morgantown, W. Va., and at the Central Library, U.S. Department of the Interior, Washington, D.C.
Items with NTIS/PB numbers are available from the National Technical Information Service, Springfield, Va. 22161; please mention the PB number when ordering.

LONGWALL MINING COMMUNICATIONS

by

Robert A. Bradburn[1] and John D. Foulkes[2]

ABSTRACT

The Bureau of Mines investigated the communication needs associated with longwall mining. The program had the following objectives:

1. Survey currently available communication equipment.

2. Review practices in European mines.

3. Determine problem areas requiring further research.

4. Develop guidelines.

5. Make recommendations for improved equipment design.

Certain problem areas associated with the use of pager phones have been isolated,and a set of design requirements for improved longwall pager phones has been prepared. Some European equipment that fulfills these requirements has also been identified.

Enhancement of a longwall communication system by the inclusion of UHF walkie-talkie radios is outlined, along with special techniques necessary to make that type of radio usable on the longwalls. Truly wireless radio for the longwall is considered achievable at special lower frequencies, and suitable hardware may be forthcoming.

The study resulted in three crucial recommendations pertaining to long-wall communications:

1. Improve communication in advance of longer term automation.

2. Pursue a variety of approaches for improved face communication.

3. Consider using European equipment.

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INTRODUCTION

Robinson Run mine near Shinnston, W. Va., has two longwall sections among several room-and-pillar working sections. Late in January 1976, 23 employees working on one of the longwall sections produced 12,395 tons of coal over a 24-hour period, a world record. Although longwall machines are common in Europe, there are only about 80 longwall systems in operation in the United States, and they mine less than 5 percent of the Nation's coal production. Virtually all of the equipment is imported, and it represents a minimum capital investment of $1 to $2 million per installation. In actuality, longwall mining presently plays a small, but specialized, role in the overall picture of U.S. underground coal mining.

In spite of these somewhat unimpressive statistics, the Federal Bureau of Mines and the U.S. mining industry are paying close attention to longwall mining. The reasons for this are threefold:

1. There is general agreement that, because of its potential for high productivity (cited previously), this mining technique will grow rapidly.

2. U.S. manufacturers are beginning to produce their own equipment, and this should reduce lead times currently needed to acquire longwall machinery and spare parts from overseas.

3. Longwall mining is becoming increasingly automated, and it is a technique that lends itself to automation.

Starting about 2 years ago, the Bureau of Mines began to investigate the communication needs and equipment associated with longwall mining. The program included a study of voice communication, both intraface and minewide, communication for control purposes, and monitoring. The Bureau learned that the three types of communication are closely interrelated in longwall mining to the extent that most European equipment integrates all of them into a single system. For example, if monitoring equipment detects a machine fault, the machine stops automatically.

The Bureau program had the following five objectives:

1. Survey communication needs and the equipment currently available to meet them.

2. Review European practices, experience, and equipment, since longwall mining is the dominant form of underground coal mining in Europe.

3. Determine the problem areas, if any, that would require further research and development.

4. Develop guidelines for design, installation, and maintenance of longwall communication systems.

5. Make recommendations in regard to new equipment design and advanced research and development.

Communication is a key and integral factor of any mining process. It is so vital, in fact, that it is clear that equipment manufacturers should include communication as an integral part of the overall longwall system design. This paper will concentrate on the voice communication aspects of longwall mining.

DESCRIPTION OF LONGWALL MINING TECHNIQUE

An understanding of the mechanics of longwall mining is essential for an appreciation of telecommunication needs. The longwall mining technique uses roof supports to enable an entire block of coal (as large as 5,000 by 600 feet) to be removed. In the United States, head and tail entries are first driven to the rear of the panel (fig. 1), and then the longwall retreats, thereby removing the entire seam between the head and tail entries.

Each longwall system installation must be custom built for the seam it is to mine. The upper portion of figure 2 shows one of the basic "building blocks" of the system, the so-called roof support, which includes hydraulic rams that allow the roof plates to be individually raised and lowered. A number of roof supports are placed next to each other (as shown in the lower portion of figure 2), to provide cover for the miners operating the mining machine. The machinery on the left is placed against the coal face. It consists of a plow or a shearer mining machine used to remove the coal and a chain conveyor for haulage.

The coal is removed from the face by using either a plow (fig. 3) or a shearer. The plow is a bidirectional cutting and loading machine which typically moves at speeds of 3 to 4 ft/sec along the face; it is pulled or driven by a chain, and takes shallow cuts a few inches deep under the control of the headgate operator; that is, an operator located on the fresh-air side of the longwall. The plows are usually the preferred longwall machine in very low coal. Figure 4 shows a Belgian miner remotely controlling the movement of a plow; figure 5 is a plan view of plow machine installations.

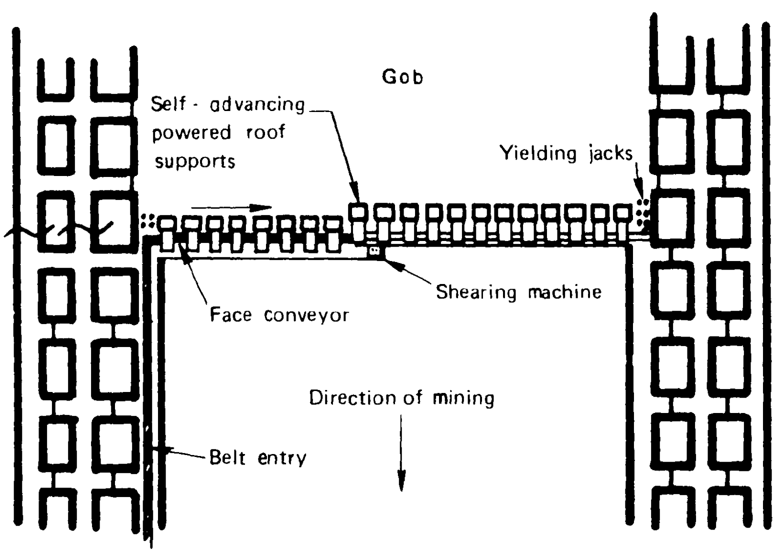


FIGURE 1. - Plan of longwall section.

The shearers are much bulkier machines than plows, and are impractical for use in very low coal because of tight

After a disaster, it has been found that workers trapped underground usually construct barricades to protect themselves from dangerous gases. In the years between 1909 and 1946, records show that in 43 coal mine disasters, barricades were employed. Out of 2,844 miners involved, 1,768 miners were killed outright and 1,076 barricaded themselves. Of these, 869 were eventually rescued through the efforts of rescue and recovery teams, and the remaining 207 died. The length of confinement ranged from 1 hour to 20 days, as in the Cherry mine disaster in 1909 when 259 men were killed in a mine fire. Twenty others saved themselves by barricading and were rescued after 7 days.

The problems of finding miners trapped underground can be illustrated by the Belva mine incident of December 26, 1945, in which 24 men were killed by an explosion. Figure 1 shows the location where nine men barricaded themselves for 53 hours in that particular incident. Rescue crews tried for 2 days to reach the active area of the mine in 5- and 6-Lefts while being hampered by caved workings, fires, smoke, gas, and loose roof. Late on December 28 while exploring 9-Right, they found footprints. After investigating, they found a chalk-marked board indicating that five men were in 4-Left entry. In 5-Left, another market was found directing searchers to second Left off of 5-Left. Seven of the nine men survived the ordeal. All might have lived if a better barricade had been constructed, or had they been reached sooner.

The time required to rescue barricaded miners is critical. In the recorded cases of barricading, 75 percent of the survivors were rescued within 10 hours.

Need for Voice Communication

The value of voice communication is not readily documented; however, any information that could be exchanged between the trapped miners and the rescuers during a rescue effort would be advantageous. Such information as unusual conditions known to the miners trapped or medical advice for them to follow until aid arrived are two examples. In other words, a system that would provide the location of trapped miners and permit communication with them would increase the probability of their rescue and reduce hazards to the rescue and recovery team.

DESCRIPTION OF SYSTEMS

Electromagnetic and Seismic Systems

The Bureau has developed two systems for locating and communicating with trapped miners: a seismic system and an electromagnetic (EM) system. The seismic system relies on detection of minute ground vibrations resulting from a miner(s) banging on the roof or ribs with some heavy object found in the mine. This system is essentially operational and is being tested at numerous mine sites.

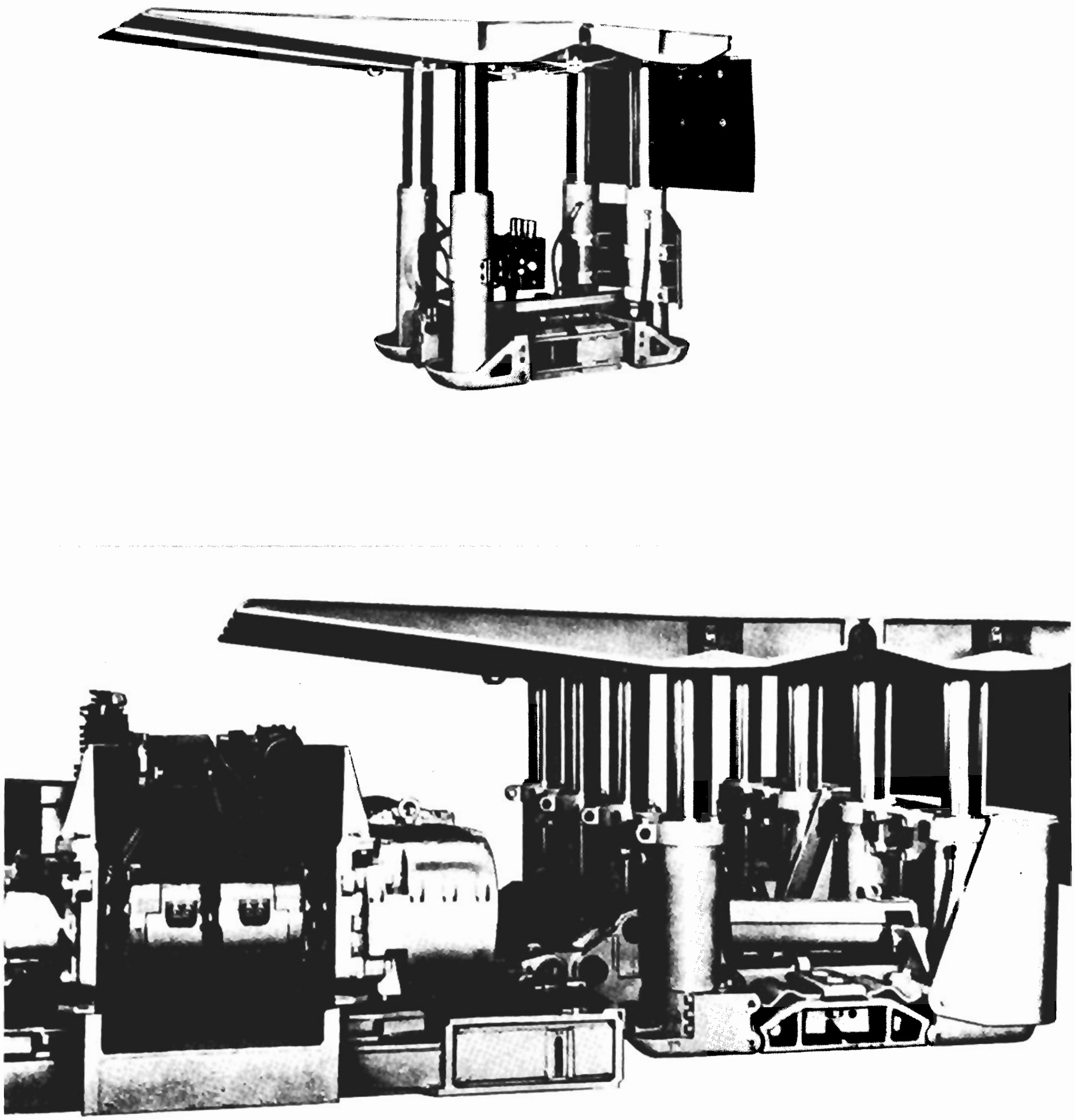


FIGURE 2. - Hydraulic roof-support equipment and chain conveyors for longwall faces.

