Underground Mine Communications, Control and Monitoring

By Staff, Bureau of Mines

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PREFACE

Since 1969, the Bureau of Mines, U.S. Department of Interior, has sponsored numerous programs aimed at improving methods of underground communication. As a result of these research and development programs, a wealth of information has been made available to the mining industry. Unfortunately, some of this material is highly analytical, and most is written in terms best understood by communication specialists. Because of the volume of data (over 100 studies have been performed) and its highly technical nature, most of the information is not readily available for practical application by mine operators. This manual brings together relevant data from all previous reports, studies, and other sources, and presents these data in such a way that they may be applied by the mining industry to improve communications in underground mines.

This report is intended as a guideline and not as a comprehensive documentary of mine equipment. Installation of equipment in a mine should be done only by people thoroughly qualified to do such work. Installations should follow procedures recommended by the equipment manufacturer and should comply with good safety practices. All installations should also comply with applicable codes and regulations.

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1.1 History of Underground Communications

Although the technology involved in removing material from below the earth's surface has a long history, communication systems in underground workings are relatively new to the industry. Communication equipment did not begin appearing in underground mines until the early 1900's. Figure 1-1 shows a miner using a Western Electric standard telephone set for underground mines in 1913. These early phones were essentially the same as those used aboveground, except that they were enclosed in cast-iron boxes as protection against moisture, acid fumes, and gases.

In the 1950's, the Chesapeake and Potomac Telephone Co. of West Virginia introduced a telephone set for use in explosive atmospheres that was designed around the philosophy of explosion containment. To contain an explosion within the telephone set required a 39-pound casing, which greatly limited portability.
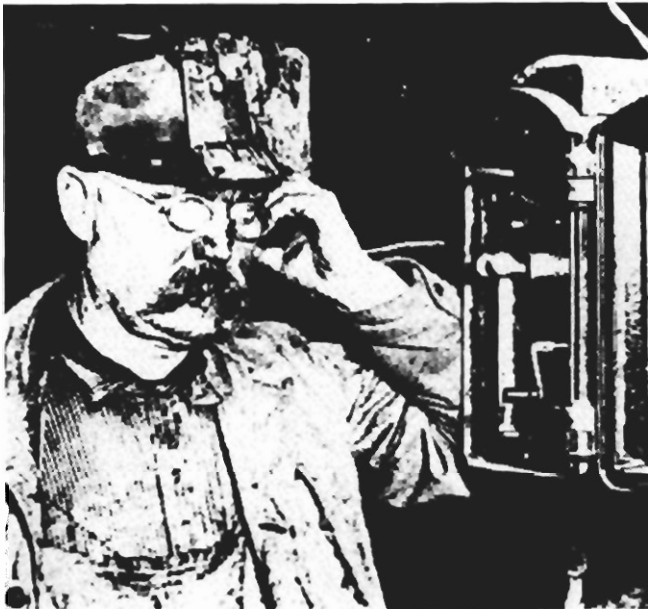
FIGURE 1-1. - Coal miner talking on an underground telephone in 1913.

Both of these telephone sets required "pipe" or conduit, not a very practical item for a 100-square-mile coal mine. A common thread prevalent in the first 40 years of design and development is that the primary effort was placed on the telephone set.

In the early 1970's, as work began on the design of modern communication systems for use in underground mine environments, the following requirements were established:

1. Must meet intrinsic safety standards.--This applies not only to coal mines, but to other explosive environments.

2. Must be compatible with the environment.--The system must withstand dust, moisture, and corrosive conditions.

3. Must be rugged in structure.-- The system must withstand maintenance by 10-inch pliers and 4-pound hammers, as well as impact from a falling piece of roof.

4. Must be size-flexible.--Whatever is built must be sized for the small operator as well as the large companies.

5. Must be a total system in design.--The system must be intrinsically safe, including cable, power supply, and station set.

6. Must work with present telephone system.--The system should be compatible with aboveground communications already in place; it should not be the single cause of change in aboveground communications.

7. Value-added pricing.--The system should be reasonably priced so that savings created by its introduction will more than offset the installation cost.

8. Full-service full-support concept.--The service offering the system must provide for maintenance, training (initial and continuing), route design, and transmission engineering.

In recent history, the most common method of underground mine communications consisted of loudspeaking- or paging-type telephones, or alternatively, magneto ringing telephones. In most cases these phones were connected on a common party line with one telephone for each working section and additional phones at other key locations, such as maintenance shops, both underground and on the surface. As mining operations became more mechanized, underground rail haulage systems were developed. Eventually, these were driven by electrically powered locomotives, and trolley carrier current communication systems were developed. While a few mines have begun to use dial-type telephones underground, their use to date has been very limited. It is expected, however, that more and more mines will install dial-and-page telephones and radio-type communication systems in the future. Today's rail transportation systems are typically equipped with carrier current phones to provide communications between vehicles and between vehicles and a central dispatcher.

Early shaft communications consisted of bells or whistle signaling systems. Today these systems have been replaced with radio and carrier current systems that allow two-way voice communication to and from personnel in the cage.

It is recognized that presently available mine communication systems need improvement. Research and development programs are continually being conducted by the Bureau of Mines, the mining industry, and equipment manufacturers to improve communication technology and techniques. The primary objective of all of these programs is to increase the productivity of the mining industry and increase the safety of miners.

1.2 Productivity and Safety

Underground mining operations, like other industrial enterprises, are tied together by communications. Adequate communication within a mine and between the surface and the underground work stations is a vital part of the proper operation of any underground facility. This communication capability is not only an important factor in the concept of safety, but also is an aid to the day-to-day operations and the task of extracting and moving the product to the surface. If a rapid, accurate flow of data is automatically and continuously presented to management, then decisions can be made sooner and more accurately. Some people consider the operation of a mine to be a relatively static operation planned many months, even years, in advance. However, the productive time per shift and productivity trends indicate that a large amount of waste time accumulates due to unpredictable daily events. If management were aware of breakdowns within minutes, attention could be more quickly focused on solving the problems, thereby increasing long-term production.

Safety can certainly be enhanced by accurate fast communication channels. Quicker medical assistance, faster evaluation of the situation underground, and accurate location of problems will be direct benefits. In addition to these obvious advantages, remote monitoring and control of equipment and conditions underground will allow management personnel to prevent accidents and other causes of production losses.

A study of 9,300 injury-causing accidents that occurred in underground bituminous coal mines during 1974 found that the financial cost totaled almost $57 million, or an average of $6,100 per accident. This figure did not include the intangible cost of reduced efficiency in fellow workers resulting from the accident. The study detected a marked

tendency of mine crews in or near the area where the accident occurred to slow down their pace of operations for a period of time, especially after a serious accident; consequently, production would drop. Such a drop was in addition to the accident itself, and to the time required to clean up after the accident. About 41%, or an estimated $23.6 million, of the total (current and future) cost of underground coal mine accidents in 1974 was borne by mining companies in the form of compensation payments to accident victims and survivors, lost coal production, and the expense of investigating the accidents. Any devices or techniques, including good communication systems, that will reduce accidents will quickly pay for themselves.

The evolution of mining technology, including underground communications, is inevitable as coal assumes a more significant role in the national energy plan. Another factor that will aid this development is the application of modern remote control and monitoring methods to increase production. Advances in remote monitoring and control of equipment and conditions underground will involve increased use of computers. Mine monitoring systems using a computer have already been installed in some mines. Basically, these systems consist of sensors placed at strategic locations, data relay stations, and a digital computer in the mine office. The computer is programed to process the data, determine when and where abnormal conditions exist, and alert mine personnel.

Six types of sensors in common use detect methane, carbon monoxide, temperature, relative humidity, airflow, or differential air pressure. Systems can include an electronic display of the mine layout, electric typewriters, and video display screens connected to the computer. The computer receives data from the remote stations in the form of electrical signals, which are translated into numerical measurements and checked against a set of standards to see if all factors are within normal limits. If any factors at a remote station exceed normal

limits, an alarm may be initiated. At the same time, the electric typewriter connected to the computer types out either a warning or a danger message to specify what is wrong and at which sensor the trouble is being detected.

In the United Kingdom, a commercial mine monitoring and control system, MINOS (Mine Operating System), is being developed. The heart of the system is a digital computer (fig. 1-2) located within the system control center. This computer is programed to obtain various data from remote sensors and monitor the satisfactory operation of the mine, giving audible and visual alarms as well as initiating automatic shutdown of equipment when necessary. Control of the conveyor system including startup, shutdown, and feed rate is also possible. Printouts and daily summaries of specified information are outputted automatically or are available on demand by keyboard commands entered at the system center. Remote control and monitoring of surface facilities and preparation plants as well as underground equipment such as pumps and fans can also be accomplished with the computer-controlled systems.

Any remote monitor and control system is relatively sophisticated, and an
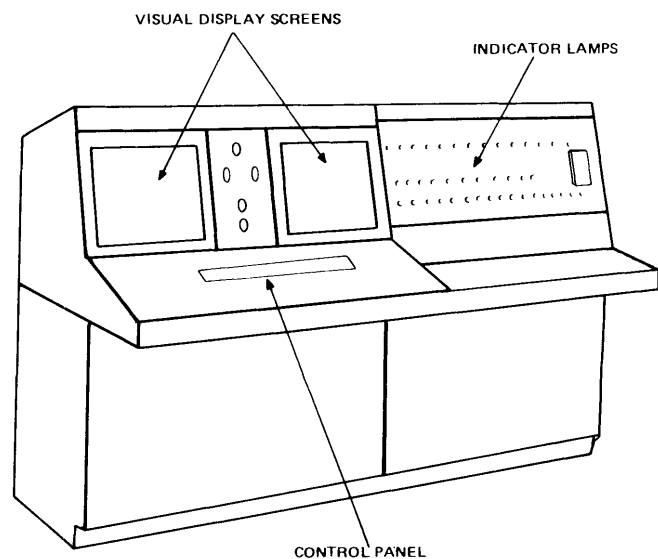
FIGURE 1-2. - MINOS system center.

economic analysis of the tradeoffs involved in the mechanization is required. However, minewide remote monitoring and control, coupled with an effective communication system, is one of the tools that can be used to increase safety and productivity in underground mines.

1.3 Constraints on Equipment

The environmental constraints on equipment expected to operate in any underground mine are severe. Equipment designed for surface operation, even if it would work underground, could not be expected to last for any length of time in the harsh mine environment.

Equipment must be protected from, or immune to, high-moisture atmospheres (0 to 100% humidity levels) and remain operable over wide temperature ranges. Dust can be expected to clog airflow passages, plug relay contacts, and cause switches to stick. Dust accumulation on electronic components can also cause heat buildup and even "short circuits." Some mine atmospheres are highly corrosive, and equipment in these mines must be constructed from materials that are resistant to the corrosion, or else protected from it. The very dry atmosphere in some mines causes gaskets and seals to quickly dry out and start leaking. Static electricity in these mines can also pose a problem for certain types of solid state electrical circuits.

In addition to the environmental constraints, physical considerations must be taken into account. Space is often at a premium in underground mines, especially in low coal seams. Communications, control, and monitoring equipment must be small in size and should be light in weight. Because it must exist in close proximity with heavy mining machinery, communication equipment must also be ruggedly designed and shock protected. Reliability and ease of maintenance are other reasons why most equipment designed for surface operation cannot be utilized in underground mines.

Much of the communication equipment in coal mines today is located in ventilated areas where there is less likelihood of an explosion. However, if a ventilation system is required to control the gas or dust hazard and basic communications must be maintained in the event of a ventilation failure, then this communication equipment must not be capable of generating an ignition spark. Thus, much of today's mine communication equipment carries a "Permissibility" label granted by the Mine Safety and Health Administration. To achieve the permissibility rating without explosion-proof packaging, all sources of sparks must be controlled by limiting voltages, currents, and the amounts of stored energy—such as in batteries, capacitors, and inductors—to safe levels. Such a device is defined as "intrinsically safe."

The amount of spark current in a resistive circuit required to ignite a methane-air mixture varies with the open-circuit voltage. Guidelines to safe operating limits, such as shown in figure 1-3, indicate a hazard at
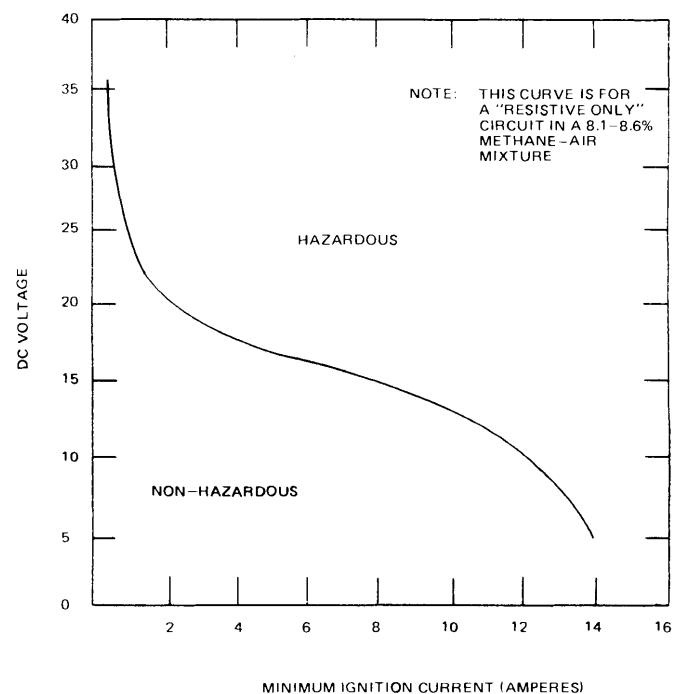
FIGURE 1-3. - Typical ignition hazard curve.

2 amperes in a 20-volt resistive circuit. However, no greater hazard exists with 10 amperes in a 12-volt resistive circuit. When reactive circuits (circuits with inductors or capacitors) or energy storage elements (batteries) are considered, limits on safe circuit design are even tighter. These safety considerations have directed the design of all the "permissible" communication devices on the market today. One of the most recent pager-type phones does not contain any inductive components other than the speaker and handset and uses only a single 12-volt battery.

In gassy mines, only permissible or intrinsically safe communication equipment should be acceptable for use in all locations under all conditions.

The permissible rating requirement rules out use of most systems designed for surface applications. For instance, a permissible rating cannot be given to a standard telephone connected to a telephone switchboard because of high voltages (48 volts dc while on hook and as much as 120 volts ac while ringing) and use of many highly inductive devices in the circuit. While placing the telephone in an explosion-proof housing could be considered as a means of making it "permissible," the cost would be unreasonable.

Other restrictions on communication equipment used underground are specified in the U.S. Code of Federal Regulations (See appendix B of this manual.)

1.4 Communication Requirements

In an ideal communication system an individual should be able to initiate and receive calls regardless of his or her position in the mine. To accomplish this, more than one communication system may be required. Communication requirements are more readily defined by separating the underground personnel in present-day mine operations into four functional groups:

Working section crew

Maintenance crew

Motormen

Inspectors and management personnel

The position of dispatcher is considered separately because he or she generally coordinates the communications as well as the haulage traffic.

In small mines and belt-haulage-type mines the communication center may be the responsibility of the hoist engineer, the supply man, or the maintenance foreman. Because hoist communication requirements are unique, they also can be treated separately.

1.4.1 The Working Section Crew

Under normal operating conditions the section forman communicates by fixed phone to the shift foreman to request supplies and maintenance services and to file periodic productivity reports. Under emergency conditions he must be able to request medical aid for personnel and report hazardous conditions in his area.

The high acoustic noise level created by the mining machinery greatly reduces the effective communications between the foreman and his crew. This noise also interferes with the foreman receiving calls. Often a motorman must deliver a call-in message to the foreman when he is transferring hauling cars in his section. Some belt haulage mines must even resort to turning off the conveyor system, thereby causing all the section foremen to call in. Communication requirements of the section crew can be satisfied by loudspeaking pager phones that can easily be moved to keep them within hearing range, or by some form of radio link (two-way radio, pocket pager, or "beeper").

1.4.2 The Maintenance Crew

Unlike a working section crew, the maintenance crew is spread throughout the mine. The maintenance foreman must be able to receive repair requests and dispatch his crews for both emergency and scheduled repair work. He should also be able to maintain communications with the individual crew members while they are in transit or after they have arrived at the repair site. The dispatcher may provide assistance by routing messages for equipment repair and parts to the foreman from the maintenance crew.

Wireless mobile communication equipment, linking the maintenance foreman and his crew together, would be ideal for the above tasks. However, any portable radio equipment used must be small and lightweight because crew members already have much to carry.

1.4.3 Motormen

The motormen are responsible for coal or ore haulage and the delivery of men and supplies to the working sections. Rights-of-way and the disposition of haulage cars must be known to all motormen to avoid accidents. In mines using tracked-trolley haulage, activities can be coordinated by a trolley wire (carrier) phone system. These are known as "carrier" systems because the communication is "carried" on a wire not intended for communication, in this case the trolley line; the term "carrier," however, refers to the technique, not the wire itself. This single-channel network keeps the dispatcher and all motormen in continuous contact with one another. This phone system also allows the dispatcher to notify all motormen of any mine emergency. The two drawbacks to this system are

1. Dead zones, which are sections of track where the phone is inoperative owing to excess electrical noise or excess attenuation of signal strength.

2. Trolley wire power failures, which cause the phones to go dead.

(Newer phones have backup batteries installed in each phone so this may not be a problem.)

In spite of these drawbacks, carrier phone systems usually meet the requirements of the motormen, except for an emergency that severs the trolley wire or otherwise removes power from the wire.

In mines without tracked-trolley haulage systems, a radio link must be established to allow motormen to remain in contact with one another.

1.4.4 Inspectors and Management Personnel

These people are underground primarily to observe mine conditions and personnel. They should be able to stay in continuous contact with the communication center for the following reasons:

To be informed of any emergencies that might arise.

To keep the center informed of their location.

To receive calls from other parts of the mine.

These requirements could be satisfied by an effective, extensive wireless mobile communication system. A vehicle-mounted system may be sufficient in some cases, such as the trolley carrier phones in track haulage mines.

1.4.5 The Dispatcher

The dispatcher's location in some mines has developed into a communication center for all underground operations. He is in direct contact with all motormen via the trolley wire phone system, and directs all vehicle traffic in the mine. In some mines, he also controls the fixed phone circuits via a small switchboard. He locates personnel by the paging phones or by relaying messages through the motormen to the sections. He serves as the human coupler between the different phone systems, and he is in the best

position to quickly notify all underground personnel of any emergency condition.

If this evolution continues, the dispatcher's job will expand to the point where he may become overworked. For safety and productivity reasons the voice traffic control and the monitoring function of the dispatcher's job cannot interfere with his prime responsibility of vehicle traffic control. Therefore, it may be desirable to transfer these responsibilities to other personnel or to automatic dialing and alarm equipment. For this reason some mines have established a separate communication system "operator" position. This person has responsibility for voice traffic control, and also for monitoring environmental conditions in the mine. The operating conditions of the haulage and mining equipment could also be monitored from the communication center.

1.4.6 Hoist Communications

A hoist-shaft communication system should satisfy the requirements for communication throughout the full travel of the cage, providing two-way voice communication between the cage and the hoistman. The system should also allow for shaft-inspection communication between the inspector and the "hoistman." For the modern, automated shaft, signals are also required for a slack-rope indication, to permit selection of level, enable interface with interlocks, and jog for exact position at any level or shaft station. Cage equipment must be small and capable of being located so that it cannot be damaged by any of the various uses of the cage such as transporting supplies and machinery into the mine.

Additional microphone-speaker stations should be located on each cage level when multilevel "man trip" cages are used. Until recently, bell signaling was the only form of hoist-shaft communication. A disadvantage of the bell signaling system is that communication with the cage when it is between levels is impossible. This deficiency is especially crucial during shaft inspection or repair, where movement of the cage must be controlled precisely. Today, however, equipment is available that allows two-way voice communication between persons in the hoist cage and the hoistman or other locations at the shaft top or bottom.

Reliable hoist-shaft communication should be considered as a vital part of the overall communication system, especially during or following an accident or disaster situation. Experience has taught that the hoist often becomes a bottleneck during rescue or evacuation operations, and good communication to and from the cage is essential.

1.5 Present Communication Systems

Communication systems currently used in many mines generally consist of two systems, the trolley wire carrier phones and the fixed pager phones. The trolley wire channel must be a party line to keep all motormen informed of one another's location. The pager phone system is often divided into multiparty circuits which are controlled by the dispatcher. For example, one mine studied used eight party line phone circuits terminated at a simple switchboard in the dispatcher's office. A logical partitioning of the pager phone network into a multichannel private line system would be to give each working section a separate line, or at the most two sections per line, and have one common line for all haulageway phones. Individual section phone lines would eliminate peak traffic demand during production reporting time and provide the section foreman with a private line during an emergency situation. Other phone lines could be used for monitoring the environment and equipment. Based on data and survey results to date, it appears that about two to eight phone lines, depending on activity of the mine, would be sufficient to provide efficient service for the working sections and also provide a common private line for the haulageways.

8

1.6 Summary

The need for effective communication between locations underground and between underground and surface locations has been recognized for some time. Unfortunately, the equipment to totally satisfy these requirements in underground mines has only recently become available. Part of the reason for lack of equipment can be blamed on the uniquely harsh environment present in underground mines.

Despite past deficiencies, equipment is now available to meet most of the requirements for effective underground communication systems. The operational requirement of the ultimate system may be simply stated as follows: Each individual should be able to initiate and receive communications regardless of his location within the mine. In practice, this ultimate requirement will normally be modified. The size and age of a mine, operating conditions, and economic considerations will affect the degree to which a system fully meets this ultimate requirement.

Vehicles operating on rails within a mine should have a communication unit mounted in every powered vehicle (required in some States). Operational safety is increased when there is an intervehicular communication system. Operators can report to each other or to a central dispatcher, thereby reducing the chances of a collision. Carried to the ultimate, the central dispatcher can control the movement of all vehicles at all times.

Often there is a need to call a man who is not near any vehicle or phone. As a minimum, some form of paging capability should be included in the overall mine phone system that can be used to tell a called party to go to the nearest phone and return the call. The ability to communicate with men underground, no matter what their location, is essential to the efficiency of any mine. Safety and productivity are directly related, and both depend upon good communications. In addition to the obvious advantages of reliable and effective communications, there are intangible benefits that may not be recognized:

1. The general attitude of the underground workforce will be improved if they know that they are not "cut off" communicationwise from the surface.

2. Mines with good communication systems should be able to more effectively compete in the labor market. High turnover rates, which are costly owing to training requirements, will be reduced.

3. Mines with effective communication systems and good safety records are usually subjected to inspections less frequently, and since studies have shown that production rates decrease when it is known that inspection personnel are on the property, the effect on production should be good.

Adequate communications within a mine and to the surface is a vital part of the proper operation of an underground facility. This communication capability is not only an important factor in the concept of safety precautions, but also an aid to the day-to-day operations and the task of moving the mined product to the surface. The mining industry exists to bring the product out and to bring it out safely and economically. Adequate communication is one of the tools available to assist in this task.

In a like manner, a judicious choice of remote monitoring and control of parameters in the underground environment and on selected machinery will yield a cost savings in production and augment safety. Many man-hours and dollars can be saved by knowing conditions before they become a problem. Situations that could be disastrous can be predicted and proper solutions implemented before the disaster occurs. Proper environmental and machine monitoring is another key to safer, more productive underground mining.

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CHAPTER 2.--COMMUNICATION SYSTEMS

2.1 Introduction

Any communication system requires at least three elements in order to function: a transmitting device, a receiving device, and a transmission line or propagation medium. Even the device children use, tin cans connected with string, consists or these three elements. One speaks into one can (transmitter), which vibrates at the same frequencies as the voice. The string (transmission path) picks up the vibrations of the can and carries them along its entire length. The other can (receiver) detects the vibration and reproduces the original sounds to a lesser extent depending on distance, tightness of string, type of string, etc. All communication systems depend on these three elements: transmitter, transmission path, and receiver.

Communication systems can be divided into three fundamental categories: wired phone systems, radio systems, and carrier current systems. Sections 2.2, 2.3, and 2.4, respectively, describe these systems and explain the basic principles of how each works.

Hybrid systems are those systems that use various combinations of the three basic communication methods. Hybrid systems are described in section 2.5.

There are some other methods of signaling (stench warning, bell signaling, etc.) that can be used in underground mines to transmit or convey information. These systems, although they cannot be considered true communication systems since they do not provide voice or even two-way communication, are briefly described in section 2.6.

2.2 Wired Phone Systems

Wired phone systems are all those that depend on a wire connection between phones with the wire carrying the voice signals. Figure 2-1 is a diagram of two typical wired phone systems. The top panel shows a simple single pair party line system. In this system each phone is connected to a common pair of wires, and a person speaking into one phone will be heard at all the other phones on the line. The bottom panel shows a multipair private line phone system. In this type of system, each phone is connected by its own individual pair of wires to a central switch or telephone exchange. To establish a call between two phones in this system, the lines between the two phones must be connected (switched together) within the telephone exchange.

In early exchanges, the connections were made manually by an operator. These exchanges are called Private Branch Exchanges (PBX's). Today, equipment within the exchange can automatically connect each phone to any other phone in the system. These exchanges are called Private Automatic Branch Exchanges (PABX's). There are many different types of automatic exchanges. Some utilize switches to physically make each connection according to the number dialed. Other, more advanced exchanges are completely solid state and may even be computer controlled.

a). SINGLE PAIR (PARTY LINE) SYSTEM

b). MULTIPAIR (PRIVATE LINE) SYSTEM
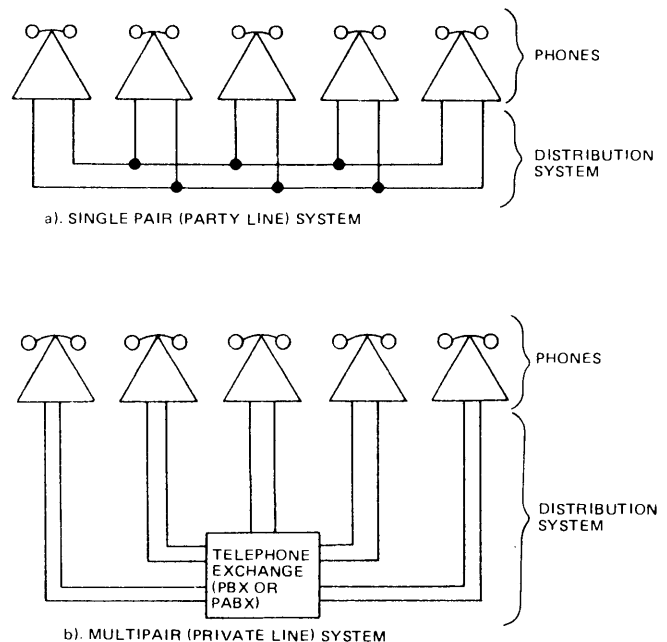
FIGURE 2-1. - Wired phone systems.

Telephone exchanges are described in section 2.2.3. The various types of phones in use today and a description of how they operate is given in section 2.2.1. Distribution systems are described in section 2.2.2.

2.2.1 General Telephone Theory

There are many different types of phones in use today, including

Magneto type

Sound-powered

Paging

Dial

Dial-and-page

These phones and the basic principles of how they operate are described in the following paragraphs.

2.2.1a Magneto-Type Telephones

One of the earliest types of underground communication instruments was the magneto phone, also known as the crank ringer phone. These phones consisted of a transmitter, receiver, hookswitch, ringer, battery, and hand generator (magneto). As the spindle handle was turned, 80 to 100 volts at 15 to 18 cycles per second was produced by the magneto. This current caused the other phones to ring. Once the called phone was answered, talking power was supplied by battery voltage.

Magneto phones were connected in party line fashion with a code of short and long rings to identify the called station. Some mines still use this type of system. However, as mines expanded in size, the system proved to lack adequate signal strength to power a large number of phones.

2.2.1b Sound-Powered Telephones

A sound-powered set is one that provides a means of voice communications with the use of no energy except that furnished by the speaker's voice. These phones have highly efficient transmitters and receivers for converting voice into electrical signals.

The sound-powered handset is comparable in size and appearance to the familiar battery-powered handset. Two of these phones were usually connected by a single line to constitute an intercom circuit. Such a circuit will reproduce speech with reasonable good quality for short distances in quiet surroundings.

For special communication applications requiring exceptionally rugged and durable sets for private communication purposes, and particularly when the line loops are short, sound-powered sets are well adapted.

Sound-powered sets find their principal application in mines, as independent intercom systems. The simplicity and convenience of operating without batteries and the service reliability and ruggedness of the sound-powered telephone when used in adverse surroundings are points in their favor.

2.2.1c Paging Telephones

The most common type of communication system used in underground mines is a paging telephone system. These phones are sometimes referred to as squawk phones or squawk boxes because of the harsh sound of the speaker. Each phone in the system is usually connected to a twisted pair cable in party line fashion. Each pager phone has internal batteries that power audio amplifiers to boost signal level for normal communication. A paging amplifier allows each phone to broadcast a page call on a loudspeaker that is also housed within each phone (fig. 2-2).

The paging telephone has gained widespread use for two reasons. First, it permits persons and station areas to be paged by name and thus does not require the miners to learn ringing codes or telephone numbers. Second, the use of page amplifiers in each phone makes the
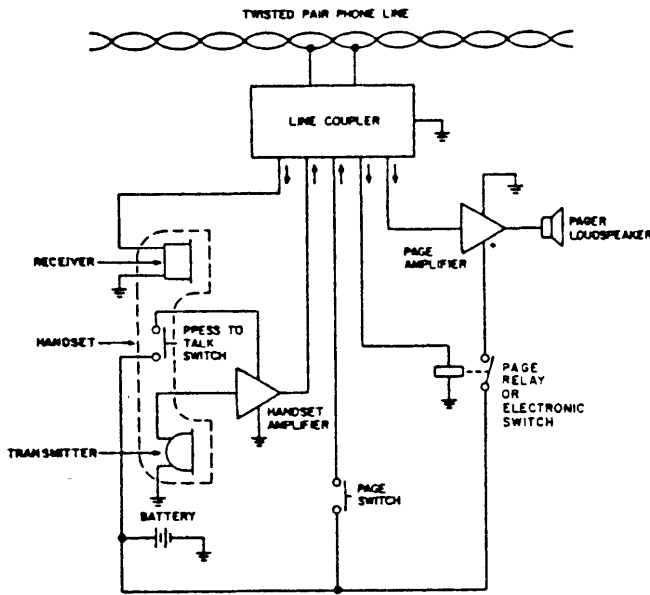
FIGURE 2-2. - Generalized two-wire pager phone.

system less affected by poor line splices and induced noise. The loudspeaker also yields a higher sound level at the receiver, which is important in the vicinity of noisy machinery. The primary disadvantage of paging telephone systems is that the telephone line must be used in a party line arrangement. This prevents simultaneous conversations in the system and reduces its usefulness for discussing maintenance problems or other uses which can tie up the system for long periods of time.

In a large mine there may be 30 to 40 phones on a single twisted pair cable. However, as the mine develops and the miles of twisted wire pair increase, a limit is reached. The limiting factor is the power available to signal the paging amplifier in other phones to turn on. The application of an electronic switch, in place of the low-voltage "page relay," has extended the operating range of newer paging phones.

A schematic of a generalized two-wire pager phone is shown in figure 2-2. When the ("Page") switch on the page phone is pressed, a dc voltage from the battery is placed on the line. All telephones connected to the line are energized through their "page relay," and the

paging amplifier at each station is turned on. The person making the call then squeezes the press-to-talk button on his handset and makes an announcement. The handset signal is amplified and then transmitted over the two-wire network to all other phones. After completing the page, the caller releases the "Page" switch. The individual paged can respond by squeezing the press-to-talk button and talking into the handset. Because the two-wire line is common to all phones, any conversation on the party line may be heard at all stations.

Most of the pager phones that are available are directly interchangeable within a system or can easily be modified to be interchangeable. Two major areas of difference among available equipment are the battery voltage used for the page-call function, and the characteristics of the internal relay that responds to the dc page signal. The two choices of battery voltage are presently 12 volts and 24 volts. The 24-volt system was the standard for several years. Most installations also used electromechanical relays to "switch in" the paging amplifiers.

In recent years, new designs using solid state switching circuits that operate at 12 volts have become popular. Besides being more reliable, solid state systems have a high impedance and thus present a minimum load to the paging circuit. In a large complex multiphone system, with several miles of interconnecting cable, the minimum loading caused by these phones means that more phones can be installed.

Options included by the manufacturers of some paging phones include a battery-test button, an improve-hearing button, and a flashing light to help attract attention in noisy areas. The battery-test button, when pressed, lights a lamp on the front panel to indicate that the battery is in good condition. When the improve-hearing button is pressed, the gain of the receiver amplifier in the handset is increased. To

assist the loudspeaker in attracting a
miner's attention, the flashing light is
turned on when the page is initiated.

2.2.1d Dial-and-Page Telephones

The use of normal surface-type tele-
phones in underground mines has two
disadvantages: The potential hazard, in
a methane atmosphere, from the 120-volt
20-hertz bell-ringing voltage; and the
inability to locate a person who is not
in his immediate work area. Surface-type
telephones also have two advantages, how-
ever: The selective call feature and the
multiple private lines.

A unique system combines the dial
telephone with the page phone. A surface
interface is provided to isolate the
potentially hazardous voltages from the
underground line, and a converter changes
ring voltage into the low-voltage direct
current required to turn on the paging
speaker in the dial-selected pager phone.
The handset switch eliminates the need
for a hook switch. Pressing the handset
switch accomplishes all functions nor-
mally accomplished by lifting the handset
of a conventional phone from the cradle.
When a call is dialed, the interface mod-
ifies signaling to interface another
underground phone or a conventional tele-
phone on the surface.

Figure 2-3 is a diagram of a dial-
and-page phone. The telephone consists
of a handset, containing a transmitter in
the mouthpiece and a receiver in the ear-
piece, and a main housing. The main
housing contains a speech dialer network,
which isolates the outgoing and incoming
signals, a pulsing switch that is actu-
ated by the rotary dial to signal a num-
ber to the surface interface, and the
paging speaker. The speech network fil-
ters noise and processes the talker's
voice. A common-page button permits
paging all phones, as is required when
searching for a roving miner or for mak-
ing a general announcement.

Automatic dial systems are used at
several mines that operate their own Pri-
vate Automatic Branch Exchange (PABX) for
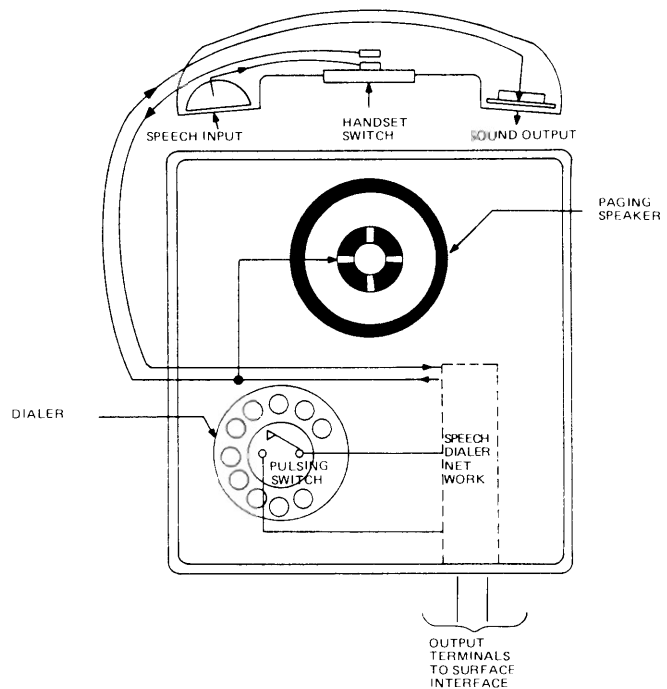
FIGURE 2-3. - Mine dial phone.

both inside and outside telephone ser-
vice. Dial systems provide for many
simultaneous conversations, but do need
to use some form of signal multiplexing
or multiconductor cables. These problems
can be minimized by using multiconductor
cables only in the main haulageway where
few roof falls or line breaks are likely
to occur and by taking conventional two-
wire cable up to each section. However,
this means all telephones in one area
must be on a party line.

2.2.2 Distribution Systems

The distribution system for wired
phones is the equivalent of the string
between the two tin cans described in the
introduction. This is the propagation
medium that carries the voice signal.
For wired phones, the distribution system
may be single pair, multipair, or a mul-
tiplex system.

All wired systems used in mines are
inherently unreliable. That is, if a
telephone line is broken or shorted by a
roof fall, for example, all telephones
beyond that point are severed from com-
munication to the outside. If the line

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is shorted, communications in the entire system may be severely affected or lost completely.

2.2.2a Single Pair

A single pair of wires is the minimum requirement for wired communications. A single twisted pair is used for magneto phones, paging phones, and intercom phones, connected in party line fashion. Single-pair wires are generally 14 AWG (0.06408-inch diameter). This relatively heavy gage wire is used in order to minimize signal loss over long distance.

The signal loss per mile, or attenuation as it is called, is dependent upon the frequency of the signal and the size of wire gage as shown in table 2-1. This table shows that as wire size increases and gage decreases, the signal loss (attenuation) decreases.

Each attenuation of 3 dB means that the signal power has decreased by one-half. For example, if the output of a communication device was 4 mW, the -3 dB attenuated value of this signal is one-half the output, or 2 mW. A 6-dB attenuation of a 4-mW signal results in a 1-mW (4 × 1/2 × 1/2) signal level.
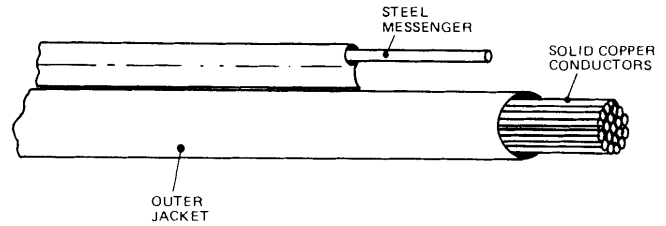
FIGURE 2-4. - Figure-8 multipair cable.

2.2.2b Figure-8 Multipair Cable

Figure-8 aerial distribution wire is shown in figure 2-4. In cross section, the wire looks like a figure-8 with a steel support wire, called the messenger, in the top half and a core of twisted pairs in the lower half. The outer jacket covering the messenger cable and twisted pair bundle is highly resistant to abrasion, moisture, and environmental stress cracking. Each wire is solid, commercially pure, annealed copper. One conductor of each pair is usually color coded by a solid body color with a contrasting spiraling color strip. The other conductor has the complementary color combination. Figure-8 cable is recommended for mine applications because the messenger cable adds considerable strength to the cable and the installation is similar to that of trolley wire.

TABLE 2-1. - Cable attenuations

Frequency (kHz)	Wire size					
	13 gage		16 gage		19 gage	
	Decibels per mile	Percent of signal power remaining	Decibels per mile	Percent of signal power remaining	Decibels per mile	Percent of signal power remaining
10	0.80	83	1.32	74	2.43	57
20	1.04	79	1.55	70	2.77	53
30	1.27	75	1.78	66	3.02	50
50	1.75	67	2.24	60	3.53	44
100	2.72	54	3.31	47	4.80	33
150	3.60	44	4.27	37	6.00	25

2.2.2c Coaxial Cable

Coaxial cable consists of an inner conductor and an outer conductor, as shown in figure 2-5. This type of cable has two main advantages over twisted pair for transmission. First, the coax usually has lower attenuation. Second, the shield over the central conductor keeps the electrostatic and electromagnetic fields contained within the coax, thereby minimizing crosstalk and interference problems.

2.2.2d Multiplex Systems

The term "multiplex" is applied to any system in which a single wire or wire pair is used for the transmission of more than one simultaneous signal. In this type of system, a means must be provided for inserting the individual signals onto the common transmission line and then separating these individual signals at the output of the line. There are two principal methods of multiplexing signals. One is based on frequency translations and is called frequency-division multiplexing, or FDM. The other is based on time-sharing the transmission line and is called time-division multiplexing, or TDM.

2.2.2d.i Frequency Division Multiplexing

Frequency division multiplexing is a process by which two or more signals are sent over the same line by transmitting each signal at a different frequency. The FDM concept can be illustrated by considering how the commercial radio broadcasting systems operate. Each radio station transmits at a specific frequency that has been assigned by the Federal Communications Commission (FCC). The signal from each radio station is transmitted by a common path (the atmosphere), with many stations being on the air at the same time. To receive a particular station, a person merely tunes his radio (receiver) to the frequency of the desired radio station.

This same principle, transmitting more than one voice signal, each at a different frequency, over a common path

(in this case a single pair of wires), can be employed in underground communication systems.

Figure 2-6 illustrates the FDM concept. At the transmitting terminal, each of the voice channels (CH 1 through CH n) is applied to a modulator. Each modulator shifts that voice signal to an assigned frequency (f_1 through f_n) and transmits the resulting signal over the common line to the receiving terminal.

At the receiving terminal, a bank of filters separates the signals according to frequency. Individual demodulators recover the original voice signal. Note that the multiplexing system shown in figure 2-6 operates in only one direction. Most communication systems require two-way voice transmission. This is accomplished by a complete duplication of
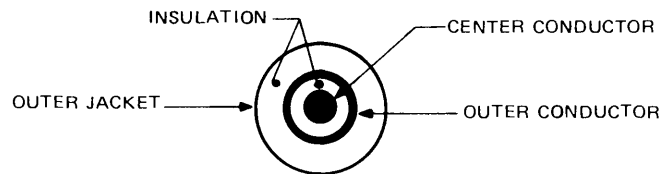
FIGURE 2-5. - Coaxial cable, cross-sectional view.
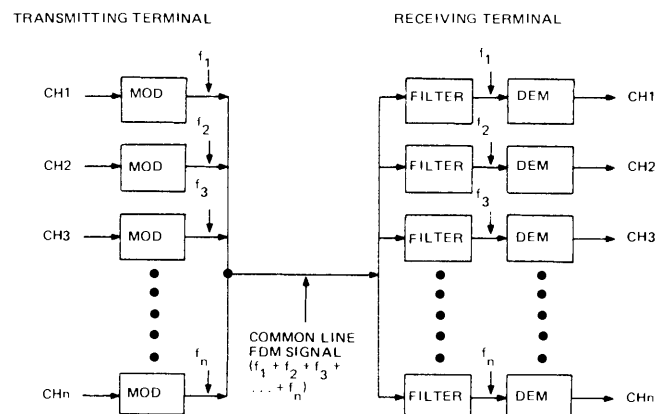
FIGURE 2-6. - Frequency division multiplex (FDM).
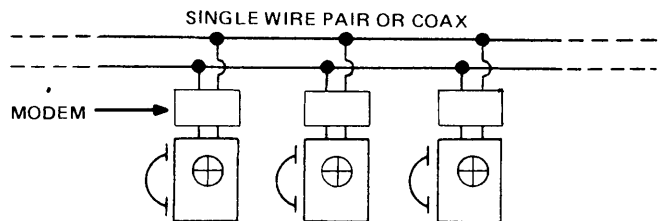
FIGURE 2-7. - Multiplex phone system.

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multiplexing facilities, with the components in reverse order and with the signal waves traveling from right to left. Each terminal has a transmitting modulator and a receiving filter and demodulator combined to form a "modem."

A block diagram of the multiplexing principle is shown in figure 2-7. Each phone is connected to a subscriber terminal unit or modem. The transmission line is a twisted pair or coaxial cable whose gage depends on the system size. Repeaters can be inserted in the line to compensate for attenuation.

2.2.2d.ii Time Division Multiplexing

Time division multiplexing is a process by which two or more signals are transmitted over the same line by allocating a different time interval for the transmission of each signal. The time available is divided up into small slots, and each of these is occupied by a piece of one of the signals to be sent. The multiplexing equipment scans the input signals in a sequential round-robin fashion so that only one signal occupies the TDM line at any one time.

The basic concept, showing two signals (A and B) being time division multiplexed together, is illustrated in figure 2-8. During time slot 1, signal B is connected to the TDM line. During time slot 2, signal B is removed and signal A is placed on the TEM line. This process is repeated with each signal alternately occupying a time slot on the TDM line. The bottom waveform in figure 2-8 shows the resulting time division multiplexed signal. The TDM signal consists of signal A during the even-numbered time slots and signal B during the odd-numbered time slots. To separate the signals, when they are received at the other end of the TDM line, a demultiplexer must be used. The demultiplexer is similar to a multiplexer except that the input and output are reversed. The demultiplexer reconstructs the original signals (A and B) from the multiplexed signal.

In order to illustrate the TDM concept, the preceding discussion considered multiplexing only two signals together. This concept can be extended to multiplex many signals together onto a single TDM line. For instance, if eight different signals are to be multiplexed, then each signal would be placed onto the TDM line each eighth time slot. Figures 2-9 and 2-10 show eight switches at one location and eight lamps at another which must be controlled by those switches.

The system shown in figure 2-9 is simple and easy to understand; however, eight separate wires must be strung between the switches and the lamps. This can be quite costly and impractical when the switches and lamps are separated by large distances. Figure 2-10 shows how each lamp can still be controlled by its associated switch using a single wire (TDM line) between the switches and lamps. With the wiper on each of the multipole switches synchronized, this system would sample the status of the first input switch (S1) at the transmitting end and communicate that information to the receiving end. At the next interval of time, both multipole switches would step to position 2. Control of the second lamp would be accomplished by sampling the status of the S2 input switch at the transmitting end. At the next time interval, both scanner switches would step to position 3 and a similar
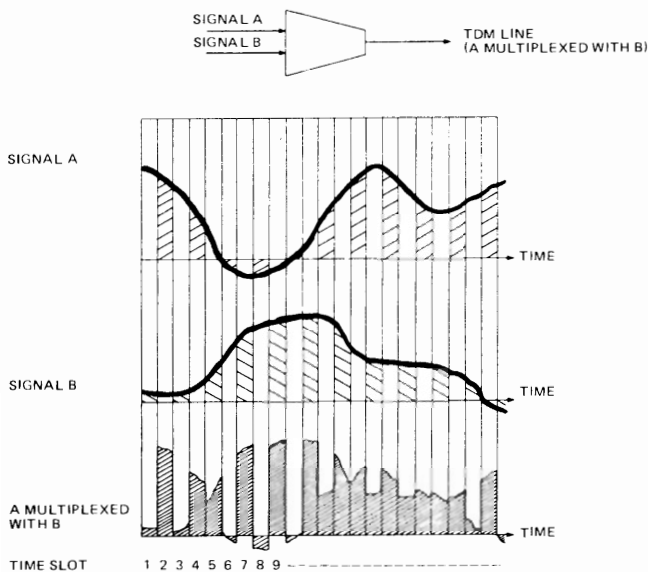
FIGURE 2-8. - Time multiplexing two signals.

SWITCHES

INDICATOR LAMPS
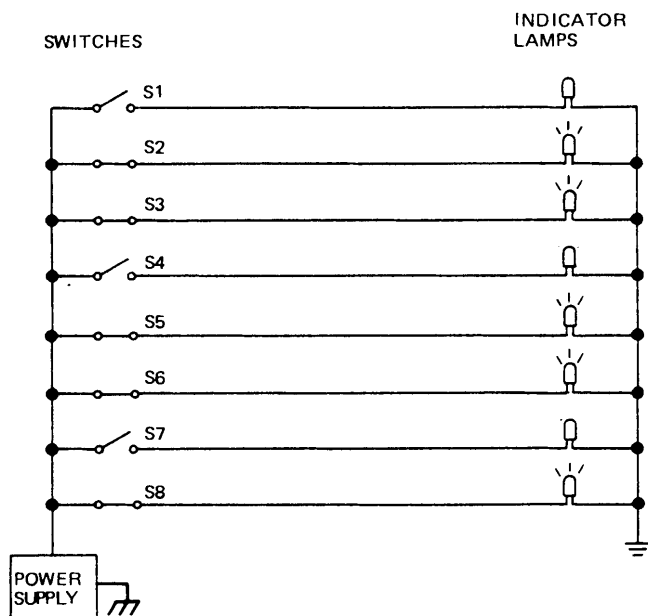
FIGURE 2-9. - No multiplexing (eight wires required).
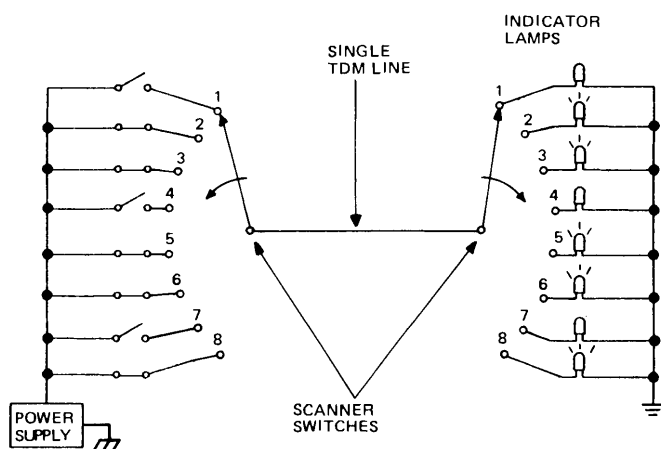
FIGURE 2-10. - Time division multiplexing (one wire).

control action would result for the third lamp. After all eight positions had been scanned, the scanner switch would return to position 1 and start the sequence over again. If the scanning were fast enough the lights would appear to glow steady and not blink. In a like manner, if this were a voice system, it would not sound chopped.

2.2.3 Telephone Exchanges

The function of any telephone exchange is to connect a calling phone to a called phone. The earliest method of connection was the manual switchboard

located within a private branch exchange (PBX). As the number of phones in use increased, the size and complexity of manual switchboards also increased. This led to the development of an automatic switching system called a private automatic branch exchange (PABX). Since telephone lines are currently used as data links for computers, teletypwriters, and various other data equipment, faster, more reliable exchanges were needed. To fill this need, the computer is presently used to control large solid state exchanges and perform many other central office (CO) functions.

2.2.3a Manual Switchboard

The earliest switchboards allowed the operator to manually patch two circuits together. When the central office received ringing current, the operator inserted the answering plug into the jack of the caller. After verbally receiving the called number, the operator inserted the calling plug of the same circuit into the called party's jack and applied ringing voltage on the ringer of the called party. After the conversation has been concluded, both parties would ring off, informing the operator that the plugs could be disconnected.

2.2.3b Private Automatic Branch Exchange

The private automatic branch exchange performs the same end function as the operator at the old manual switchboard. It makes a connection between the phone line of a caller to the line of the phone being called. Connections through PABX's can be made using electromechanical devices (rotary switches, relays, etc.) or solid state electronic circuits.

In rotary dial phone system, the phone loop, which includes the two speech wires and the telephone set, is momentarily interrupted by the dial switch as the dial runs down. The number of loop interruption electrical pulses thus generated corresponds to the number dialed. In pushbutton-type phone systems, the numerical information (each digit dialed)

is transmitted to the switching equipment in the form of coded frequency or voltage signals. In either case, the PABX switching equipment must receive and decode the "number dialed" signals from the calling phone to determine what phone is being called.

2.2.3c Computer-Controlled Switches

Modern solid state exchanges under computer control can efficiently handle thousands of phone lines. In addition to being faster and more reliable, computer-controlled equipment occupies only a fraction of the space required by systems using mechanical relays or rotary switches.

Alterations to these systems no longer require a lot of time and hardware since the switching is under control of a computer program. Changes such as adding phones, deleting phones, changing a phone number, etc., can be made by simply changing the program. The computer also can keep track of billing functions and special events. Special features, such as conference calls, automatic call forwarding, and abbreviated dialing, can be incorporated into computer-controlled exchanges by making changes to the computer program.

System maintenance can also be handled by computer program. Instead of many labor hours spent in attempting to locate and correct a fault, the computer can cycle through all parts of the system and locate a trouble spot within a matter of minutes. Because computer operations are very fast, they can be performing maintenance functions even while handling the switching function for thousands of calls.

2.3 Radio Systems

Radio systems do not depend on a wire connection between transmitter and receiver. There are many types of systems in this category: one-way voice, one-way signal, and two-way voice. In one-way operations, the transmitter sends a code or voice signal to the receiver.

Two-way voice utilizes a device called a transceiver (combined form of transmitter and receiver).

2.3.1 General Radio System Theory

Voice frequency (VF) signals could be transmitted directly from one antenna to another; however, because of the low frequencies (and therefore long wavelengths) involved, the antennas required would be very large. For this reason, VF signals are combined with higher frequency RF (radio frequency) carrier signals which can be effectively transmitted and received by antennas of reasonable size. The two primary methods of combining VF signals and RF carriers are amplitude modulation (AM) and frequency modulation (FM).

2.3.1a Amplitude Modulation

In amplitude modulation the height, or amplitude, of the RF carrier is made to vary with the VF signal. This principle is illustrated in figure 2-11. The top waveform shown in figure 2-11 is a typical VF signal. The middle waveform of figure 2-11 represents an RF carrier that will easily propagate between antennas of convenient size. The bottom waveform shows the result of "amplitude modulating" the RF carrier with the VF signal. This signal retains the basic shape of the original VF signal but will also easily propagate between antennas because it is being transmitted at the RF carrier frequency. The original voice signal is regenerated by demodulation circuits in the receiver.

2.3.1b Frequency Modulation

A voice signal may also be superimposed on a carrier frequency through the use of frequency modulation techniques. In FM, the frequency of the RF carrier is made to vary at the VF signal rate. As the amplitude of the VF signal changes, the frequency of the RF carrier (instead of the amplitude) changes.

Figure 2-12 shows the principles of frequency modulation. The voice signal
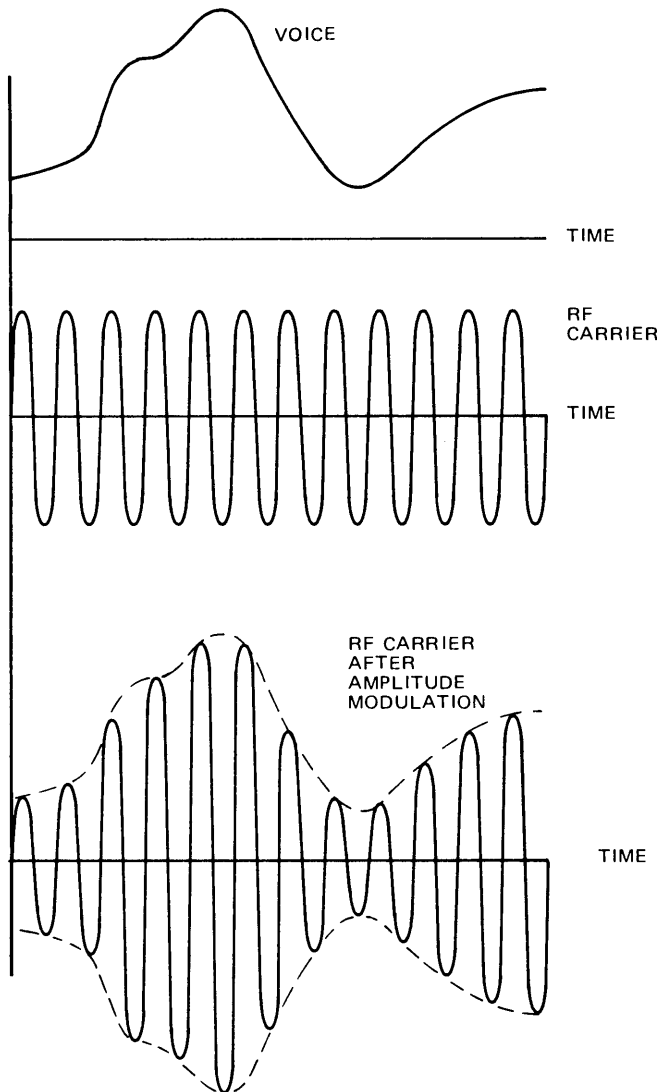
FIGURE 2-11. - Amplitude modulation (AM).

FIGURE 2-12. - Frequency modulation (FM).

is shown by the top waveform and the RF carrier by the middle waveform. The bottom waveform shows the resultant frequency-modulated RF carrier. As the voice signal increases to its maximum value, the carrier frequency increases (the waves bunch up). As the voice signal decreases to its minimum value, the carrier frequency decreases (the wave spreads out). The amount of carrier frequency change is referred to as frequency deviation or carrier deviation. The unmodulated carrier frequency is referred to as the center frequency. The amount of carrier deviation is proportional to the amplitude of the voice signal, with maximum carrier deviation occurring at the peaks of the voice signal.

FM receivers are less susceptible to noise when receiving a signal of only moderate strength or when the background electromagnetic (EM) noise is almost as "loud" as the signal. This advantage of FM over AM can become an important consideration in underground mining operations where electrical equipment is being operated and the amount of EM noise being generated is large.

2.3.2 Distribution Systems

For the most part, the distribution system or propagating medium for radio transmission is not hardwired but takes the form of electromagnetic (radio) waves in the air. (Radio waves at certain frequencies will also propagate directly through the earth.) Electromagnetic energy (radio waves) in empty space travel at the speed of light. Because the speed of any traveling wave is its

wavelength times its frequency, we have a formula of propagation (fλ = speed of light) where λ is the wavelength and f is the frequency. λ and f are thus inversely proportional (as f increases, λ decreases), as shown in figure 2-13. Commonly used units are λ in meters and f in hertz (Hz) (cycles per second). If the wave is traveling through anything other than empty space, its speed is reduced depending upon the electrical properties of the medium through which it is passing. Radio waves are slowed down only slightly by the earth's atmosphere. In solid insulating materials the speed is generally much slower; for example, in distilled water (which is a good insulator) the waves travel only one-ninth as fast as they do in free space. In good conductors such as metals the speed is so low that opposing fields induced in the conductor by the wave almost cancel the wave itself. This is the reason why thin metal enclosures make good shields for electrical fields at radio frequencies.

2.3.2a Antenna Theory

In normal electronic circuits the physical size of a circuit is small compared with the wavelength of the frequencies being used. When this is the case, most of the electromagnetic energy stays in the circuit itself or is converted into heat. However, when the physical dimensions of wiring or components approach the size of the wavelength being used, some of the energy escapes by radiation in the form of electromagnetic, or radio, waves. Antennas can be considered as special circuits intentionally designed so that a large part of the energy input to the antenna will be radiated as electromagnetic energy.

Usually an antenna is a straight section of conductor, either a wire or hollow metal tubing, which is suspended in space. When a radio transmitter is connected to the antenna, rapidly varying electrical currents are set up in the antenna. These currents cause electromagnetic waves to radiate from the antenna and travel through the atmosphere or other surrounding medium. When these waves strike another antenna they induce electrical currents in it similar to the current flowing in the transmitting antenna. These currents, although they may be very small if the antennas are far apart or if they are transmitting through the earth, can be amplified by electronic circuits (receivers) to reproduce the original signal. The range of radio distribution systems can be extended by leaky feeder cable (special coaxial cable designed to allow radio waves to "leak" from the cable to the surrounding atmosphere and/or radio repeater stations.

2.3.2a.i Half-Wave Dipole Antenna

The strength of the electromagnetic field radiated from an antenna is proportional to the amount of current flowing in the antenna. It is, therefore, desirable to make the current as large as possible. This can be accomplished by adjusting the length of the antenna so that it resonates at the operating frequency.

If a straight wire, or antenna element, were to be suspended in space, the lowest frequency at which it would resonate has a wavelength of twice the length of the wire. When used to transmit or receive RF energy that has a wavelength of twice the length of the wire,
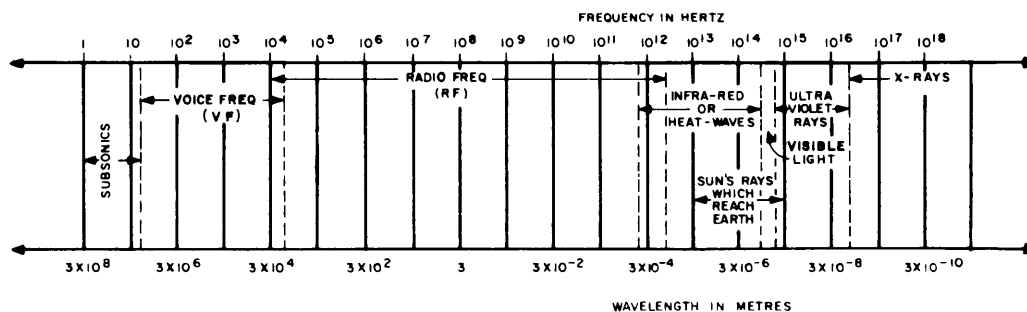
FIGURE 2-13. - Electromagnetic energy spectrum.
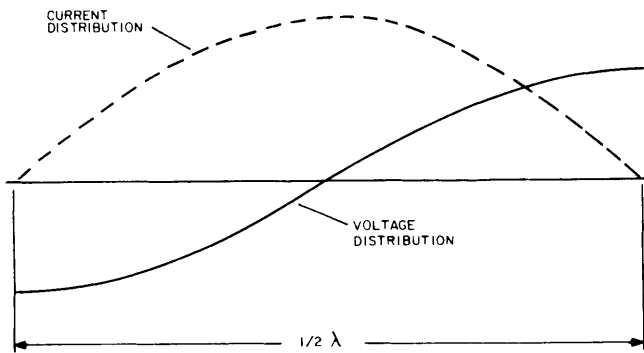
FIGURE 2-14. - Half-wave antenna, voltage and current distribution.
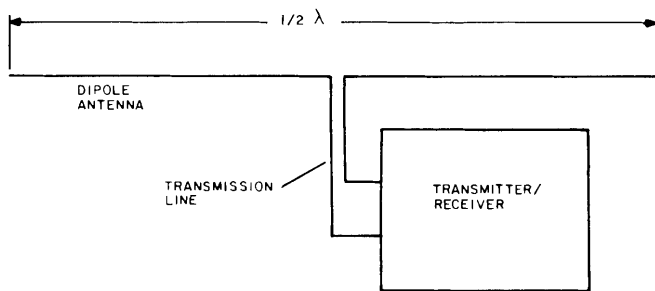
FIGURE 2-15. - Dipole antenna.

FIGURE 2-16. - Quarter-wave antenna, voltage and current distribution.

the wire is known as a half-wave antenna. The current and voltage distributions along such a wire are shown in figure 2-14. Such an antenna, when connected to a receiver as shown in figure 2-15, is called a dipole.

2.3.2a.ii Quarter-Wave Antenna

An antenna may also be a quarter wave in length. This is possible because of its connection to ground, which electrically acts as the other quarter-wavelength. Refer to figure 2-16. The ground plane reflects the quarter-wave antenna so it has electrical characteristics similar to those of a half-wave antenna.

An antenna of this sort may be any odd multiple of a quarter-wavelength: $1/4\lambda$, $3/4\lambda$, $5/4\lambda$, $7/4\lambda$, etc. These antennas are commonly used for low- and medium-frequency applications. If a quarter-wave whip antenna is installed on a vehicle, the vehicle becomes the ground plane. A modified quarter-wave antenna is commonly used for citizens' band (CB) radios on vehicles.

2.3.2a.iii Long-Wire Antenna

A long-wire antenna is one that is long with respect to the wavelength of the incoming and outgoing signals. The length should be an integral number of half-wavelengths (2λ, $2-1/2\lambda$, 3λ, $3-1/2\lambda$, etc.) to radiate effectively. A $1/2\lambda$ (dipole antenna) is said to operate on the fundamental frequency, λ operates on the second harmonic, $1-1/2\lambda$ operates on the third harmonic, 2λ operates on the fourth harmonic, and so on.

2.3.2a.iv Loop Antenna

Loop antennas can be utilized for through-the-earth radio transmissions or as receiving antennas in direction-finding systems. These antennas can be composed of one or more turns of wire on a round or square form, or the loop can be established by simply laying the wire in a loop on the ground or floor of a mine tunnel.

2.3.2b Leaky Feeder Systems

Figure 2-17 shows a cross-section view of a standard coaxial cable and the lateral variation of its associated fields. In such cables, the bulk of the radio frequency electromagnetic energy is transported down the cable between the center conductor and the shield. However, the shields of most coaxial cables do not provide perfect containment of the internal electromagnetic fields or isolation from external fields. As shown in figure 2-17, a small fraction of the cable's internal field is leaked to the external space. External fields also leak into the cable in a similar manner.

The leaky feeder system is based on the use of semiflexible cable with specially designed shielding that has a greater coupling to the external space. Therefore, this cable easily leaks radiated signals and saturates the area around the cable with these signals. One type of leaky feeder cable is shown in figure 2-18. The cable has a solid copper shield in which holes have been machined to increase the amount of leakage to and from external space. In large mines, repeaters may also be used to amplify and retransmit incoming and outgoing signals to roving miners carrying portable radios. The spacing of these repeaters along the cable is governed primarily by the receiver sensitivity, the longitudinal attenuation rate of the cable, the coupling loss from the cable to the portable units, and the transmitter power. Since the portable unit's transmitter power is generally lower than that available for fixed repeater or base stations, the portable units set the coverage limits for two-way communications.

FIGURE 2-17. - Coaxial cable, field strength.

2.3.2c. Waveguide Propagation

A waveguide is a hollow conductor, through which electromagnetic waves (radio waves) may propagate. Such a waveguide may be made of copper (the ideal), or other materials, such as coal or shale (nonideal). Hence, a mine entry is a waveguide. In order for a wave to efficiently propagate in a rectangular waveguide (mine entry or haulageway), the wavelength must be equal to or less than two times the greater dimension (a or b of figure 2-19). Table 2-2 shows the frequency spectrum designations with their wavelength ranges. The dimension of "a" that would be common in underground communications is 3 meters. This limits the lowest frequency range of signals that will effectively propagate within mine tunnels to the upper VHF and the UHF range. A communication device such as a CB radio has no application since it operates at approximately 27 MHz, a frequency which is too low.

FIGURE 2-18. - Cutaway view of leaky feeder cable.

TABLE 2-2. - Frequency spectrum designation

Abreviation	Description	Frequency	Wavelength range
VF..........	Voice frequencies............	300-3,000 Hz.............	10^6-10^5 m
VLF........	Very low frequencies........	3-30 kHz................	10^5-10^4 m
LF..........	Low frequencies..............	30-300 kHz..............	10^4-10^3 m
MF..........	Medium frequencies...........	300-3,000 kHz...........	10^3-10^2 m
HF..........	High frequencies.............	3,000-30,000 kHz........	100 -10 m
VHF........	Very high frequencies.......	30-300 MHz..............	10 - 1 m
UHF........	Ultra high frequencies......	300-3,000 MHz...........	1 - 0.1 m
SHF........	Super high frequencies......	3,000-30,000 MHz........	10 - 1 cm
EHF........	Extremely high frequencies..	30-300 GHz..............	1 - 0.1 cm

Other factors that influence waveguide propagation are wall texture (the smoother the wall, the better the propagation) and tunnel straightness, and electrical properties of the roof, walls, and floor.

2.3.2d. Repeaters

Two general types of repeaters will be considered for application in the mine environment: Single-frequency (F1-F1)
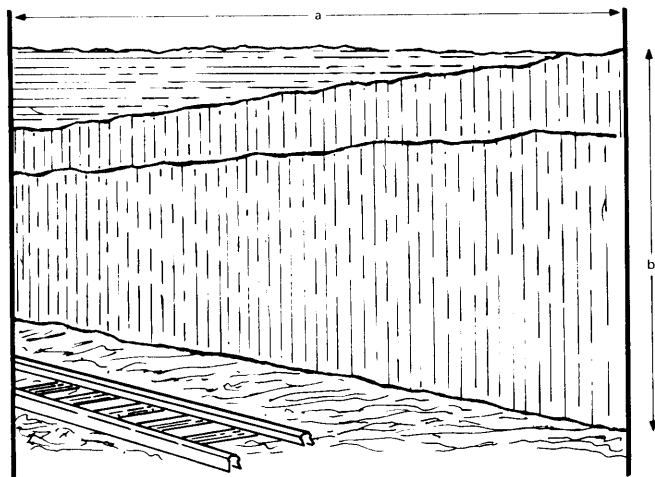
HAULAGEWAY (NON-IDEAL)
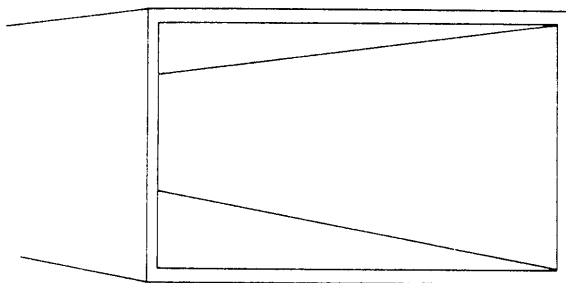
COPPER WALLS (IDEAL)

FIGURE 2-19. - Waveguides.

repeaters and frequency translation (F1-F2) repeaters. In its simplest form a repeater consists of two basic elements, a receiver unit and a transmitter unit, as shown in figure 2-20.

2.3.2d.i F1-F1 Repeater

Single-frequency repeaters are used in most wired systems such as coaxial systems where the transmission energy is confined within the coax. These repeaters function as signal amplifiers. The attenuated input signal is detected, amplified, and retransmitted. Since the signals are confined to a separate coax, isolation between transmitter and receiver is maintained.

Single-frequency repeaters are also used in some wireless repeater systems, but extreme caution must be used to prevent feedback between repeater transmitter and receiver. Isolation must be maintained between the transmitter output and receiver input to prevent the transmitted signal from being received and amplified by the same unit. This

RECEIVE ANTENNA OR COAX

TRANSMIT ANTENNA OR COAX

RECEIVER

TRANS-MITTER
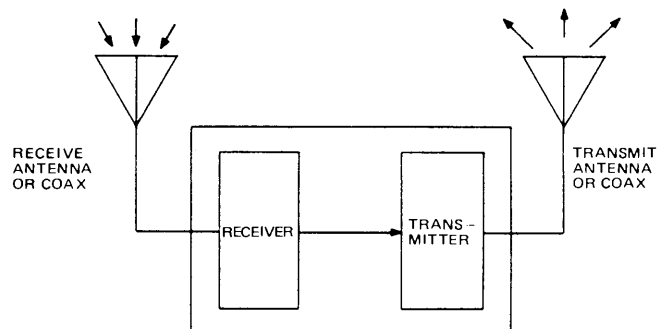
FIGURE 2-20. - Basic repeater block diagram.

feedback can cause an oscillation or squealing problem very similar to that caused by placing a microphone in front of its own speaker. Directional antennas can be used to minimize this feedback problem; however, the use of high-gain directional antennas is not considered practical in the mine environment owing to installation problems and their susceptibility to mechanical damage.

Another method of overcoming these problems is to use special repeaters that do not depend on directional antennas. In general terms, these units function by separating the transmit and receive signals with time division multiplexing. The repeaters transmit pulses of RF energy and receive between these pulses. In this type of system all repeaters must be phase-locked with each other to synchronize the time division process.

2.3.2d.ii F1-F2 Repeater

F1-F2 repeaters receive signals from a portable unit on one frequency (F1) and retransmit these signals on another frequency (F2) to another portable unit. The mobile radios transmit on F1 and receive on F2. In this mode, all information goes to the repeaters, then back to the portable units. Some portable units are also capable of transmitting on F2 and, therefore, are able to talk to one another without the repeaters on a local simplex basis. With these systems, the receive and transmit antennas at the repeater are often covering the same general frequency bands and they can be combined so that only one antenna is required.

Thus far, repeaters have been discussed only as a means to permit communication over greater distances than would be possible using direct transmission between portable radios. However, the audio link between the transmitter and receiver in the repeaters allows radio access to and from other types of audio circuits, such as specialized paging consoles or the telephone system.

One possible system configuration which includes both a telephone link and talk-through capability is shown in figure 2-21. This configuration allows for two modes of communications: F1-F2 would be used for a local mode, that is, miner to miner within the working section through the repeater; and the second mode could support communications between a miner located in a working section with a second miner located somewhere else in the mine. The audio link (fig. 2-21) between the receiver and transmitter of a repeater can be used to customize repeaters to fit a variety of applications. An audio wireline can also be used to link a number of repeaters together to provide complete radio coverage of the mine on a party line basis as shown in figure 2-22.

2.3.3 Through-the-Earth Radio

VF (0.3- to 3-kHz) radio waves will penetrate, to some extent, directly through the earth. Although signal strength is greatly attenuated, experiments have shown that up to 1,000 feet
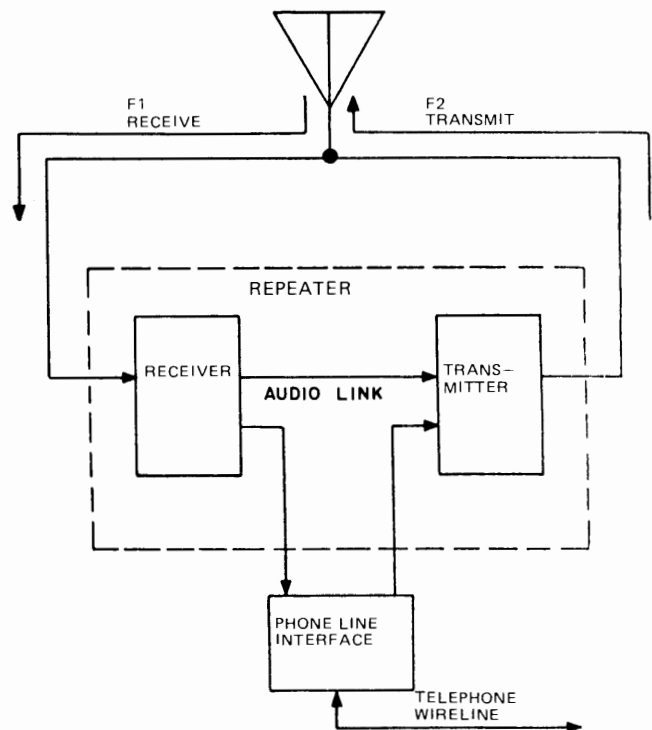
FIGURE 2-21. - Repeater linked to telephone system.
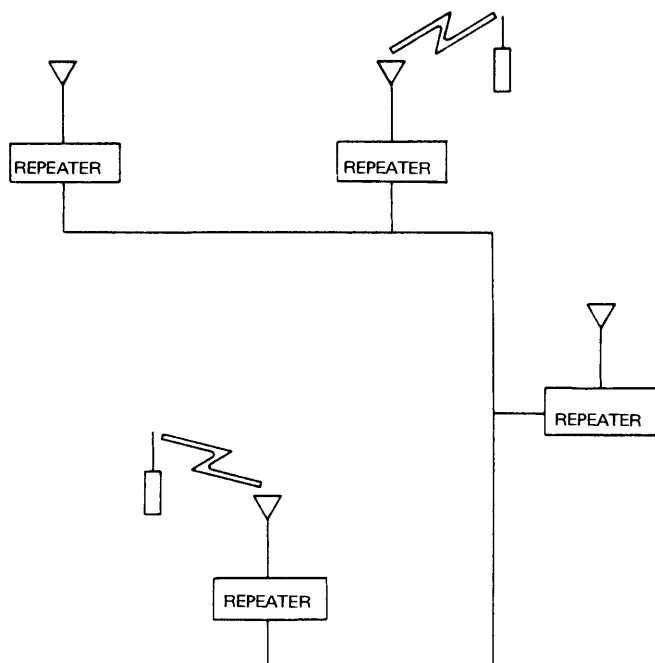
FIGURE 2-22. - Minewide repeater system linked by audio pair.