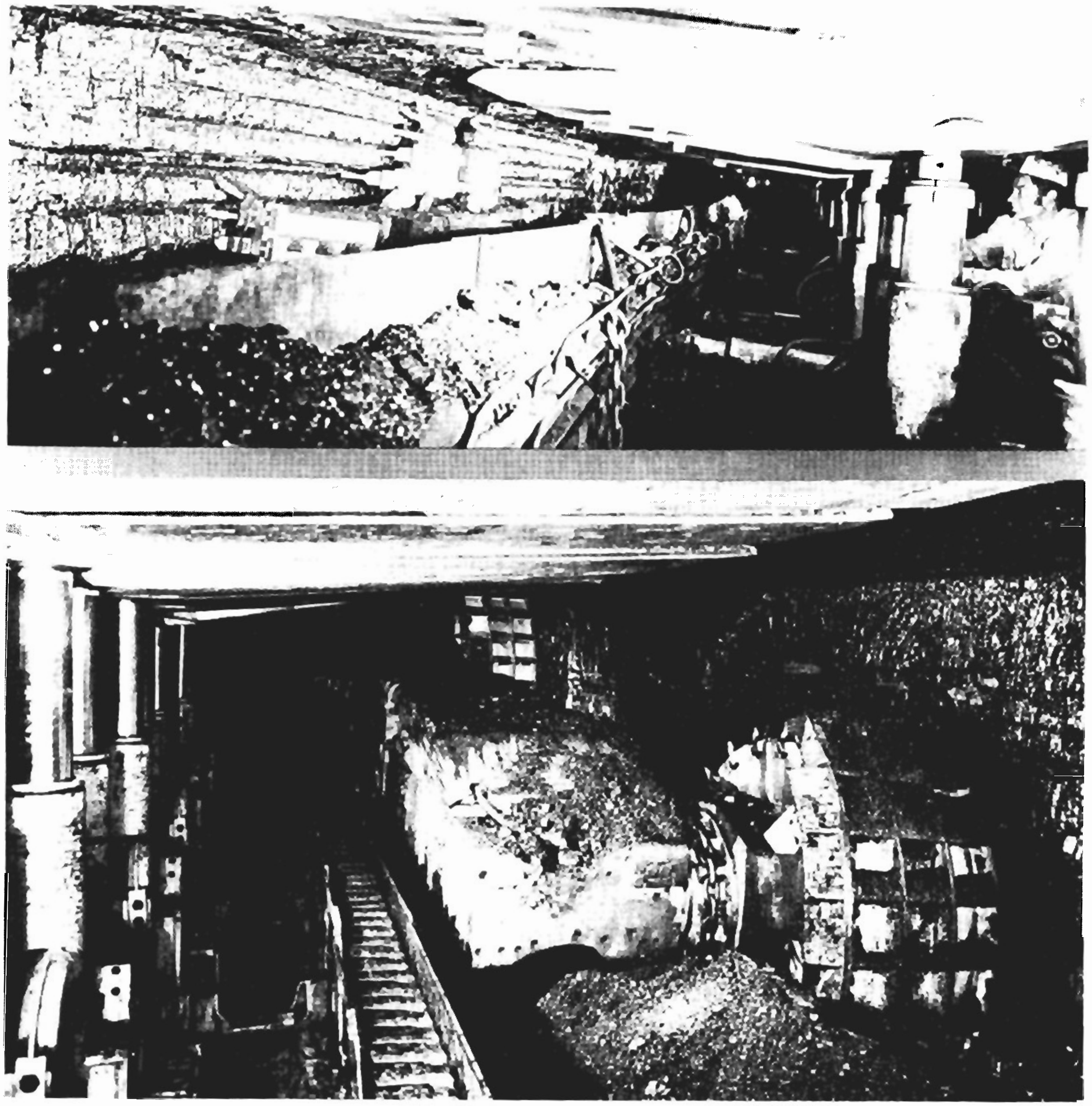


FIGURE 3. - Coal being removed from face by plow (top) and shearer (bottom).

clearances and dust problems. However, shearers may be selected in preference to plows where there are hard inclusions in the coal seam, or when roof conditions are difficult. The shearer usually rides on the conveyor and requires an effective guidance system to avoid damage to the pan line and to prevent derailment. As the shearer moves along the face, cutting typically to a depth of 2 feet, it is controlled by traveling operators. In Europe, the shearers are radio-remote-controlled to reduce the exposure of operators to dust and enable them to work from a more effective vantage point. In the United States, the use of radio remote control is still under investigation.

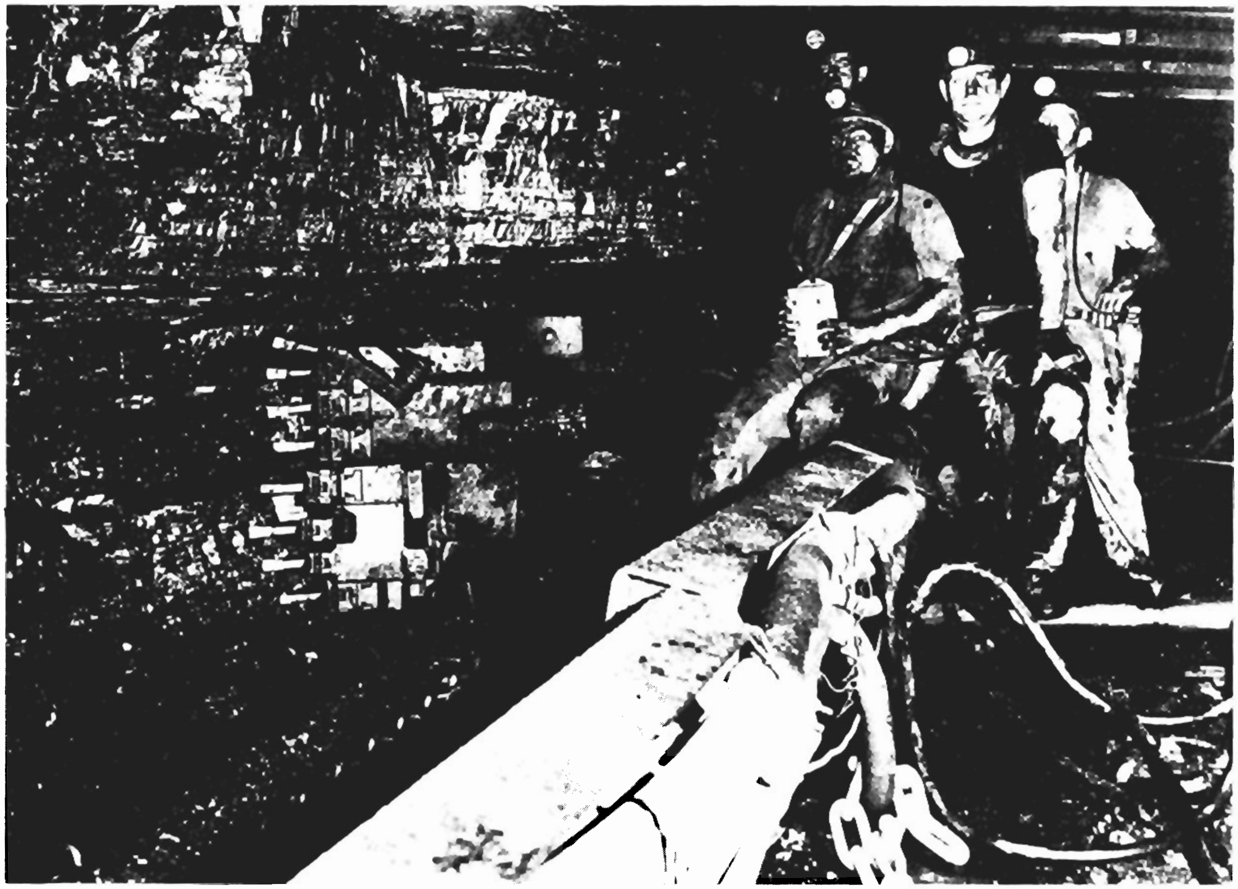


FIGURE 4. - Belgian miner controlling movement of plow by remote control.

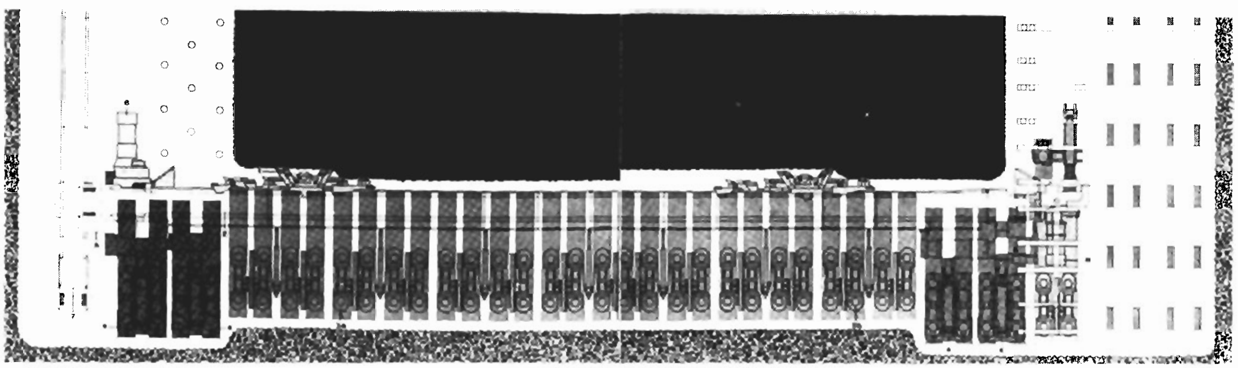


FIGURE 5. - Plan view of plow-machine installations.

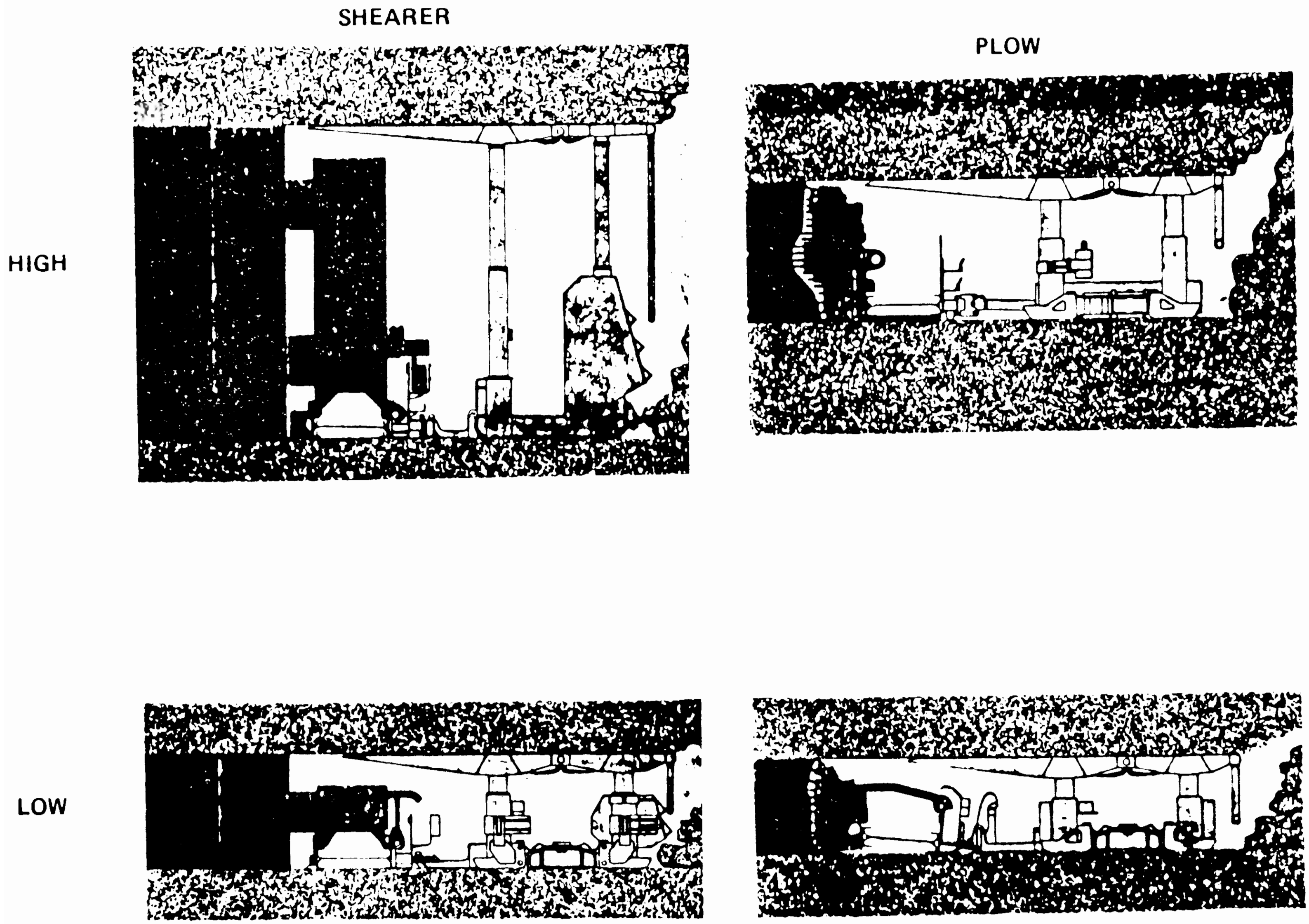


FIGURE 6. - Cross-sectional views of shearer and plow equipment installed on longwalls in high and low coal.

Figure 6 (cross-sectional views of the equipment) shows how shearer and plow equipment is installed in high and low coal. After a few feet of the coal face has been removed, the roof supports are moved forward, one at a time, by lowering the roof plates and operating a hydraulic ram to pull the unit forward. Figure 7 shows a typical longwall site. Here again, communication equipment that allows longwall mining to be done remotely is an important factor being investigated.

FIGURE 7. - A typical longwall operation.

VOICE COMMUNICATION ON LONGWALLS

Requirements

A representative longwall face crew might be comprised of a foreman, two shearer operators, three chock advance miners, one or two mechanics, and headgate operator, and one miner at the tailgate. Voice communication is frequently required between the headgate and tailgate and to the section foreman, wherever he is located.

Figure 8 typifies the conditions encountered in longwall mining. Since the miners must work under rather crowded conditions, starting and stopping the conveyor and mining machines are particularly crucial operations when it is essential that everyone on the face knows what is happening. During maintenance operations, frequent interchange of information between miners working at various points along the face is typical. With improved communication channels, the capability of describing and locating problems and coordinating maintenance efforts reduces downtime--and downtime is critical in longwall productivity.

Figure 9, a longwall installation in low coal, dramatically illustrates the limited working space in longwall mining. The area consists of a long lateral tunnel in which equipment may be easily damaged. Moreover, it is fatiguing to travel any appreciable distance to get to pager phones placed along the face, and the noise background is high. Therefore, a pager phone designed specifically for longwall mining applications should meet the following requirements:

1. Minimum size.

2. Rugged case.

3. Direct acoustic energy along the face.

4. Rugged cable and connector design to survive in a harsh environment.

5. Sufficient power to permit operation along the maximum length of the longwall.

6. Certain control and signaling features that can be incorporated into the pager phone system.

7. Speakers protected from blasting damage.

Pager Phones

U.S. longwall faces commonly use standard U.S. pager phones as a means of intraface communication, but the U.S. pager phones do not provide an adequate face communication system. Major problems are as follows:

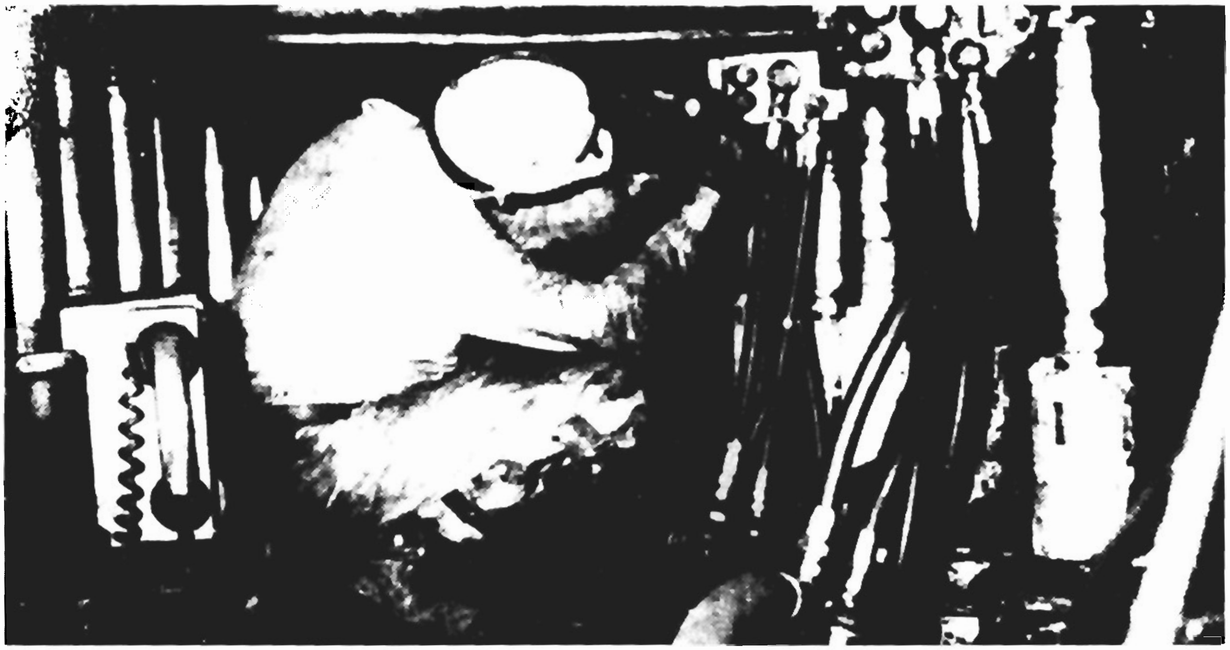


FIGURE 8. - Typical conditions encountered in longwall mining.

FIGURE 9. - Difficult working environment found in longwall mining.

1. The phones and cables are easily damaged due to close quarters and severe environment.

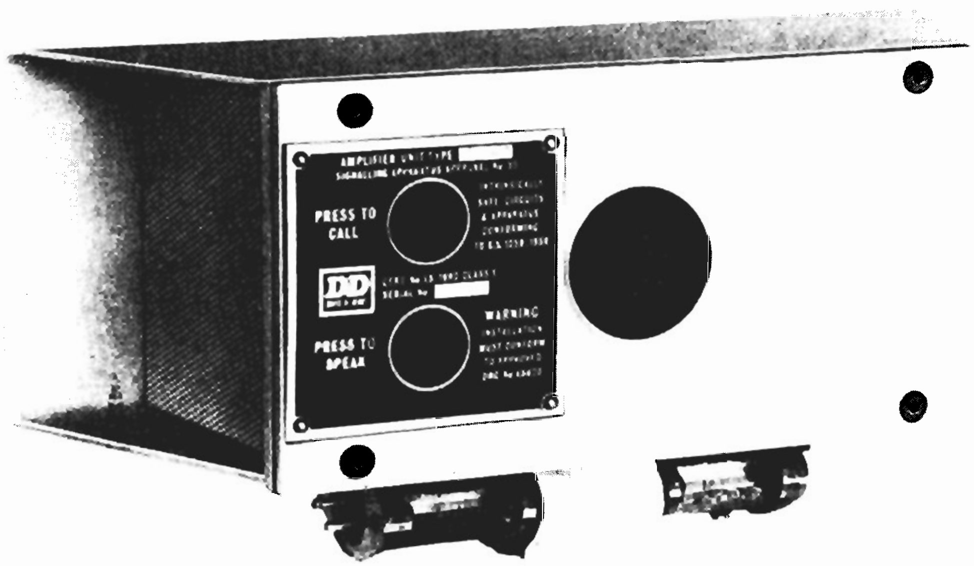
2. Miners on the face have to travel 50 to 100 feet to use phones; sometimes phones can survive only at the headgate or tailgate, which is marginally acceptable on a short face, say 250 feet, but unsatisfactory on faces as long as 400 feet; in contrast, phones are placed 40 to 50 feet apart in West Germany.

3. The conveyor creates a high-noise environment, and shearer noise often makes it impossible for shearer operators to hear a page.

4. Communication, of course, takes place laterally along the face, and U.S. pager phones direct acoustic energy perpendicular to this direction, and this mounting also makes them sensitive to blasting.

The small size of the U.S. market means that no U.S. manufacturer is likely to launch a program to develop an improved pager-phone system that satisfies the listed requirements.

Several European systems, however, are available that do meet them. Representative of these is the British Sivad[3] system, which is marketed in this country. Figure 10 shows the Sivad pager phone, which has already been installed in a few U.S. longwalls and is reportedly well accepted. Figure 11 shows the Sivad main control unit, which is installed at the headgate. Other European systems suitably rugged for the longwall environment are the German



Amplifier Unit Type 15840

FIGURE 10. - British Sivad pager phone.

[3] The use of company names is for informational purposes only and does not imply endorsement by the Bureau of Mines.