(305 meters) of overburden may be penetrated.

The transmitter may be a simple generator with a loop or grounded wire antenna. The receiver may be a loop antenna connected to a power amplifier with a set of earphones or a meter. When the transmitter is activated, it sets up a magnetic field directly through the earth (the overburden).

These characteristics of through-the-earth radio can be utilized in emergency situations to detect, locate, and even communicate with miners trapped underground. Once the position of an underground transmitting antenna has been determined using direction-finding techniques, a loop antenna can be positioned on the surface directly above the underground position. The trapped miner has a method of pulsing his transmitter off and on, such that a coded message may be sent to the surface. A high-power transmitter attached to the surface loop may also be utilized to establish down-link voice communications with the underground location.

2.3.4 Radio Pagers

Radio pagers are usually small FM radio receivers. The simplest type of radio pager is a one-way signal detector or "beeper." These devices emit an audible tone and/or blink a small light on and off. The miner must then go to the nearest phone to receive the message.

Another type of radio pager is a one-way voice pager. These devices are similar to the simple beeper-type pagers except that the caller can deliver a short verbal message to the person being paged. A common type of one-way voice pager sounds a tone to alert the miner that a message will follow, and then broadcasts the verbal message. A disadvantage of these pagers is that, although it is possible to transmit instructions, such as "turn off the power to number 4 left," it is not possible for the caller to know for sure that the instruction was even received, let alone carried out. For this reason, one-way voice pagers should not be used to instruct personnel to perform specific tasks that may affect safety.

Some one-way voice, and even beeper, pager systems allow the caller to selectively page a specific section or an individual miner. The heart of these systems is an encoder, which translates the number of each pocket pager to a specific frequency or code that activates only the designated pager.

2.4 Carrier Current Systems

Any underground wire or cable, when fed an RF signal, tends to distribute that signal throughout its length. Carrier current systems utilize this fact to establish communication paths using existing mine wiring. The wire used may be ac or dc power lines, neutral lines such as the hoist rope, existing phone lines, or other wiring.

Carrier current devices are basically FM radio transceivers that transmit

and receive over existing mine wiring instead of using an antenna system. The LF (low-frequency) and MF (medium-frequency) RF ranges propagate best in carrier current systems. A common example of a carrier current system is the trolley carrier phone systems presently used in many mines using trolley or rail haulage. Another example is the shaft communication systems that utilize the hoist rope itself to establish communications to and from the cage. The most modern system, based on MF, promises to be the most effective of all.

2.4.1 Trolley Carrier Phone

A simplified block diagram of a typical trolley carrier phone is shown in figure 2-23. As mentioned earlier, the basic elements of any carrier current phone are the FM receiver and transmitter.

In a trolley carrier current phone system, the receiver and transmitter are connected to the trolley wire through a coupler capacitor. The coupler capacitor acts as a short circuit at the frequency of the FM voice signals, but as an open circuit to the trolley wire dc power voltage. The high voltage levels on the trolley wire are thus blocked from entering the receiver and transmitter sections of the carrier phone, while the FM voice signals pass freely through the coupler capacitor.

The FM transceiver shown in figure 2-23 contains a power supply that converts trolley wire high voltage down to low voltage levels to provide power to the carrier phone circuits. The power supply may also contain a battery for backup power in case power on the trolley wire is lost. Such a system operates in the push-to-talk, release-to-listen mode.

2.4.2 Hoist Rope Radio

Figure 2-24 shows a block diagram of a hoist rope carrier current system. The system consists of two signal couplers and two transceivers. Each unit is
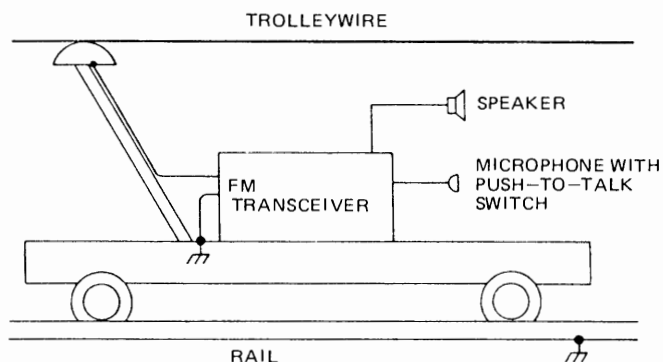
FIGURE 2-23. - Trolley carrier phone, block diagram.
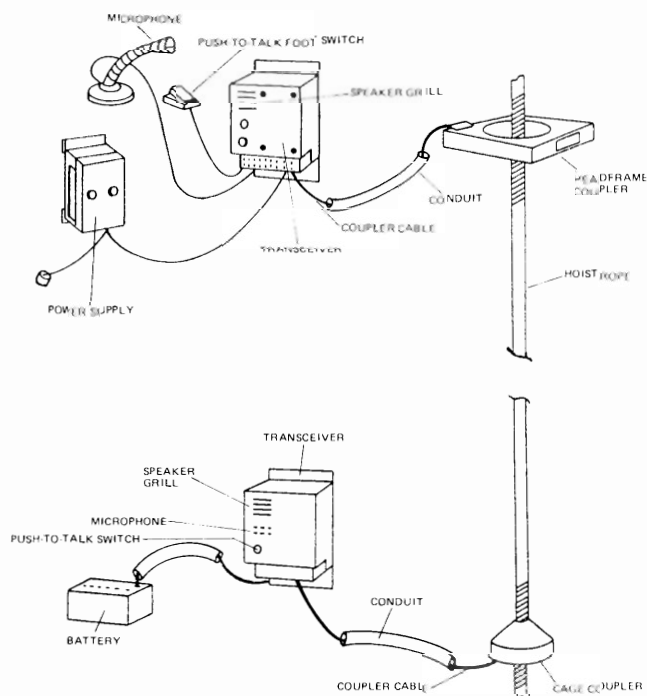
FIGURE 2-24. - Hoist radio hardware.

of the push-to-talk, release-to-listen design. During transmission, the sending unit feeds its coupler with a frequency-modulated (FM) carrier. The coupler induces a signal in the hoist rope, which is then picked up by the coupler of the second unit. Both couplers are electrically identical, and each operates both as a transmitting and as a receiving element. Operation of the hoist radio is the same as for a trolley carrier phone, except that the hoist radio signal is inductively coupled to the propagation medium (hoist rope). Some hoist phones

are simply modified trolley carrier phones. Other hoist phone systems have been specifically designed for operation in a vertical shaft and usually provide better coverage.

The transceivers of the hoist room and cage are identical, except for the battery required in the cage. The hoist room power supply provides the power for the surface equipment. Surface equipment also may include a boom-type microphone and a foot-actuated push-to-talk switch to facilitate hands-free operation.

2.4.3 Medium Frequency (MF) Radio

Although radio transmission on the surface of the earth is well understood, transmission in an underground environment generally is not. Complex interactions occur between the radio wave and the environment. Characteristics of the geology (stratified layering, boundary effects, conductivity, etc.) and the mine complex (entry dimension, conductors, electromagnetic interferences, etc.) had to be measured and understood before a practical mine radio system could be built. To this end, considerable research has been directed.

In a confined area such as a mine, radio waves can propagate useful distances only if the environment has the necessary electrical and physical properties. The "environment" takes into account the natural geology and manmade perturbations such as the mine complex itself. As an example, if the wavelength (λ) of a radio wave is small compared with the entry dimensions, a waveguide mode of propagation is possible. Attenuation depends primarily upon the physical properties of the entry such as cross-sectional area, wall roughness, entry tilts, and obstacles in the propagation path. Secondary effects such as the dielectric constants and earth conductivity also influence attenuation.

Mine radio systems based upon this effect are available commercially. These are UHF systems operating around 450 MHz which provide useful but limited coverage. In high coal (6.5 feet), line-of-sight ranges of 1,000 feet are often possible. Range is reduced severely in non-line-of-sight, such as when going around a coal pillar. In lower coal, or when obstacles exist in the propagation path, range is reduced even more. For this reason, conventional UHF radio systems require an extensive network of leaky feeder transmission cables and repeaters to become useful. Even so, range from the cable is not usually in excess of 30 to 50 feet, and equipment cost is very high. Clearly another approach is desirable.

An important contribution to underground radio communications was made by the Chamber of Mines of South Africa. As early as 1948, programs were in place to develop radio systems for deep mines, primarily gold mines. The result was that by 1973, an advanced 1-watt single sideband (SSB) portable radio system had been developed that apparently worked well. The Bureau of Mines procured several of these units for evaluation. Performance in U.S. coal mines was not satisfactory. There were several reasons for this. First, U.S. mines are highly electrified, producing considerable electromagnetic interference (EMI) not normally found in the South African mines, which completely desensitized SSB radios. Second, 1 watt was not enough power. U.S. mines are mostly room and pillar, which means that any radio system would have to have reasonable range from local conductors. Third, geological electrical parameters were less favorable in the United States. For these reasons, the South African system was not acceptable.

The Bureau's approach was to first determine the actual propagation characteristics of MF in U.S. mines, and then

to relate the propagation to the underground environment such as the geology, entry size, existing conductors, and EMI. Several exhaustive in-mine measurement and analysis programs were conducted. These programs formed the foundation for the first true understanding of how MF propagates in a stratified medium of various electrical parameters, which are often interlaced by manmade conducting structures (rails and power lines) and artificial voids (entryways).

Figure 2-25 is a simplified geometry of an in-mine site that illustrates one of the most important findings of the measurement program, the "coal seam mode." For this mode to exist, the coal seam conductivity (σ_c) must be several orders of magnitude less than that of the rock (σ_r). A loop antenna that is at least partially vertically oriented produces a vertical electric field (E_z) and a horizontal magnetic field ($H\phi$). In the rock, the fields diminish exponentially in the Z-direction. In the coal seam, the fields diminish exponentially at a rate determined by the attenuation constant (α), which in turn depends upon the electrical properties of the coal. An inverse square-root factor also exists because of spreading. The effect is that the wave propagates between the highly conducting rock layers bounding the lower conductivity coal seam. The fact that the coal may have entries and crosscuts is of minor consequence.

In the presence of conductors, the picture changes considerably. In this case, the effects of these conductors can totally dominate the effects of the geology. In general, the presence of conductors (rails, trolley lines, water pipes, air lines, phone lines) is always of advantage.

MF can couple into, and reradiate from, continuous conductors in such a way that these conductors become not only the transmission lines, but also the antenna system, for the signals. The most favorable frequency depends to some extent on the relationship between the geology and
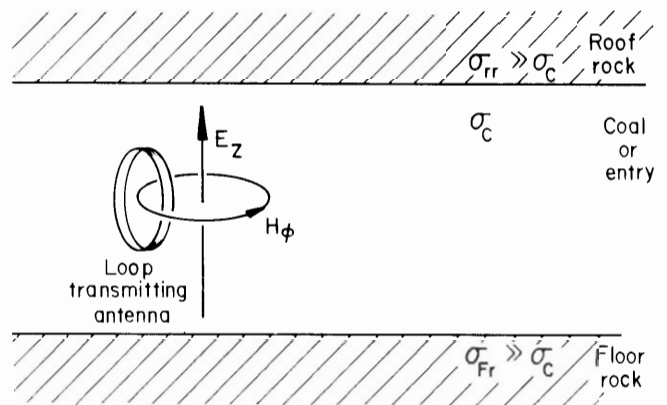
FIGURE 2-25. - The coal seam mode.
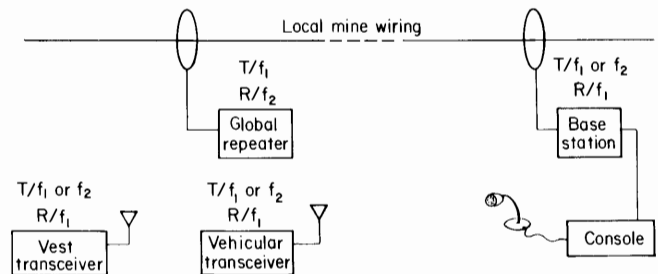
FIGURE 2-26. - Global repeater concept.

existing conductors. The frequency effects are quite broad. Anything from 400 kHz to 800 kHz will usually be adequate.

The MF system described here is based upon vehicular and personnel transceiver units, base stations, and repeaters. It applies prior fundamental research in the area of MF and utilizes the existing mine wiring network (power cables, trolley line, etc.) to achieve whole-mine coverage. The basic system configuration is shown in figures 2-26 and 2-27.

Figure 2-26 illustrates a minewide repeater-base station concept known as the global maintenance net. In this configuration, mobile units (persons using transceiver vests and/or vehicular transceivers) can maintain local communications by operating at frequency f_1. The range of communications in this case is solely dependent on point-to-point radio

propagation, aided by parasitic coupling. A transmission on f_2 causes repeater action to occur, permitting the two mobile units to be separated very large distances. To achieve this repeater action, it is only necessary for the transmitting unit to reach the repeater, either directly or by parasitic effects to the repeater line coupler. Communications with a base station are also possible.

Figure 2-27 illustrates a local repeater concept constituting a local cellular net. This local repeater is known as a "cellular repeater" because it illuminates a "cell" or area of the mine, such as a working section, only. The antenna for the cellular repeater is a dual wire loop attached to timbers or the rib. An interface to the mine telephone system permits communications "off section."

The system design is distributed in the sense that each net can be operated independently of the other. In practice, a net can be easily installed by coupling a base station (at the portal) to electrical conductors in the wire plant (phone lines, power lines, etc.). Mobile transceivers operating on the assigned net frequency communicate with each other and the base. Other nets use different frequencies and are installed in the same way.

Two types of mobile transceivers have been developed for the system. These transceivers consist of vest units for individuals and vehicular units for rolling stock. Functionally the two are equivalent, differing only in power levels and physical configuration. These transceivers are shown in figures 2-28 and 2-29.

An important human factor problem was solved by the vest design. By placing the radio circuit modules in pockets on the vest, the weight and bulk of the transceiver have been evenly distributed. The loop antenna is sewn into the back of the vest. The pockets are located where medical records show less frequency of injury. Sound is directed toward the
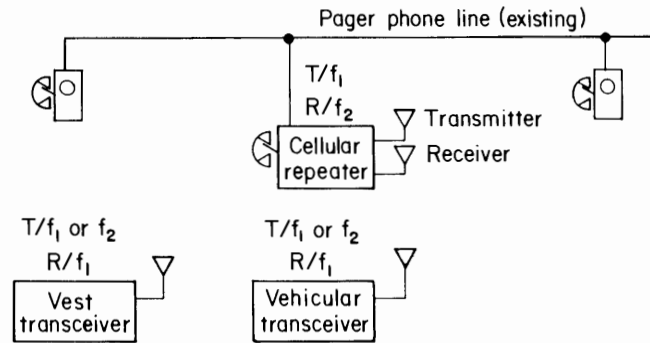
FIGURE 2-27. - Cellular repeater concept.

FIGURE 2-28. - Vest transceiver.

FIGURE 2-29. - Vehicular transceiver.

ears from epaulet speakers. A hinged control head is conveniently located on the front. The design allows the miners to maneuver in tight quarters and perform normal mining tasks without catching the radio on obstructions.

The vehicular unit can be conveniently placed on any mine vehicle. It is used in conjunction with a special loop antenna of advanced design that produces high magnetic moment. Mechanically, the antenna is enclosed in high strength lexan and is attached to the vehicle via special brackets. The lexan will not break even if severely flexed by impact.

Besides the mobile transceivers discussed above, the system also consists of fixed transceivers such as repeaters and base stations. (See figures 2-26 and 2-27.) For proper system operation it is necessary that these fixed transceivers have very efficient antennas so that the local wire plant can be properly illuminated and signals on the wire plant are properly received. This efficiency is paramount for whole-mine coverage.

The cellular repeaters use dual-loop antennas (for transmit and receiver) attached to the rib or posts in such a way that there is little danger of damage in normal mine activities. The transmit antenna produces a large magnetic moment that provides the signal for local cellular coverage, which is usually aided by parasitic coupling and reradiation effects. The receive antenna is similar.

The global repeater and base station use a newly designed RF line coupler (see fig. 2-30) that permits very efficient coupling to the mine wire plant. Like a current probe, the coupler can be easily clamped around local conductors. MF signal current flowing through the wire plant conductors produces a coupler output signal (V_0), which is applied to the input of the base station or repeater.

The base station is intended to be placed where mine management finds it most advantageous, usually in the surface office complex or with the dispatcher. If desired, the base station can be controlled remotely via signal lines that allow the control console to be placed in a surface building for convenience, while the actual base transceiver is placed in the mine where it can more efficiently couple into the local wiring. Both the global repeater and the base station utilize the RF line coupler for maximum efficiency. The cellular repeater is generally located in a working section. It enables the vest to operate as a mobile pager telephone by switching voice signals between the local pager telephone network and the vest. Vehicular radios can also operate in this mode.

The system was developed around an interchangeable set of plug-in radio circuit modules. The same receiver, synthesizer, and transmitter modules are used in the vehicular transceiver, base station, and repeaters. Servicing the equipment only requires troubleshooting to the board level. Since the equipment uses the same radio circuit modules, the performance specifications of all transceivers are similar. The signaling used depends upon the specific network requirements. All receivers are designed with an adaptive noise-operated squelch network that allows every transceiver on the net to hear the same message (party line).

The transmitters are designed with both subaudible (100 Hz) and in-band (1,000 Hz) tone oscillators. A
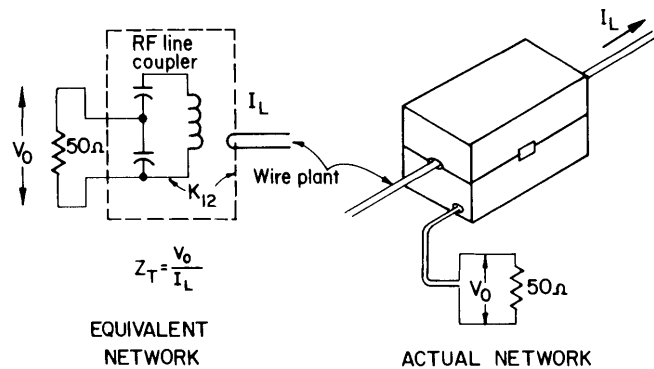
FIGURE 2-30. - RF line coupler for base stations and repeaters.

subaudible tone is used in the vest transceiver to cause the cellular repeater to switch the message (page) to the pager telephone network. The repeater includes both a noise-operated squelch and a subaudible tone squelch for use in telephone switching. Subaudible tone signaling is useful in identifying "stuck on" transmitters that can block the communications net. In-band signaling is useful in emergency situations.

2.5 Hybrid Systems

Each of the communications systems already discussed has some individual shortcomings. However, one system may complement another system to alleviate certain problem areas. A hybrid is an interconnection of two or more subsystems, taking advantage of the benefits of each.

2.5.1 Improvements in System Versatility

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

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

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

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3. Ability to communicate over private channels.

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

5. Ability to communicate with surface public phones.

The following techniques are capable of satisfying the foregoing needs using hybrid systems:

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

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

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

4. Very-high-frequency radio can be used with leaky feeder cable or coaxial cable and antennas, as a technique for guiding radio waves throughout the mine haulageways and entries. This technique can be used to provide whole-mine communications with hand-held radios carried by key mining personnel.

5. Ultra-high-frequency radio can provide wireless communication between key roving miners carrying radios within a working section, without the aid of additional wiring.

2.5.2 Dial Phone-Pager Phone Systems

Interconnect devices are avilable that permit mine paging telephones to be interconnected with the public phone system on a selective or temporary basis. The intent of these systems is to provide greater emergency communication capability during off-hours. These systems enable a person at a mine pager phone to gain access to the public phone system, or permit access to the mine page or phone system from any public phone.

Figure 2-31 shows one system in which the interconnect between public phone and mine phone is made automatically. In this type of system small hand-held tone-generators are required to activate the automatic interconnect at the mine office.

If a person in the mine wants to reach a prearranged public telephone from his mine phone, he sends a tone via the tone generator and mine phone to a telephone interconnect unit of the surface. At this surface interconnect, the tone is detected and activates a relay which, in turn, automatically dials the preset telephone number.
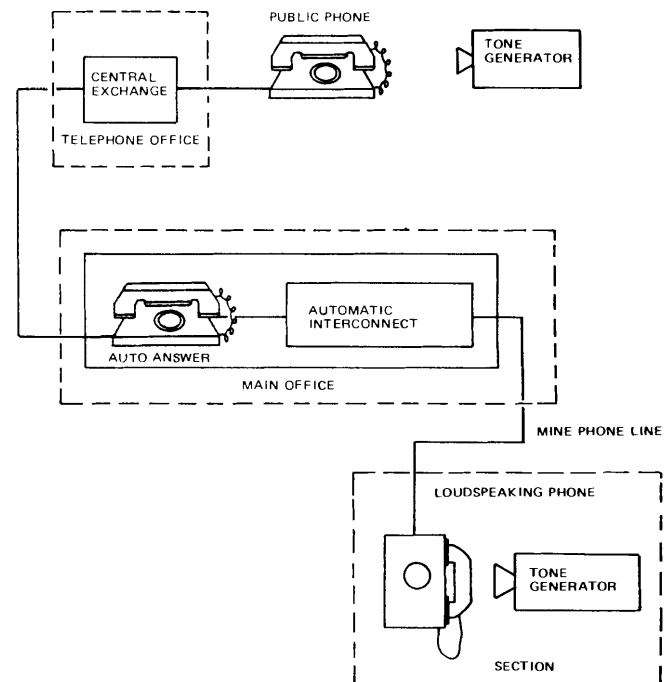
FIGURE 2-31. - Dial phone to pager phone hybrid.

When a person calls the "auto answer" telephone number from a public phone, the interconnect unit automatically answers the phone, and upon reception of the audio tone from the outside party, connects the incoming call directly to the mine pager phone line, thereby enabling the calling person to page and talk to the desired person in the mine.

Systems also exist where the interconnection between the mine phone system and the public telephone system is made manually, such as by a person on the surface.

2.6 Other Systems

2.6.1 Seismic Systems

A seismic system can be used for trapped miner location. If a miner strikes a roof bolt, floor, or rib of the mine with a heavy object, the vibrations travel through the earth to the surface and can be converted into electric signals by seismic transducers called geophones. These signals can be amplified, filtered, and recorded. Because the shock waves reach individual geophones at different times, the seismic recordings can be analyzed and the location of the miner can be determined. Analysis of seismic signals is a highly specialized field and beyond the scope of this manual. This method requires the assistance of an individual trained in seismic methods. However, the seismic system is the only trapped-miner system presently in operation and accepted by MSHA. Every miner should have a sticker (fig. 2-32) affixed to the inside of his helmet that he can refer to if entrapment should ever occur.

2.6.2 Stench System

Stench is used primarily as an evacuation warning. It should be introduced into the underground system at as many locations as possible, with the intake

WHEN ESCAPE IS CUT OFF

1. **BARRICADE**
2. **LISTEN** for 3 shots, then...
3. **SIGNAL** by pounding hard 10 times
4. **REST** 15 minutes, then **REPEAT** signal until...
5. **YOU HEAR 5** shots, which means you are located and help is on the way.

FIGURE 2-32. - MSHA signaling sticker.

air and the compressed air as priority. Wherever miners may be in the mine, driven air is required and eventually the driven air and stench will arrive at their location. Stench may be any clearly distinguishable odor.

The delay time in a stench warning system is one of its most important drawbacks. Another very important negative point is that stench warning cannot inform the miner what has happened, where it has happened, or what he should do. Many times this type of information can be worse than no information at all.

2.6.3 Hoist Bell Signaling

Much of the communication between the various levels of a mine and the hoist room consists of hoist bell signaling. This is a one-way communication system by which miners can request a cage and/or desired level.

In the hoist room, there is a power source for the system and a buzzer. Each shaft station has a buzzer and a pull bottle. The bottle, when pulled, closes a switch that sounds the buzzer in the hoist room and at all other levels (fig. 2-33). The number of times the bottle is pulled corresponds to a command code.
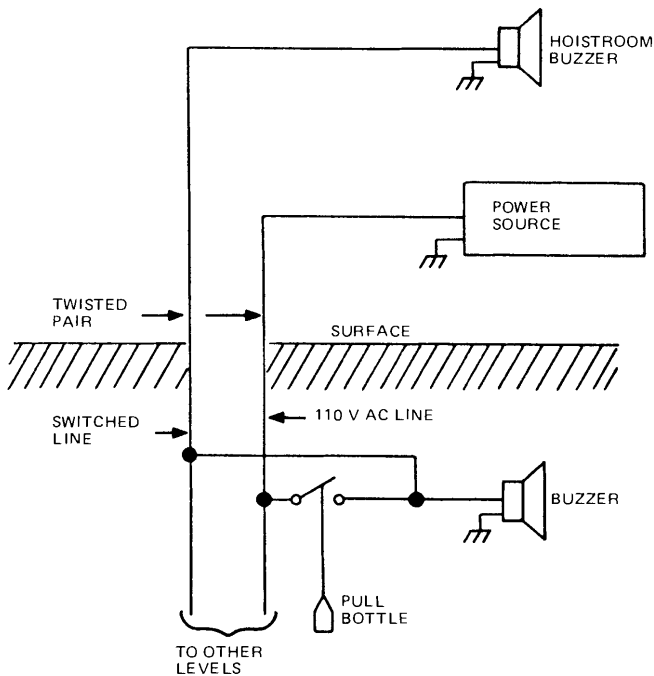
FIGURE 2-33. - Hoist bell operation.

2.6.4 Visual Pagers

One of the most common type of mine communication devices is the pager phone. However, with these systems, many calls are lost because the phone is too far from a working face or the page is not heard owing to high ambient noise. Visual pager systems are being developed that may eventually alleviate this problem.

The most common type of visual pager system consists of strobe lights located at strategic locations in the mine. These lights are controlled by a dispatcher who can set or reset them as required. They are usually used in conjunction with pager phones. Some modern multichannel phones have a light on the face of the phone that provides the visual paging function.

2.7 Summary

There are three basic types of communication systems used in underground mines: wired phone systems, radio system, and carrier current systems. Wired phone systems include common dial telephones, pager phones, dial-type pager phones, magneto phones, intercoms, and sound-powered phones. These may be connected in party line fashion using a two-wire pair, or in selective calling fashion using multipair or multiplex techniques. Wired phone systems may have no switchboard (party line) for small systems, a manual switchboard, an automatic exchange, or a more sophisticated computer-controlled switch. A major disadvantage of any wired phone system is that a roof fall could disrupt communications between miners and the surface.

Radio systems include all wireless communication systems. Coverage is limited in radio systems because of poor propagation of radio waves underground. Voice frequency ranges can be used for through-the-earth radio. Ultra-high-frequency radio can be used when it is combined with leaky feeder cables, antennas, and repeaters to extend coverage. Personal radio pagers can be used to summon an individual to a wired phone.

Carrier current systems utilize existing mine wiring to propagate RF signals. An RF signal from a carrier phone is induced onto a cable and transmitted throughout the length of that cable. A transceiver, inductive or capacitive coupled to the carrier cable, receives the RF signal, strips off the carrier, and lets the electromagnetic voice signal activate a speaker or earphone.

Modern MF radio systems are being developed that combine the best features of radio systems and carrier current systems. In these systems, no physical contact to existing mine wiring is required.

Since one system cannot usually satisfy all the communication requirements in a mine, interfaces have been developed to make hybrid systems. Hybrids (two or more systems interconnected) take advantage of the beneficial qualities of one system to alleviate the deficiencies of another system.

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CHAPTER 3.--SOLUTIONS TO THE COMMUNICATION REQUIREMENTS

3.1 Introduction

Three types of communication systems have become popular in solving communication requirements underground: Loudspeaking pager phones, carrier current phones, and magneto ringing phones. Basically, all three are simply single-channel party line systems. Although these systems are quite reliable, the single channel creates a variety of problems. For example--

1. Since no call is confidential, messages are sometimes purposely made vague, especially if accidents or safety topics are being discussed.

2. A potential user must literally "wait in line" until the channel becomes clear for his use; thus, when foremen have to wait to call in reports or supply requests, this single chan-nel creates a serious productivity bottleneck.

3. In many large mines, there are independent branch lines that must be tied together by a dispatcher, adding further delays to the system.

To solve these problems, some mines have installed other phone systems-- mostly commercial dial phones in industrial enclosures that offer extra channel capacity and private line features. Others have installed a system that combines both dial- and page-phone features in a single unit.

Although these do represent improvements, they do not truly solve the overall problems that face modern mines. Besides extra channels, a communication system should have the following features to enhance productivity and safety:

1. A means of paging a roving miner to alert him that he is wanted on the phone.

2. Wireless-to-wired system interconnects by which a miner can talk on the wired phone system by using a remote portable radio.

3. Remote monitors that alert personnel when there is a toxic or explosive gas buildup.

4. Control interfaces that allow remote control of fans, pumps, or other devices.

5. Transmitters and receivers that can serve as emergency links.

6. Loopback that allows an alternate path of communications if the main path is cut.

This chapter focuses on equipment and methods to meet the special communication needs of individuals in various places of the underground mine. The communication requirements can be broken down into four categories:

1. The mine entrance (shaft communication).

2. Permanent and semipermanent locations (shop areas, lunchroom, crusher stations, etc.).

3. Mining areas (the room-and-pillar sections, longwall faces, block caving areas, etc.).

4. Haulageways (tracked trolley haulage, diesel, belt haulage).

Methods of implementing systems to meet the communication needs of these areas are described in sections 3.2 through 3.5.

Section 3.6 discusses methods of satisfying special communication requirements that exist. Major topics in this category include communications with roving personnel, the isolated miner, and motorman-to-snapper communications.

Emergency communication systems are described in section 3.7. Detecting and

locating the trapped miner, rescue team communications, and emergency warning systems are discussed.

Although the methods of establishing communications throughout a mine are broken down and described in separate sections, as outlined above, it is important to realize that these systems should be tied together or interconnected in some way. The overall design plan must include provision for integrating the various communication subsystems together into a minewide system. Such a system, designed with the total mine operating plan in mind, will be the most effective. In a like manner, a judicious choice of monitored parameters in the underground environment and selected machinery will yield a cost savings in production and augment safety. Many man-hours and dollars can be saved by knowing conditions before they become a problem. Situations that could become disastrous can be predicted and proper solutions implemented before the disaster occurs. Because proper environmental and machine monitoring and control is another key to safer and more productive underground mining, these factors should also be considered in the overall plan of any communication system.

3.2 The Mine Entrance

The entrances to underground mines are either vertical shafts, slope entrances, or horizontal drifts. Slope and horizontal drift entrances can be considered as a continuation of a haulageway and are treated in section 3.5. This section is devoted primarily to shaft communications.

In the past, operators of single-level mines with overburdens less than 1,200 feet have felt that communications between the top of the shaft, the bottom, the hoistroom, and possibly a communications center were adequate. Many mines in this category (which includes most underground coal mining operations) did not have the capability of two-way voice communication with personnel in the cage.

One of the biggest reasons for this deficiency in communications to and from the cage has been that reliable equipment simply was not available for establishing this vital two-way voice communication link. This reason is no longer valid. Today, equipment is commercially available to implement effective two-way voice communication, even while the cage is moving, down to depths in excess of 10,000 feet.

A useful hoist-shaft communication system must satisfy the requirements for communication throughout the full travel of the cage, providing voice communication between the cage and the hoistman, as well as to underground shaft stations. An effective system should also provide for shaft-inspection communication between the inspector and the hoistman, and should have a slack-rope indication. For the modern, automated shaft, signals are also required to permit selection of level, enable interface with interlocks, and permit jogging for exact position at any level.

The limited space within the cage places an operational restraint on equipment. Equipment must be small and should be located so that it cannot be damaged by any of the various uses of the cage such as transporting supplies and machinery. An additional microphone-speaker station may also be desired for multi-level cages or when several cages are joined together.

A reliable hoist-shaft communication system should be considered as a vital part of any overall communication system. Shaft communication is especially important during or following an accident or disaster situation. Experience has taught that the hoist often becomes a bottleneck during rescue or evacuation operations, and good communication to and from the cage is essential.

Traditionally, bell signals have been used between those requesting the cage and the hoistman, and until recently, bell signaling was usually the only form of hoist-shaft communication.

Today, however, equipment is available that allows two-way voice communication between persons in the hoist cage and the hoistman or other locations at the shaft top or bottom.

Presently available methods of implementing two-way voice communication with the hoist cage include trailing cable systems, radio systems, and hoist rope carrier current systems.

3.2.1 Bell Signaling Systems

There was a time when bell signaling was the only form of communication between those requesting a cage and the hoist operator. Because of this, bell signaling systems have gained widespread acceptance and are used on many hoists.

Figure 3-1 shows a simplified schematic diagram of a typical shaft buzzer signaling system. In the system depicted, a single twisted pair wire is run down the mine shaft and "tapped off" at those shaft stations where signaling is required. Figure 3-1 shows a system with the twisted pair tapped at three levels
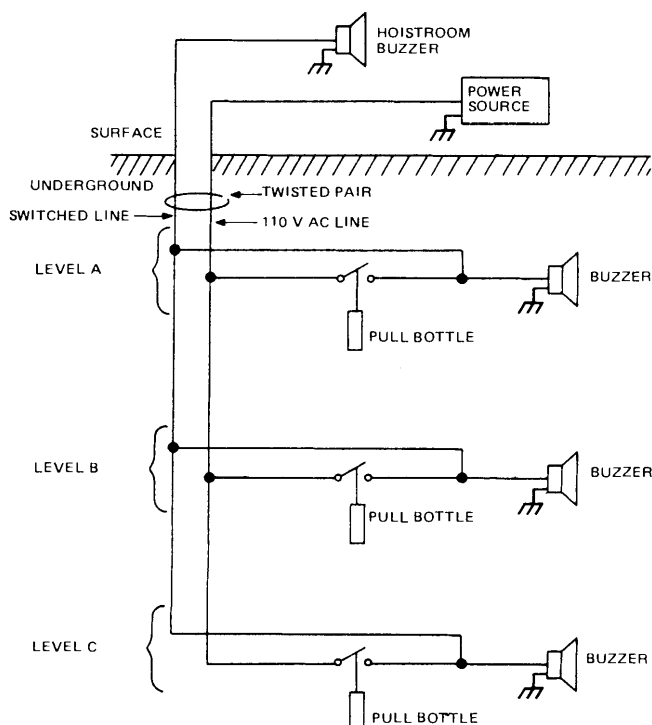
FIGURE 3-1. - Bell signaling system.

(level A, level B, and level C). To signal the hoist operator, a miner at any level pulls the pull bottle, causing the associated switch to close. This applies voltage to the buzzer at that level, and also to the hoistroom buzzer and all other buzzers, through the switched line of the twisted pair.

Bell signaling systems, although proven to be reliable, do have some severe shortcomings. First, there is no way to convey special messages to the hoistman. Special equipment or assistance or unusual cage movements cannot be requested unless a signaling code has been defined for that specific request. A second disadvantage, especially for mines with many shaft stations, is that the bell codes required can become quite long. Long or complicated bell codes are obviously more difficult to remember and can become a source of confusion, especially during an emergency or disaster situation. During these critical periods of high emotional stress, mistakes are easy to make even when signaling codes are posted. Some mines with many levels and/or shaft stations have partially overcome this disadvantage by assigning an employee to the hoist cage. Because this miner, called a cager, is permanently assigned to act as the hoist cage operator, the bell signaling code has become "second nature" to him.

Another disadvantage of the bell signaling system is that communication with the cage is impossible when it is between levels. This deficiency is especially crucial during shaft inspection or repair. Some mines have partially overcome this problem by running a pull cord down the shaft. This cord is kept in a position next to the shaft timbers by staples and can be used for emergency stops and signaling between shaft stations. This system does provide some degree of emergency communication from the cage while it is between shaft stations; however, operation of the system can be extremely dangerous since it requires the operator to reach out of the cage and grab a cord, which may be moving relative to the cage.

3.2.2 Trailing Cable Systems

One method of establishing two-way voice communication with the hoist cage is by using a trailing cable. In this type of system. A communications cable is physically attached to the bottom of the cage and allowed to hang down the shaft below the cage.

Figure 3-2 shows a typical trailing cable system. In the figure, three phones (one in the hoistroom and one at each of the two shaft stations) are connected by a phone line that has been strung down the shaft to a junction box located about halfway down the shaft. Connections are made within the junction box to the trailing cable which provides the link to the phone mounted in the cage. The trailing cable system can be

tied into the existing wired communication system in the mine, or it can be implemented as an independent, shaft-only, communication system.