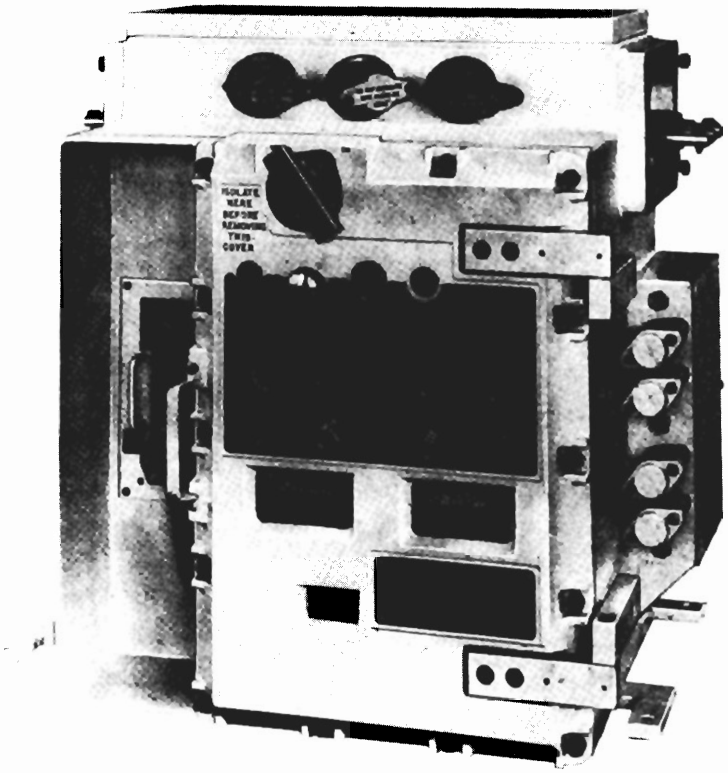


FIGURE 11. - Sivad system main control unit.

Funke and Huster pager phone and the French Phonilec system. These two systems, however, have not been marketed in the United States but, hopefully, will be available in the future. Some of the features of European longwall pager phone systems are pull-wire signaling, machinery lock-out buttons, prestart warning, fault detectors (in some cases) which stop the machinery, blast-proof design, and a central power supply at the headgate with standby batteries in the individual phone units.

For the potential U.S. user, there are, of course, problems associated with this equipment. The first is expense. A 10-phone system incorporating all of the desired features may cost around $25,000. A 10-phone system with voice-only capabilities might cost only about $6,000 to $7,000, but this is still at least twice as much as a U.S. pager phone system. Secondly, there are a limited number of suppliers. Thirdly, a mine may have to either carry its own inventory, or expect long lead times in getting spare parts. Finally, in-house maintenance skills have to be developed. However, given the high cost of a longwall system (on the order of $1 to $2 million), a proper understanding of the value of a good pager phone system in reducing downtime indicates that solutions to these problems are worth considering.

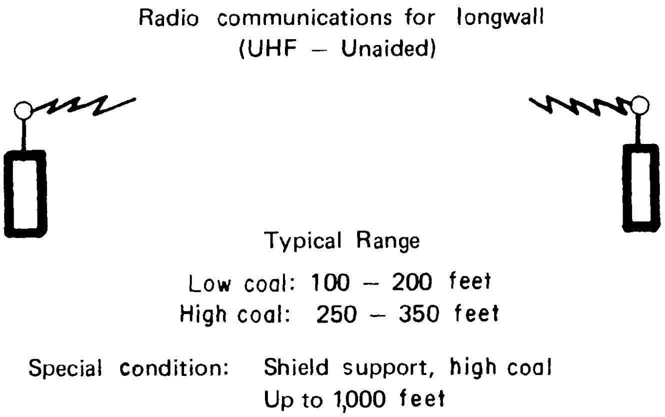


FIGURE 12. - Typical ranges found in longwall UHF radio communications.

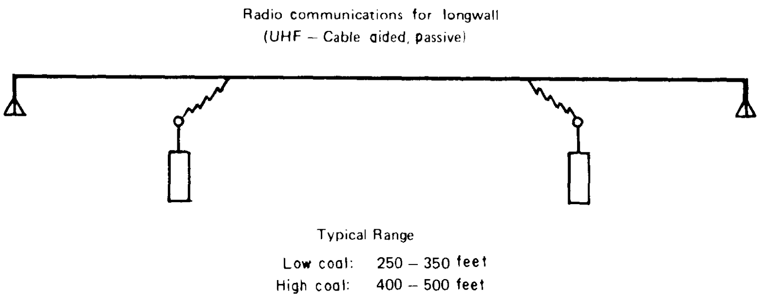


FIGURE 13. - Enhancement of UHF radio communication range using leaky-feeder coaxial cable.

UHF Radio Equipment

Within the scope of the Bureau's program, the feasibility of using two-way portable radio equipment was investigated. Ideally, all the miners on the longwall face would carry small, light, walkie-talkies, making wireless communication possible to any part of the face area, and, to a limited extent, down the head entry. The Bureau has conducted several experiments using UHF radios for this purpose. In these experiments, 2-watt, mine-permissible, portable walkie-talkies were used. As shown in figure 12, when the units are used by themselves, effective communication is limited in low coal to a distance ranging from 100 to 200 feet, and in high coal from 250 to 350 feet. (Under some special conditions, such as a shield support system in very high coal, the range is good for about 1,000 feet.) These distances can be increased if a leaky feeder coaxial cable is strung along the face and terminated with antennas (fig. 13). A passive cable of this type assists transmission and increases the communication distance to 250-350 feet in low coal and 400-500 feet in high coal.

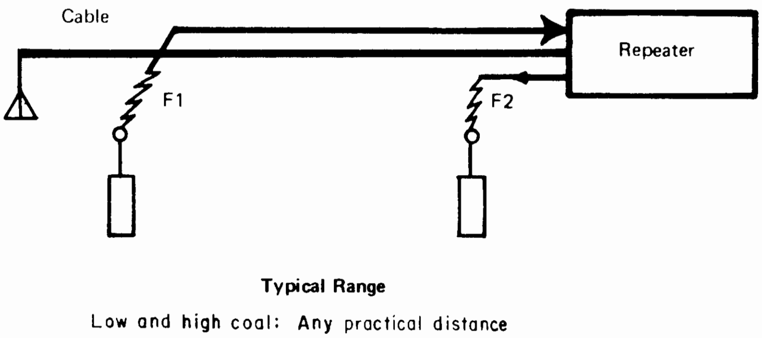


FIGURE 14. - Enhancement of radio communication range by using repeater and leaky-feeder coaxial cable.

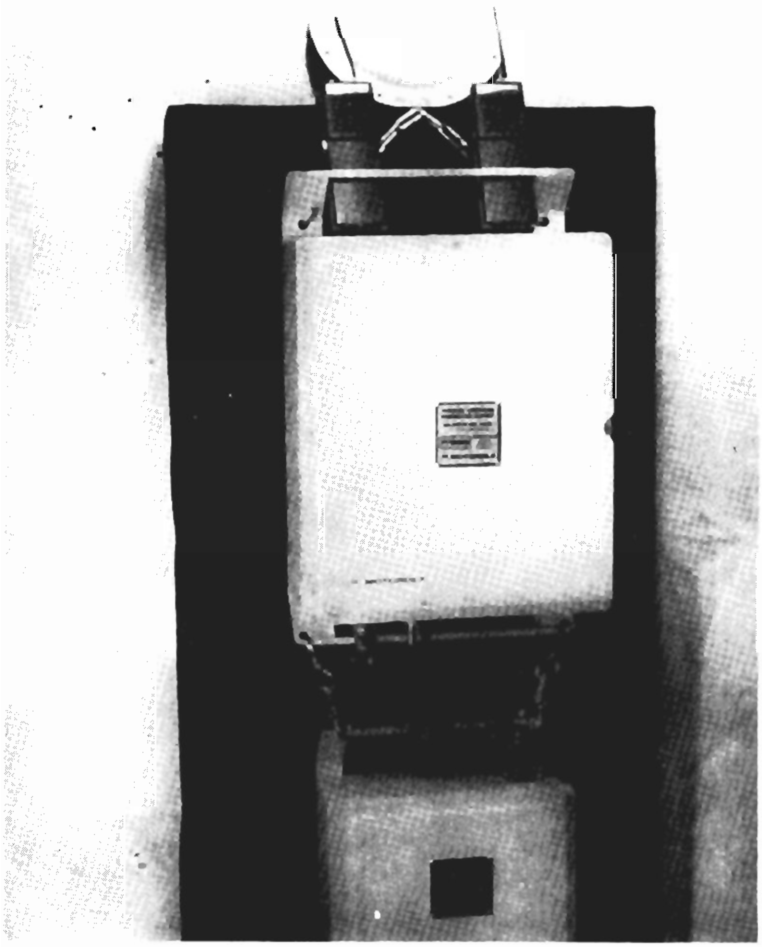


FIGURE 15. - MESA-approved Motorola UHF repeater and battery pack with "hardhat" antenna and HT 220 walkie-talkies.

Transmission can be further enhanced by adding a repeater to the cable at the headgate and terminating it in an antenna at the tailgate (fig. 14). For this application, a MESA-approved, battery-operated, radio repeater is marketed by Motorola (fig. 15). By using the repeater and cable, communication can be established over any practical distance for both high and low coal.

Some MESA-approved portable UHF radio equipment is shown in figure 16. An older type walkie-talkie is shown in contrast to the newer, more compact types. Figure 17 shows several types of antennas that can be used to terminate the leaky-feeder cable. A special cable, known as RADIAX, is marketed by Andrews Corp. for leaky-feeder applications. The Bureau of Mines has also experienced success in using less expensive RG8/U cable, which has the advantage of mechanical flexibility. This type cable, however, is not recommended for passive systems, but only those using a repeater. Other forms of leaky-feeder cables have been developed in Europe.

One of the disadvantages of the standard walkie-talkie is that it requires at least one hand to operate it, and some longwall miners require both hands free to operate their equipment. Figure 18 shows a

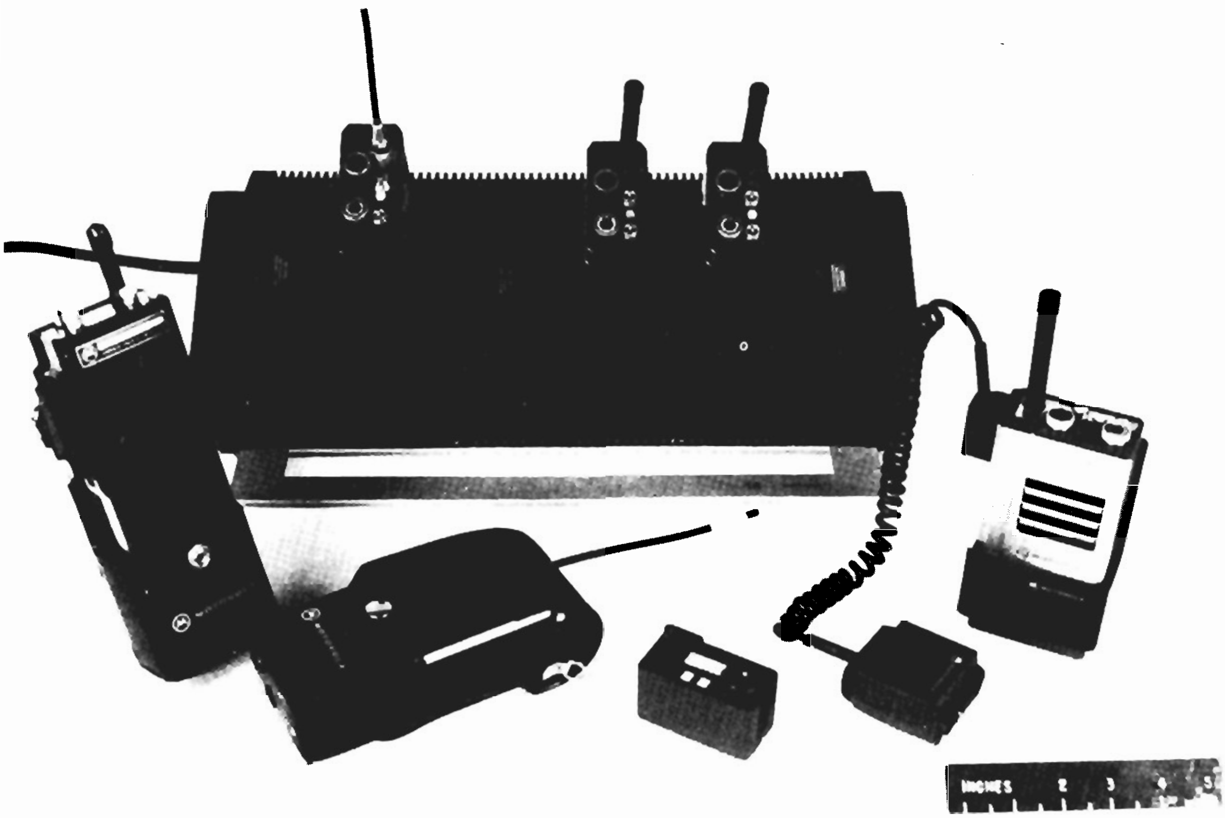


FIGURE 16. - MESA-approved portable UHF radio equipment and accessories.

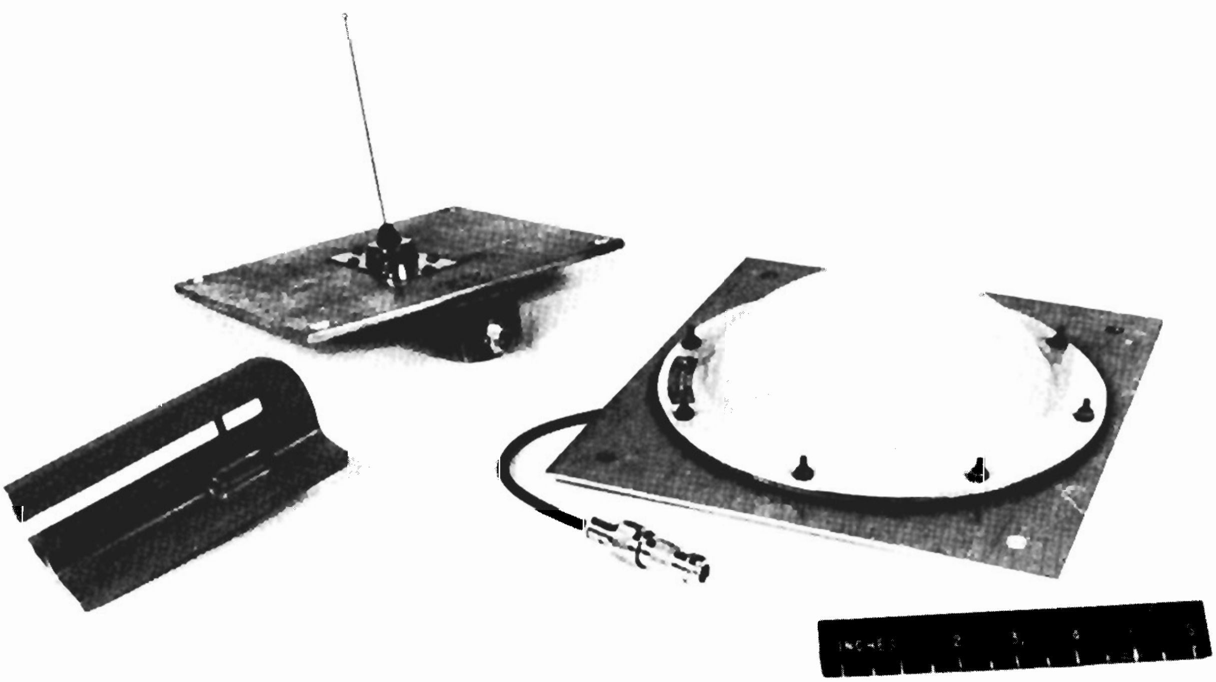


FIGURE 17. - Three types of UHF antennas used to terminate leaky-feeder cable.

FIGURE 18. - Chest-mounted UHF radio offers "hands-free" operation.

chest-mounted radio in an experimental interface, designed by the Bureau, which provides "hands-free" operation. The push-to-transmit switch is actuated by movements of the miner's elbow.

Low- and Medium-Frequency Radio

A limited number of experiments have been carried out using low or medium frequency as opposed to UHF radios. The advantage of these frequencies is that both theory and experiment tend to show that they can provide truly wireless communication along the longwall face. The problem, of course, is the lack of commercially available equipment that is sufficiently small and rugged for the mine environment.

Figure 19 shows a Japanese low-frequency inductive radio that was tried, with limited success, on a low-coal longwall section. The Lee Engineering Division of Consolidation Coal Co. has recently developed a medium-frequency radio that may have promise as a useful longwall communication aid (fig. 20).

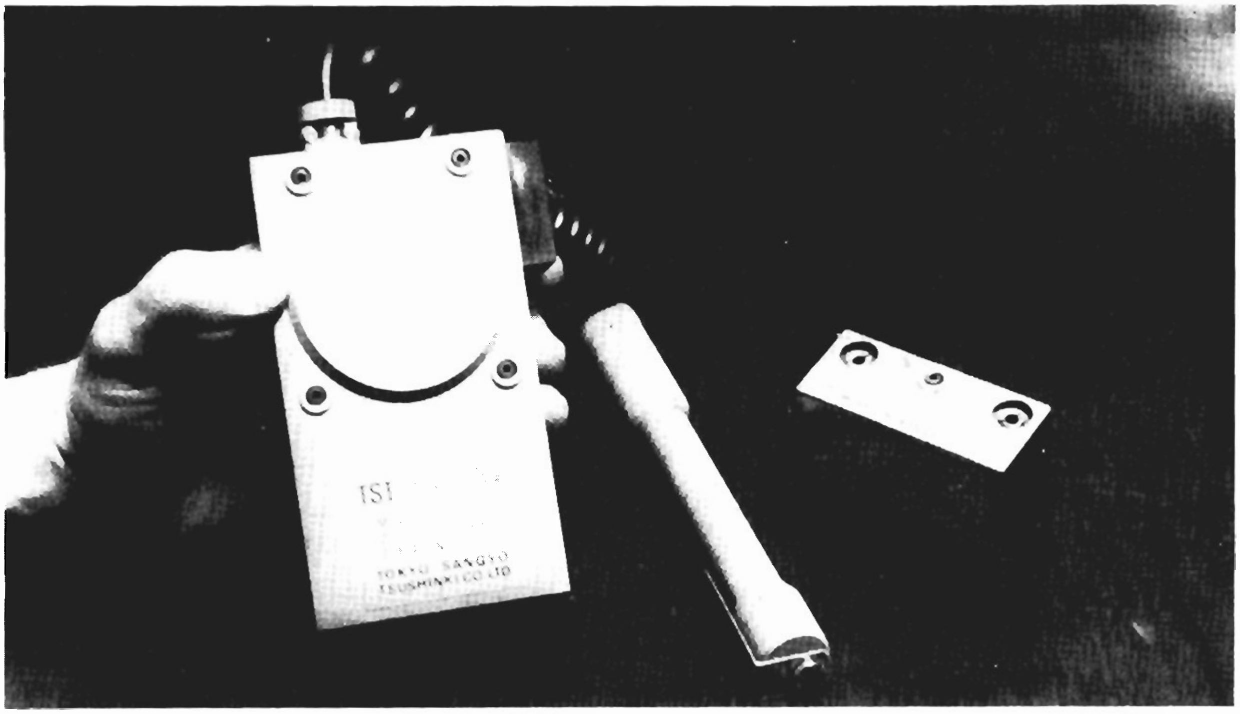


FIGURE 19. - Low-frequency radio manufactured by Japanese firm.

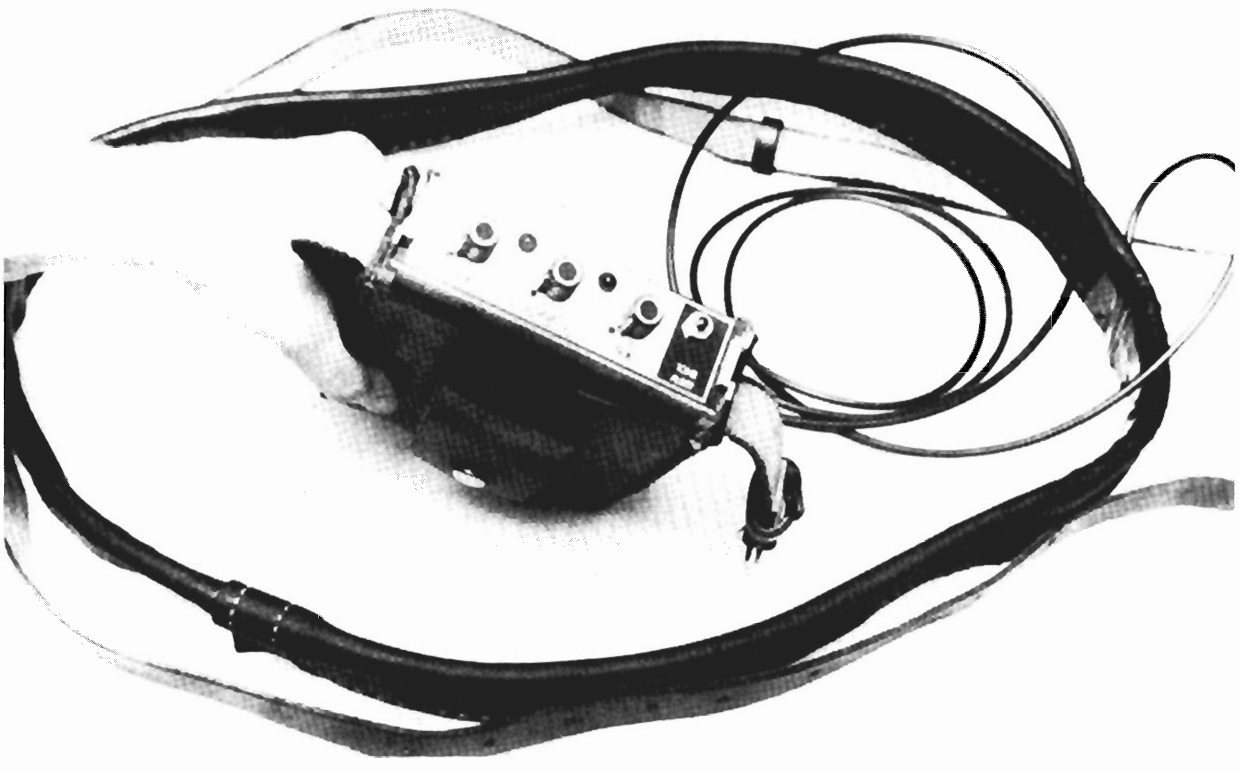


FIGURE 20. - Medium-frequency radio and antenna developed by Lee Engineering.