In addition to the disadvantages associated with any wired communication system (normal cable maintenance and line breaks), the trailing cable system has limitations in terms of depth because of the amount of cable that can be trailed from the cage.

3.2.3 Radio Systems

Another approach to satisfy the voice communication requirements with personnel in the cage is by using two-way radio systems. Some recently installed radio systems are meeting the hoist communication requirements. One radio system currently being used at an iron ore mine is illustrated in figure 3-3. In this system, portable police-type 150-MHz FM radios were used in 19-foot-diameter shafts. The surface antenna is a dipole mounted on plywood bolted to the steel collar at the top of the shaft. A coax runs from the dipole to the hoist room, a distance of about 500 feet. In the cage, the radio and 12-volt battery are mounted in a plywood box.

Results of studies indicate that the attenuation of radio signals increases

TRAILING CABLE

JUNCTION BOX LOCATED ½ WAY DOWN THE SHAFT

FIGURE 3-2. - Trailing cable system.

HEADFRAME ANTENNA

HOISTMAN'S RADIO—CONNECTED TO ANTENNA AT HEADFRAME

RADIO SIGNAL

ANTENNA

RADIO IN CAGE— CONNECTED TO ANTENNA ON TOP OF CAGE
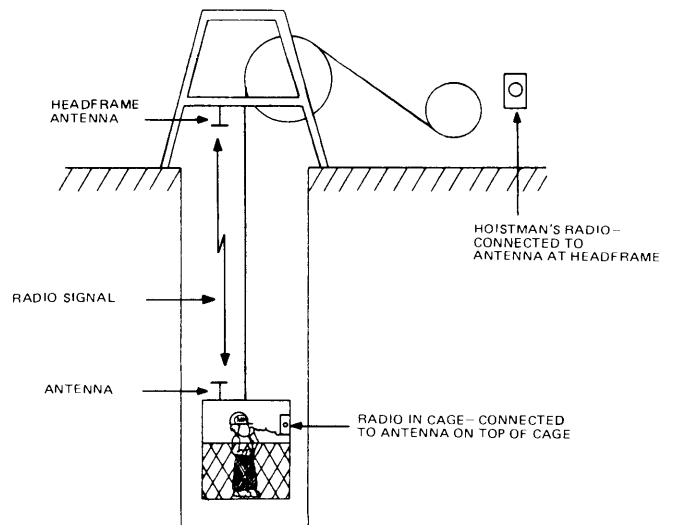
FIGURE 3-3. - Hoist cage radio.

sharply as shaft size is decreased. For straight, unobstructed shafts with a diameter in the neighborhood of 12 feet, radios operating in the frequency range of 500 to 1,000 MHz should provide communication to a depth of approximately 1,500 feet. For smaller diameter shafts, radio communications will only be possible over shorter distances.

3.2.4 Hoist Rope Carrier Current System

A carrier current system using the hoist rope as the carrier has been developed that provides reliable two-way voice communication between the cage (even while in motion) and the hoistman to cage depths in excess of 10,000 feet. The principle of operation of the hoist rope carrier current system is similar to that of the carrier current commonly used in trolley carrier phone systems. Both systems transmit and receive RF energy over a transmission line. In a trolley system, the transmission line is the trolley wire. In the hoist system, the carrier signal is transmitted on the hoist rope. Both systems utilize transmitters and receivers (transceivers) that communicate with each other by RF currents superimposed on a cable.

The principal difference between the trolley carrier system and the hoist rope carrier system is the way in which RF energy is transferred to, and received from, the transmission line. Because the hoistman's transceiver at the headframe cannot be physically attached to (or even touch) the hoist rope, a different method of superimposing RF energy onto the rope must be used.

The solution is to inductively couple the hoistman's transceiver to the hoist rope. Figure 3-4 shows a block diagram of a hoist rope carrier current system. The system consists of two signal couplers and two transceivers. Each transceiver is of the push-to-talk, release-to-listen design. During transmission, the sending transceiver feeds its coupler with an FM carrier. The coupler induces a signal into the hoist rope, which travels up and down the hoist
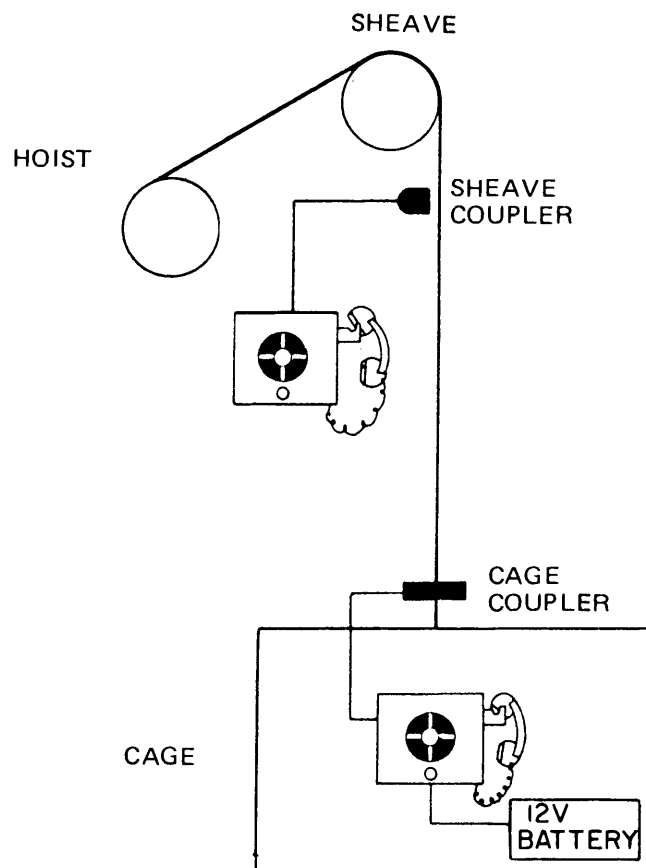
FIGURE 3-4. - Hoist rope carrier current system.

rope and is picked up by the coupler at the other transceiver. Each coupler operates as both a transmitting and receiving element. The cage coupler is clamped to the hoist rope at a point just above the cage. The coupler for the surface transceiver should be permanently mounted below the sheave wheel and about 6 inches from the rope. Coaxial cable should be used to connect each coupler to its transceiver.

3.2.5 Hoist Signaling Summary

The pull-bottle shaft bell has been the universally accepted means of cage signaling. More than 60% of the hoists, notably those in bedded deposit mines, have only one underground level; hence this type of signaling system is simple and effective. In multilevel mines, signaling codes become complex to the point where a full-time cageman may be required to control the cage during all man and equipment lifts. Depending on the size

and nature of the shaft, commercial radio equipment operating at 150 or 450 MHz can provide a voice link down to 2,000 or 3,000 feet.

For a very deep (2,500 feet or greater) or narrow shaft (less than 10 feet in diameter), communication systems are available that inductively couple RF signals to the hoist cable. These carrier current systems provide two-way communication with the cage in even the smallest shafts down to depths in excess of 10,000 feet.

3.3 Permanent and Semipermanent In-Mine Locations

Looking only at the permanence of a telephone installation, phone locations can be divided into the following three categories:

Permanent (life of the mine).

Semipermanent (more than a year between moves).

Frequently moved (weekly to monthly).

Permanent locations include surface sites, the dispatcher's station, underground offices and shop areas, lunchrooms, rail or belt heads, storage areas, the crusher operator, and along main haulageways.

Semipermanent phones would be found mostly in the submains of a mine. After panels have been fully developed, most of the phones in the submain would be relocated to more active sections. One or two phones would remain for use by roving personnel. If a submain became part of the haulage system, in all likelihood more phones would remain in use to meet the operating practices of the mine.

Frequently moved phones are primarily located near the working faces of the mine, typically in working sections off submains. These phones are moved with the section in order to maintain close communication with the dispatcher,

maintenance, and management personnel. Communications equipment associated with advancing or frequently moved face areas is treated in section 3.4.

The single-pair wired phone system is the communication system commonly employed to satisfy the requirements of permanent locations. Magneto phones were first used, but although many are still in use, they have been largely replaced by loudspeaking pager phones.

In a few mines the conventional telephone with a rotary dial and ringer (mounted in an explosion-proof housing) has been used. Systems using these dial phones are usually an extension of an aboveground private automatic branch exchange (PABX) or a single-party independent system with a small switchboard. Recently multipair cable and even multiplex systems have been used to interconnect phones and to connect individual phones to an aboveground PABX.

3.3.1 Single-Pair Pager Phones

Pager phones were specifically designed to meet the requirements of permanent and semipermanent locations for underground mining operations. They differ from a conventional telephone in that instead of a ringer, a loudspeaker is used in each phone to alert the person being called, and each phone has its own batteries for power instead of being centrally powered. In a single-pair installation, the pager phones are interconnected by a single twisted pair of wires and all phones are on a single party line. A 14- to 18-gage copper pair with a neoprene jacket is most often used.

Figure 3-5 shows a hypothetical, moderate-sized room-and-pillar coal mine with an average working section size of 300 feet by 400 feet, and an average panel size of 800 feet by 1,200 feet.

The upper half of figure 3-5 shows the main haulageway, the operational submains, and the working sections and illustrates how a single-pair pager phone

ROOM AND PILLAR PANELS
(800 X 1200 PANELS)

■ SPLICE CASE
⊘ FREQUENTLY MOVED PHONE
○ SEMIPERMANENT PHONE
● PERMANENT PHONE

DISPATCHER   SHOP

SEMIPERMANENT
PHONE IN
SUBMAIN

FREQUENTLY MOVED
PHONE IS KEPT
NEAR THE WORKING
SECTION

PERMANENT PHONE IN MAIN
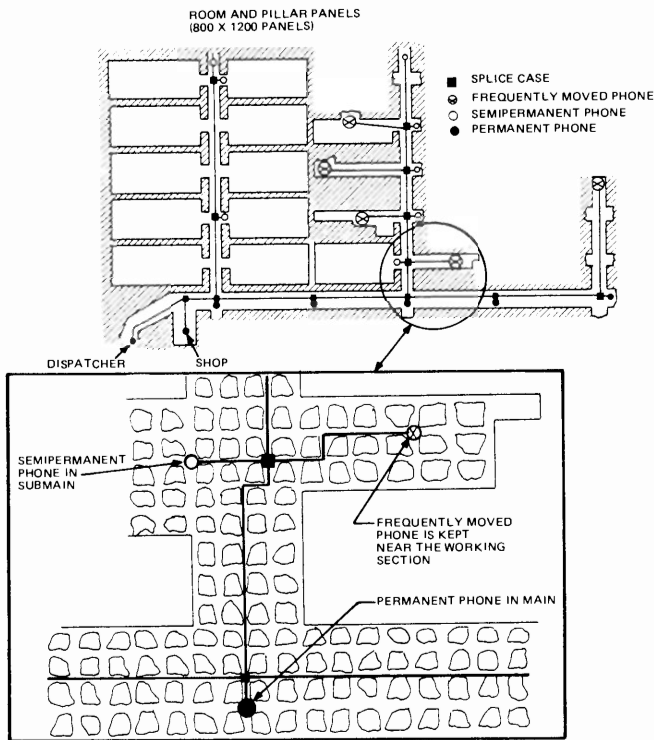
FIGURE 3-5. - Single-pair pager phone installation.

system would be wired. The solid black line represents the single pair. The black squares represent splicing points, and the circles represent the telephones. Telephones can be seen at the dispatcher's office, in the underground shop area, and along the main haulageways; there is one at each butt entry and one near each working section, and a twisted pair is shown running to the pager phone at each working section. When a panel is worked out, the phone at that butt entry may be removed and installed at another location. Usually, as shown in figure 3-5, a few phones are left behind along the submains in worked-out sections. These phones may be used periodically by roving maintenance personnel or inspectors.

A mine is not static; its architecture or layout changes, but fortunately these changes are usually known well in advance so that cable selection and the phone line layout in the mine can be planned to accommodate future growth. As far as changes are concerned, the phones shown in the example of figure 3-5 fall into the three basic categories as follows:

1. Telephones in the dispatcher's office, shop area, and main haulageway, and opposite each submain, would rarely, if ever, be moved (permanent).

2. Telephones opposite each butt entry would remain in place for one year or so until more panels in the submain have been developed (semipermanent).

3. Mine safety regulations require that a communication link must be established within 500 feet of the working face; hence, telephones at the working sections are required to be moved frequently (perhaps once a week).

3.3.2 Multipair Systems

For a multipair access installation (fig. 3-6), planning for future mine growth becomes important. The figure shows an example of how a multipair system may have grown in our hypothetical mine, which has four working sections (A, B, C, and D). In this example, when the system was installed, working section A did not exist, so three-pair cable was used to give sections B, C, and D private lines. (The telephone at the working face is an extension of the butt entry phone, which may not be reasonable in low coal.) When section A came into operation, either more cable had to be installed or more telephones had to be converted into extensions without private lines. Figure 3-6 shows that six-pair cable was run along the main haulageway, so that at this stage of development, several telephones were forced to share a pair.

Several telephones are extensions, and as long as that is a satisfactory condition, six-pair cable in the main haulageway is sufficient. However, if the objective is to provide every telephone with its own pair (which really is the point of a multipair dial access system), additional cables have to be run down the main haulageway. The lesson, of course, is to keep future needs in mind when planning cable layouts, particularly in areas like main haulageways and maintenance areas where telephone locations are unlikely to change for many years.

44
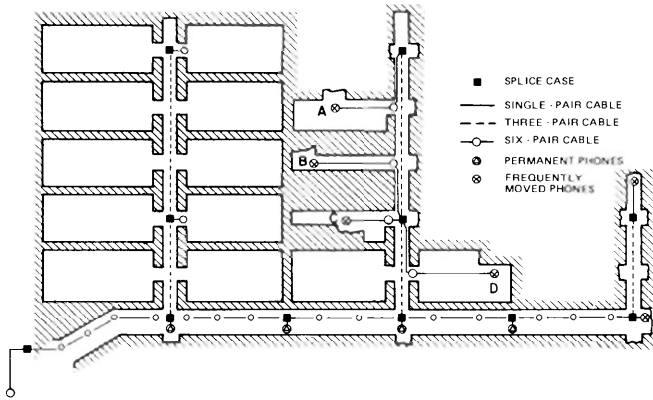
FIGURE 3-6. - Multipair installation.

Figure 3-7 shows details of the multipair system; once again, the three categories of telephones--permanent, semipermanent, and frequently moved telephones--can be seen.

3.3.3 Multiplexed Systems

Various types of multiplexed systems can also be implemented to satisfy communication requirements of permanent and semipermanent locations underground.

One system using multiplex equipment and a small PABX has been installed in a deep, multilevel, metal mine in the Western United States. This system utilized an existing twisted pair already strung through the mine to establish two seven-channel private communication links. A simplified diagram of the system is shown in figure 3-8.

The single twisted pair utilized by the systems extended from the surface, down shaft A to the 3,700-foot level, horizontally through a 5,000-foot-long
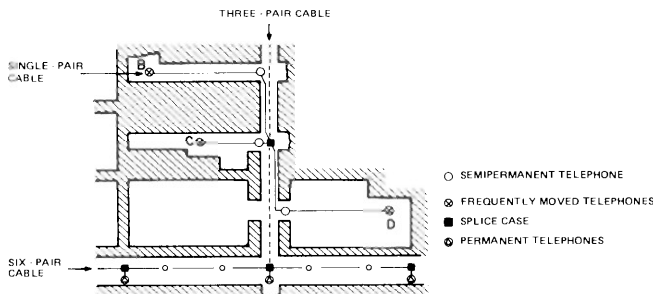
FIGURE 3-7. - Detail of multipair.
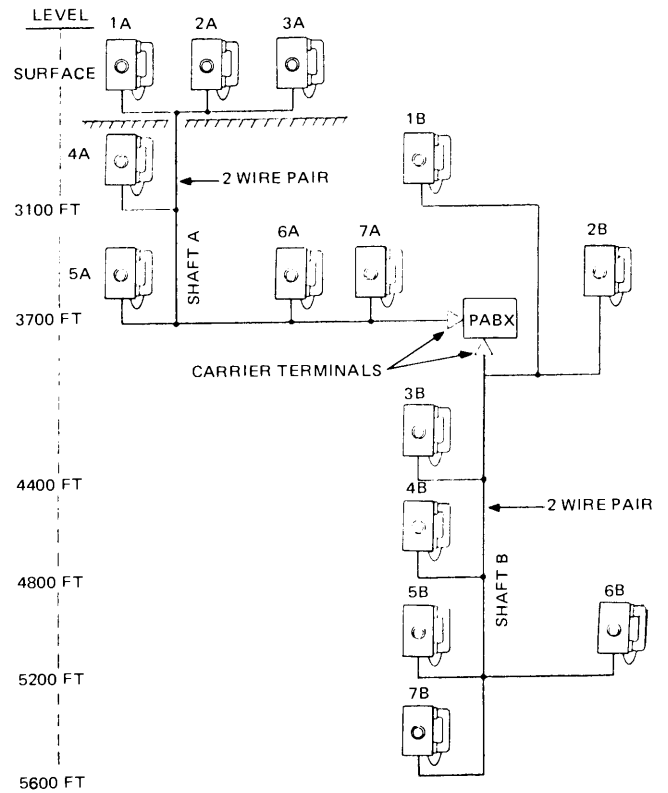
FIGURE 3-8. - Multiplex system with PABX.

drift to the underground headframe of shaft B, and then down shaft B to the 5,600-foot level. An air-conditioned room was available in the shaft B area at the 3,700-foot level that met all environmental requirements of commercially available PABX systems. Additionally, this location was approximately centered with respect to the physical locations of the desired phones. The single twisted pair was opened at this point, thereby forming two independent wire pairs (one running back to the surface, the other running down shaft B). A carrier system was then installed on each pair, and these two independent carrier systems were then connected to the PABX line circuits. This provided 14 private channels (1A through 7A and 1B through 7B) for communication within the mine. This system (described in more detail in appendix A), not being intrinsically safe, is not suitable for use in coal mines.

Presently, there is no intrinsically safe multiplexed telephone system designed for mine use that is commercially

available. However, the Bureau of Mines is developing such a system. This system provides eight full duplex channels, some of which can be dedicated to monitor and control functions. The system uses inexpensive twisted shielded pair and is not under control of any central switching or control center. Because of this, the system will not be made inoperative because of a cable break or a central PABX failure. Other features include a message-leaving light on each phone, low-battery indicators, and compatibility with standard loudspeaking pager phone systems.

3.4 Mining Area

Safety regulations require that a communication link must be established within 500 feet of the working face. In coal mines a butt entry portable phone meets that requirement at the beginning of a panel's development, but a frequently moved section phone must be installed once the face has moved 500 feet from the butt entry phone. Weekly movement of the section phone might be necessary to keep the section foreman within range.

Under normal operating conditions the section foreman communicates by fixed phone to the shift foreman to request supplies and maintenance services, and to file his periodic productivity reports. Under emergency conditions he requests medical aid for personnel and reports hazardous conditions in his area. His primary concern is the safety and productivity of his crew.

The high acoustic noise level created by the mining machinery greatly reduces the effective communications between the foreman and his crew. This noise also interferes with the foreman receiving calls. Often a motorman must deliver a call-in message to the foreman when he is transferring haulage cars in his section. A standard procedure in some belt haulage mines is to turn off the conveyor system, thereby causing all the section foremen to call in. The working section crew primarily depends on the fixed pager phone system for direct

communication with other parts of the mine.

Most existing mine communication systems stop at the last open crosscut of the section. Present mine communication systems are aimed at satisfying the need that the mine section foreman be able to communicate with the mine shift foreman. However, in some mines there may be additional communication needs within the mine section. Needs that are not adequately met include communications between the continuous miner operator and the shuttle buggy operators, between the shuttle buggy operators and the "gathering" locomotive operator, and between the general maintenance foreman and the section maintenance man repairing a machine. By satisfying these needs, both the safety and efficiency of mining operations can be improved. The existing power trailing cables to the face machine provide one means to achieve these communications capabilities in a reliable and economic manner. Another method of establishing voice communications between miners working at the face is by a radio system.

The operational and safety advantages of communication capabilities are several and diverse. The shuttle buggy operator will be able to alert the continuous mining machine operator of an impending roof fall. The shuttle buggy operators will be better able to coordinate their activities as they go in to dump on the belt or into the cars. The maintenance mechanic will be able to communicate with the surface while working at a face machine. When maintenance on a face machine is required, the maintenance mechanic can be called directly from the troubled machine.

3.4.1 Radio Systems

The use of two-way radios can result in better coordination of section activities, especially during the movement of mobile machines that must work in concert with each other at the face area. In many cases the operators cannot see one another, but with a system of

communications they can still effectively work together. Safety will also be improved by better communication with isolated workers; 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 or on longwall sections. Repairmen, mechanics, and utilitymen can be quickly reached and dispatched to their place of need at the time of need. In spite of these advantages, two-way voice communication using portable radios is only now becoming practical for use in underground working sections. This has been due to the limited range that could be attained using the small handheld units.

Almost anyone who has ridden in an automobile is familiar with the radio fade that occurs when a car enters a tunnel. One might expect, then, that radio wave propagation would be very poor in mines, and it is still not feasible to design practical "wireless" portable radios capable of full mine coverage, except possibly for the smallest mines. However, both theory and experience show 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 MHz, tunnel propagation is adequate 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 better radio wave propagation. Figure 3-9 shows a comparison in the ability of 450-MHz UHF radio waves to propagate in high coal (7 feet) as opposed to low coal (3.5 feet), assuming a 16-foot-wide entry. The comparison also assumes that 2-watt UHF walkie-talkies are the source of signal. As indicated in figure 3-9, 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.

Corners also present obstacles to the propagation of UHF radio waves. 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, propagation 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 cross-sectional area of the tunnels or entries. Table 3-1 shows that when shuttle cars are present, the range is typically reduced by 200 feet in high coal and by 50 feet in low coal.

At 450 MHz

Radio path	High coal	Low coal
Straight line	1500 ft	400 ft
Around but near one corner	900 ft	300 ft
More than 20 ft around one corner	400 ft	200 ft
Second corner	Poor penetration	
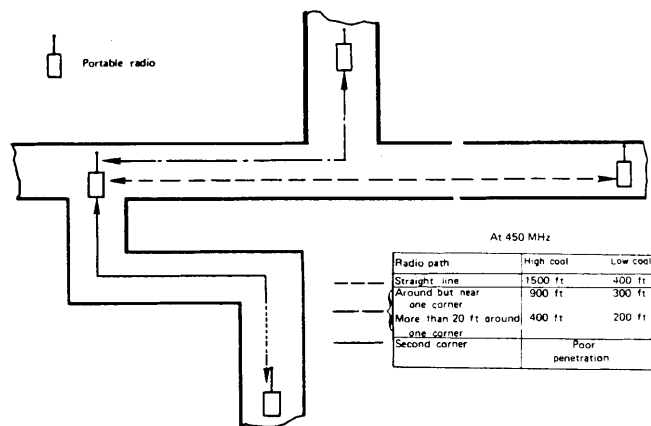
FIGURE 3-9. - UHF radio wave propagation in high and low coal.

TABLE 3-1. – Typical range reduction due to tunnel obstructions at 450 kHz

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

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. Referring to figure 3-10, 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 it 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 be installed in the tunnel to pick up and carry the signals to and from the repeater and portable radios. Figure 3-11 shows a sample cable installation for use with the repeater. In this case, the signals from radio A are picked up by the radiating cable itself, carried to the repeater, retransmitted as F2 signals onto the cable, carried along by the cable, and leaked into tunnels where they are received by radio B. The reverse occurs for transmission from B to A.

Even though a radio repeater such as shown in figure 3-10 can extend the operating range of radios A and B, this still provides only local coverage such as a working section. However, a radiating cable-repeater system such as shown in figure 3-11 can extend the operating range for many miles. The limiting factor in this case is the ability of a radio to transmit to and receive from the radiating cable.

The implementation of a UHF radio system for a mine working section can be approached from the standpoint of a basic

FIGURE 3-10. - Extending range with radio repeater.
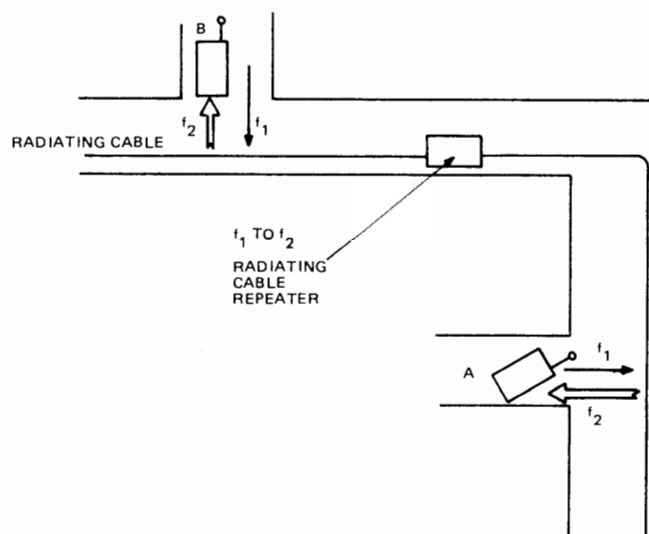
FIGURE 3-11. - Extending range with radiating cable.

"building block" philosophy as shown in figure 3-12. The fundamental building block is the UHF walkie-talkie radio itself. Several of these are sometimes all that is required for an effective sectionwide 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 may be necessary to extend the range of communications beyond that achievable when transmitting directly between portable 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 receives weak signals from distant radios and retransmits them at full power. Further enhancement is possible by connecting the repeater to its antenna by means of a long length of special "radiating" cable that can be run through areas of poor coverage, such as the area along a longwall chockway. Radiating cable, also known as leaky coax or leaky feeder, allows signals to leak out of or into itself at a controlled rate. It effectively behaves as a long antenna that can guide radio waves around corners and bends.

For a more comprehensive system, an interconnect may be installed to interface the radio system with other communication systems, such as a pager phone or carrier phone system. This would be useful 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 radio interconnect is commercially available.

UHF section radio has been used successfully on room-and-pillar working sections at several mines. One such mine had a single conventional room-and-pillar section as shown in figure 3-13. 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 radios operating on two channels, 454 and 457 MHz. The purpose of the repeater was twofold: (1) To extend coverage beyond the direct portable-to-portable range,

FIGURE 3-12. - UHF radio system "building blocks."
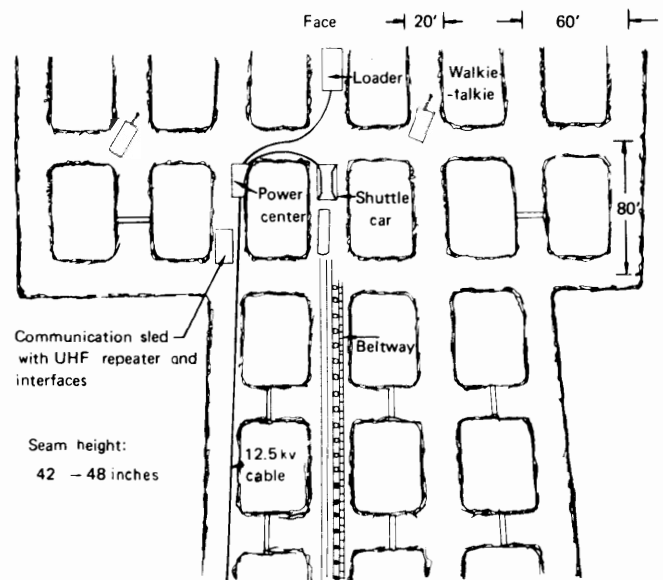
FIGURE 3-13. - Section layout of room-and-pillar section.

and (2) to provide an interconnect between the radio system and a system of carrier 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 radios 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, as shown in figure 3-14. At this mine the portable radios by themselves were usable over an area encompassing more than half of the working section. With the repeater, sectionwide radio coverage was possible.

A similar system was used at another room-and-pillar mine utilizing continuous mining machines. This section radio communication system also included machine-mounted carrier phones and a surface-to-section interface at a communication sled. Conditions at this mine were much more favorable for radio communication,

FIGURE 3-14. - Radio link between surface and communication sled.

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; however, this could be rectified by extending the repeater antenna toward the face area by means of a coaxial cable.

3.4.2 Longwall Mining

With investment in a longwall face being in the millions of dollars, and production delays amounting to hundreds of dollars a minute, positive control and communication must be obtained. A representative longwall face crew might comprise a foreman, two shearer operators, three chock advance miners, one or two mechanics, a headgate operator, and one miner at the tailgate. Voice communication is frequently required between each of these crew members and between the headgate and tailgate. Since miners at the face must work under rather crowded conditions, starting and stopping the conveyor and mining machines are particularly crucial operations. 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 required. Good communication will improve the capability of describing and locating problems and coordinating maintenance efforts to reduce downtime.

Figure 3-15, 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 a phone placed along the face. Acoustic
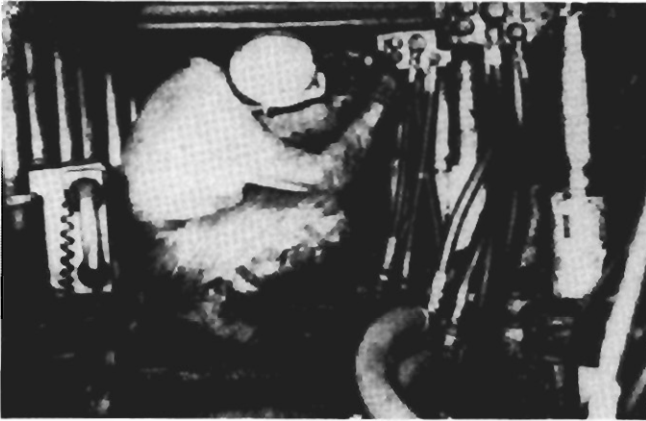
FIGURE 3-15. - Typical conditions encountered in longwall mining.

noise is also very high. Therefore, a communication system designed specifically for longwall mining applications should meet the following requirements:

1. Minimum size.

2. Rugged.

3. Direct acoustic sound along the face.

4. Rugged cable and connector design to survive in the 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 phone system.

U.S. longwall faces commonly use standard U.S. pager phones as a means of implementing interface communication. However, these systems do not provide an adequate face communication system. Major problems are as follows:

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

2. Miners on the face may 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 is required laterally along the face, and U.S. pager phones have not been designed with this in mind.

Several European systems, however, are available that have been specifically designed for longwall applications. Figure 3-16 shows one type of phone, which has already been installed in a few U.S. longwalls and is reportedly well accepted. Figure 3-17 shows the main control unit, which is installed at the headgate. Some of the features of European longwall pager phone systems are pull-wire signaling, machinery lockout 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 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
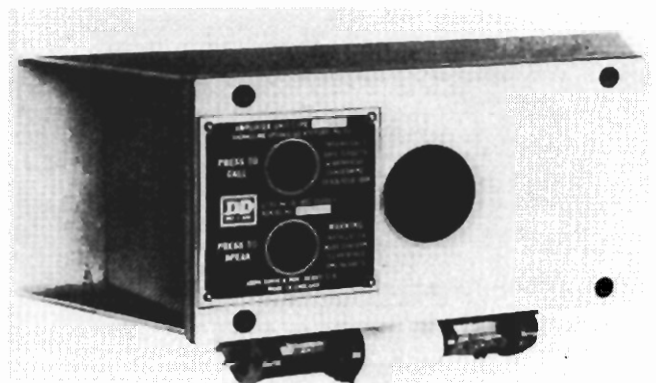
FIGURE 3-16. - Longwall phone.
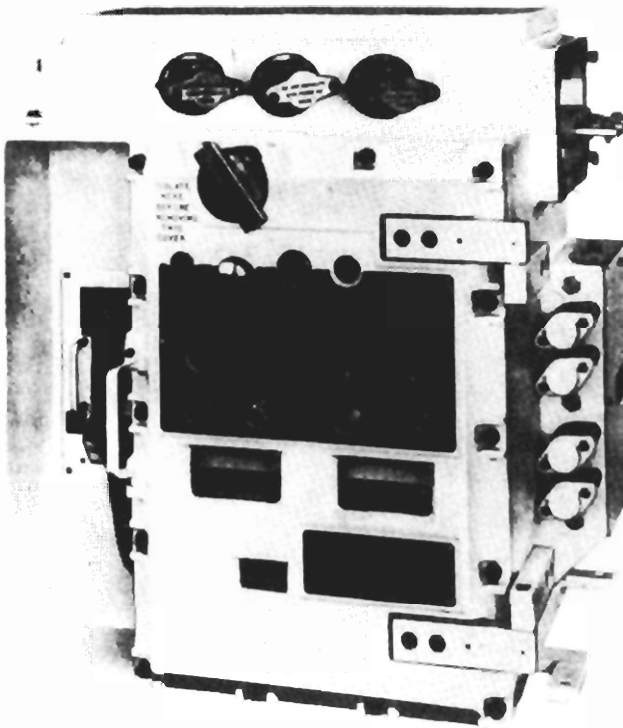
FIGURE 3-17. - Main control unit.

FIGURE 3-18. - Repeater-based UHF radio system layout for longwalls.

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 ($1 to $2 million), a proper understanding of the value of a good phone system in reducing downtime indicates that these systems are still worth considering.

With any system, certain individuals should be able to communicate from any location along the chockway without the fatiguing ordeal of crawling to a phone. This requirement cannot be totally met by any wired phone system, and with some exceptions wireless radio for longwalls

is not feasible at ultrahigh frequencies. Table 3-2 summarizes the important points regarding the design and implementation of a longwall UHF radio system. However, cable-aided UHF radio is feasible and may be another choice for obtaining the linear tunnel coverage required on a longwall section.

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, may be needed on longer faces, or when coverage to the head entry outby the headgate is required. A repeater-based configuration for a longwall UHF radio system is shown in figure 3-18. 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 MSHA approved (fig. 3-19).

TABLE 3-2. - Ranges of completely wireless communication system for longwalls at 450 MHz

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

52
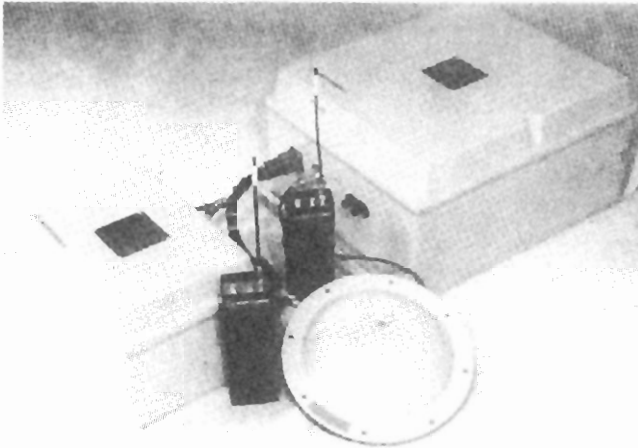
FIGURE 3-19. - MSHA-approved UHF repeater and battery unit, with "hardhat" antenna and portable radios.

3.5 Haulageways

Operators of vehicles in underground haulageways must be able to communicate with one another and with other areas in the mine to improve safety and increase production.

The type of systems that can be implemented to meet the communication requirements of underground haulageways depends upon the method of haulage itself. From the standpoint of communications, haulage systems can be considered as either trolley or nontrolley.

Trolley haulage, as used in this manual, means vehicles that are tracked (ride on rails) and are electrically powered from an overhead trolley wire. In mines using this type of haulage, a carrier phone system using the trolley wire is almost always used to satisfy the communication requirements. The trolley wire and tracks serve as the carrier current path. Methods, techniques, and ways of improving carrier phone systems are given in section 3.5.1. Special control, monitoring, and communications requirements involved when moving off-track equipment under an energized trolley wire are described in paragraph 4.4.3d of chapter 4.

All other forms of haulage systems are grouped into the nontrolley category.

The reason for this is because the solutions to the communication requirements in these systems are similar. Nontrolley haulage systems include the following:

Rail vehicles with self-contained power sources (battery or diesel powered).

All rubber-tired vehicles.

Communication systems applicable to nontrolley haulage systems are described in section 3.5.2.

3.5.1 Trolley Haulage

As previously mentioned, carrier phones are usually used to satisfy the communication requirements in haulageways where rail vehicles that draw power from an overhead trolley wire are used. One reason carrier phones have become so popular is that they operate over the existing trolley wire dc power circuits to provide two-way voice communication between the tracked vehicles and with fixed stations in the mine. No additional wires or cables must be installed in the mine. In underground mining, these carrier systems are used extensively for traffic control of the tracked haulage equipment and personnel carriers. These phones are FM push-to-talk transmitter-receiver units designed for common talk (party line) operation.

Carrier frequency couplers consisting of bypass capacitors are used to provide continuity of the RF signal path between sections of trolley served by different dc power centers. These carrier systems typically operate in the 60- to 200-kHz range. (See section 2.4 for basic theory of operation of carrier current phone systems.)

The carrier phone located on each tracked vehicle is primarily used for control of vehicle traffic. All vehicles are kept in communication with each other and the dispatcher over the single-channel (party line) carrier phone system. This single-channel network keeps the dispatcher and all motormen in

continuous contact with one another so that right-of-way and the disposition of haulage cars will be known to all. One inherent advantage of the trolley carrier phone system is that it is a party line system. In certain applications, this would be a disadvantage since private communication channels are not available. For haulageway traffic control, however, it is beneficial if each motorman does hear conversations between other motormen and the dispatcher. This phone system also allows the dispatcher to notify all motormen of any mine emergency. The two drawbacks to this system follow:

Trolley wire power failures, which cause the carrier communication system to go dead unless backup batteries are installed.

Dead zones, which are sections of track where the phone is inoperative due to excess electrical noise, excess attenuation of signal strength, or standing wave effects.

The first drawback, loss of communication due to power outage, can be corrected by the use of backup batteries in each vehicle (required by law if the carrier current system is the only communication system in the mine). The backup batteries would normally be trickle-charged to full capacity and then maintained at full charge. In the event of a power failure on the trolley wire, the backup batteries would automatically power the carrier phones and allow for voice communications for many hours. Because the haulage system is vital to mine operations, extended power outages on the trolley line are not tolerated. Any trolley power failure is immediately recognized and corrected as soon as possible. Thus, communication outages due to power failures are minimal.

The second problem associated with some carrier phone systems is that of "dead zones." There are areas where two-way communication between a vehicle and a dispatcher or between vehicles is not possible. Dead zones are caused by extreme attenuation of signals, excess noise, standing waves, and/or inadequate

squelch control. The most significant of these causes is the extreme attenuation of the carrier phone signals on the trolley wire-rail. The trolley wire-rail is a poor radio frequency transmission line for several reasons, the most dominant of which is the presence of many bridging loads between the trolley wire and rail. Branches and the lack of good electrical terminations contribute to the problem as well. The bridging loads, which both absorb and reflect power, comprise such items as personnel heaters, rectifiers, pumps, haulage vehicles (motors), locomotive and jeep lights, insulators, signal and illumination lights, and even the carrier phones themselves.

Because of the importance of good communications in the haulageways and because a large number of mines use carrier phones to meet these requirements, many programs have been sponsored to improve trolley carrier phone systems.

One program was designed to (1) identify poor performance of trolley carrier phone systems, (2) assess the causes of poor performance and classify them on the basis of equipment, coupling, or transmission problems, and (3) propose and verify the means to overcome these problems.

Figure 3-20 illustrates the signal-attenuation rate for an "unloaded" trolley wire-rail transmission line; a band of rates is shown because the actual rate depends on the conductivity of the surrounding medium. If an attenuation rate of 1 dB/km is used, a trolley carrier phone line having an allowable transmission loss of 70 dB (from 25 volts to 8 millivolts) yields a communication range of 70 km (43 miles). This performance, in the absence of bridging loads, can be compared with that of a sample trolley wire-rail loaded as illustrated in figure 3-21. Here, just three bridging loads of modest value (typical of vehicles and personnel heaters) reduce the signal 55 dB over a distance of just 4,500 feet. The figure also shows the signal level that would exist over the same distance on a properly terminated
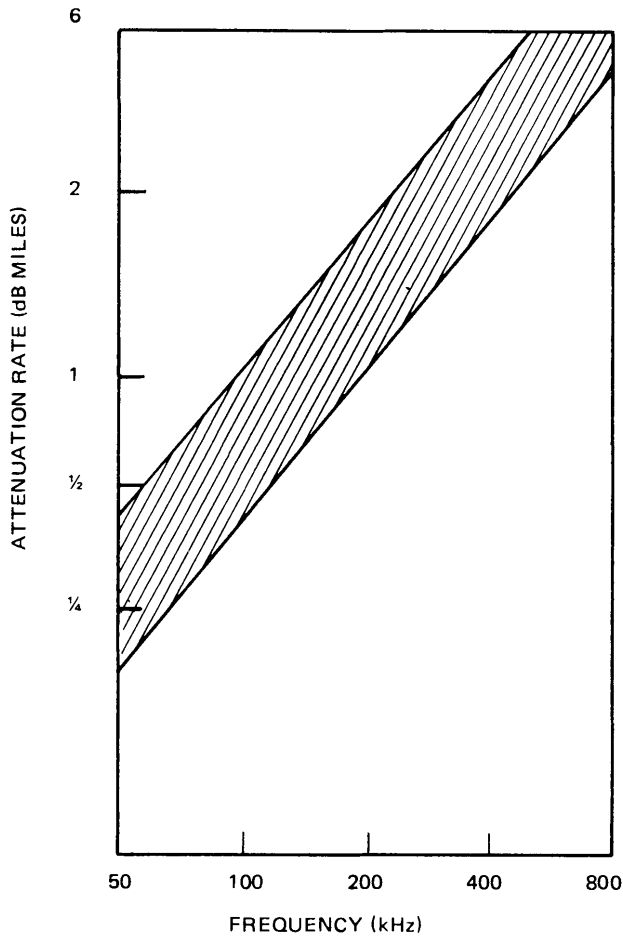
FIGURE 3-20. - Signal-attenuation rate for an "unloaded" trolley wire-rail transmission line.

FIGURE 3-21. - Signal level on simulated trolley wire-rail.

trolley wire-rail without bridging loads. With such signal reductions, it is easy to see why it is difficult to obtain long-range transmission of carrier signals using the trolley wire.

There is one approach that appears to have merit in overcoming the exceptionally high attenuation rates that can be expected on the trolley wire-rail—the dedicated wire technique.

3.5.1a Dedicated Wire

The best approach to overcoming the extremely high attenuation rates imposed by bridging loads is a single-purpose, or "dedicated," wire. The characteristics of an unloaded trolley wire-rail are such that it forms a low-loss transmission line. Therefore, a separate wire strung in an entryway, with the same rail return

path as the trolley wire but unloaded by any bridging loads, would similarly serve as a low-loss line. Such a configuration forms a three-wire transmission line.

Studies have shown that the primary mode of propagation for such a configuration is a low-loss mode supported by the dedicated wire, with the rails serving as the return signal path. The signal improvements that can be expected from such a configuration are illustrated in figure 3-22, which shows the voltage signal strength versus the distance along a heavily loaded trolley wire-rail with a parallel dedicated wire.

Four separate conditions of transmission and reception are shown in
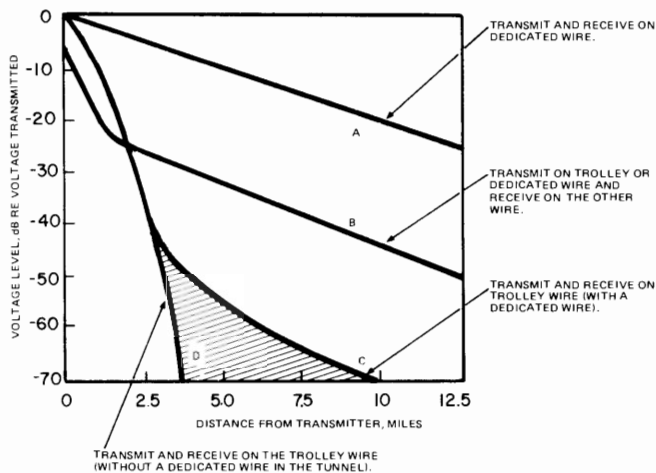
FIGURE 3-22. - Voltage signal strength versus distance along heavily loaded trolley wire-rail with a parallel dedicated wire.

figure 3-22. For example, if the dispatcher transmits on the dedicated wire and the motor operators receive on the trolley wire, then the dispatcher's transmission will produce a curve of trolley signal level versus distance like curve B. At a distance of approximately 12.5 miles the dispatcher's signal shows only a loss of 50 dB. The remaining signal level is entirely adequate for operation of the carrier phones, since the allowable transmission loss is about 70 dB.

The crosshatched area between curves C and D illustrates the improvement that can be obtained when both the dispatcher and motor operators still transmit and receive on the trolley wire but when a dedicated wire has been installed along the haulageway.

Curve A shows the signal loss between fixed base stations, both of which can transmit and receive over the dedicated wire.

The dedicated wire is installed with no direct connection to the trolley wire-rail; however, a strong electromagnetic coupling exists between the dedicated wire-rail and the trolley wire-rail, simply because of their physical proximity. Thus, the dedicated wire is not jeopardized by direct coupling to the high-voltage trolley wire and is not influenced by its loads.

Tests indicate that excellent results can be obtained with a dedicated wire. The dedicated-wire concept permits installation of a transmission line with controlled branching that can be terminated to avoid standing-wave patterns. The price paid is that the wire has to be installed and maintained in a haulageway.

A recent study (26)[1] recommends that the dedicated-wire method is usually the most effective and practical way of upgrading trolley carrier phone systems.

. Another research program provided a set of five guidelines for operating personnel to improve their carrier phone systems. These guidelines give detailed instructions for installing trolley carrier phone equipment onboard mine vehicles and at the dispatcher's room, converting a rail haulage trolley wire-rail and feeder system into a functional carrier-frequency-transmission line, checking the performance of the trolley carrier phone system, and using portable test equipment to aid in system maintenance. A detailed description of the conclusions and the recommendations set forth in these guidelines are presented in chapter 6 of this manual.

Rather than offering detailed comments on the contents of each of these guidelines here, we focus on just one aspect of the guideline concerned with converting the trolley wire-rail into an efficient transmission line. In the preceding discussion on the causes of poor performance, the extremely poor propagation characteristic of the trolley wire-rail was cited. Apparently, this poor propagation dominates in determining the performance of trolley carrier phone systems. Thus, it is appropriate that serious consideration be given to determining the signal and noise levels on each trolley wire system. Signal strength and

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[1]Underlined numbers in parentheses refer to items in the bibliography at the end of this chapter.

electromagnetic noise level measurements should be made at points along the trolley and noted on a mine map. The procedure is simple. The dispatcher's transmitter is used as the signal source, and both the strength of the signal along the haulageway and the corresponding noise level are measured. This measurement is conveniently made by equipping a jeep with a tuned voltmeter. The jeep moves along the haulageway, stopping at intervals of about 2,000 feet. The operator calls the dispatcher and asks for a 10-second keying-on of his transmitter. The received voltage on the tuned voltmeter is noted on a mine map, and the noise level is also noted. This map then identifies regions of the mine where excess noise may be the problem, as well as regions where weak signal levels cause problems. The map also aids in identifying the key bridging loads branches, or unterminated lines that can cause problems. This signal- and noise-mapping process is the key to identifying the major causes of poor signal reception in a particular mine.

Once the probable source of difficulty has been identified, the remaining part of the guidelines can be consulted to determine possible ways of treating the problem. For example, if a rectifier is affecting signal propagation, the guidelines provide three different ways to treat the rectifier to reduce the problem.

3.5.1b Summary

Communications with moving tracked vehicles in a rail haulage mine pose a difficult problem. These communications take place from dispatcher to vehicles or from vehicle to vehicle via the trolley line, which is a very poor communications line. As a result, dead spots and high-noise areas can occur anywhere along the line; also, signal strength can decrease simply as a function of distance.

Although trolley carrier phone systems leave much to be desired for haulageway communications, the fact remains that they do represent one practical means of dispatcher-vehicular communications. Most problems associated with these systems are transmission line related; a trolley line was never intended to be a good communications line, and it certainly is not. However, techniques do exist for improving overall communications. These techniques can be easily implemented, and the results are often excellent.

3.5.2 Nontrolley Haulage

An increasing number of both newly developed and older mines have been abandoning tracked trolley vehicles and are conducting their haulage, maintenance, and personnel transport operations with other types of vehicles. Obviously, communications to and from vehicles operating independently of a trolley wire cannot be implemented by the trolley carrier phones discussed in the previous section.

Communication systems required for battery- or diesel-powered rail vehicles or rubber-tired vehicles have one common characteristic. Because these vehicles are not physically attached or connected to any wiring or other conductor in the mine, some form of radio link must be utilized to establish the final voice link with the vehicle. If voice communication exists from a nontrolley vehicle, then an antenna-radio link of some form must be used to replace the direct connection provided by the trolley wire.

Several methods exist for providing communication between nontrolley mining vehicles. Studies have been conducted of high-frequency systems utilizing the so-called leaky-coax cable to carry signals throughout a mine. Other studies in the wireless radio area have shown that at medium frequencies, signals follow the existing mine wiring for great distances.

3.5.2a Leaky-Coax Systems

A leaky coax is a special type of coaxial cable that allows radio frequency signals to leak into and out of itself. With this type of cable, signals can be transmitted to and received from mobile

radio units near the cable. Leaky coax is therefore ideally suited for haulage applications. In effect, the cable guides the radio signals down the tunnel (fig. 3-23). Although signal strength does attenuate along a cable run, repeaters or in-line amplifiers can be used to extend the range of coverage. Several techniques have been used:

1. Borrowing from conventional mobile radio communications practice, individual fixed-base stations can be installed at intervals as necessary to provide the total range, all stations being under a common remote control with the first. Such a system has been in use at a British mine since 1970.

2. A series of one-way in-line repeaters, such as the daisy-chain system shown in figure 3-24, is effective; it does have a slight disadvantage in that

an audio return line is required and, when branches are required, the system can become complex.

3. Multiple-frequency repeater schemes (fig. 3-25) have also been used successfully; the simplest uses one transmitter and one receiver.

Communication benefits of a leaky-coax system are typified by one system developed for an iron ore mine (block-caving operation) using rubber-tired, diesel-powered vehicles. The system chosen to satisfy the communication requirements at this mine consisted of a UHF leaky-coax system. Figure 3-26 is a simplified diagram of the system.

In addition to providing communication to personnel carriers, maintenance and production vehicles, and the ambulance (fig. 3-27), the system provides communications for roving miners, foremen, fan-hole-drill operators, and supervisors. Communication requirements were satisfied by using (1) UHF wireless radio, (2) a radiating coaxial cable or "leaky" transmission line to carry the signal throughout the haulage and subdrifts of the mine, (3) interconnected VHF and UHF repeaters, (4) portable transceivers, and (5) vehicle-mounted transceivers.

FIGURE 3-23. - Cable "guiding" radio signal down a tunnel.
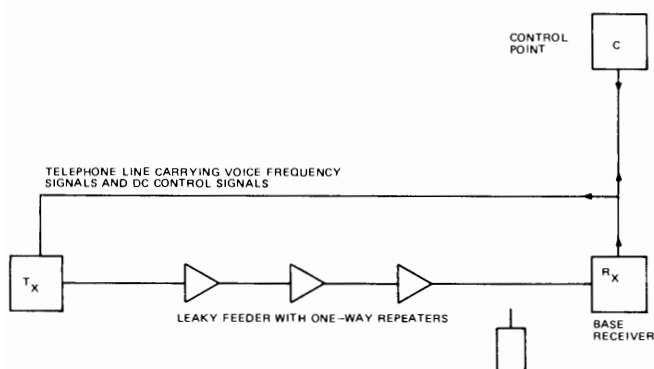
FIGURE 3-24. - Block diagram of a daisy-chain repeater system.
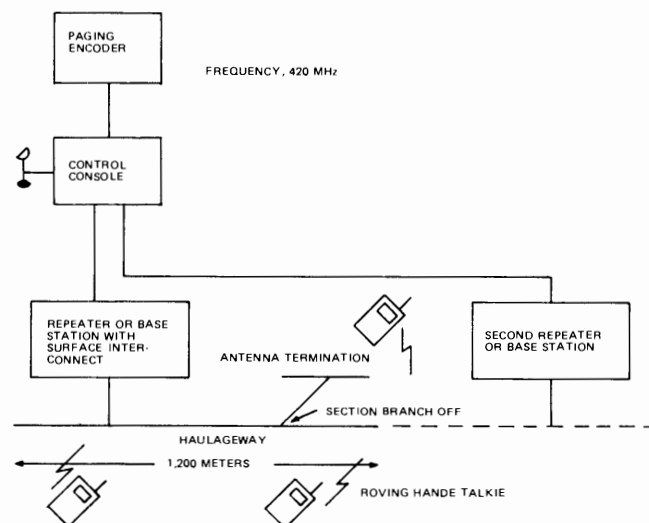
FIGURE 3-25. - Two-frequency repeater concept.
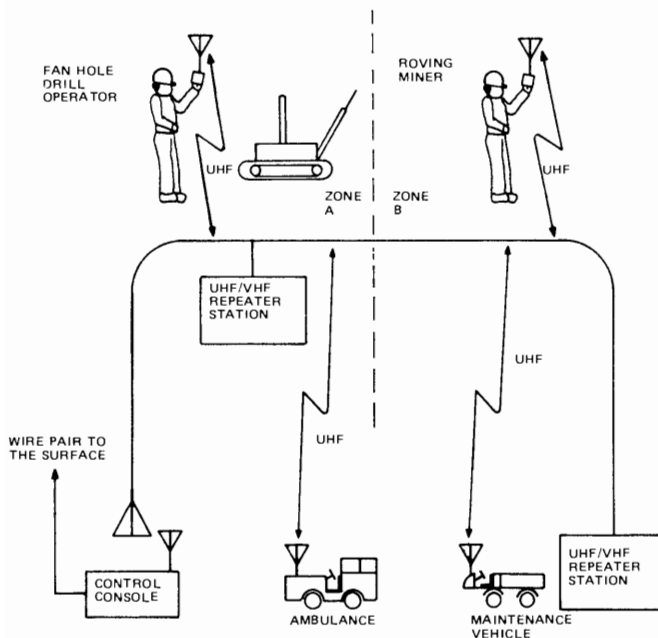
FIGURE 3-26. - RF leaky-coax communication system.

FIGURE 3-27. - UHF mobile radio mounted on underground ambulance.

The mine was divided into two RF regions, with each region (zone) containing one UHF-VHF repeater station and associated runs of leaky coax. The system of cables effectively wires the mine for UHF signals between portable and mobile units. Each repeater station can receive and transmit signals on the cable at both UHF and VHF. VHF signals are used on the cable as a communication link between the stations, while the UHF is used for the communication link to and from the portable and mobile units. The two UHF repeaters transmit on F2 and receive on F1 as shown in figure 3-28. The VHF repeaters use frequencies F3 and F4 to interconnect the two UHF zones. Each UHF-VHF repeater station can simultaneously transmit and receive on both UHF and VHF.

The mobile radios transmit on F1 and receive on F2. All information therefore goes to the repeaters, then back to all other units. The portable radios are also capable of transmitting on F2 and therefore are able to talk to one another without the repeaters on a local simplex basis. Audio control lines are provided from the crusher console to repeater station A and from the surface guardhouse to the shaft bottom station, thus providing system access from two hardwired locations as well as an important emergency link to the surface.

As an example, suppose that a mobile radio in zone A wants to talk to a roving miner equipped with a portable radio in zone B. The operator in zone A keys his radio and talks into his microphone to transmit his message on UHF F1. The UHF signal is coupled to the leaky coax and travels to the UHF-VHF repeater in zone A. Repeater A rebroadcasts the message back to zone A on UHF F2 and also sends the message to the repeater in zone B on VHF F4. This signal travels on the coaxial cable to UHF-VHF repeater B where it is picked up by the VHF receiver. The signal is then converted to UHF F2 and routed onto the leaky coax for distribution in zone B.
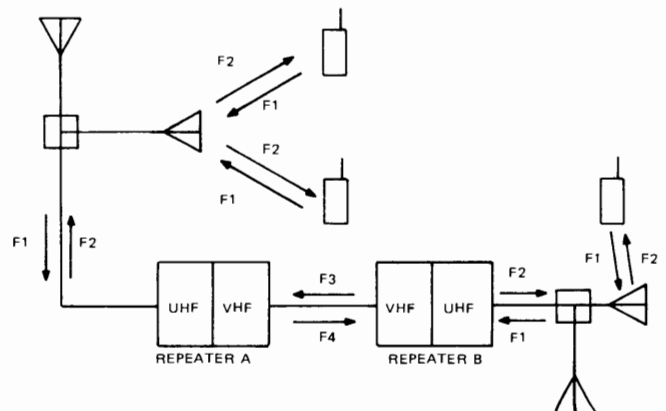
FIGURE 3-28. - UHF-VHF repeater system.

For this type of installation, specifications recommended that the cable be supported every 5 feet. To avoid installing a large number of anchors in the rocks, a 3/16-inch steel messenger wire was attached at 20-foot intervals to roof-bolt-supported T-bars (fig. 3-29). The cable was then strapped to the messenger wire with standard cable ties.

A vehicle-mounted work platform, which could be mechanically raised or lowered and which was equipped with a frame for supporting cable reels, facilitated cable installation. The factory cut the cable to predetermined lengths, installed connectors, and tagged the cable with location identifiers. In mine areas that were so far removed from the main cable that radio transmissions could not be established, a stub cable was installed with one end connected through a power divider to the main cable and the other end terminated with an antenna.

3.5.2b UHF Reflective Techniques in Underground Mines.

UHF radio (300 mHz to 3 gHz) is the only way of achieving true radio propagation in an underground mine. Propagation is possible because the mine entries function as waveguides that confine the transmitted energy. Several thousand feet of range, line-of-sight, is often possible without leaky feeder cables if the entries are large enough.

FIGURE 3-29. - Radiax cable installation on messenger wire.

However, the nature of UHF is such that propagation around bends and corners introduces tremendous signal losses. In this regard, it is similar to the transmission of light and, like light, it can be reflected by flat metallic surfaces. These characteristics of UHF make possible a whole-mine communication system that does not rely on leaky feeder cables. The Bureau of Mines evaluated such a system in an underground limestone mine that had large dimension haulageways. A UHF reflective radio system was designed to allow communication between supervisory personnel, maintenance personnel, haulage operators, and surface operations. Communication was also provided between the hoist operator and slope car occupants. A closed circuit television (CCTV) system allowed continuous, remote visual monitoring of critical belt transfer points and underground dust disposal operations.

The Black River Mine was selected as a typical metal-nonmetal room and pillar mine. It is nearly 4,000 feet in diameter, 650 feet deep, and has essentially straight crosscuts approximately 30 feet wide and 24 to 40 feet high with pillars approximately 35 feet square. Entry is through a 2,200-foot slope by means of a single drum, hoist-powered flat car and enclosed man carrier. Rubber tired, diesel powered mine vehicles travel along designated haulage and travel roads from the active faces on the mine's perimeter to two rock crushers, the shop area, and the base of the slope.

Tests of communication between hand-held, 2-watt UHF transceivers in the room and pillar limestone mine were satisfactory for approximately 2,000 feet through straight haulageways but the range of communication at right angles to haulageways into intersecting crosscuts was quite limited. It was evident that the radiation from the transceivers was not being reflected by the limestone pillars into the intersecting crosscuts.

To improve communication in intersecting haulage roads, 27 passive reflectors were designed and installed at

major intersections. The reflectors were formed from 4- by 8-foot sheets of No. 16 gage soft aluminum sheet that were suspended from wires attached to roof plates and bolt anchors. The roof height was sufficient to allow haulage vehicle clearance at each installation. Two distributed antenna systems were designed to provide either an antenna or reflector at the intersection of principal haulage and travel roads. Each antenna system consisted of approximately 1,200 feet of 7/8-inch low loss foam dielectric transmission line which fed, through 2:1 power dividers, four 5-dB gain mobile whip antennas that were suspended at intersections.

A leaky coaxial cable anatenna system along the principal haulage and travel roads was considered but rejected because the range of communication at right angles to the leaky cable into intersecting crosscuts would have been much less than the range of communication from antennas. The leaky cable system is appropriate for long tunnels but not for intersecting roads in a room and pillar geometry. Also, a leaky cable would be more expensive.

One central, or "backbone" coaxial cable carried 60 Hz power, radio signals, and CCTV signals for the entire system. Redundant routing of the backbone cable insured continued system operation in the event of a cable break.

Fourteen 11-watt mobile radios equipped with automatic identification and emergency alarm encoders were installed on vehicles in the mine. The encoders are used on mine haulage trucks to automatically send three status signals; truck bed up (dumping), truck bed down, and hot engine. This information is displayed by number codes along with the truck's identification number on display units in the engineering office above ground and the mine foreman's office underground. A record of all calls, status, and alarm messages is automatically printed in the engineering office.

Fifteen 2-watt portable transceivers equipped with automatic identification and emergency alarm encoders are used by mine department heads, foremen, and personnel in the mine.

Signal margin measurements of the base-repeater station signals along haulage and travel roads were made after both distributed antenna systems had been completed, which demonstrated that approximately 75% of the mine area received satisfactory signals, but active mining areas along the perimeter of the mine were not adequately served. The distributed antenna system would have to be extended to serve additional antennas near the mine faces. However, the cable attenuation would drastically reduce the power radiated from the antennas and the signals received from the mobiles and portables so that very little improvement would be realized. Additional base-repeater stations were considered; however, the added complexity and cost of multiplexing equipment and for extending the backbone cable control system stimulated the development of a low-cost, two-way multichannel signal booster system. A prototype signal booster was constructed and tested. Six amplifier signal boosters, 10,000 feet of cable, and 16 additional antennas were installed in the mine. Subsequent signal measurements showed adequate coverage of all desired areas.

3.5.2c Dedicated-Wire Radio Systems

It is possible to use trolley carrier current techniques and hardware to communicate with vehicles that do not use a trolley line, such as battery-powered railed or rubber-tired vehicles. However, in this case, a "dedicated wire" is essential for proper operation. Such a system is shown in figure 3-30.

The dedicated wire takes the place of the trolley line. However, since the carrier phone on the jeep communicates with the dedicated wire by a loop antenna, instead of touching it like it
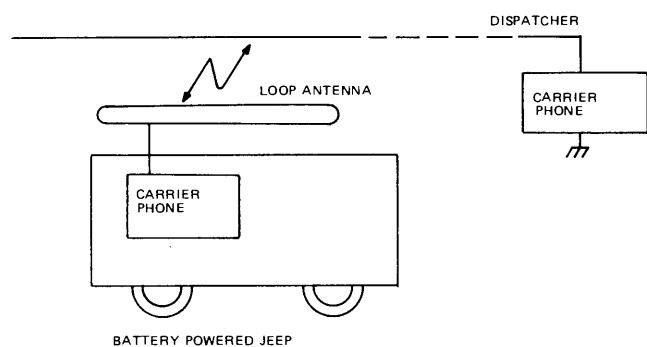
FIGURE 3-30. - Dedicated-wire radio system.

would a trolley line, this system is relatively inefficient. In general, it is usually necessary for the loop antenna to be rather close to the dedicated wire for communications. This problem is caused in part by the fact that carrier phones were never intended to use antennas, and cannot operate at high enough frequencies to make this approach efficient.

However, research has shown that such a system operates well if medium frequencies are used. These frequencies, usually around 500 to 900 kHz (as opposed to 100 kHz typical of trolley carrier phones) can operate with loop antennas very efficiently. Considerable research is being done by industry and the Bureau of Mines to develop whole-mine medium-frequency systems.

3.5.2d Wireless Radio System

An obvious advantage of any true radio system is that the system requires no transmission lines or cables. These systems are immune to communication outages caused by line breaks due to roof falls or damage from machinery. However, the underground mining industry cannot take for granted the utilization of wireless communications as can their counterparts on the surface. As an example, at CB radio frequencies, reliable communication in a mine entry is limited to about 100 feet. Two options are available to the underground mine operator: (1) To use frequencies that are high enough to utilize the entries as waveguides, or (2) to use frequencies that are low enough that propagation through the earth, or by parasitic coupling, can be insured. Before

discussing the advantages and disadvantages of each technique, the subject of radio interference and signal attenuation in underground mines must be considered.

3.5.2d.i Interference

During normal operation, the machinery used underground creates a wide range of many types of intense electromagnetic interference (EMI), which is a major limiting factor in the range of a radio communication system. EMI generated in mines is generally a random process. Therefore, the most meaningful parameters for EMI are statistical ones. In work by the National Bureau of Standards, time and amplitude statistics have been used in order to unravel the complexities of EMI noise in mines. Without going into the details of data collection techniques or advanced statistical analysis, we will summarize the findings and conclusions on EMI affecting haulageway radio communications. Figure 3-31 shows interference levels measured along haulageways in four different mines.

The EMI noise levels shown for mine 1 are based on measurements made in a mine located in southwestern Pennsylvania. Room-and-pillar techniques were used with mining accomplished using a continuous miner, shuttle cars, and electric trolley rail haulage.
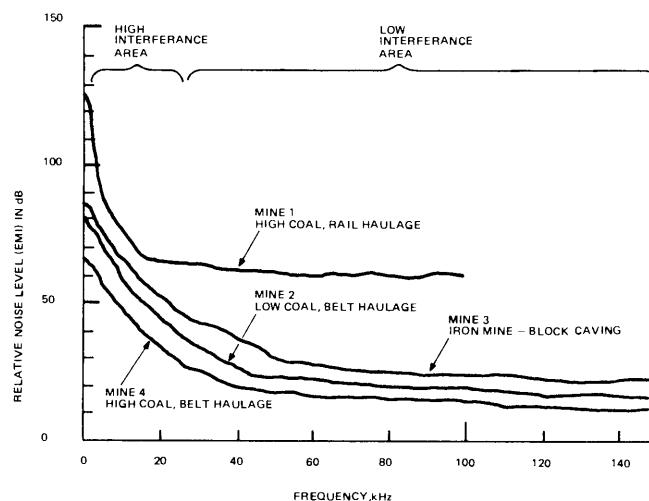
FIGURE 3-31. - Interference levels measured along haulageways in four mines.

The majority of noise measurements were made in an area where the overburden ranged from 600 to 900 feet. The entire mine, including all machinery, is powered by 600 volts dc. All conversion from alternating to direct current is done on the surface, with the result that no ac power is brought into this mine.

The EMI noise levels shown for mine 2 are based on measurements made in West Virginia. The coal in this mine occurs in a narrow seam, approximately 3 feet thick, and is called low coal. The measurements were made in the two sections of the mine using the longwall mining technique where overburden was between approximately 900 and 1,500 feet. The mine also had seven conventional room-and-pillar sections. This mine used 250-volt dc trolley haulage to carry coal out of the mine, and ac-powered conveyor belt haulage from the section to the trolley. All of the section longwall mining equipment was ac powered, with the exception of a dc-powered cable winch which was used occasionally to advance portions of the longwall equipment. The face and associated longwall equipment were 450 feet long. There were a total of six electric motors in the section ranging from 15 to 300 hp. The shear and face conveyor were powered by 950 volts, and the stage loader and hydraulic pumps operated from 550 volts. The stepdown transformer supplying these voltages was kept approximately 150 to 700 feet back from the face and was supplied with 13,200 volts.

The EMI noise levels shown for mine 3 are based on measurements made in a Pennsylvania iron mine. The level where measurements were taken was approximately 2,300 feet below the surface. The ore body is a large, flat, oval deposit about 300 feet thick, mined by undercutting and allowing the ore to cave into drawpoints called entries. Air-cooled, V-8 diesel-powered, rubber-tired, load-haul dump (LHD) vehicles were used to haul the ore to the underground crusher and dump it into the ore crusher; it

was transported by conveyor belt horizontally 825 meters, then lifted to the surface by a skip. The other types of haulage equipment used in this mine also were diesel powered and rubber tired. All haulageways were through reliable rock or were heavily reinforced with concrete and steel. The mine used a mixture of incandescent, mercury-arc, and fluorescent lighting.

The noise levels for mine 4 were made in a West Virginia mine where room-and-pillar mining techniques were used. The measurements were made primarily in a section where overburden was approximately 600 to 900 feet. Mining was accomplished using a continuous miner, head-loader, shuttle cars (buggies), conveyor belt, and electric trolley haulage. The electric trolley and the shuttle cars were powered by 300 volts dc. All other equipment, including fans and rock dusting machines, was ac powered.

The noise measurements taken in haulageways of these mines tended to show magnetic field strengths typically 60 to 70 dB μA/m up to a few kilohertz, which then decreases sharply above 8 to 12 kHz.

As seen in figure 3-32, the EM noise amplitude decreases with increasing frequency; however, three propagation mechanisms must be considered: (1) Through the earth, (2) through the entries supported by metallic structures and conductors, and (3) through the entries where they serve as a "waveguide." For propagation through the entries, it would appear, from the data presented, that selection of frequencies much greater than 100 kHz would be desirable.

For situations in which the propagation is directly through the earth, attenuation (signal loss) increases as frequency is increased. Because of lower attenuation at lower frequencies, better signal-to-noise ratios exist at low frequency despite the higher noise levels.
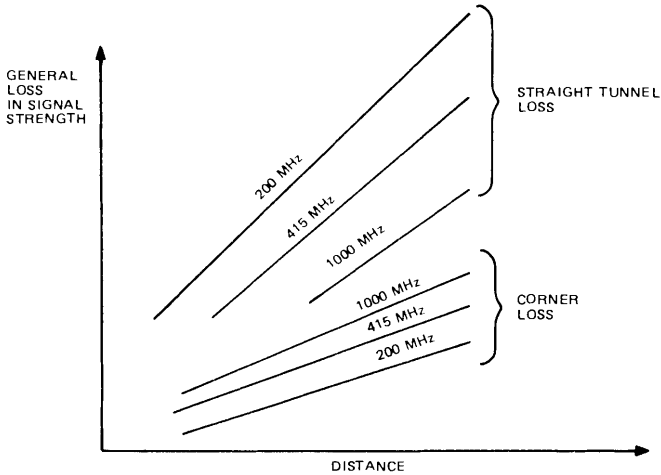
FIGURE 3-32. - EM noise amplitude decrease
with increasing frequency.

3.5.2d.ii Signal Attenuation in the Haulageway

As a radio signal travels down a haulageway or tunnel, its strength decreases. Typical signal attenuation along a straight tunnel, for three different radio frequencies, is shown in figure 3-32. Transmission loss may be combined directly with transmitter power and antenna gains to determine the received signal for any candidate UHF system. In terms of transmission loss, a pair of 1-watt UHF walkie-talkies has a range of 143 to 146 dB.

Significant propagation characteristics apparent from figure 3-32 are—

Attenuation (in decibels) increases nearly linearly with increasing distance.

Transmission loss decreases significantly at a given distance as the frequency is increased.

3.5.2d.iii Signal Attenuation Around Corners

Observed signal attenuation around a corner is also shown in figure 3-32. Corner attenuation is plotted in decibels relative to the signal level observed in the center of the main tunnel.

Figure 3-32 shows that signal attenuation around a corner is considerable. Because of the high attenuation of a single corner, propagation around multiple corners is even more severely attenuated.

Although it is an advantage to operate at a higher frequency in a straight tunnel, the higher frequencies suffer the greatest loss in turning a corner. Therefore, the choice of frequency is often dictated by the type of coverage desired.

Based on the interference and signal attenuation rates observed, the effective communication range for UHF radios can be predicted. Figure 3-33 shows the predicted range for a 1,000-MHz, 1-watt portable transceiver.

The presence of stoppings for direction of airflow, passages blocked by machinery, or blockage caused by a roof fall seriously limits the communication range of a UHF system. Obstructions highly attenuate all UHF signal transfer, thus making the same systems impractical for some mine applications.
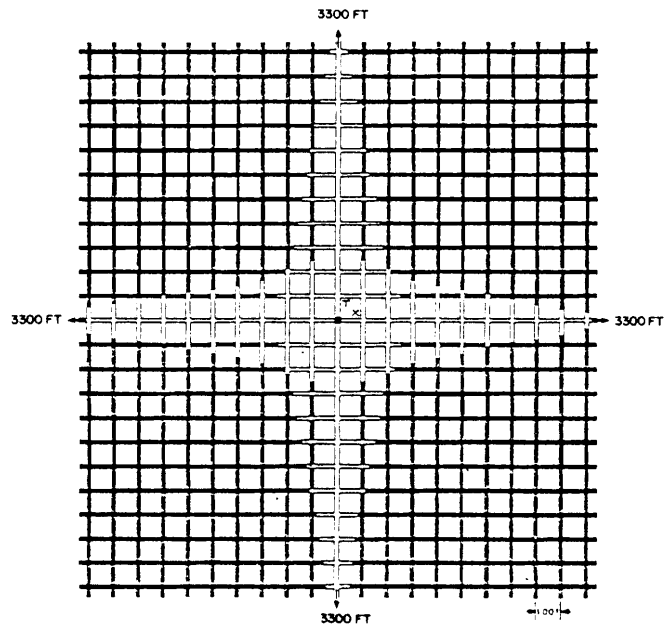
FIGURE 3-33. - Predicted range for 1,000-MHz, 1-watt portable transceiver.

3.5.3 Belt Haulage

Mines using conveyor belts to move coal or ore underground usually have a secondary transportation system for the movement of men and materials. When the man-material transportation system is tracked-trolley, the obvious solution to haulageway communication requirements is the trolley phone system described in section 3.5.1. If the man-material transportation system is nontrolley, then some form of radio, leaky feeder, or wired phone system is required.

A common practice in mines using belt haulage is to locate telephones at the intersections of all mains and submains, and at the head and tail of all working conveyor belts. (Belt fires most often occur at these points.) In the absence of trolley phones, belt haulage mines also usually locate phones approximately every 600 feet along the belts. These phones are installed for the life of the mine and are seldom moved.

Although a fully developed submain might have butt entry ports every 600 feet along its length, telephones are required only at the active or working butt entry ports. This usually limits the maximum number of phones per submain to six, owing to the capacity of most haulage systems. These phones are moved about every year or so until all panels in the submain have been developed. If a feeder belt is used in the submain, additional phones are recommended at the head and tail of these belts.

Phones permanently installed at the head and tail, and at other strategic locations along the belt, usually meet the communication requirements during normal day-to-day operations. The drawback to any wired phone system is that a miner must be at a phone to make or receive a call. Communication with belt maintenance or inspection personnel moving along the haulageway can only be accomplished by some form of radio link.