RECOMMENDATIONS

Effective communication is an integral and vital part of the longwall mining process. As a result of this study, it is believed that four important recommendations can be made. The first is that equipment manufacturers should include communications equipment as an integral part of the design of the overall longwall installation. The second is that a variety of alternatives to the face communication system can and should be considered for meeting the needs of specific longwall installations because no single type of system is suited to all situations. These alternatives include the following:

- Rugged pager-phone systems designed specifically for the face environment, and incorporating signaling and control functions, as well as the loud-speaking telephone.

- UHF portable radio operating either wireless or cable-aided.

- Low-frequency/medium-frequency portable wireless radio communication when it becomes available.

The third recommendation is that in spite of the potential problems of dealing with an overseas manufacturer, present and future owners and operators of longwall systems should consider using European equipment. The fourth is that development of improved communication systems and remote control equipment for longwall operations can and should proceed in advance of the longer term projects aimed at achieving substantial automation of longwalls.

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MEDIUM-FREQUENCY MINE WIRELESS RADIO

by

Robert L. Chufo,[1] Robert L. Lagace,[2] and Lawrence R. Wilson[3]

ABSTRACT

The Bureau of Mines is developing a medium-frequency, wireless communications system for use in the working areas and haulageways of U.S. coal mines to satisfy needs not met by present radio equipment. Signal strength measurements taken at several mines to date have shown that the low frequency-medium frequency wireless range attainable in different coal seams can be highly variable, but that the most favorable overall performance occurs in the medium-frequency band of approximately 300 to 1,000 kilohertz.

Two prototype portable medium-frequency radio units and a fixed station radio unit have been designed and fabricated to provide two-way voice communications between roving miners. A range of 1,350 feet in conductor-free areas is the goal. These prototype units are being tested in several mines across the country, in conjunction with a signal-strength measurement program to determine the most favorable operating frequencies and methods of improving the performance and applications of medium-frequency mine wireless radio.

INTRODUCTION

MF mine wireless radio is intended to meet roving miner communication needs similar to those met by UHF section-to-place radio. As described in the paper dealing with UHF section-to-place radio being presented in this seminar session, the miners involved are typically section foremen, maintenance workers, ventilation crews, and machine operators. An effective medium-frequency radio system would answer the following communication needs:

1. Miners working on basic room-and-pillar sections and on sections with special needs, such as longwalls, and sections having full-dimension haulage systems.

2. Miners operating vehicles in mines with trackless and trolleyless haulage (discussed in IC 8744).

3. Members of rescue teams during mine rescue operations, thereby removing the need for inconvenient trailing wires.

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[3]Collins Radio Group, Rockwell International, Cedar Rapids, Iowa.

Present commercially available UHF portable and mobile radio equipment is well suited for satisfying many of these communication needs. However, radio signals in the UHF band suffer from one disadvantage that can sometimes be serious; for example, in cases where it is essential that two miners communicate around more than one corner and through certain kinds of permanent ventilation stoppings. The UHF radio communication range can be severely reduced in either case. This range reduction occurs because UHF radio waves tend to be confined within the boundaries of mine tunnels. Medium-frequency waves, on the other hand, propagate or travel through the coal seam as if the network of mine tunnels were not there.

The underground coal mining industry's extensive and long-standing experience with trolley-wire carrier-phone systems has shown that a mine's electrical wiring, tracks, trolley wires, phone lines, and air lines can be used to carry low-frequency radio signals throughout underground coal mines, even to locations some distance from the trolley wire-rail haulage system. Recently, the Bureau of Mines bought and tested underground some prototype 335-kilohertz portable radios that are manufactured in South Africa. The wireless communication ranges obtained with these units were quite good and, in fact, much greater than originally anticipated from theoretical predictions. However, the tests left some doubt as to whether 335 kilohertz was the most favorable operating frequency in U.S. coal mines. In addition, these particular units showed some size, weight, and supplier disadvantages.

In view of these problem areas, the Bureau of Mines initiated a measurements and hardware development program to resolve these issues and help to develop a medium-frequency unit that would meet the portable wireless communication needs that remained unsatisfied by UHF radio. The program objectives were to determine which operating frequencies in the low- and medium-frequency radio bands are best suited to wireless applications in U.S. room-and-pillar coal operations, to design associated small, lightweight portable equipment for use by the U.S. mining industry, and to achieve a radio range of 1,350 feet without the aid of mine wiring.

DISCUSSION OF EQUIPMENT AND MEASUREMENTS

The medium-frequency wireless program is being pursued simultaneously on two fronts:

1. A prototype hardware development effort, based on the favorable results of an initial set of radio propagation measurements in the Pittsburgh coal seam.

2. A more extensive set of propagation measurements, covering several coal seams, to acquire data on which to base improvements to the prototype hardware.

Medium-Frequency Mine Wireless Radio Hardware

The present prototype medium-frequency mine wireless radio is a single-frequency (520-kilohertz) FM system developed by Collins Radio for the Bureau of Mines. It provides push-to-talk, party-line radio communication in a manner similar to that experienced with mine trolley carrier phones. Such a system allows all miners equipped with portable radios or fixed station units within communication range of the system to talk with one another. These single-frequency, transmit-receive medium-frequency units provide for a simpler design than the two-frequency (one to transmit and another to receive) UHF portable radios discussed in the UHF section-to-place radio paper. On the other hand, the single-frequency design does not lend itself to the use of repeaters to effectively double the range of communication, as is the case with commercially available UHF radios. Thus, it may be desirable eventually to incorporate two-frequency operation into the medium-frequency wireless radios.

Figure 1 shows a miner equipped with a portable medium-frequency radio consisting of a belt-carried transmitter-receiver unit and a bandolier-type, oval-shaped loop antenna. The transmitter-receiver electronics of the prototype portable and fixed station units are identical; the transmitters are capable of generating 20 watts, and the receivers are of conventional superheterodyne, single-conversion design characterized by high sensitivity. All transmitter-receiver electronics are mounted on two printed circuit boards and a an inner chassis contained in the upper compartment of the belt-carried unit. The lower, detachable compartment houses the rechargeable battery and intrinsic safety protection circuitry.

FIGURE 1. - Miner equipped with portable medium-frequency mine wireless radio and loop antenna.

Figure 2 illustrates the size and shape of the oval-loop antenna and the easily accessible controls and connectors located on the top of the portable unit. Included are three connectors: one for the speaker-microphone, one for the antenna, and a third for connecting a battery charger. Thus, the battery may be conveniently charged through a connector without removing the battery compartment.

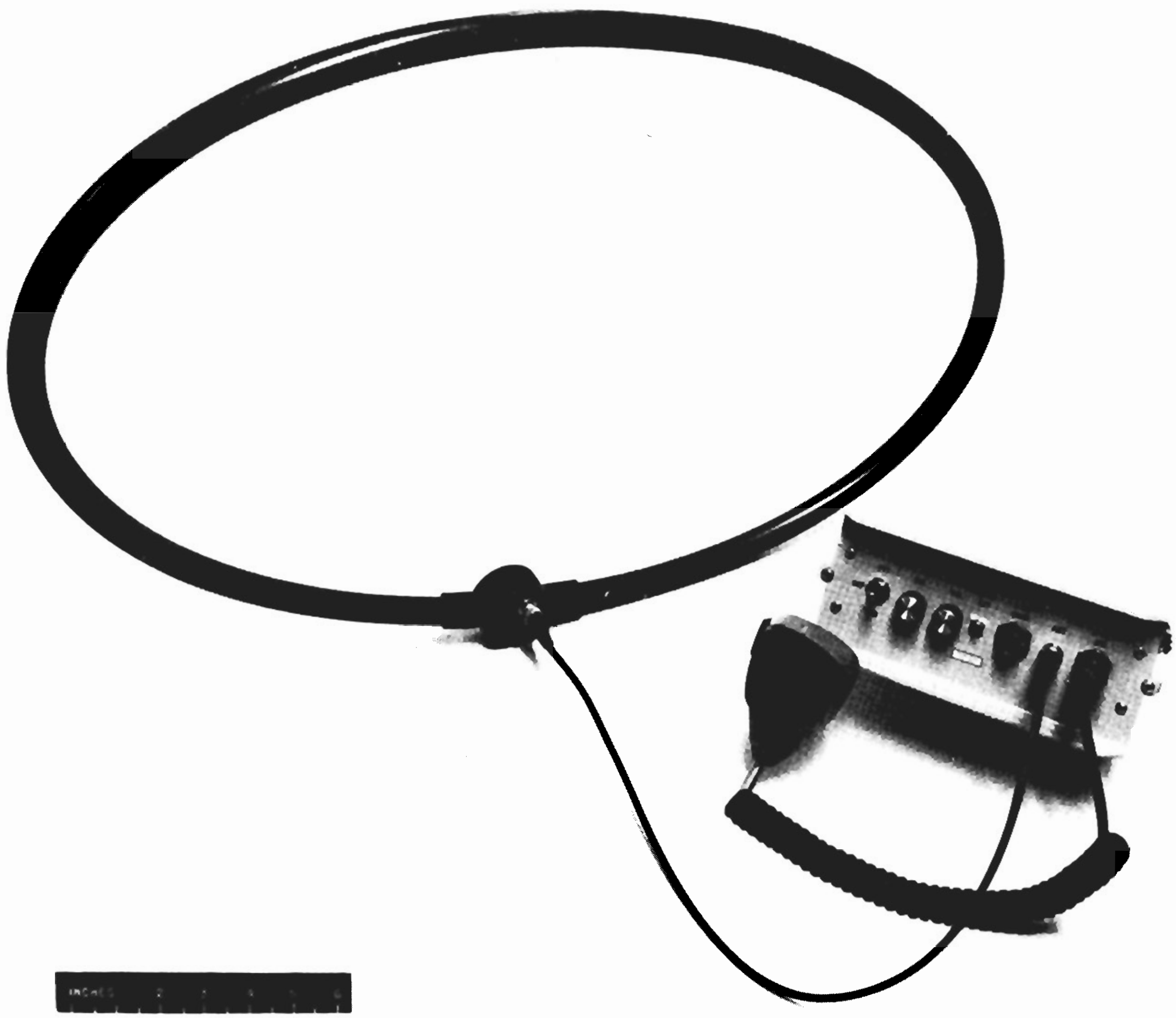

FIGURE 2. - Closeup of portable medium-frequency mine wireless radio and oval-shaped bandolier loop antenna.

The unit has also been designed so that the transmitter-receiver electronics in the upper compartment are not exposed when the battery compartment is removed. Continuous controls for volume and squelch, and a toggle-switch control for push-to-talk (PTT), voice-operated transmission (VOX), and on/off functions are included.