The same systems described in section 3.5.2 (nontrolley haulage) can be utilized to meet the communication requirements in belt haulageways.

3.6 Special Requirements

This section describes ways of meeting those special communication requirements not directly related to the mine entrance (section 3.2), permanent and semipermanent locations (section 3.3), mining areas (section 3.4), and haulageways (section 3.5). Major topics included in this area of special requirements include communications with roving or isolated personnel and motorman-to-snapper communications.

3.6.1 The Roving or Isolated Miner

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

Inspectors and other management personnel may also be anywhere in the underground complex. These people need to stay in continuous contact with the communication center so that they can be informed of any emergencies that might arise and/or make management decisions.

The maintenance crew is also spread throughout the mine. To receive repair requests and dispatch his crews for emergency or nonscheduled repair work, a maintenance foreman must be able to contact individual crew members dispersed throughout the mine.

Communication requirements to and from these key individuals can only be completely satisfied by a wireless (radio) paging or walkie-talkie system. Several paging systems are presently available to meet these requirements. The small lightweight pagers that can be carried by roving personnel are classified as one of three types:

Beepers (call alert).

One-way-voice (pocket pagers).

Two-way-voice (walkie-talkies).

One shortcoming of the first two types of systems (beepers and pocket pagers) is that the person initiating the page has no way of knowing if the page has been received. This can be especially critical in the case of the pocket pager systems where voice messages can be transmitted to the person being paged. Because the pocket pager is a receive-only device, the person being paged cannot directly notify the dispatcher or person making the page that he has received the message. Therefore, one-way-voice (pocket) pagers should only be used for paging messages ("call the dispatcher," "report to the maintenance area," etc.). Instructions such as "shut off the number 2 pump" should not be given using one-way communication devices unless it can be verified that the message was received and acted upon. The advantages gained by any of the three types of paging systems are directly related to the reduced time required to contact key individuals when their location underground is unknown. Even with the simplest beeper systems, the person being paged can, within a few seconds, be headed for a section phone to take a message.

3.6.1a One-Way-Voice (Pocket) Pagers

In a mine that uses rail haulage vehicles powered from an overhead trolley wire locomotive or jeep, carrier phones allow the vehicle operators to communicate with each other and with a dispatcher who controls the flow of traffic. As explained in section 2.4, the trolley line itself is the communication link between all the vehicles and the dispatcher.

However, communication need not be limited to phones connected to the trolley line. A special carrier-current tone signal can also be impressed on the trolley line, which will function as a long-line antenna, broadcasting the tone signal into the mine where it can be received by special pocket radio pagers (fig. 3-34). Hardware is now commercially available that allows a dispatcher to voice-page selected individuals, deliver short messages, or inform them where to go to receive detailed instructions. Figure 3-35 is a block diagram of a general radio paging system based on carrier-current techniques. A carrier phone, located at some central loction such as a dispatcher's room, is equipped with a small pushbutton-encoder unit. This unit causes the carrier phone to transmit short tone bursts whose frequency depends on which pushbutton was pushed. These tone bursts are transmitted from the carrier phone in exactly the same way that a voice signal would be sent out.

FIGURE 3-34. - Miner equipped with pocket radiopager.
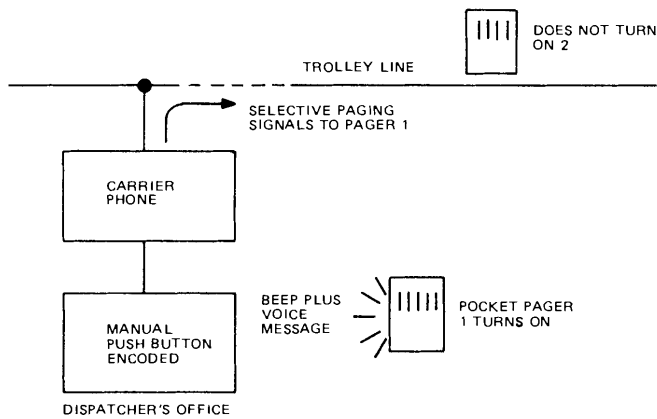
FIGURE 3-35. - Block diagram of general radio-paging system.

The pocket receivers that have been developed to respond to these tones are really small FM radio receivers that are activated by the tones and remain on for about 15 seconds. Once the tones have been sent, the dispatcher then talks into his carrier phone in the usual manner. Only the pocket pager activated by the tones will receive the message, so that the dispatcher can selectively radio-page any individual. In an emergency, a special tone can activate all pagers at once. The pocket pager is a receiver only and cannot be used to talk back to the dispatcher. Therefore, the system should be used only for paging, not for giving instructions.

The system shown in figure 3-35 is designed so that only the dispatcher can initiate a page, because he is the only one who has a carrier phone equipped with an encoder. However, other encoders could be used with other carrier phones, if necessary. Figure 3-36 shows a system in which the encoder is remotely accessed by a dial telephone line. Thus, any dial telephone associated with the mine switchboard (PBX) could be used to initiate a page without ever being near the encoder. Such a system offers an advantage should many people have to page into the mine from several surface locations. To operate the system, a user goes to a telephone and dials the number assigned to the pager he or she wishes to call. The encoder converts the telephone dial pulses into tones and transmits them via the carrier phone. The tones turn on the
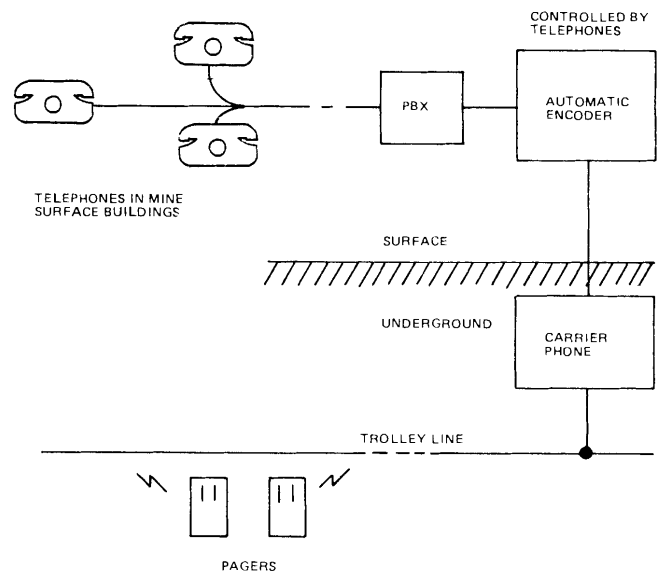
FIGURE 3-36. - Block diagram of system with remotely accessed encoder.

desired pager, at which time the user can speak into the mouthpiece to deliver the voice message.

Existing pager receivers are equipped with a small internal timer that automatically turns the device off after a preselected time, usually 15 seconds. A continuous "On" mode is usually not desirable because it wastes battery power. With the automatic time-out feature, batteries last for months. However, there are times when the continuous monitoring of the radio paging system is important to certain maintenance personnel.

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

A radio paging system can incorporate both the automatic encoded system (fig. 3-36) and a roof-bolt antenna system (fig. 3-37). The automatic encoder and carrier phone can be located on the surface; all else is underground. The in-mine roof bolts are separated by about 300 feet and connected to the carrier
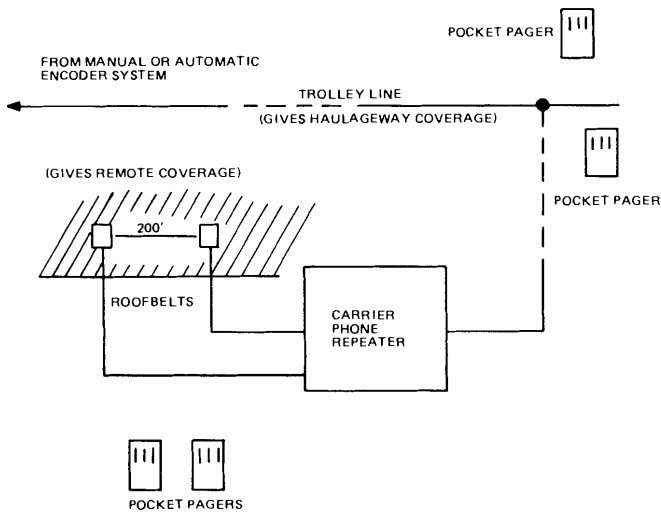
FIGURE 3-37. - Block diagram of system using roof-bolt-type antenna.

phone by No. 12 wire. With this system, paging can be accomplished from as far as 500 feet from a roof bolt antenna.

3.6.2 Motorman-to-Snapper

Many mines use loading track loops for loading mined coal or ore at the sections before transporting it to the surface. This type of operation involves the coordinated activities of two individuals: a "snapper" or "swamper" who couples and uncouples the cars; and a locomotive operator, or motorman, who moves the train backward and forward at prescribed times. If the snapper is not in the clear when the train is moved, its sudden motion can injure or kill him. Thus, effective communication between the motorman and snapper is vital.

Because of the curvature of the loop track (fig. 3-38) and the location of the locomotive on the main haulage track, the two individuals are not usually within sight or hearing of each other. Without communication or at least some system of signaling, coordination is difficult unless other workers are stationed alongside the track to relay information. However, this wastes time and manpower. It is clear that the safety and efficiency of the loading operation would be vastly improved if there were a reliable communication link between the motorman and snapper.
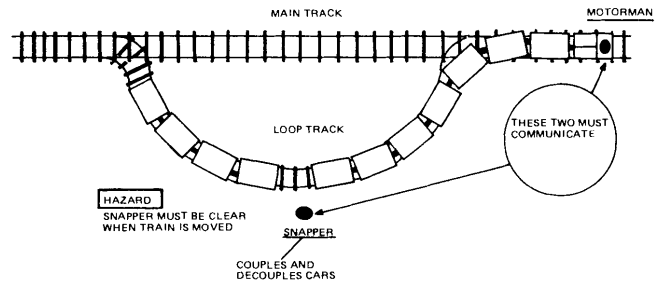
FIGURE 3-38. - Diagram showing need for communication in haulage loop-around.

The design of any practical system to meet the communication needs between motorman and snapper requires that it does not interfere with other communications, is convenient, has a restricted range so that similar systems can be used elsewhere in the mine, and can be built with commercially available hardware. Typically, a range of 1,500 feet or less is all that is necessary to assure adequate coverage for the maximum separation between the snapper and motorman. Two systems that can presently be implemented using commmercially available hardware are the telephone and trolley-carrier phone system and the walkie-talkie radio system.

3.6.2a Telephone and Trolley-Carrier Phone System

In the telephone and trolley-carrier phone system (fig. 3-39), the snapper communicates by means of a belt-carried,
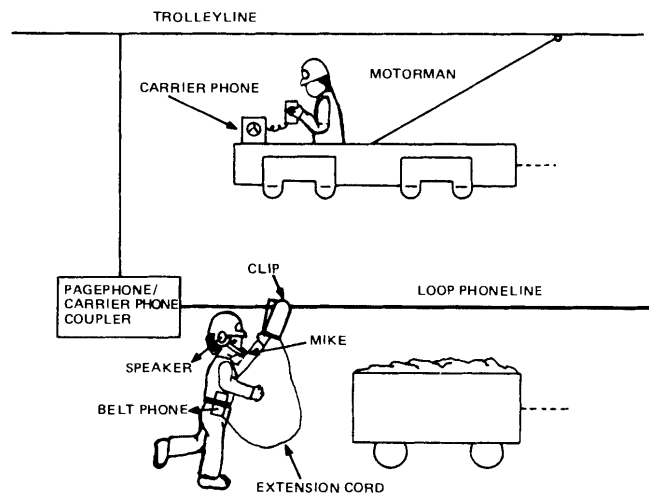
FIGURE 3-39. - Telephone and trolley-carrier phone system.

miniature mine telephone known as a belt phone. A phone line is installed on the rib or roof of the mine along one side of the loading track. The belt phone can be connected to this line by an extension cord that has insulation-piercing clips at one end. Alternatively, receptacles that allow the belt phone to be plugged in at convenient points can be provided on the line.

A pager-phone-to-carrier-phone coupler connects the phone line and the trolley line. Phone line signals are converted to trolley line signals and vice versa by this coupler. The motorman communicates by a trolley phone, which operates on a frequency different from that of the haulage communications.

> CAUTION.--Indiscriminate use of this procedure is not recommended. MSHA inspectors should be consulted before any carrier-phone-to-pager-phone coupling is installed.

If duplicate systems are used in a mine, the range of the trolley line signals has to be restricted by appropriately attenuating the transmitter output. This system can be implemented using standard trolley phones and phone-line-to-trolley-line couplers. In addition, a belt phone (fig. 3-40) is now commercially available. Equipped with a hardhat-mounted speaker and an adjustable-boom-type microphone, it has outgoing paging capability and will operate compatibly with available phone-line-to-trolley-line couplers.

At least one mine has successfully used an interface system between the phone and trolley lines to provide motorman-snapper communication. The system is diagrammed in figure 3-41. A remote interface, fabricated by technicians at the mine, acts as a coupler between the trolley line and a dedicated phone line. The motorman can communicate via the existing carrier phone system, whereas the snapper must communicate via

FIGURE 3-40. - Miner wearing belt phone.
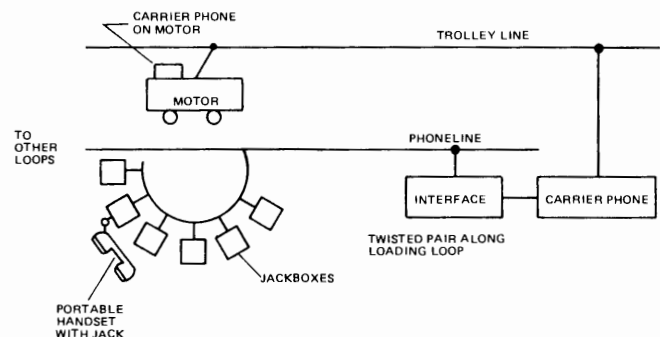
FIGURE 3-41. - Diagram of interface system between phone and trolley lines.

the phone line using a modified telephone handset. A twisted-pair phone line, with jackboxes connected at 50-foot intervals, is strung up in the loop-track area and connects to the dedicated phone line. The snapper plugs his handset into a nearby jackbox to establish communication to the motorman.

3.6.2b Walkie-Talkie System

The walkie-talkie radio system uses UHF portable radio equipment. Both the motorman and snapper are equipped with walkie-talkies (fig. 3-42).
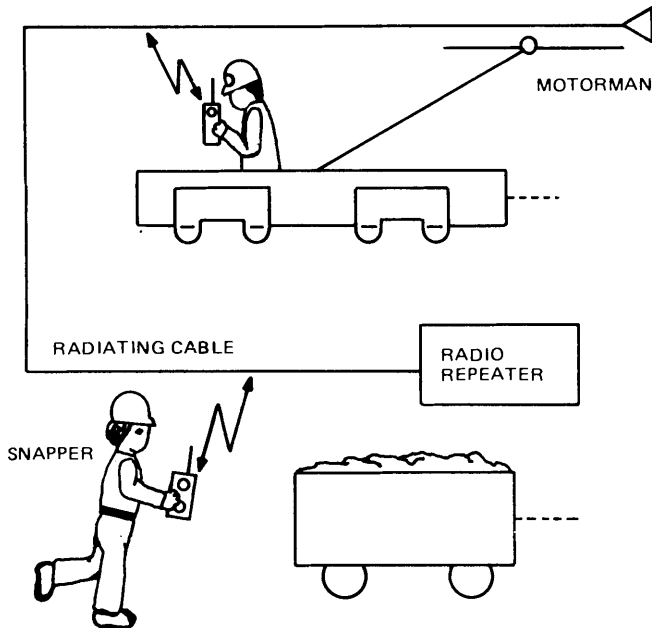
FIGURE 3-42. - Motorman and snapper walkie-talkie system.

Because of the curvature of the loop tunnel, propagation of radio waves at UHF is severely restricted. In fact, direct radio communication between the two individuals may not be possible in some cases. However, this deficiency can be overcome with a dual-frequency radio repeater connected to a radiating cable. The cable carries the radio signals, and the repeater effectively boosts them to a higher power level. The coaxial cable extends along the loading track and down the main haulageway far enough to assure communication coverage to the motorman. Cables several hundred feet shorter can be used if an approprate antenna is connected at the end. Commercially available portable radio transceivers and repeaters can be used to implement this system.

A medium-frequency radio transceiver (520 kHz) with sufficient range has been developed that makes snapper-motorman communications possible without installing additional cables. Transmission is aided by the conductors normally present in the loop-around.

Effective communication between the snapper and motorman can provide the coordination needed to eliminate uncertainties regarding train movement in the mine. This results in improved efficiency and a reduction in the num-ber of accidents related to the loading operation. Systems can be custom made from available telephone and carrier phone equipment. Leaky-feeder UHF equipment is similarly available for custom systems.

3.7 Emergency Communications

There are two conditions under which a communication system should operate. These are normal operations (regular day-to-day operation) and emergency conditions. The need for reliable underground communications following a disaster is obvious. Two major requirements for any emergency communication system follow:

1. The system must work following the disaster. (This implies that the system worked before the disaster and that the system is protected from, or immune to, fire, explosion, roof fall, etc.)

2. Miners must be familiar with operation of the system. (Mistakes are easy to make during periods of high emotional stress.)

It should be recognized that there are advantages in combining any emergency communication system into the system used for normal day-to-day operations. In this way, miners can become familiar enough with the system to operate it during disaster conditions. Daily use of the system also provides a mechanism of regular testing, thus insuring that the system will be operational.

3.7.1 Detecting and Locating the Trapped Miner

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 a successful rescue, but will also reduce the risks to the rescue team by keeping them from searching the wrong locations.

The problems of finding miners trapped underground can be illustrated by a disaster that occurred in 1945, in which 24 men were killed by an explosion. Figure 3-43 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. Three days later, 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 mark was found directing searchers to second Left off of 5 Left. Seven of the nine men survived the ordeal. All might have lived if their location had been known so they could have 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.
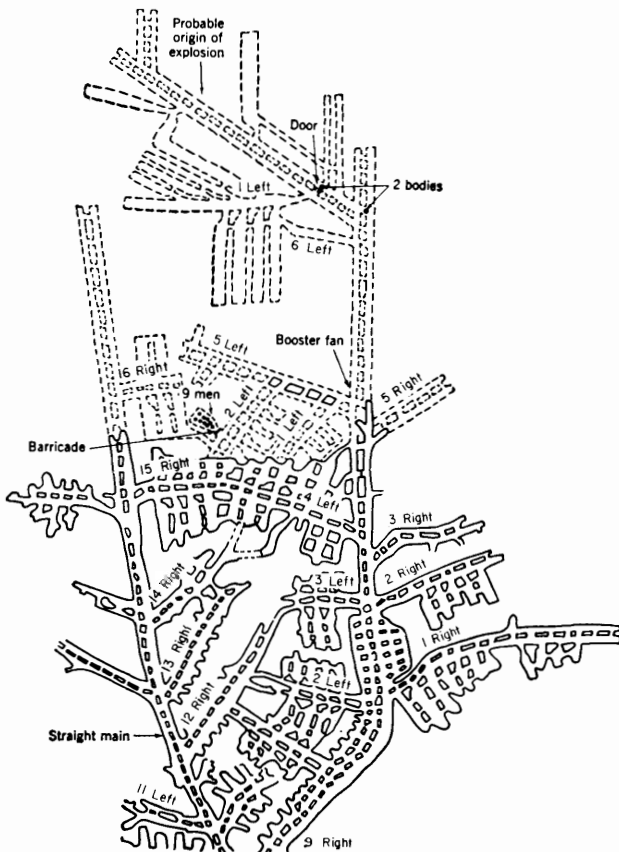
FIGURE 3-43. - Part of mine showing area to which miners retreated and erected imperfect barricade.

After a disaster, 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 disaster can also be used in locating survivors, but all of these techniques are based on guesswork. Accurate knowledge of the location of trapped men is required to increase their chances for survival and to reduce the hazards to the rescue team that might otherwise conduct an unnecessary, futile search in dangerous, incorrect areas.

It is obvious that any information that could be exchanged between the trapped miners and the rescuers during a rescue effort would be advantageous. Information such 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 also reduce hazards to the rescue and recovery team. Two systems for locating and communicating with trapped miners have been developed: a seismic system and an electromagnetic system.

The seismic system relies on detection of small ground vibrations resulting from a miner(s) banging on the roof or ribs with some heavy object. This system is presently operational and is being improved continuously. In this system, the trapped miner signals on the mine floor or roof with any heavy object and seismic detectors (geophones) on the surface are used to detect these signals. Computation of the location of the trapped miner by using the difference in the arrival time of the signals at various geophone positions on the surface has been quite successful. A seismic location system has the advantage that the miners do not require any special equipment and need only to be trained in how and when to signal. The disadvantage is that discontinuities in the overburden can significantly affect rescue signal propagation relative to both detection and computation of location of the signal.

Additionally, in a rescue and recovery operation, the time required to deploy and relocate, if necessary, a massive geophone array may hamper the progress desired. However, the seismic system does provide the trapped miner with an additional degree of protection when no other method of communication can be established. The Mine Safety and Health Administration maintains a seismic rescue system as part of its Mine Emergency Operations group. All miners should obtain MSHA stickers for their hard hats (fig. 2-26) in case they should become entrapped.

The electromagnetic system relies on a small voice frequency (VF) transmitter that can be carried by the miner, and surface receivers that "listen" for the signals broadcast directly through the earth or through the mine workings by the miner's transmitter. Basic development of VF EM systems is completed, and prototype hardware is in the testing phase.

A typical trapped-miner transmitter (fig. 3-44) weighs one-half pound and can be worn on the belt. Cap lamp battery

units also exist. In an emergency, and when it is decided that all routes of escape are closed, the antenna wire is uncoiled, laid out in as large a loop as possible, and connected to the transmitter. The transmitter and loop antenna produce a magnetic field, as shown in figure 3-45. 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 location of the antenna can be determined within a few feet.

After detecting and locating a trapped miner, the surface search team can establish a voice down-link communications path to the men underground. This voice link is established by deploying a large loop antenna directly above the trapped miners and connected it to a very powerful amplifier and voice system (fig. 3-46). By speaking into the microphone associated with the system, strong electromagnetic signals are generated and transmitted by the loop antenna. These signals penetrate the earth, and the trapped miners can hear actual voice from the surface on their transceiver. The surface can then ask key questions to

FIGURE 3-44. - Underground-miner-carried VF equipment for signaling surface rescue crew.
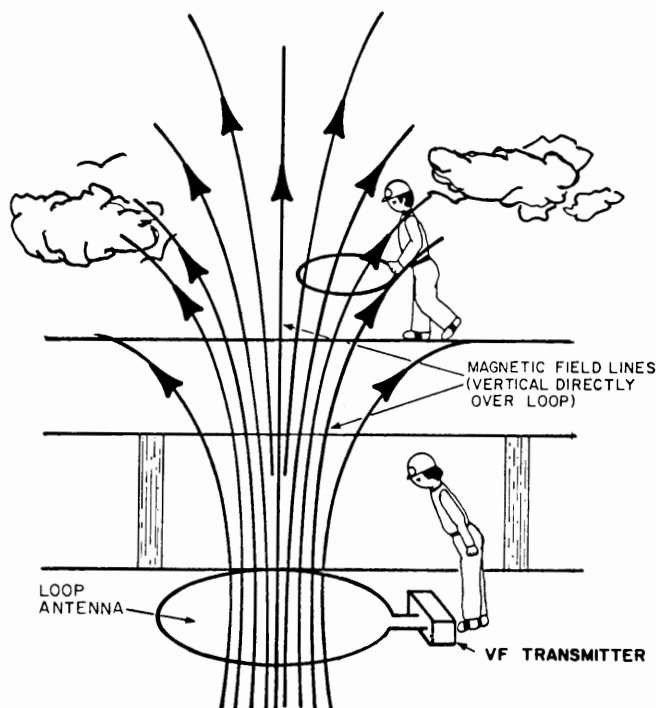
FIGURE 3-45. - Production of a magnetic field by transmitter and loop antenna.
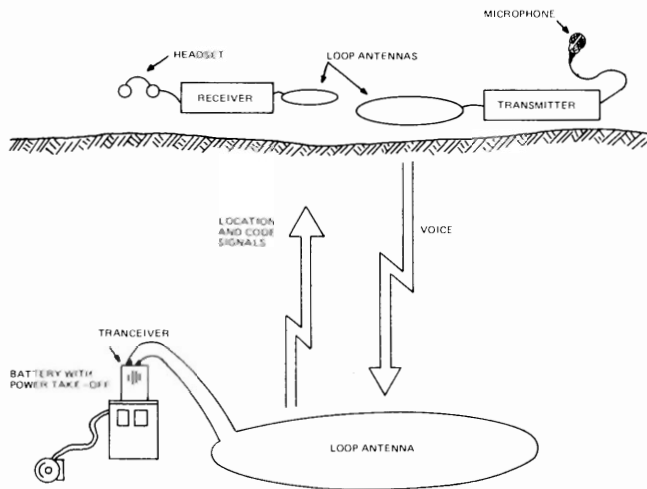
FIGURE 3-46. - Through-the-earth transmission system.

FIGURE 3-47. - Surface VF receiver and loop antenna in use at simulated mine disaster.

ascertain the conditions underground. As an example, they can ask the trapped miners to key three pulses of signal for a "yes" answer and two pulses for a "no" answer. This type of down-link voice and up-link code signaling system allows the surface team to learn anything they wish about the situation underground and also allows them to give instructions or information concerning escape routes and rescue attempts.

One advantage of an electromagnetic system over a seismic system is that the EM transmitter operates continuously once deployed and will function for many hours, or even days, from one cap lamp 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. Another advantage is that the detection receiver can be readily carried by one miner (fig. 3-47) 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. With this unit, large areas can be scanned quickly. Once a signal is detected, portable surface-carried units can obtain an exact fix. The surface gear for a 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 especially difficult problems.

3.7.2 Refuge Shelter

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. Although many miners have been rescued from behind barricades, some have died behind inadequately constructed barricades. As a solution to this problem, sectional or central refuge chambers have been established by some companies. If a chamber is constructed, some form of communication to the surface should be included to inform rescue crews that the chamber is being used and of the condition of its occupants.

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. The in-mine telephone system would be the least reliable after an explosion unless the cable

installation had been specifically hardened. Boreholes would be highly reliable but would require a new borehole for each refuge chamber or whenever a refuge chamber was moved.

3.7.3 Rescue Team Communications

Even though searching a mine after a fire or explosion is a slow and often dangerous job, the rescue team must reach any trapped or barricaded miners as soon as possible. Effective communication between the rescue team and the surface or base camp, as well as communication between individual members of the team, is an essential element in any successful rescue attempt.

One method that has proven effective in maintaining communication to and from the rescue team is illustrated in figure 3-48. In this relatively simple system the rescue team splices into a good phone line and then unrolls line from a spool as they advance into the mine. During a recent rescue, this type of system provided good communication even after the rescue team had traveled approximately a mile along a haulageway and then descended another 1,200 feet down a shaft from an underground headframe.
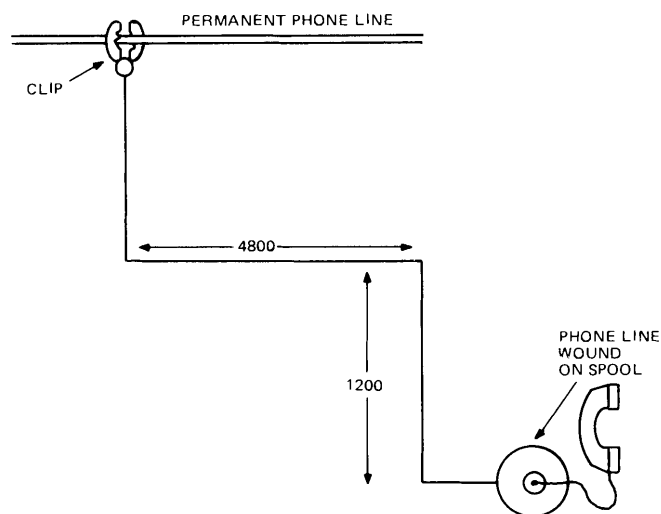
FIGURE 3-48. - Effective method for maintaining communication to and from rescue team.

The primary advantage of this type of system is that it is simple and yet usually provides good-quality voice communication. Also the phone wire trailed behind the rescue team provides a physical link back out of the search area. This link can become an important factor if the team must retreat under conditions of poor visibility, or if a second rescue team wishes to "follow" the first team. The disadvantages of this type of system are (1) the wire spool, which may be heavy, must be transported by the rescue team, and (2) the wire strung behind the rescue team is susceptible to damage from secondary explosions or roof falls.

3.7.4 Medium-Frequency Rescue Systems

Considerable research has been conducted within the last 8 years in the area of underground MF transmissions. This research showed that MF signals could propagate for great distances in most geologies and offered the hope of a whole-mine radio system. The Bureau of Mines and the South African Chamber of Mines (SACM) pursued research independently.

Around 1974, SACM introduced a new single-sideband system and followed up later with another designed especially for rescue team use. Performance in South Africa was reported to be good. The evaluation of these units in U.S. mines showed them to be inadequate. The type of modulation used [single sideband (SSB)] made them sensitive to electromagnetic interference (EMI). In addition, power level was far too low and inefficiencies in both circuit and antenna designs produced short-range performance.

The Bureau's approach to the problem was more fundamental. A program was designed and executed to study in-mine MF propagation and learn how it interacted with the complex environment. This environment consists of various geological factors such as stratified layers of different electrical parameters, entry size, local conductors, EMI, etc.

Figure 3-49 is a simplified geometry of an in-mine site that illustrates one of the most important findings of the measurement program--the "coal seam mode." For this mode to exist, the coal seam conductivity (σ_c) must be several orders of magnitude less than that of the rock (σ_r). A loop antenna that is at least partially vertically oriented, produces a vertical electric field (E_Z) and horizontal magnetic field (H_ϕ). In the rock, the fields diminish exponentially in the Z-direction. In the coal seam, the fields diminish exponentially at a rate determined by the attenuation constant (α) which in turn depends upon the electrical properties of the coal. An inverse square-foot factor also exists because of spreading. The effect is that the wave, to a large degree, is trapped between the highly conducting rock layers and propagates long distances within the lower conducting coal seam. The fact that the coal may have entries and cross-cuts is of minor consequence.

In the presence of conductors, the picture changes considerably. In this case, the effects of these conductors can totally dominate over the effects of the geology. In general, the presence of conductors (rails, trolley lines, phone lines) is advantageous.

MF signals can couple into, and re-radiate from, continuous conductors in such a way that these conductors become not only the transmission medium but also the antenna system for the signals. Figure 3-50 illustrates this concept. The most favorable frequency depends to some extent on the relationship between the geology and existing conductors. The frequency effects are quite broad. Anything from 400 to 800 kHz is usually adequate.

3.7.4a Specific Application of MF Communications to Rescue Teams

The low attenuation of MF signals in many stratified geologies, such as coal mines, can be of great benefit to rescue teams. If existing mine wiring (like
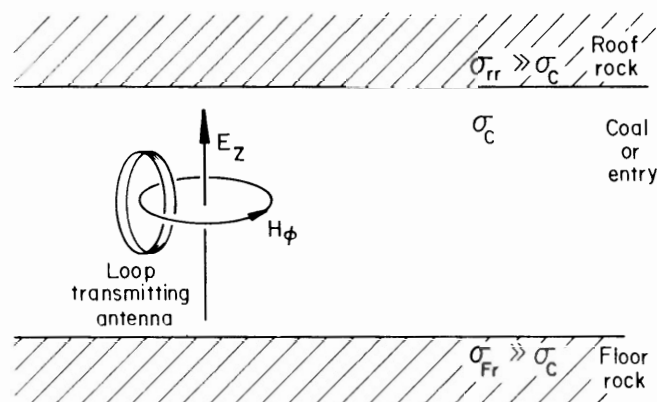
FIGURE 3-49. - Coal seam mode.
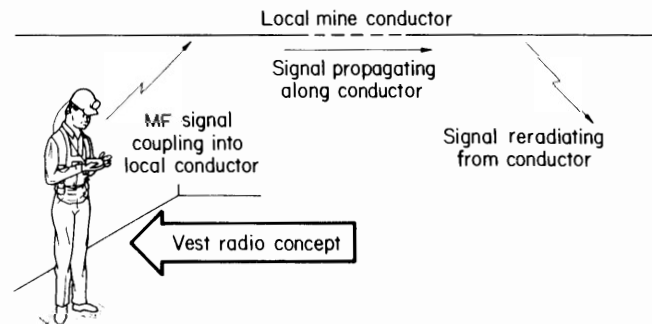
FIGURE 3-50. - MF parasitic coupling and reradiation.

powerlines or belt lines) are present, the range is even greater. This permits a rescue team member to stay in communication with other members, the fresh air base, and outside disaster control centers.

To date, MF technology has not been specifically applied to rescue team communications. Such application is the second step in the Bureau's overall MF communications program. However, there is no basic difference between operational MF systems and postdisaster MF systems. By October 1982, the Bureau's operational MF systems was in place in several cooperating underground mines. By October 1983, performance evaluation of the systems will be completed. As the performance proceeds, emphasis will be directed to specific postdisaster-rescue applications.

3.7.4b System Concepts

The main advantage of MF communication is simplicity. Figure 3-51 shows a rescue team member equipped with a prototype MF vest radio. This vest radio permits rescue team members to maintain local communications (fig. 3-52).

In most cases, rescue teams will utilize a lifeline for rapid retreat in case of smoke when visibility is limited. The lifeline offers interesting possibilities for MF radio communications. Some rescue teams actually use the line already to carry communications via sound-powered telephones. Such a scheme is both archaic and often ineffective.

Since this line is a continuous conductor back to the fresh air base, it provides a convenient parasitic path for MF communication as shown in figure 3-53. To assure even more reliable communications, physical audio links could be made with the lifeline as shown in figure 3-54. Such an approach provides redundancy via simultaneous audio and radio links.

Figure 3-55 illustrates a total MF base station for rescue team use. At the fresh air base, the briefing officer (as the individual is sometimes called) is equipped with a standard intrinsically safe base station or repeater; the officer could also be equipped with a vest. With such an arrangement, communications are possible not only between rescue team members, but also with the surface and with other distant rescue teams. In addition, it also provides a possible link to the trapped miners.

Since existing mine wiring is extensive and minewide, it is easily seen that it provides yet another redundant link for the rescue team members. Since other rescue teams are also in the vicinity of mine wiring, interteam communications are possible if desired. This concept of interteam communications is a radical departure from existing procedures. It will permit one rescue team, in one part of the mine, to modify the ventilation in such a manner that it does not degrade

FIGURE 3-51. - Rescue team member with MF vest radio.
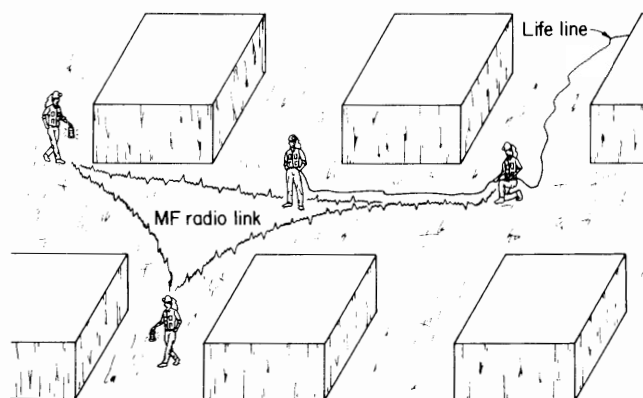
FIGURE 3-52. - Basic MF communications among rescue team members.
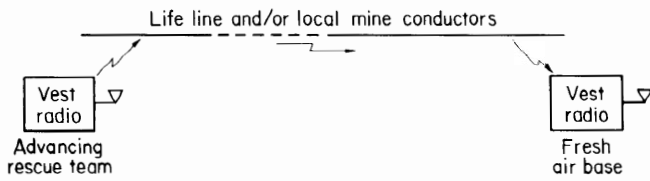
FIGURE 3-53. - Lifeline as a parasitic MF path.
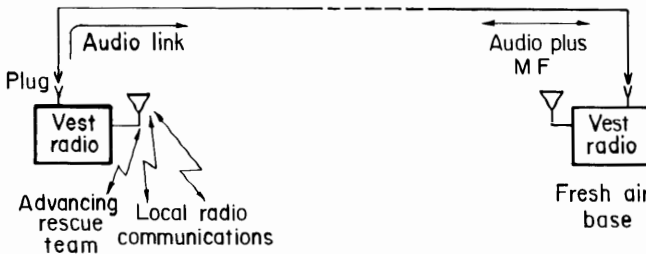
FIGURE 3-54. - Lifeline as a redundant communications line for MF and audio communication.
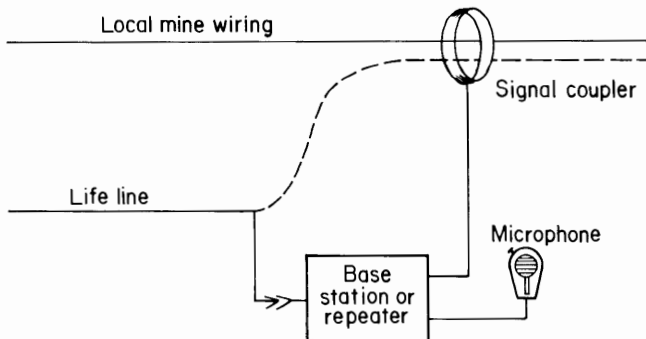
FIGURE 3-55. - Total MF base station for rescue teams.

the ventilation in the vicinity of another rescue team. Equally important is the fact that trapped miners are also probably in the vicinity of existing mine wiring.