Figure 3 shows a miner using an in-mine fixed-station installation consisting of a transmitter-receiver unit and rib-mounted single-turn rectangularly shaped loop antenna (approximately 6 by 24 feet). Figure 4 is a closeup view of the fixed-station transmitter-receiver unit. The electronics and rechargeable battery are mounted in a heavy-duty, splashproof enclosure that is corrosion-resistant to withstand the mine environment. The loudspeaker provides paging capability to miners near the fixed station and is

FIGURE 3. - Miner using fixed-station medium-frequency mine wireless radio and rib-mounted loop antenna.

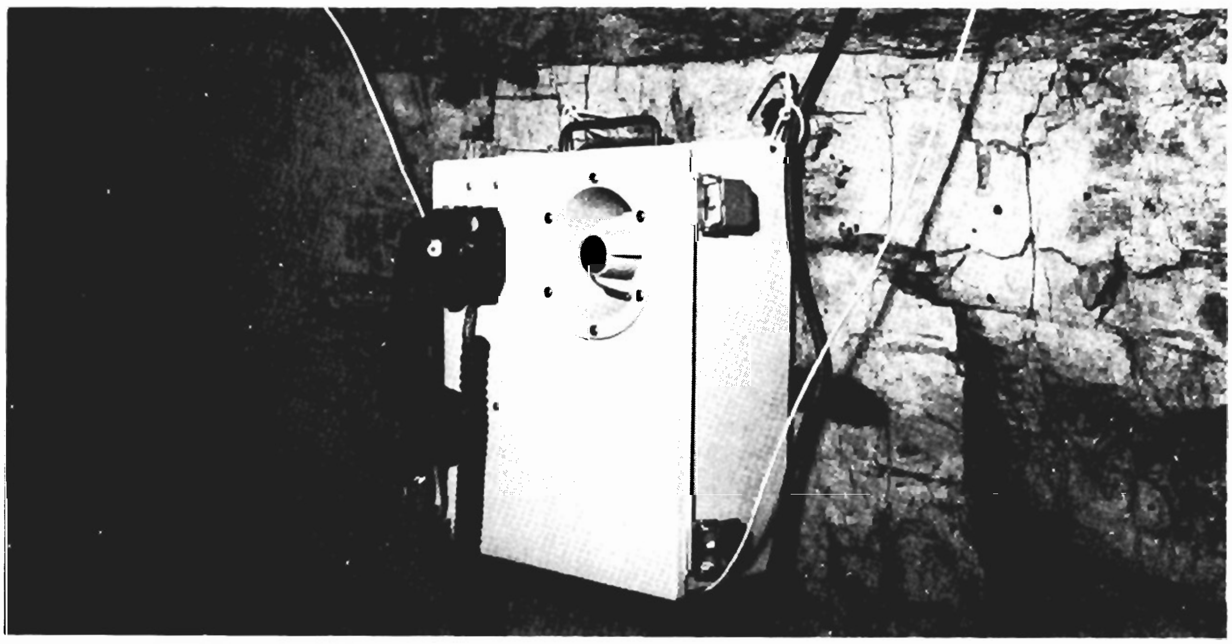

FIGURE 4. - Closeup of fixed-station medium-frequency mine wireless radio.

automatically disabled when the handset is removed from its receptacle to answer or initiate a wireless call. All fixed-station controls are located inside the housing for protection from moisture and mishandling. The transmitter-receiver circuitry and speaker are mounted to the hinged front panel of the housing, providing easy access for testing and maintenance. A battery and a power supply-charger are enclosed in the same housing, and provision is made for connection to the alternating current mine power.

Radio Propagation Measurements

The initial set of comprehensive measurements were made in a conductor-free area of Consolidation Coal's Ireland mine in the Pittsburgh seam. The 60- to 900-kilohertz frequency range in the low-to-medium frequency band was covered. An analysis of the data showed the following:

1. Longer communication ranges than anticipated were achieved (over 1,000 feet).

2. Maximum ranges occurred at higher frequencies than expected (between 300 and 900 kilohertz).

3. Radio waves were not influenced by the presence of the network of tunnels in the coal seam.

4. The waves remained largely "trapped" within the coal seam.

5. The best performance occurred when the planes of the loop antennas of the transmitting and receiving parties were oriented vertically and parallel to each other.

Figure 5 illustrates the preferred antenna orientation in the coal seam waveguide within which the radio waves propagate or travel.

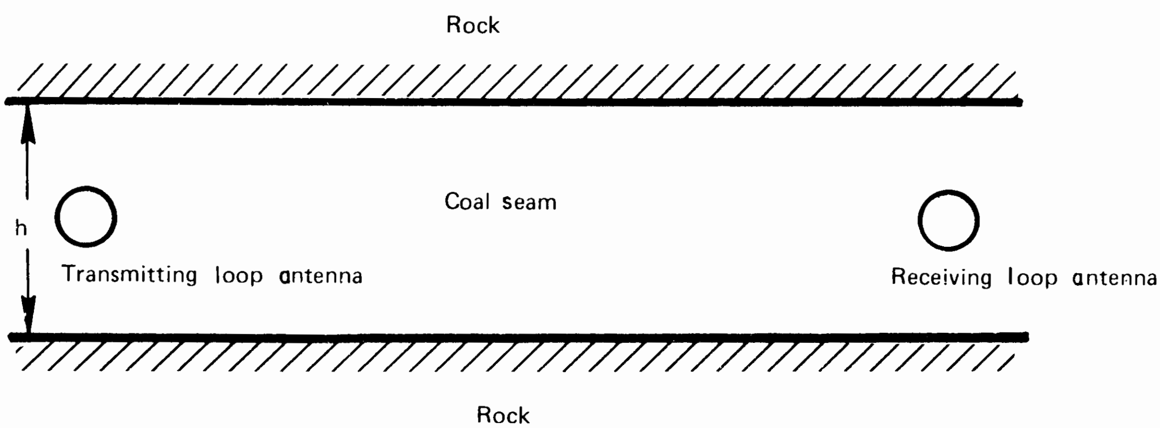

FIGURE 5. - Coal seam waveguide and preferred antenna orientations for medium-frequency mine wireless radio.

The "trapping" occurs mainly because the electrical conductivity of the surrounding rock above and below is much higher than that of the coal. This trapping, together with the very low value of coal seam conductivity at the Ireland mine, is the primary reason for the better-than-anticipated signal propagation results.

The operating frequency of 520 kilohertz for the prototype medium-frequency radio equipment was chosen on the basis of these results, and a previous finding (from comprehensive in-mine noise measurements by the National Bureau of Standards) that mine-generated electrical noise levels generally decrease with increasing frequency. A higher frequency was not selected to avoid the AM broadcast band which starts at 540 kilohertz.

To determine whether the favorable Ireland mine propagation conditions are typical or exceptional for U.S. coal mines, similar propagation measurements are being performed and analyzed for other mines in the Pittsburgh seam and for mines in other major U.S. coal seams. These measurements are expected to provide a firmer foundation on which to base the selection of the most favorable operating frequencies for the MF mine wireless radio equipment, and on which to predict the expected radio performance in different mines.

The need to verify the expected propagation conditions in other mines is illustrated by table 1, which shows the dramatic differences in attainable communication ranges for two widely separated values of coal seam conductivity (σ_{coal}) at selected frequencies in the 10- to 1,000-kilohertz band. The range estimates for $\sigma_{coal} = 1.4 \times 10^{-4}$ mho/m represent the Ireland mine conditions; those for $\sigma_{coal} = 10^{-2}$ mho/m represent a mine with coal conductivity near the high end of the range of values expected for bituminous coals. It is also worth mentioning here that although the quiet-location range estimates are readily applicable to conductor-free areas, the noisy-location range estimates are probably pessimistic. The noisy locations are likely to occur in the vicinity of electrical conductors, which aid signal propagation as well as introduce electrical noise.

TABLE 1. - Range estimates for medium-frequency wireless portable FM radios[1]

Coal conductivity, σ_{coal} (mho/m)	Frequency, kHz	Communication range, feet	
		Quiet locations (receiver noise only)	Noisy locations (mine electrical noise dominating)
CASE I			
1×10^{-2}	10	150	50- 150
1×10^{-2}	100	200	100- 200
1×10^{-2}	1,000	150	75- 125
CASE II			
1.4×10^{-4}	57.5	450	50- 450
1.4×10^{-4}	350	950	400- 950
1.4×10^{-4}	920	1,200	575-1,125

[1]For two high-coal seams having different coal conductivities, but the same high-conductivity rock above and below the coal.

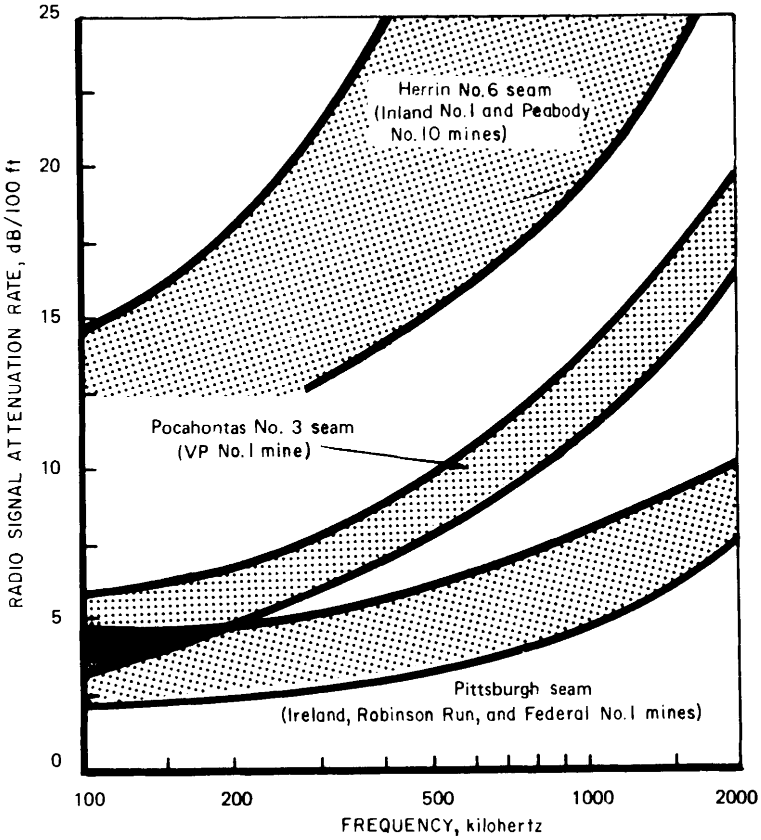

FIGURE 6. - Medium-frequency radio signal attenuation rates for mines in three coal seams.

Results from the in-mine propagation measurements program through March 1977 show that signal attenuation rates can vary widely, particularly between mines in different coal seams. Furthermore, the Pittsburgh seam is the most favorable of the seams measured to date. Figure 6 illustrates the radio signal attenuation rates obtained in mines in three coal seams; namely, the Pittsburgh seam in northern West Virginia (Consolidation Coal's Ireland and Robinson Run mines, and Eastern Associated Coal's Federal No. 1 mine), the Pocahontas No. 3 seam in Virginia (Island Creek's VP No. 1 mine), and the Herrin No. 6 seam in southern Illinois (Inland Steel's No. 1 mine and Peabody Coal's No. 10 mine). The Herrin No. 6 seam exhibits the highest losses to date, the Pittsburgh seam the lowest.