3.7.4c   Location and Communications Systems for the Rescue of Trapped Miners

So far this section has primarily addressed the application of MF communication to rescue teams. However, the ultimate objective of the rescue

operation is to reach trapped miners in a timely manner before they succumb to the effects of injury, exposure, or toxic atmospheres. To this end, rescue team communications is but a part. The key to successful rescue lies in the rapid location of the trapped miners. Without this, valuable time can be wasted in diverting rescue efforts to the wrong area, often with tragic results.

Bureau research in the area of location has been addressed by through-the-earth seismic and EM systems. In the seismic system, trapped miners pound on the roof or ribs of the mine to generate seismic vibrations. These vibrations travel through the overburden to the surface where they can be detected by sensitive transducers called geophones. Computer analysis of the arrival times of the seismic signals at the various geophones permits the source to be accurately located. This system is operational and is kept in readiness by MSHA Mine Emergency Operations. Present Bureau research in EM means to locate and communicate with trapped miners is shown in figure 3-56. The system consists of two parts, a transceiver that is normally carried on the miner's belt and a surface system for detection and communications.
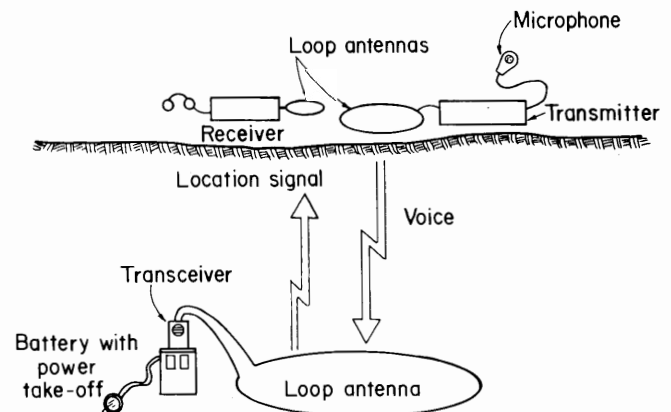
FIGURE 3-56. - Voice frequency electromagnetic system for location and communication with trapped miners.

In operation, the trapped miner removes the transceiver from the belt, deploys a self-contained loop antenna, and attaches the transceiver to a special cap lamp battery. This antenna consists of 300 feet of No. 18 wire that must be deployed in the largest area possible to be effective. A location signal is transmitted directly through the earth.

On the surface, sensitive receivers detect the signal and locate the source. Once detection and location are made, a large surface transmitter is deployed above the trapped miner. This transmitter is powerful enough to send voice messages by radio, directly down through the earth.

The trapped miner's transceiver receives this voice. The surface personnel then ask the miner "yes-no" questions concerning his or her condition and that of the mine. The miner responds by simple on-off keying of the transceiver. In this manner a two-way communications link is established, entirely through the earth, and rescue operations can start in the most efficient manner.

Details of this EM system can be found in numerous reports. This is known as a voice frequency (VF) system because all communications take place in the VF band of 300 to 3,000 Hz.

The seismic system is very effective in mines up to 2,200 feet deep, and does not require the miner to be equipped with any special devices. However, it does require the miner to be able to pound. Injury or lack of a sufficiently heavy object with which to pound may render the system ineffective. The most serious drawback is that of time. The surface receiver station (geophones, field truck with computer, etc.) may take too long to set up. Bad weather and terrain can further delay the surface station deployment.

The EM-VF receiver system is less affected by adverse conditions on the surface because it is lighter and more easily transportable. However, it has its own disadvantages. The trapped miner must be equipped with a special transceiver, and must be able to deploy the antenna in a sufficiently large area. Injury or confined quarters may prevent deployment. In addition, under the best of conditions, the system has a range limit of about 1,000 feet. Although a new system is under development that will increase the range to 3,000 feet, this improvement comes about only with complex, slowly deployed surface equipment. Therefore, it will be subject to the same delays as the seismic system.

MF communication offers advantages over through-the-earth approaches by permitting in-mine communications to the trapped miners. This could be in addition to, or in place of, through-the-earth schemes that may fail because of excessive overburden or the inability of the trapped miner to deploy his or her end of the system successfully. Figure 3-57 illustrates this concept.

In this illustration, the trapped miner is equipped with a small MF transceiver built into the top of the cap lamp battery or worn on the belt. Note that this is exactly the same packaging concept used for the VF through-the-earth system shown in figure 3-56. The intent, however, is not to send a signal through the earth, but rather to induce a signal onto local mine wiring. If this is accomplished, the in-mine rescue team also
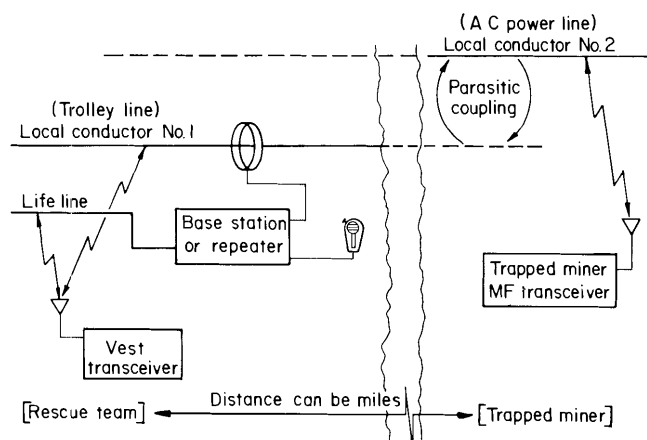
FIGURE 3-57. - MF in-mine location and communication system.

is likely to be in the vicinity of mine wiring and can receive the signal. It must be pointed out very clearly that mine wiring does *not* mean that one continuous assembly of wiring is involved. If the trapped miner is near a power cable and not near a trolley line, and the rescue team is near a trolley line and not near a power cable, this does not mean that a communications link between the two cannot exist. An induced MF signal on one type of conductor will parasitically couple to all others, even if there is no physical connection. This is the uniqueness of MF communication.

In operation, the trapped miner would deploy an MF loop antenna or coupler, preferably onto available local wiring. The coupler could be a small device of small volume similar to a current transformer. The loop could be a coupler that was unwound. In either case, the antenna is small. If nearby wiring does not exist, the loop could be deployed in hope of coupling to distant wiring. When so deployed, the transmitter sends out MF signals of narrow bandwidth that parasitically couple onto mine wiring, and are widely distributed. This can be received by the in-mine rescue team. If this occurs, they will use their more powerful MF equipment (vests or base stations) to establish a voice link to the trapped miner. By asking the trapped miner yes or no questions, his or her location can be learned. However, direct location via MF communication is impossible. The parasitic coupling characteristics of MF signals do not permit the through-the-earth VF type of location; the signal could be on many conductors.

Obviously VF and MF systems could be combined such that the benefits of both VF (fig. 3-56) and MF (fig. 3-57) could be obtained. Equally important is the fact that the MF trapped miner device could be used in nonemergency situations as a page receiver and thereby be a cost effective addition to a general mine communication system. Table 3-3 lists MF communication system specifications.

TABLE 3-3. - MF communication system specifications

Emissions, narrowband FM:
Occupied bandwidth......................kHz..	10
Rf frequency.............................kHz..	60-1,000
Peak deviation...........................kHz..	±2.5
Modulated frequency.....................Hz..	200-2,500

Receiver, superheterodyne:
Sensitivity....................................	1.0 μV (12-db sinad)
Selectivity....................................	8-pole crystal filter
IF 3-dB bandwidth (minimum)...........kHz..	12
IF 70-dB bandwidth (maximum)..........kHz..	22
RF bandwidth.............................kHz..	60-1,000
Squelch.......................................	Noise operated and tone

Transmitter, push-pull, class B:
Output power, W:
Vest..	4.0
Vehicular.....................................	20.0

Antenna magnetic moment (ATm^2):
Vest..	2.1
Vehicular.....................................	6.3

RF line coupler, transfer impedance (Z_T):
1-in coupler, ohms:
350 kHz.......................................	10.0
520 kHz.......................................	11.2
820 kHz.......................................	17.8

4-in coupler, ohms:
520 kHz.......................................	10.6

3.7.4d Performance Data

In order to evaluate the potential of MF signals as a means to locate and communicate with trapped miners, and to provide communications for the actual rescue team operation, a test was conducted at the York Canyon Mine near Raton, N. Mex., in June 1982. This mine is a coal mine located in the York seam of the Raton Basin. The terrain is hilly such that the mine overburden varies from about 200 to 800 feet.

The mine has four main drift entries that are about 7,000 feet long. Off these entries, submains were driven and longwall mining occurs. A borehole is located at about the 7,000-foot mark. This borehole contains a twisted pair cable that is associated with the fire monitoring system on the longwall panels.

This is an ac mine that transports the coal by belt. Rubber-tired vehicles provide transportation for personnel and supplies. The distance from the portal, down the main entries to the longwall faces, can be nearly 15,000 feet).

At the mine portal, a MF signal coupler was attached to the mine telephone lines. This coupler was controlled by a standard MF base station. A second coupler and base station were placed at the top of the borehole. The coupler was clamped around the cable that went down the borehole.

Two personnel entered the mine and, by vehicle, traveled down the main entries to the vicinity of the borehole (7,000 feet). These personnel were equipped with MF vest transceivers that had a magnetic moment of 2.1 ATm^2 and a sensitivity of 1 V at 520 kHz. The intent of the test was to ascertain whether or not these personnel could communicate with the base at the portal, or the base at the top of the borehole. If so, it would demonstrate that MF-equipped rescue teams could communicate with the outside command center without deploying their own communications line, or relying on the integrity of the mine phone line that may, or may not, be intact. In addition,

it would demonstrate that if a trapped miner was equipped with a MF transceiver of similar specifications, he or she could directly communicate with rescue teams in the mine, or search crews on the surface who were monitoring any conductors egressing the mine.

The result of the test showed that communications were possible from almost anywhere in the haulage and belt entries to either base station. It was even possible for the base at the portal, on the telephone line, to communicate with the base atop the borehole, on the fire monitor line, even though there was no physical connection between the two. Whenever a vest was within a few feet of mine conductors, there was an obvious improvement in clarity and signal strength.

Although this test was preliminary, it clearly highlights the potential of using MF communications for search and rescue operations. Much more work is necessary to measure range from mine wiring whenever the mine is not operating as would be the case during search and rescue operations. An operational mine produces considerable levels of acoustic and EM noise which reduces MF system range.

3.7.5 Emergency Warning Systems

Many types of emergency warning systems are available for alerting underground personnel. One example is the stench warning system, which introduces a distinctive odor into the airstream. Visual signals or radio paging could also be used to alert underground personnel. A preferred warning system would operate over existing wiring, such as the twisted pair of a pager phone system, and broadcast an audio warning that can be heard throughout the active areas of the underground complex. Before deciding on an alarm system, factors that affect the range over which an audio alarm can be heard should be considered. The most important factors are the noise background found in mines, the attenuation that the mine environment imposes on the alarm signal, and the attention-getting quality of different alarms.

The intensity of a sound is the energy in the sound wave. It is customary to express intensities or pressure levels in decibels. The term "loudness" refers to the response of the human ear to sound. Experiments have established that the loudness of a tone is a function of both frequency and intensity, with the ear most sensitive to frequencies in the region of 1 to 2 kHz. In other words, for tones with the same intensity, tones in the 1,000-to-2,000-Hz region appear louder than those above or below this region.

Figure 3-58 shows the noise level for a typical continuous miner, with noise samples taken at the operator's position and with the conveyor running. To estimate the masking effects of these samples, we must first transform the curves so that they refer to sound levels on a per cycle basis. This has been done in figure 3-59. The center curve, labeled "Mask noise source," plots the average of figure 3-58 in terms of the sound level per cycle of bandwidth. The upper curve, labeled "Detection threshold at noise source," shows the estimated threshold level as a function of tone frequency. The curve shows that tones

FIGURE 3-59. - Detection thresholds.

between 250 and 1,500 Hz require a level in excess of 80 dB to be just detectable. If we allow an additional 10 dB to insure detectability, alarm tones would have to have a sound level of at least 90 dB at the operator's position.

If we move 15 feet away from the operator's position (the bottom curve in figure 3-59), these sound levels are reduced considerably. This curve shows that at 800 Hz a level of 60 dB is required, and thereafter the required level decreases until at 6,000 Hz it is about 40 dB.

As mentioned earlier, the ear is most sensitive in the region of 1,000 to 2,000 Hz and decreases at higher frequencies. Figure 3-59, however, shows that the higher the frequency of a tone (up to 8,000 Hz), the more detectable it is. The spectrum of the masking noise is the cause of this apparent contradiction. The background noise is high at the frequencies where the ear is sensitive and decreases with frequency.

In addition to overcoming background noise, planners must compensate for attenuation of the warning tone. Experimental and theoretical investigations are in close agreement on the attenuation of sound in room-and-pillar mines. Figure 3-60 shows a plan of one experiment on attenuation of sound. For this experiment, a 100-dBA source was mounted at the position shown in the figure, and

FIGURE 3-58. - Cutting with conveyor on (operator position).
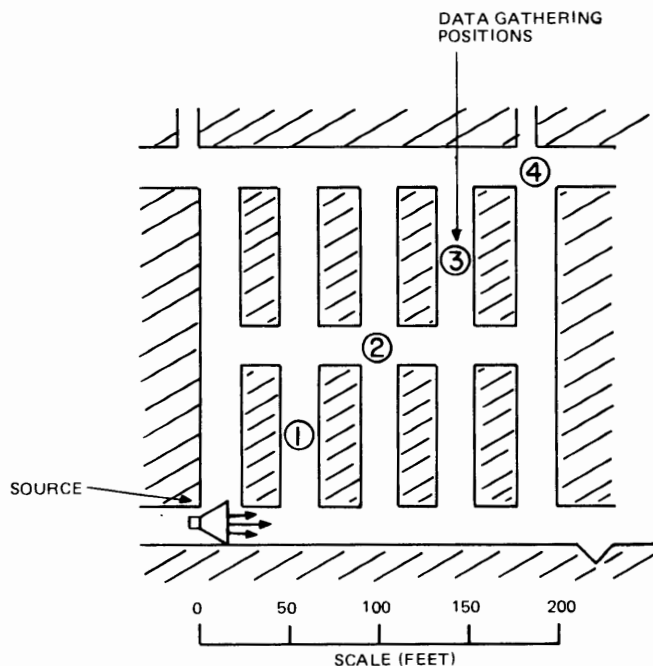
FIGURE 3-60. - Plan of mine in which experiment was conducted. (Coal seam height, 76 inches.)

FIGURE 3-61. - Attenuation as a function of frequency.

the sound levels at the points labeled 1 through 4 were recorded. Figure 3-61 is typical of the data obtained. It plots attenuation as a function of frequency at the four points.

In practice, an audio warning source must be some distance from the personnel it is intended to alert, and it is desirable that the warning be detectable above the background noise from as far away as possible. The greater the distance the sound must propagate, the louder the source must be; hence, the greater the hazard that the source will damage the hearing of someone who is inadvertently close to it when it is actuated. In an actual emergency, the risk of subjecting a miner to intense sound may be

considered justified; but to insure reliability, warning systems must be routinely tested, preferably in an operationally useful way, such as signaling the end of a shift. (Fire stations routinely test their sirens by sounding off at noon or some other prearranged time.) In addition, any system is subject to false alarms and/or pranks. Considering these factors, the presence of a really intense noise source might be regarded as an unwarrantable menace.

Table 3-4 combines the effects of background noise level and attenuation of the alarm tone to show the sound level required at the source for the warning to be just detectable by the operator of a continuous miner. The significance of these numbers is best explained by taking a particular example. The entry for 1,000 Hz under 210 feet is 100. This means that at 1,000 Hz the source level required to just alert the operator of a continuous miner who has "normal hearing" is 100 dB when the source is 210 feet away from him.

TABLE 3-4. - Sound level required at source for warning to be just detectable at operator's position on a continuous miner, dB

Frequency (Hz)	Distance from source			
	70 ft	140 ft	210 ft	280 ft
250	93	96	100	101
500	95	99	103	105
1,000	94	96	100	103
2,000	91	95	99	103
4,000	88	91	102	107

There are systems commercially available that can satisfy the requirements of audio warning systems using existing mine wiring. These systems use the mine paging telephone network as the emergency alarm system. This approach requires the addition of an alarm signal generator compatible with the pager phone operation. The paging telephone and external remote speakers act as the alarm sounding units. The alarm signal can be transmitted using a standard mine paging telephone and an acoustically coupled alarm signal generator or by using a dedicated on-line alarm signal generator, as shown in figure 3-62. Alarm signals are fed onto the pager phone line in one of two ways.

The first way uses the small portable alarm signal generator shown at the top of figure 3-62. When operated, this unit emits an audio alarm via a small speaker. The speaker is equipped with a suitably sized rubber gasket that enables the sound to be efficiently coupled into the microphone of any standard pager phone. Units of this type are commonly used in conventional telephone applications to remotely control such items as telephone answering machines and WATS line access. It can be seen that sounding an alarm in this way is a little awkward since three buttons must be pushed simultaneously, but this provides a safeguard against an accidental alarm. In addition, the portable units need only be entrusted to responsible individuals, which is a safeguard against pranksters.
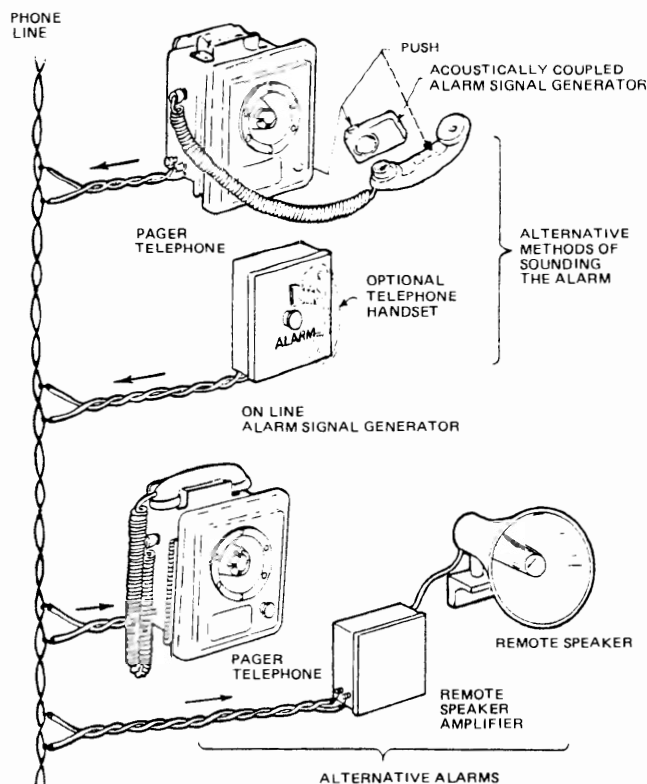
FIGURE 3-62. - Use of the existing pager telephone network as an emergency alarm system.

The second way of sounding an alarm on the system is to use the on-line alarm signal generator shown in figure 3-62. When the button on this unit is pressed, it places the correct dc signals on the line to actuate the pager phones and electronically transmits the alarm signal.

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CHAPTER 4.—COMPUTERIZED MINE MONITORING[1]

4.1 Introduction

Monitoring systems can have numerous uses in the mine. They can aid in the efficient management of the mine by providing environmental trend data, production and maintenance control, and communications. In some cases, they can provide justification to petition the Mine Safety and Health Administration (MSHA) for a variance of one of the mandatory safety standards. They may also increase the gross revenues of the mine by increasing the amount of coal produced or increase profits by reducing the cost of producing that coal.

No single system will satisfy the requirement of all mines. Some may require simple hard-wired status-reporting systems; others, multipurpose computer-based systems that collect, analyze, and store data and perhaps control some mine functions. Even though systems vary in complexity, they are all composed of three functional components. The first component is *sensors* that measure the environmental or production parameters and produce an electrical signal that is fed into the telemetry. The second is *telemetry* devices that receive the signal from the sensors and transmit it in either analog or digital format to the third component, *analysis and display equipment*. This equipment receives the transmitted signal and either stores it for later analysis or displays it. The analysis-display equipment ranges from simple strip chart recorders with preset alarms to computers, cathode-ray tubes (CRT's), and line printers that can also provide production reports.

4.2 Uses of a Mine Monitoring System

A list of potential uses for mine monitoring systems, including both production-related functions and those related to health and safety, was used to develop a questionnaire. It was presented to representatives of the mining community to determine their current monitoring priorities.

The responses indicated that the industry's priorities fall into the following two categories:

First priority—

Production and haulage

Maintenance

Second priority—

Ventilation

Communication

Fire monitoring

Personnel

The survey shows that production-oriented systems were the most appealing to the questionnaire respondents. Since even small improvements in production efficiency and maintenance can have a large financial impact, the desirability of monitoring systems that focus on these areas is understandable.

The results are summarized in table 4-1. The function that scored 100 was viewed as the most beneficial monitoring function.

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TABLE 4-1. - Survey results, weighted rank score

1.	Output by section................	100
2.	Belt monitoring and control....	99
3.	Scheduled routine maintenance..	99
4.	Equipment repair history.......	97
5.	Spare parts inventory..........	95
6.	Assist in diagnosis of failure.	94
7.	Power: Fault location.........	73
8.	Face equipment operating time..	68
9.	Personnel: Shift organization..	66
10.	Ground fault detection.........	63
11.	Trailing cable failure.........	62
12.	Power center monitoring........	62
13.	Monitor car haulage system.....	59
14.	Personnel: Locate skills; assist in locating people with needed or critical skills......	58
15.	Ventilation: Eliminate inspections; eliminate or reduce frequency of some periodic inspections....................	50
16.	Communications: Reliability....	49
17.	Communications: Intelligibility	45
18.	Paging.........................	45
19.	Plan new ventilation; help in planning ventilation, including new ventilation shafts.........	45
20.	Inspection scheduling; alert foremen or others to scheduled or predictable inspection or repair.........................	43
21.	Fire: Beltways; a system to detect and warn of incipient fires in the beltway due to hot rollers or other problems......	42
22.	Beltway for intake air; the use of improved fire detectors and monitoring system so as to qualify for a variance and enable use of the beltway for intake air.......................	41
23.	Communication: Station-to-station........................	40
24.	Emergency signaling; direct people during any emergency by signaling......................	40
25.	Detect leaky stoppings; ventilation monitor to detect open doors, blockages in air course, and leaky stoppings...........	37
26.	Personnel: Emergency; assist in locating and aiding people during an emergency...........	30
27.	Fire: Haulage; detect incipient fires in trolleyways.......	29
28.	Ventilation: Control regulators; monitor ventilation, and adjust regulators to improve flow distribution.............	25
29.	Roof fall prediction; automatically plot falls and/or microseismic activity to predict roof fall......................	20
30.	Cage; monitor the operation of the cage to predict failures or minimize delays................	18
31.	Fire: Gob; monitor gob areas for fire.......................	18
32.	Inventory expendables..........	10
33.	Rock bursts....................	10

Responders were also asked to indicate the relative importance of other cost and technological factors that may affect user acceptance. Results, on a 100-point scale, were

1. Reliablity of monitoring equipment in mine environment........ 100

2. Maintenance cost................ 90

3. Initial cost.................... 88

4. Skills required to maintain equipment....................... 75

5. New technology to mining........ 62

Reliability of the equipment was the most frequently cited "very important" factor.

4.3 Petitions for Modification

Mine monitoring systems can be used to provide a cheaper and safer alternative to satisfying the mandatory safety standards set forth in 30 CFR 75, provided that the alternate method (in this case, the monitoring system) guarantees no less than the same measure of protection afforded by the standard (30 CFR 44). The extent to which the industry currently takes advantage of these usages can be determined by reviewing the Petitions for Modification of Mandatory Safety Standards.[2] Since ventilation regulations appear to be the most likely candidates for modification petitions, petitions were reviewed under subpart D, "Ventilation," in the following sections:

75.305 Weekly examinations for hazardous conditions.

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[2]Sources include the Federal Register, the Bureau of National Affairs, Inc., "Mine Safety and Health Reporter," and the McGraw-Hill 1979 "Guide to Modification of Safety Standards in Coal Mines."

75.306 Weekly ventilation examinations.

75.307 Methane examinations.

75.310 Methane in virgin territory.

75.326 Aircourses and belt haulage entries.

This review identified a number of cases where continuous monitoring was used in a petition for a variance and a number of others that could have used continuous monitoring. Included in the review were petitions that were granted and petitions that were filed, but not acted upon as of the writing of this report. General comments on the petitions follow.

75.305 Weekly Examinations for Hazardous Conditions. - This section requires weekly inspection of at least one entry of each intake and return aircourse, in its entirety, for both methane and for compliance with the mandatory health and safety standards. Typical petitions state that because of poor roof conditions it is not possible to travel the aircourses in their entirety, and offer checkpoint measurements as an alternative. Continuous methane (75.305) measurements could be made with a monitoring system at these checkpoints. Required airflow measurements (75.306) could also be made with the same system.

Only 1 of the 62 petitions that were granted offered continuous monitoring. An additional 20 petitions were filed, but there was no record of any final decisions. One of these petitions did propose to install two methane monitors at specified points.

75.307 Methane Examinations. - This section requires tests for methane at each working place immediately prior to energizing electrically operated equipment.

One petition was noted in which methane monitoring devices were installed on permissible electric water pumps in the face area to eliminate the methane examinations by a qualified person required prior to energizing the pumps.

75.310 Methane in Virgin Territory. – This section requires that all electric power be cut off and men withdrawn when air returning from virgin mining areas contains 2% or more methane.

Three petitions for modification were granted under the stipulation that continuous automatic methane monitors were used in the return as an alternative to measurements made by certified mine personnel.

75.326 Aircourses and Belt Haulage Entries. – This section requires that entries used as intake and return aircourses be separated from belt haulage entries.

Fourteen petitions that were granted and ten that were filed but not acted upon were reviewed. Of these, seven petitions were granted on the basis of continuous monitoring systems, and seven of the filed petitions proposed continuous monitoring of carbon monoxide. A review of MSHA tests that demonstrate the "equivalency" of carbon monoxide sensors and the customary point-type heat sensors is presented in reference 15.

In summary, at least 11 continuous monitoring systems have been installed in U.S. underground coal mines for purposes of obtaining a variance from the mandatory health and safety standards. Eight additional petitions for modification mention such systems.

4.4 Technical Factors

The key technical issues are whether the sensors can actually provide the needed input information, the ability of the processing system to interpret correctly the telemetered information, and, finally, overall system reliability.

4.4.1 Sensors

Sensors are the critical element in mine monitoring systems since they provide the input data. If the input data are not correct or are not representative of the required measurement, the entire monitoring process is meaningless, i.e., "garbage in, garbage out." One problem with sensors is that their output represents the response of the sensor to a number of parameters in addition to the one that is to be measured. Typical examples are the response to changes in temperature and the poisoning of environmental sensors by other gases in the mine.

The critical problem relates to the ability of the sensor actually to measure the parameter of interest. In particular, ventilation monitoring systems use point air velocity measurements to represent the total airflow at a cross section in the mine. The total airflow is determined either from an empirically derived factor and the point measurement or from actual calibration of the cross section. The problem is further complicated because the only safe location for the sensor is on the rib or roof in the low-flow boundary layer. It is possible to have large changes in the overall airflow with little or no change in the velocities in the boundary layer and consequently in the sensor output. The reader is referred to reference 13 for guidelines for avoidance of these problems in airflow measurement.

4.4.2 Telemetry

The telemetry system obtains the data from the sensor, converts them to a standard format, sends them to another unit that receives them, checks their authenticity, and then refers them to the analysis-display device. The principal problem in this area is data security, i.e., the error rate for information transmission. The problem is not so much that an error is transmitted but that an error in transmission goes undetected because of the noise on the transmission line. The sensitivity to erroneous data transmission depends upon factors such as the cable used, the local noise field, length of cable run, and data formatting.

Techniques for detecting erroneous data transmissions have been devised principally by computer manufacturers. Notable among these are IBM's synchronous data link control (SDLC) and Digital Equipment Corp.'s digital data communications message protocol (DDCMP).

Bureau research (4-5),[3] indicates that the maximum transmission distance for one undetected random error per year varies between 1.3 and 6.8 miles in an average noise field, and between 0.1 and 0.6 mile in an estimated maximum noise field. Since cable runs are frequently several miles, occasional undetected transmission errors can be expected. For typical monitoring applications with frequent data refresh, this should not be a factor that causes worry; however, in the case of control systems or the least favorable monitoring circumstances, error rates can be unacceptably high, and corrective measures such as more secure transmission systems and improved error detection protocols are necessary.

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[3]Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

4.4.3 Reliability

The final area of concern is system reliability. The questionnaire identified reliability as the prime concern. The Bureau is currently sponsoring research that provides a methodology for determining the reliability of systems (12, 17, 21). This methodology has been used to evaluate expected failure rates of current mine monitoring systems.

Reliability in monitoring systems takes a number of forms. The first is mechanical reliability of the components. The underground mining environment is notoriously hard on equipment because of water, dust, potential damage due to moving equipment, and rough handling. Therefore, the enclosures for remote stations should be rugged enough to withstand the day-to-day rigors typically encountered in underground service. The enclosures should have tight and durable seals if the internal components are sensitive to moisture or dust. All exterior switches and buttons should also be sealed or be durable enough to withstand constant use in the presence of dirt and moisture. Cables should be durable enough to withstand occasional rough treatment.

The second aspect of reliability is electrical power reliability. Since power outages are all too common in underground mining, some type of backup power or uninterruptable power supply should be provided for this system. Such a power supply is particularly important for monitoring systems that provide essential health and safety information such as main fan operation, fire detection, and methane content. Obtaining these data is important during the common day-to-day, short-term power outages, but it is just as important to have such information during emergency situtions such as roof falls, fires, or explosions. It is also required for system approval.

4.5 Commercially Available Mine Monitoring Equipment

4.5.1 Introduction

The mine monitoring systems discussed in this report are electromechanical systems that remotely sense various environmental and operational parameters and transmit the data to a central location where the data are analyzed and/or displayed. On the basis of this definition, it is reasonable to discuss the system in terms of three basic functions: sensing, data transmission (or telemetry) and data analysis and display. In the case of monitoring and control systems, such as systems that automatically and remotely deenergize face equipment when the methane content at a specified location reaches a predetermined level, the control operation presents a fourth function.

Sensing can be divided into two general categories: environmental and operational or production sensing. The first category of sensors is designed to measure various aspects of a mine's environment to assist in maintaining a safe environment for underground personnel. The parameters that are ordinarily of concern are gas (i.e., carbon monoxide, methane, oxygen, etc.) content, air velocity, air temperature, differential pressure, and humidity. Typically, the data are used to detect and locate potentially hazardous conditions (i.e., fires, gas bursts, etc.) so that the appropriate measures can be taken. Production sensors are used to monitor the operating status of various pieces of underground equipment to detect production bottlenecks, equipment malfunctions, maintenance requirements, etc. Examples of production parameters that are typically of interest are belt output, face equipment operation, belt slippage, blockages, and bearing temperatures or vibration.

Telemetry is the process of transmitting the data output of the sensors to the control center that is usually located aboveground. The output of the sensors can be either a simple status indication, sometimes called a binary, contact closure, or status output (such as high-low, open-closed) or it can be a continuously variable function of time (such as air velocity, methane concentration, etc.). While the continuously variable data can provide significantly more information than the simple status data, how much more depends on the accuracy of the measurement.

As a practical matter, it is generally not feasible to run a separate conductor or conductor pair to each sensor. Therefore, telemetry systems typically incorporate several remote stations or "outstations," each of which accepts and encodes the output of a number of sensors and transmits the encoded data along a common cable to the control center. The two most common encoding techniques are (1) frequency domain multiplexing and (2) time domain multiplexing. Frequency domain multiplexing has the advantage that data from all monitoring points are received at all times, although the number of monitoring points is limited by the overall bandwidth of the system. Time multiplexing can be expanded, at least in principle, to accommodate as many monitoring points as desired. However, each point is sampled only intermittently (i.e., the receiver obtains data from only one monitoring point at a time) since the system interrogates the monitoring points sequentially. The cycle time, or time between successive samplings of the same point, is the time the system requires to interrogate all of the monitoring points.

Time multiplexed systems, the more common of the two, often transmit data in the digital format. That is, a series of high-low state indications is transmitted to indicate the status of the monitor point. A common technique to accomplish this transmission is to use frequency shift key (FSK) encoding. This encoding

process uses two different frequencies (for example, 3,000 and 2,000 Hz) to represent the high and low states, rather than high and low level signals of the same frequency. The FSK encoded data are less affected by noise on the transmission line than data transmitted in simple high-low digital format. In addition, current signal detection techniques make it very easy to detect single frequency signals in the presence of noise.

The third basic function of a monitoring system is the analysis and display of the measured data. These operations are normally accomplished in an above-ground control center. Most of the systems have the ability to trigger audio-visual alarms if a sensor detects that its predetermined threshold (such as 1% methane in a return airway) has been exceeded. Most of the systems can also provide hard copy documentation of the alarms and display the actual values detected by the sensors, either on meters or CRT's. The computer-based systems have the added capability of data storage for trend analysis, record keeping, and reporting.

In the following discussion on commercially available equipment, a distinction is made between the system suppliers and the sensor suppliers. The distinction is made since in many cases the system supplier expects the mine to select not only the parameters to be monitored but also the sensors to be used. The system supplier then configures a monitoring system using both in-house hardware and hardware from outside suppliers to provide the mine with the desired information. Ordinarily, the data telemetry-analysis and display equipment is the supplier's own brand, while the sensors are obtained from outside companies. In most cases, the supplier will assume "full system responsibility." That is, it will not only provide the telemetry-analysis and display equipment, but will also ensure proper interfaces for any sensors selected by the mine, provide software to process the data,

and assist the mine during installation, testing, and operator training. The costs for these services, however, may sometimes be broken out separately from the hardware costs. For mines that prefer to use in-house personnel for these tasks, systems suppliers that restrict themselves to providing the hardware alone may be worthwhile.

4.5.2 Telemetry-Analysis and Display Systems

Table 4-2 summarizes the major mine monitoring systems currently available in the United States. Three of the systems, Davis, Hawker Siddeley, and Transmitton, were originally based on the MINOS system developed by the National Coal Board in Great Britain. Systems offered for sale in the United States may, however, differ from the original MINOS system. Most of the systems have the capacity for accepting input from a wide variety of environmental and production sensors. An indication of the extensive use of monitoring systems abroad can be obtained by comparing the U.S.-foreign installations for the two British systems. While these systems are used extensively abroad, they are just beginning to be accepted in the United States.

As discussed previously, most of the systems use an FSK format for data transmission. The exceptions are Conspec, Mundix, and Transmitton, which use a direct binary transmission.

While the range in the number of monitoring points and cable length is substantial, most systems should provide sufficient capacity for typical usage.

In terms of system costs, one manufacturer uses a "rule-of-thumb" of $50,000 for the central station and $20,000 per mine section.

The final category of table 4-2 indicates which suppliers usually assume overall system responsibility.

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TABLE 4-2. – Mine monitoring systems currently available in the United States

	Aquatrol	Conspec	Davis	Giangarlo	Hawker Siddeley	Kidde
Current installations:						
Coal mining..............	1	4	1	14	>100	4
Metal-nonmetal mining...	1	12	0	0	NA	0
Other industries........	3,000	Several	0	8	NA	100
Specifications:						
Data transmission.......	FSK	DB	FSK	FSK	NA	FSK
Maximum number of monitoring points.	NA	768	[1]5,080	[2]6,400	[1]6,944	1,024
Cable (number of conductors).	2	4+S	2+S 4+S	2+S	7+S	1+S Coax.
Maximum cable miles.. length.	[1]1	[1]0.8	20	20	8	10
Power requirements, V:						
Ac.....................	110	110	110	110	110	110
Dc.....................	NAp	12	NAp	12	NAp	NAp
Cost, thousand dollars:						
Central station.........	40-75	25	100	15-23	NA	75-100
Outstation..............	5-10	0.25	25	[3]3-7	NA	3-4
Overall system responsibility.	Yes	Yes	Yes	Yes	Yes	Yes

	MSA	Mundix	Outokompu	R.F.L.	Sangamo Weston	Trans-mitton
Current installations:						
Coal mining..............	1	0	0	1	0	200
Metal-nonmetal mining...	0	1	1	0	1	0
Other industries........	0	1	>100	100	>100	0
Specifications:						
Data transmission.......	FSK	DB	FSK	FSK	FSK	DB
Maximum number of monitoring points.	72,000	[2]4,096	Unlimited	[4]128	8,192	7,392
Cable (number of conductors).	2+S	4+S (HF)	2+S	2+S	2+S 4+S	4+S
Maximum cable miles.. length.	8	128	>6	>10	[1]2	10
Power requirements, V:						
Ac.....................	110	110	110	NAp	110	110
Dc.....................	12	24	24	12	12	NAp
Cost, thousand dollars:						
Central station.........	25	80	5-100	1.3-1.5	15-100	50-60
Outstation..............	1	3	3.3	0.7	5-15	4-8
Overall system responsibility.	Not normally.	Yes	Yes	Not normally.	Not normally.	Yes

DB   Direct binary.   NA   Not available.   S Shield.
FSK   Frequency shift key.   NAP   Not applicable.
[1]Extendable.   [3]Includes CO monitor.
[2]Digital inputs.   [4]# per station.