Data is expected from an additional five mines, including mines in low-coal seams. The results of these measurements will not only be used to define the most favorable operating frequencies for production versions of the medium-frequency mine wireless radio equipment, but also to establish guidelines to assist the coal industry in selecting and installing such equipment for use in underground coal mines.

OUTLOOK

The prototype medium-frequency wireless radios have been tested in underground mines in two coal seams: Inland Steel's No. 1 mine near Sesser, Ill., in the Herrin No. 6 coal seam, and Island Creek Coal's VP No. 1 mine, Keen Mountain, Va., in the Pocahontas No. 3 seam. These tests were conducted as part of the Bureau's program to investigate the propagation characteristics of mines in different coal seams. The test results for these 520-kilohertz prototype radios indicate a conductor-free area communication range of about 500 feet in VP No. 1 and Inland No. 1, the range at a specific frequency being largely dependent on the conductive properties of the coal and, to a lesser extent, on seam thickness and conductive properties of the surrounding rock. Somewhat longer ranges are expected for mines in the Pittsburgh coal seam, which appears to have more favorable propagation conditions. The test results also showed that ranges well in excess of the 1,350-foot goal are possible when the radios are used in the presence of mine conductors along haulageways and on working sections. Similar results have been obtained by the Lee Engineering Division of Consolidation Coal Co. with a 425-kilohertz portable medium-frequency radio recently developed by Lee Engineering for use on longwalls and haulage loop-arounds.

Further underground testing of the prototype MF mine wireless radios will be performed in conjunction with the propagation measurements planned for several mines in high-production coal seams. The results of these tests and the propagation loss measurements will be used to improve the design, performance, and application of future models of the medium-frequency mine wireless radio.

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REFUGE SHELTER COMMUNICATION SYSTEM

by

H. Kenneth Sacks[1]

ABSTRACT

Communication systems capable of transmitting ultralow-frequency signals through the earth have been developed, and a contractual effort is now in progress to develop a reliable refuge shelter communication system based on through-the-earth signaling concepts. Designs have been completed, and the first working model will be finished and ready for testing in mid-1977.

INTRODUCTION

When it appears to be impossible to escape, or imprudent to attempt escape, following a mine fire or explosion, miners are trained to isolate themselves from toxic gases and smoke by erecting barricades of brattice cloth on a wooden frame. From 1909 to 1961, more than 800 trapped coal miners were rescued from behind barricades. In the past two decades, 62 miners were rescued from behind barricades and 27 died behind inadequately constructed barricades.

The majority of deaths following explosions result from carbon monoxide poisoning. Barricading, when possible, can be a life-saving measure. However, roof falls and secondary explosions pose further hazards to miners trapped underground. In three instances in the last 20 years, multiple explosions have occurred. As a solution to this problem, the National Academy of Engineering has suggested sectional or central refuge chambers.

Central refuge chambers have been established by some companies. Small chambers (fig. 1) in earlier times were not uncommon for protection during shotfiring. The main disadvantage of a central chamber is that it is likely to be some distance away when needed. An analysis of mines on an individual basis would be needed before selecting this type of protection. However, if a chamber were constructed, some form of communication to the surface would be necessary to inform rescue crews that the chamber was being used and of the condition of its occupants.

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

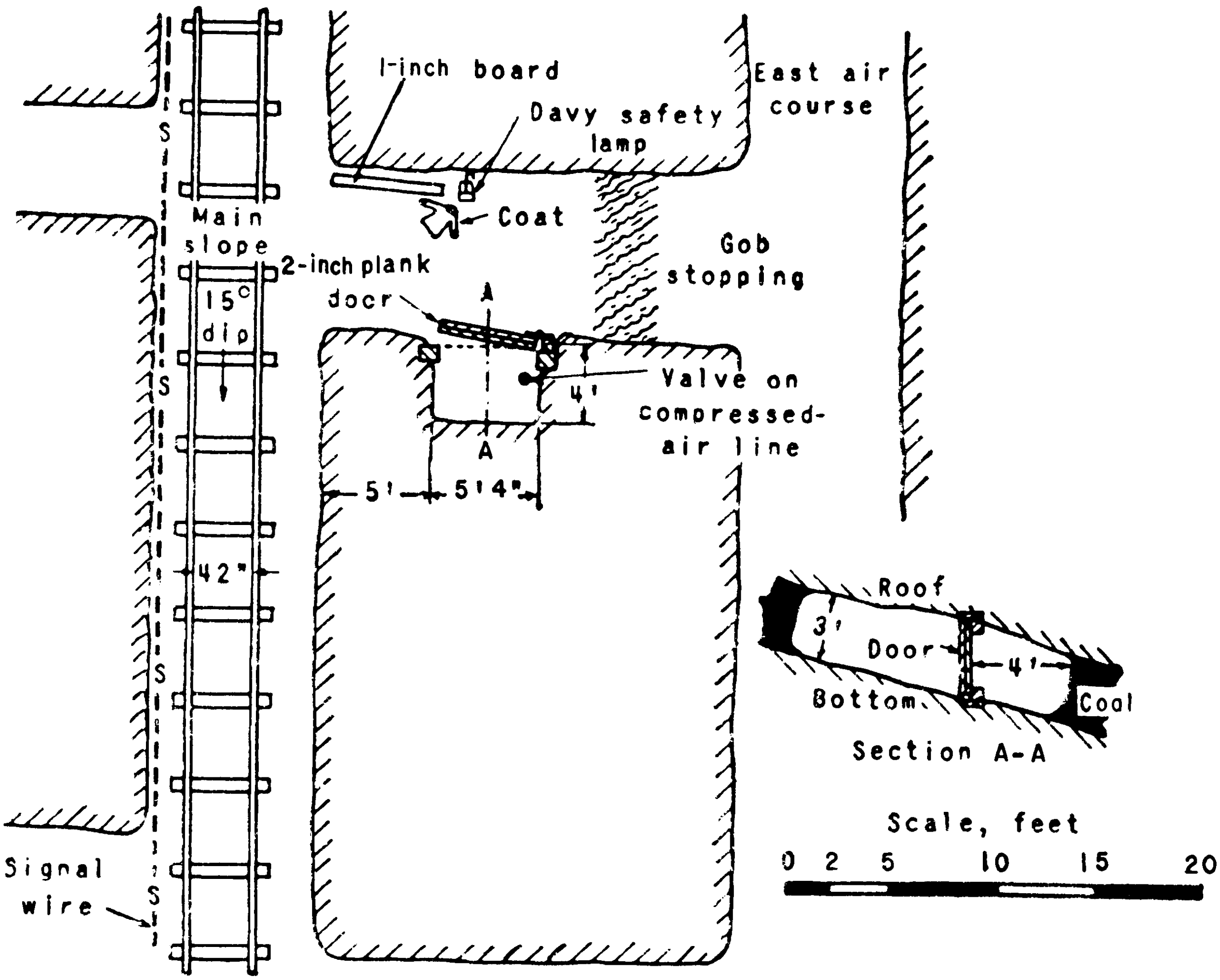

FIGURE 1. - Diagram of refuge chamber.

DISCUSSION OF PLANNED SYSTEM

Communication to a refuge shelter could be provided by means of a borehole equipped with a telephone pair connecting to the surface, by existing wiring within the mine, or by some form of through-the-earth system. In all probability, two systems would be used. The in-mine telephone system would be the least reliable after an explosion, unless the cable installation had been specifically hardened. Boreholes could prove highly reliable, but a problem could assuredly occur if the chamber locations were moved.

The most reliable alternative would be a through-the-earth communication system. As a result of the Bureau's trapped-miner location and roving miner paging programs, systems for transmitting ultralow-frequency signals through the earth have been developed. In fact, contractual effort is now in progress to develop a reliable refuge shelter communication system based on these through-the-earth signaling concepts.

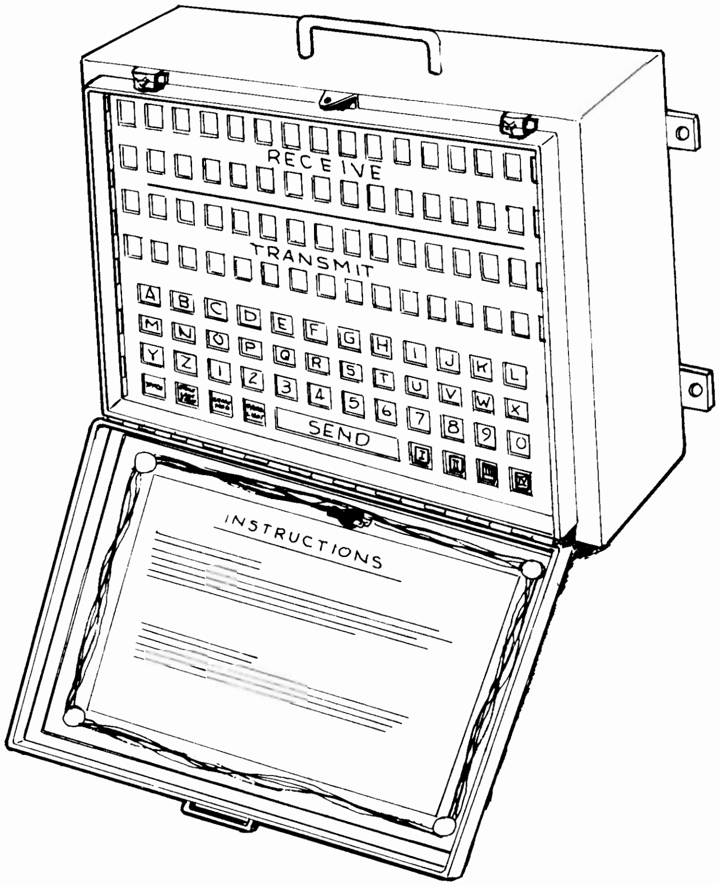

FIGURE 2. - Artist's concept of the refuge shelter transmitter-receiver unit.

The system as presently conceived would be similar in function to a teletype. It would be able to send and receive typed messages at about one character per second. The reason for this typed-message format, as opposed to voice, is available power. If an unlimited source of electrical power were certain to exist underground after an explosion, voice transmissions would be practical. The use of typed characters allows wireless communication through at least 1,000 feet of overburden with a reasonably compact battery-operated unit. In addition to letters and numbers, several "canned" messages will be available for transmission to conserve time and power. Figure 2 is an artist's concept of the finished unit.

In case of an emergency, the cover of the through-the-earth transmitter-receiver will be opened. This will automatically turn the system on and cause it to begin transmitting a special low-power drain signal. Until this uplink signal is answered by associated surface-based equipment, no other messages can be transmitted by the underground unit. This mode of operation was chosen to prevent a drain of battery power by futile message transmissions before the arrival of people and equipment to receive the transmissions on the surface above the shelter. Once an answer has been received from the surface-based unit, the full range of allowed two-way communication will be possible.

PROGRESS TO DATE

All designs have been completed, and the first working model will be finished in the summer of 1977 for subsequent testing underground.

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APPENDIX.--COMMUNICATION REPORTS

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

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

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

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

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

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

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

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

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

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