4.5.2a Systems Suppliers

The system is typically purchased from a vendor who will supply the telemetry-analysis and display equipment. Since this vendor will usually ask the mine operator to specify the sensors used in the system, sensor operating principles and available sensors are discussed separately.

All of the systems suppliers, with the exception of R.F.L., provide computer-based systems with printers, CRT's, software packages and auxiliary power in case of main mine power failure. The listing is of necessity incomplete, it does not represent endorsement by the Bureau of Mines, nor is responsibility assumed for any errors that may have occurred in system performance descriptions. Much of the material was abstracted from telephone conversations with and brochures received from the designer-manufacturers.

Aquatrol Corp.
2258 Terminal Road
St. Paul, MN 55113
(612) 636-3950

Aquatrol Corp. markets an Intel 8085-based monitoring and control system that is sold primarily to water treatment facilities. It has full system capability including color CRT, printer, and 262,000 random-access memory (RAM) floppy disk storage. The system will accommodate up to 98 outstations on the master trunk, with up to 18 data channels per outstation. Each channel can be analog, resolved to 12 bits, or the 12-bit digital word can be treated as individual binary level inputs.

Similarly, each outstation can output up to 6 analog channels or 12 binary drive levels for each analog channel less than 6.

The cable is two-conductor voice grade, operable to 5,000 ft or, with an extender, further. Power is 110-volt ac or 12-volt dc for both the central or the remotes.

Telemetry is at 300 baud using RS232C format.

A training program about a week long is offered at their plant. They will assume system responsibility and quote a maintenance contract if desired.

Conspec Controls, Inc.
901 Fuhrmann Blvd.
Buffalo, NY 14203
(716) 854-4769

The Conspec Senturion Series 200 monitoring system consists of a central processor that has a CRT display and keyboard, two printers, one or more "data concentrators," which are interface devices, and a capability for up to 768 sensing (monitoring and/or control) points on any of four trunks, each capable of carrying 128 locations. At the sensing location, the electronics necessary to interface a sensor onto the trunk (including entering its address) are housed on a 4- by 6-inch accessor card, which in many cases is incorporated into the sensor package.

Transmission is over four-conductor cable; two for power and two for signal. The power required is up to 30 volts dc, and the maximum end-to-end length is 4,000 ft. If greater distances are required, a trunk extender can be used; powered by 110 volts ac, it permits operation to 40,000 ft. A 600-baud (bit per second) FSK telephone modem is also available.

Data transmission is in a noise-resistant binary format. There are no remote stations, other than the accessor at each measurement location. Either binary or analog data can be transmitted.

Display is in a 20-character alphanumeric format (20 letters or numbers) so that interpretation is simplified. A complete software package is offered that has the capability to alarm on thresholds and set high-low points. Set points can be entered from the keyboard. There is central reset of remote points, a programed restart or load-shedding feature,

time of day or week programing, and sequencing initiated by alarm or keyboard entry.

Alarm states are printed and displayed separately. Routine information such as end of shift reports may also be generated.

Standard accessors available include interfaces for thermistors, pressure, RTD, power, current (4-20 mA, 0-5 volts, 0-1 mA), potentiometer, alarm states, two- or three-state load control, and electrical demand.

> John Davis and Sons (Derby) Ltd.
> Alfeton Road
> Derby DE2 4AB
> England
>
> Service Machine Co., Inc.
> Box 8177
> 6072 Ohio River Road
> Huntington, WV 25702
> Attn: Mr. J. H. Nash

Davis of Derby offers a data transmission system consisting of a surface master station with two video displays, a control keyboard, and a communications switchboard. Associated with this central station are up to 127 outstations, each capable of monitoring up to 40 transducers. Interconnection is by either two- or four-conductor shielded cable. Telemetry is accomplished digitally with FSK coding.

Outstations can be wired to accommodate prestart warning, belt slip, and other transducers, including temperature and pressure.

Virtually all Davis of Derby underground equipment is housed in flameproof housings, and most circuitry is designed to be intrinsically safe. Certification and design are to international standards, such as Cenelec Standard 50 020 and IS1902 Class I. Circuitry is low-power CMOS. Standby battery power is available with automatic changeover.

A variety of system configurations is available. Outstations have been designed primarily for haulage, machinery monitoring, and communication. For example, the type 25200 equipment accepts eight thermal probes and two other transducers, such as pressure and flow. Thresholds are set locally with a potentiometer. Such a unit would be appropriate as a compressor, fan, or pump monitor. There are local and remote stop modes.

Similarly, the FMS1 type 25000 accommodates six transducer inputs, and has six relay outputs for indication and/or control. It can perform level detection, temperature detection, and time delay functions. Applications listed include haulage, bunker, pump, and refrigeration plant monitoring. It is powered with 110-volt main power.

Other communication, conveyor control, and signaling devices are also offered.

> Giangarlo Scientific Company, Inc.
> 2500 Baldwick Road
> Pittsburgh, PA 15205
> (412) 922-8850

The Giangarlo system consists of a central processor with associated outstations. The outstations are microcomputer controlled and are capable of accepting up to five input boards. Each board may consist of either 8 analog inputs, 16 digital inputs, or 8 relay inputs, and each board has light-emitting diode (LED) status lamps for troubleshooting. There is battery backup power. Telemetry requires a three-conductor shielded cable with data packaged in an ASCI II serial FSK digital format, run at 300 to 1,200 baud. Remote stations can alarm on their own, with visual and audible alarms.

At the central computer, software is available that will use redundancy checks of data to identify faulty transmission. It can display data, set remote alarm thresholds, and perform control

functions. Central computer alarms are independent of remote alarm status.

There is provision for interface from the central computer to a teletype, CRT display, disk memory, or another computer.

Input parameters that might be measured and transmitted to the central station include carbon monoxide, carbon dioxide, methane, temperature, air velocity, radon, belt slippage, belt speed, weight, pressure, power, etc.

Hawker Siddeley Dynamics
 Engineering Ltd.
Manor Road
Hatfield, Hertfordshire AL10 9LP
England
Hatfield (07072) 68234

United Technologies Bacharach
301 Alpha Drive
Pittsburgh, PA 15238
Attn: Mr. David M. Nelson
(412) 784-2137

Hawker Siddeley is one of the qualified manufacturers of the MINOS system. It offers systems for environmental monitoring, conveyor and bunker control and monitoring, and mine cage monitoring. The "Dynalink" system for conveyor control and monitoring consists of a surface control center with provision for local control and monitoring or for remote control from the remote station. Outstations are connected to the central station with six-conductor cable at distances up to several miles. Sixteen outstations can be carried on one cable, and seven cables can be accommodated

The control station has a dual visual display. Monitored data, or change of state, or even mimic diagram graphics can be displayed. The central computer is a DEC PDP 11/34 or CAI ALPHA LS1-2/20G. Microprocessors used are Intel 8080 and 8085. There is dual control with automatic switchover for reliability.

Each outstation can accommodate 32 input channels, expandable in increments

of eight. Power is 110 volt, 50 Hz, or any standard mine supply.

The bunker-conveyor monitoring and control system can automate haulage from the vicinity of the face to the surface, including bunker monitoring and metering.

Their mine cage monitor maintains the cage within speed and distance limits, comparing cage performance to a desired operation profile every 0.1 sec and making the appropriate corrections.

The environmental monitor can accept either analog or digital inputs from sensors such as anemometers, methanometers, pressure sensors, and bearing temperature probes.

Kidde Automated Systems
(Formerly S.R. Smith Co., Inc.)
7256 County Line Road
Deerfield, IL 60015
(312) 272-8012

The S.R. Smith System uses a remote "data collection panel" architecture. Each remote station is capable of receiving up to 16 contact closure inputs. The remote stations also contain relays that are capable of control functions such as starting-stopping belts. A new system has a capability for the transmission of analog levels.

The central computer facility uses Digital Equipment Corp. display and analysis equipment. A CRT displays information from any of 1,024 monitor points, connected to any of 64 remote stations per channel. Telecommunication is over a two-wire pair, or coaxial line, or 3002 Telco for each channel.

A complete interactive software package is available that displays alarms in a prioritized list. Data are also printed on a high-speed printer, as an aid to failure diagnosis and as a permanent record. Up to 700 characters of description and instruction are possible per alarm point.

Intended applications include belt monitoring (slip, alignment, power, chute plugging, etc.), power center monitoring (breaker position, voltage in range, open ground, etc.), environmental monitoring (methane within limits, air velocity within limits, etc.), fire monitoring, and fan monitoring (operating, temperature in range, etc.). The system can be used with a card reader to control and monitor people underground or in a controlled area.

Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA 15235
(412) 273-5000

Catalyst Research Corp.
3706 Crandall Lane
Owing Mills, MD 21117
(301) 356-2400

Catalyst Research Corp. has designed and tested a computer based supervisory control and data acquisition system (SCADA) which is also available from MSA. The system can accommodate up to 38 field data stations. Each data station is capable of receiving eight analog inputs, plus any one of the following: 16 digital inputs or 4 digital outputs.

Remote stations can be up to 18 miles from the central station. Cabling is by two-conductor No. 19 gage twisted pair. The central station is computer based. It uses a Digital Equipment Corp. LSI11 microprocessor with 64,000 bytes of memory. Data transfer from remotes to the central station uses RS232 at up to 2,400 baud.

Interactive, user friendly software is available. Alarm states are indicated audibly and automatically printed. Hourly and daily summaries can be generated.

Mundix Control Systems, Inc.
5495 Marion St.
Denver, CO 80216
(303) 296-1790

Mundix offers a supervisory control and data acquisition system that can accommodate up to 128 outstations. Each outstation can be configured with four electronic interface cards (extensible to 16). Each card can accommodate any one of the following: four analog inputs (12-bit resolution), eight digital inputs, eight digital outputs, or four analog outputs.

The total system capacity is 4,096 digital inputs or 1024 analog. Telemetry to the central station is accomplished using a 500-kHz digital phase modulation technique (Manchester coding). As a result, the system uses two-conductor shielded cable. The maximum transmission distance is stated to be 128 miles.

The central station is computer-based, and BASIC language programable. There are printers and color or black and white CRT monitors available. Power to the central station is 110-volt ac, while remotes can be powered with either 110-volt ac, 24-volt dc, or 120-volt dc.

Outokumpu Engineering
4680 Packinghouse Road
Denver, CO 80216
(303) 371-0540

There are hundreds of Outokumpu monitoring systems installed in Europe, primarily in power control applications. It is a computer based system (DEC) with an interactive English control software. The system has a capability for up to 30,000,000 bytes of storage on a Winchester disk and printer, CRT options.

The remote outstations are typically configured to accept 4 analog inputs, 16 digital inputs, and 16 digital control outputs. There are two types of outstations, the miniremote described above, and larger, higher capacity units. Outstations can be interconnected in any series parallel configuration. Analog data is resolved to a 12-bit precision.

Telemetry is accomplished using a serial RS232 FSK format at 300 baud (50-600). Outstations can be up to 6 miles distant. Two-conductor twisted pair cable is required.

Power to the central and remote stations is 110-volt ac, 220-volt ac, or 24-volt dc.

R.F.L. Industries, Inc.
Boonton, NJ 07005
(201) 334-3100

R.F.L. Industries manufactures telemetry equipment consisting of building blocks that can be combined to satisfy progressively more demanding system requirements. The simplest system consists of frequency-multiplexed transmitter-receiver pairs that operate with center frequencies between 300 Hz and 30 kHz in spacings of 100 and 120 Hz or more. These devices are available in two configurations: an AM system, in which the carrier is keyed on or off with a 12-volt dc input status, or a system with a switch closure. A more secure frequency-shifted version uses the same audio band center frequencies, but frequency-shift codes the data in any of four codes including a two-frequency code (mark-space) and a three-frequency code (mark-center-space). Both systems are powered by 12-volt dc. If standard CCITT channel spacing is used, there are 46 carrier channels between 300 Hz and 10 kHz, with more at higher frequencies.

If there is a need to transmit analog data, the model 64B series converts input voltages in the 0.4- to 2-volt range, or input current 4 to 20 mA, 10 to 50 mA, etc., into a square wave output, frequency coded in the 5- to 25-Hz range. After voltage- or current-to-frequency conversion, these low-frequency codes are transmitted by using the frequency shift transmitter-receiver described.

If large numbers of status-control signals are to be telemetered, the model 66A encoder-decoder will accommodate 16 input channels. These data are then time-division-multiplexed (TDM) with a redundant transmission (normal and polarity-inverted, doublescan format) to ensure reliable transmission. There are two parity check bits, so that parity errors up to the third order can be detected. Once again the data are telemetered with one of the frequency-shift, frequency-multiplexed transmitter-receiver pairs. The scan time with the normal 60-baud system is 1.1 sec with doublescan and 0.6 sec with single scan. Input data can be binary level or switch closure inputs. Power is 12 volts dc.

Analog channels can also be accommodated on the TDM system. Analog inputs are channeled, one at a time, to an A-D converter. The analog quantity is digitized and this parallel digital signal, together with a corresponding digital address, is fed to a 66A encoder. Transmission is now similar to that in the foregoing paragraph. At the receiving station, the message is decoded, and the digital output is channeled to the corresponding D-A converter to produce an analog output.

Sangamo Weston, Inc.
Industrial Products
P.O. Box 3041
Sarasota, FL 33578
(813) 371-0811

Sangamo Weston manufactures three different monitoring and control systems. Their RECON I has a capability for up to 127 remote stations, each with 12 analog inputs, resolved to 12-bit precision, and 12 output levels. Channels can be extended fourfold as an option. Operation is either manual or by computer control. Cycle time is 0.5 sec per channel.

The RECON II has eight channels per remote and can accommodate eight analog channels each, resolved to eight-bit precision (0.4%). It is controlled by an Intel 8080. The output is a printer terminal. Cycle time is 0.5 sec per channel.

The RECON III is a computer-controlled system that uses a Digital Equipment Corp. PDP-11/24 programed in RSX11M. Peripherals include a color CRT and printer. It is capable of 256 remote stations. Reporting is by exception (report when exceed limits). Each remote is capable of 16 analog inputs and has 16 output control relays (KU series 20A relays). Resolution of input signal is 12 bits (0.024%). The system has a data base and graphics edition and a capability to download to remotes over the data line. Remotes can scan subremotes.

A microprocessor-based system, MIC-RECON, is under development and will be released soon.

> Transmitton Ltd.
> Smisby Road
> Ashby-De-la-Zouch
> England LE6 5UG
> 0530-415941
>
> Reliability Technology
> 150 Plum Industrial Court
> Pittsburgh, PA 15239
> (412) 325-3121

Transmitton Ltd. is also qualified to manufacture the British MINOS system.

The Transmitton control consol consists of one or two color video displays, a keyboard, two switch panels, and a communications center. The Transmitton system, represented in the United States by Reliability Technology, is designed to monitor and control the operation of conveyors, pumps, electrical switches, shaft elevators, ventilation fans, and bunkers, as well as environmental parameters such as methane, carbon monoxide, air velocity, air pressure, temperature, and smoke.

The system consists of a central control station and up to 168 outstations. Data are transmitted in a digital format, but not frequency coded; i.e., high-low states are transmitted. A four-conductor cable is used.

Conveyor monitoring includes belt speed, misalignment, belt weight, torn belt, motor voltage current and temperature, vibration, and alarm states. Sonic and visual alarms are available locally and can be controlled locally or remotely. Belt start sequencing can be done automatically, so that belts can be shut down to conserve power.

Pump monitoring might include diagnostics, such as electrical current drain, pressure, flow, etc. Energy shedding can be accomplished. Power center monitoring can be used to reset breakers remotely or to locate a problem. Software for summary analysis is included.

The Transmitton systems have been installed in hundreds of deep coal mining operations, internationally.

4.5.2b Summary

A summary of the monitoring systems offered by suppliers currently marketing in the United States is given in table 4-3.

TABLE 4-3. - Mine monitoring system summary

	Aquatrol	Conspec	Davis	Giangarlo	Hawker Siddeley	Kidde
Trunks.................	1	4	1	1	7	2
Outstations per trunk..	98	128	127	512	16	64
Total input channels per outstation.	18	1 analog or 16 digital in; 1 digital out.	40	5 boards	32	24
Inputs per outstation:						
Analog...............	<18	1 (16 bit)	8	[1]8	NA	8
Digital..............	[2]18 analog	16 (1 bit)	32	[1]16	NA	16
Outputs per outstation:						
Analog...............	<6	NAp	NAp	NAp	NA	NAp
Digital..............	[2]6 analog	1 (1 bit)	4	[1]16	NA	8
Transmission distance..	[3]1 mi	[4]4,000 ft	20 mi	20 mi	8 mi	10 mi
Cost, thousand dollars:						
Central station......	40-75	25	100	15-23	NA	75-100
Outstation...........	5-10	0.25	25	[5]3-7	NA	3-4
	MSA	Mundix	Outokompu	R.F.L.	Sangamo Weston	Trans-mitton
Trunks.................	3	1	Unlimited	1	32	6
Outstations per trunk..	38	128	32	1	8	28
Total input channels per outstation........	[6]24	[7]16 boards	20	8 boards	32	28
Inputs per outstation:						
Analog...............	8	[1]4	4	[1]16	16	16
Digital..............	16	[1]8	16	[1]16	16	28 analog
Outputs per outstation:						
Analog...............	NAp	[1]4	NAp	NAp	16	2
Digital..............	4	[1]8	16	[1]16	8	28
Transmission distance..	8 mi	128 mi	>6 mi	>10 mi	[3]2 mi	10 mi
Cost, thousand dollars:						
Central station......	25	80	5-100	1.3-1.5	15-100	50-60
Outstation...........	1	3	3.3	0.7	5-15	4-8

NA Not available. NAp Not applicable.
[1]Per board.   [4]Typical, 40,000 ft maximum.   [7]4,096 digital and 1,024 analog,
[2]Times 12.   [5]Includes CO monitor.   maximum.
[3]Extendable.   [6]575 maximum data points.

4.5.3 Sensors

While mine monitoring systems can include both environmental and production sensors, this report focuses on environmental sensors. Of particular interest in environmental monitoring are air velocity, methane and carbon monoxide concentration, and respirable dust.

Air velocity can be measured by using either vane anemometers or acoustic vortex-shedding anemometers. Vane anemometers are basically mechanical devices in which the airflow causes the vanes or impellers to rotate at a speed proportional to the airflow. Although they are most commonly used underground as direct reading, portable instruments, they can also be adapted to a mine monitoring system. However, despite the advantage of mechanical simplicity, they are susceptible to dirt and moisture concentration. Vortex-shedding anemometers, on the other hand, have no moving parts and use acoustic signals to measure turbulence caused by the airflow. Both anemometers have the disadvantage that they are fixed

point measurements normally made in the boundary layer near the roof or rib and therefore do not necessarily represent a true measure of the average airflow.

Methane and carbon monoxide concentration can be measured by either heat of combustion (i.e., catalytic combustion) or infrared absorption techniques. For carbon monoxide, electrochemical analysis is also commonly used. The heat-of-combustion sensor is based on the principle that catalytic oxidation (i.e., burning) of a combustible gas such as methane will result in a temperature rise in the sensor in proportion to the gas concentrations. This technique is widely used in the methane monitors required for face equipment in this country. The infrared sensors are based on the fact that different gases have different infrared energy absorption characteristics. These sensors have been in use in South African and German mines for a number of years. Electrochemical analyzers measure the carbon monoxide concentration by chemical reaction with electrodes that are immersed in an electrolyte. These sensors have been used recently as part of an early warning belt fire detection system (that in some cases allowed the use of the beltway for intake air).

Remote monitoring of respirable dust presents a number of technical difficulties. Of the various measurement techniques currently in use, the beta-attenuation and optical devices appear to be the most suitable for integration into mine monitoring systems. The former uses beta radiation to detect dust concentration, i.e., the amount of beta absorption due to the dust deposited on a sample plate is proportional to the dust concentration. The optical sensors are based on the principle that the dust concentration is proportional to the amount of light reflected by the dust-laden air sample.

The following sections describe the sensing or measurement techniques for the four parameters of interest that are most applicable to underground mine monitoring. That is, only sensors that are

suitable for remote, fixed point operation underground and that provide an electrical output that can be interfaced with standard telemetry equipment will be discussed.

4.5.3a Air Velocity Sensors

There are two basic types of air velocity sensors that are applicable to underground mining: rotating vane anemometers and acoustic vortex-shedding anemometers.

The rotating vane anemometers are mechanical devices with vanes or impellers that are rotated or turned by the air flowing through the anemometer. The better instruments use ball bearings that reduce the turning friction of the main shaft on which the vanes are mounted to improve the accuracy at low air velocities. Portable (typically hand held) vane anemometers have been a standard air velocity measuring instrument in underground mines for a number of years. The Davis vane anemometer is probably the most common example of these direct reading instruments. Recently there has been some interest in adopting these instruments to remote monitoring systems; for example, American Mine Chemical Co. is currently distributing the British Abbriko anemometer that provides an electrical pulse count output proportional to the air velocity. However, while the device does have certain advantages because of simplicity of operation, its susceptibility to excessive dirt and moisture represents a significant disadvantage. The National Coal Board, experimenting with such anemometers (such as its BA.1 and BA.2), found that increasing the vane diameter increased the torque on the center shaft and thereby reduced the potential of the shaft seizing because of dirt accumulation (9).

The second category of anemometers, acoustic vortex-shedding, measure air velocity by sensing the frequency at which vortices are shed from a rod placed in the airstream. The vortices, or eddies in the airstream, are sensed by the effect they have on an acoustic (actually

ultrasonic) pulse transmitted through them. A typical configuration would consist of a relatively compact package containing transmitting and receiving transducers mounted on opposite sides of a small rod and the electronics required to transmit the data to the appropriate outstation or control panel. Since vortex shedding anemometers have no moving parts, they are particularly well suited for underground mines. However, while they are less susceptible to contamination than the vane anemometers, they are also typically more expensive than the mechanical anemometers.

It should be pointed out that both types of anemometers are fixed point units and as such have the disadvantage of being able to measure the airflow at only one point in the airway. This restriction is usually compounded by mounting the unit close to the roof or rib of the airway, i.e., in the boundary layer where changes in the average airflow cannot always be accurately sensed. Although there are empirical methods of compensating for this measurement deficiency, they do not always provide the most satisfactory solution.

The two major suppliers of acoustic anemometry equipment in this country are J-Tec Associates and Mine Safety Appliance (MSA). The J-Tec model VA-216B is approximately 12 by 7 by 4 inches in size and can measure air velocity in two ranges; 50 to 3,000 fpm and 150 to 10,000 fpm (±2% of full scale). The unit operates on a 12 to 21 volts dc at a maximum of 35 mA. While the standard output is 0 to 5 volts dc, the unit can also provide 1 to 5 mA or 4 to 20 mA as an option. Calibration, performed at the sensor, is typically recommended at 6-week intervals. The price of the unit runs between $1,000 and $1,500, including output electronics.

The MSA sonic anemometer can measure air velocities up to 25,000 fpm. The sensor requires 110 volts ac power (30 w) and produces either 0-1 mA or 4-20 mA outputs. The list price of the unit is between $500 and $600.

4.5.3b Methane Sensors

There are two primary techniques of detecting and measuring methane concentration that are suitable for use in mine monitoring systems: heat of combustion and infrared absorption. Of the two, the heat of combustion, or catalytic combustion, sensors are the most common in this country. These sensors detect the presence and concentration of methane by measuring the temperature rise of a catalytic element that oxidizes (i.e., burns) the methane at very low temperatures without a flame. The temperature rise in the catalyst is proportional to the methane content of the air surrounding the sensor.

There is some difference in the technique by which the sensors expose the catalyst to the gas mixture to be measured. Some devices rely on diffusion of the gas mixture through a porous metal flame arrestor screen. These are often referred to as "diffusion-head" type sensors. Others use mechanical pumps to drain air samples across the catalyst. A third method, referred to as "sniff and sneeze," alternately draws the sample in and then exhales prior to the next sample. While the diffusion devices have a slower response time they are simpler and do not rely on mechanical pumps that may be affected by dust and moisture. Diffusion-type methane sensors are typically used in the monitoring and automatic deenergizing devices required on face equipment in U.S. coal mines. Although catalytic combustion sensors are relatively rugged and simple in operation, they do have (at least in principle) a disadvantage in terms of specificity. That is, the catalyst temperature will rise in the presence of any combustion gas, not just methane. However, this disadvantage is not always a major problem and can be reduced somewhat by operating at a specified temperature or selecting a catalyst that favors a methane-oriented chemical reaction. A second, and possibly more important, disadvantage is that catalytic sensors are not generally suitable for measuring methane concentrations above 5%.

The second methane sensing technique is based on the absorption, by different gases, of different amounts of infrared radiation. In a typical configuration, infrared energy is passed through a sample cell that has windows that do not absorb in the infrared band. Either the sensor is equipped with a reference cell or the sensor is calibrated by purging the sample cell with nitrogen prior to making any measurements.

An infrared detector, located on the opposite side of the cell, produces an electrical signal proportional to the difference between the reference and the sample. This signal is, in turn, proportional to the methane concentration. Infrared sensors can be used to measure methane concentrations in the entire range between 0% and 100%. While these devices are relatively sensitive and specific, they are typically more complex and expensive than the catalytic sensors.

Table 4-4 summarizes the methane sensors currently available in this country. Although only one infrared sensor is mentioned, it should be noted that several infrared sensors have been developed in other countries, among them the South African SPANAIR and the German UNOR.

TABLE 4-4. – Methane sensors

Company	Model	Measuring principle	Range, %	Electrical output	Power requirements	Cost[1]
Appalachian Electronics.	102A	NA.......	0-99	Digital	110 V ac	$1,800
Bacharach..........	CD800	Catalyst.	0- 5	0-100 mV	110 V ac	1,100
CEA................	RI550A	Infrared.	0- 2 / 0- 5	0-10 mV	110 V ac	2,200
CSE................	140	Catalyst.	0- 5	0-100 mV	110 V ac / 270 V dc	2,200
Dynamation.........	1210EX	...do....	0-50	0-1 mA	110 V ac / 12 V dc	NA
ERDCO..............	250	...do....	0- 5	0-50 mV / 0-100 mV	110 V ac / 24 V dc	1,200- 3,000
GasTech............	1620	...do....	0- 5	0-100 mV	110 V ac / 12 V dc	1,100
General Monitors...	480	...do....	0- 5	4-20 mA	110 V ac / 24 V dc	1,200
J-Tec..............	VM101B	...do....	0- 5	0-5 V dc	12-21 V dc	500- 1,000
MSA................	3	...do....	0- 2	0-1 V dc / 4-20 mA	110 V ac	500
NMS................	1810-0073	...do....	0- 5	4-20 mA	12 V dc	300
Scott Aviation.....	40008561 / 40008015	...do....	0- 5	4-20 mA	24 V dc	400
Texas Analytical...	1930B	...do....	0- 5	0-1 mA / 4-20 mA	110 V ac / 12-24 V dc	1,400

NA Not available. [1]Rounded to nearest $100.

4.5.3c Carbon Monoxide Sensors

There are three techniques of carbon monoxide sensing that may be considered suitable for use in mine monitoring systems: electrochemical reaction, catalytic-combustion, and infrared absorption.

Electrochemical sensors contain a sensing electrode, a counter electrode, and sometimes a reference electrode in an electrolyte (such as sulfuric acid solution for the Energetic Sciences Ecolyzer 2000). The air to be sampled either is allowed to diffuse into the sensor or is drawn in by a mechanical pump. The carbon monoxide in the air reacts with the electrodes, generating an electric signal proportional to the carbon monoxide concentration in the air sample. General Electric Co. has developed, in conjunction with the Bureau of Mines, a fuel cell carbon monoxide sensor that uses a solid polymer electrolyte. This design, of course, has the advantage of not having a liquid electrolyte that can spill.

The catalytic combustion technique is quite similar to that discussed earlier for methane sensing. That is, the air sample is oxidized in the presence of a catalyst, with the resulting temperature rise in the catalyst being proportional to the gas concentration. As mentioned earlier, the basic technique is nonspecific, and carbon-monoxide-specific catalysts and appropriate filament temperatures are required to reduce the interference of other combustible gases.

The infrared technique is also similar to that described for methane detection. The sensor is made selective for carbon monoxide by modifying the receiver transducer to detect changes in the infrared wavelengths that are absorbed by carbon monoxide molecules. For a nondispersive system, the absorption filters must be changed, and for the dispersive systems, the refraction grating may have to be changed.

Table 4-5 lists several representative carbon monoxide sensor suppliers. While no infrared carbon monoxide sensors are listed, at least one is manufactured in South Africa. It is called the SPANAIR, and it can also be modified for use as a methane detector.

TABLE 4-5. - Carbon monoxide sensors

Company	Model	Measuring principle	Range, ppm	Electrical output	Power requirements	Cost
Dynamation.........	CO-2300	Catalyst.......	0- 300	0-1 mA	117 V ac	$950
	CO-300	...do..........	0- 300	0-1 mA	110 V ac 12 V dc	925
Energetic Sciencies	4125	Electrochemical	0- 50	0-1 V dc	110 V ac 14-28 V dc	1,700
General Electric...	15ECS6	Fuel cell......	0-1,000	0-20 mA	7-38 V dc	NA
MSA................	571	Electrochemical	0- 100 0- 500	0-1 V dc	115 V ac 19-60 V dc	1,830
Neutronics.........	910	...do..........	0-4,000	4-20 mA	110 V ac	1,200

NA Not available.

4.5.3d Dust Sensors

Although there are many types of techniques to measure dust concentrations in mine air, a number of technical difficulties limit the availability of dust sensors that would be suitable for use in automatic, remote, mine monitoring systems. For example, while the Bendix-type personal dust sampler has been used successfully for a number of years, it is not amenable to remote monitoring because the filters must be manually removed, weighed, and replaced. Three measurement techniques that might be adopted to remote monitoring are described below; they are optical sensing, piezoelectric sensing, and beta attenuation.

In optical sensors, a beam of light (from either an incandescent or laser source) is directed into a chamber that contains a sample of the dust-laden air. The intensity or brightness of the light that is scattered by the dust cloud in the chamber is governed by the surface area of the dust particles. The intensity of the reflected light is typically determined by comparison with a portion of the direct light. While the device is normally manual in operation (the direct light is passed through a variable filter that is adjusted until the intensity of the direct light equals the reflected light), at least one company manufactures an optical dust monitor with an electrical output. The Japanese-made Horiba monitor provides an output of 0 to 20 mA, but since it requires 110 volts ac (10 W), MSHA approval is necessary if it is going to be used in a return airway. Another unit, GCA model RAM-1 dust monitor, measures concentrations in the range of 1 to 200 mg/m^3, has a 0- to 10-volt dc output and runs on 110 volts ac. The cost of this unit is approximately $6,000.

The main disadvantage of this technique is that a direct comparison between dust concentrations by this technique and other methods is possible only when the particle size distribution of the dust in the air sample is the same as that used for instrument calibration.

The second method is piezoelectric sensing. In this type of dust sensor, particles are drawn through an orifice and deposited on the face of a quartz crystal. This crystal is part of an oscillator whose resonant frequency changes linearly with small changes in crystal thickness (or mass). As particulate mass collects on the crystal face, the frequency decreases. Therefore, the rate of frequency change is proportional to the airborne mass concentration.

The third technique is beta attenuation. In beta attenuation instruments, the aerosol is drawn through an orifice, and particles impact on a suitable surface. The impact surface is positioned between a beta radiation source and a counter. The amount of beta absorption recorded by the counter is proportional to the dust concentration. The major example of this technique is the GCA high-concentration dust monitor that GCA developed in conjunction with the Bureau of Mines.

The major advantage of the GCA dust monitor over the light-scattering monitors is that (within certain limits) the GCA unit measures the mass concentration independent of the type of dust and particle size distribution.

4.6 Existing Mine Monitoring Systems

Monitoring systems have been installed in a limited number of U.S. coal and metal and nonmetal mines. In addition, numerous systems are installed in foreign countries. In this section, several installations are described; the reasons for their development and comments that are relevant to the central issue of monitoring and/or control in underground coal mining are given. In cases where the data have been published and are available, the name of the mine is listed. In cases where data were obtained from mine personnel and are not generally available, only a letter designation for the mine is provided.

4.6.1 U.S. Undergound Coal Mines

Mine A

Coal producer A operates a coal mine in support of its steelmaking operations. A very extensive monitoring and data acquisition system was installed in 1978. The system has production, management, maintenance, and safety components.

In 1978, production was lagging and morale was poor. A human relations audit indicated that section foremen and others felt isolated and left to fend for themselves. Communications were poor. Support to section foremen was perceived as slow and often ineffectual.

The system that was installed focused on improved communication and backup support. It monitors production, provides maintenance support from a data base system, supports underground management with improved reporting and communication, and enhances safety with tracking and followup of unsafe conditions.

At present, phone reports are required from each section foreman every 2 hours (soon to become every hour when a leaky coaxial radio link system becomes operational). The status reports are received by an operator who codes the status, including mechanical problems and repair effort underway, onto a data base reporting system. These reports include

Conditions on section.

When loading of coal started.

Mechanical delays.

Nature of delay.

Start-stop time.

Mechanical problems are keyed to machine and location. Information is coded by a communications coordinator, then telemetered over phone lines to a central office computer. Since a communications coordinator is the only one to enter the data, it is coded in a uniform fashion.

In turn, section foremen are able to interrogate the system at any of the three underground communication centers (one at base of portal, and one each at East and West mains).

Spare parts inventory software was generated from an existing program used in the mill activity. A detailed, pictorial blowup with parts number callout is available near each section. As a result, the inventory status, location, and ordering (reorder from vendor, if necessary) can be accomplished quickly underground. Similarly, management can track problems by interrogating the system.

Because the bihourly reports are relatively complete, formal end-of-shift reports are no longer necessary, and ongoing foremen have a current status sheet on which to base their plans.

This mine installed the cable for the system, purchased modems to enable communication of the data over phone lines, and then leased the remainder of the system, including dedicated phone lines to the computer facility, line printers, CRT displays, etc.

Software was developed in-house, although some of it already existed, since it was in use in the associated steel mill. Software development times were estimated to be

Production system.... 14 man-months.
General underground.. 18 man-months.
Maintenance.......... Existed.
Safety............... 12 man-months.

Surprisingly, one of the most troublesome links in the system has been the leased commercial phone lines (2,400 baud) used to telemeter data to the central computer facility. There have been instances of outages for days.

Mine B

Coal producer B has a monitoring system that uses equipment built by Larse Corp. of Palo Alto, CA. It is a hard-wired, time-domain multiplexed system (channels interrogated sequentially in time), designed originally for building, process control, or energy monitoring. The producer uses the system for belt monitoring and for carbon monoxide and temperature monitoring on the slope (the mine has a propane preheat system).

The history of the system is that in 1975, local management personnel had decided to upgrade the telephone system to a dial-phone system. Their chief electrical engineer urged simultaneous installation of a monitoring capability, perhaps integrated with the new phone system. He obtained mine managers' approval, and invested approximately one-third of his time during the next 3 years selecting, purchasing, installing, and testing the system. He was assisted underground with cable stringing and other installation tasks about one-sixth of the time.

The Larse system that was purchased is capable of transmitting only binary data. The sequence time is 3 sec per station. Transmission is over a spare twisted pair of conductors in the mine phone cable. An independent electronics and manufacturing firm developed and fabricted solid-state interface circuitry designed to convert voltages on control switch terminals to logic levels compatible with the Larse system. The converter was optically coupled so that belt sequencer circuitry is uncoupled from the monitor, and the converter has no moving parts, enhancing reliability. A printer is used to generate hard copy of alarm or status change. A light panel is also used to display status.

Mine personnel are evaluting the desirability of installing a J-Tec velocity and methane system. Their most likely application would be a continuous monitor of worked out panels, eliminating the need for a 4-hour inspection mandated by the State.

Extensions of this system might include ventilation control. In that case, a variable-speed synchronous motor drive on their fan might be used to reduce energy demand when the full output is not needed. At present, 1,600 hp is drawn for ventilation. Original plans called for some airflow and methane monitoring, but this step was deferred as "too expensive with little payback."

The monitoring system is maintained by one man, who also maintains the telephone system (which requires much more time than maintaining the monitoring system).

Mine C

Operator C has several mines that have very gassy seams and heavy overburden with difficult roof control problems. As a result, personnel at this mine have received a variance from MSHA allowing the use of beltways as an inlet aircourse.

They have 5 years of experience with carbon monoxide monitors, using Energetic Sciences sensors. The current Energetic Sciences monitors that are purchased have two level alarms and a built-in battery pack for uninterruptable power supply.

The telemetry system is an S.R. Smith system that transmits digital information only and necessitates a dual threshold modification to the Ecolyzer. False alarms are generated with the Ecolyzer as the result of power intermittencies, a prime factor in the insistence on an uninterruptible battery supply. To enhance reliability, redundant PDP-11/4 computers have been installed to analyze and display data. Maintenance by DEC has sometimes been slow, although the system has been completely down only once in the last 2 years, thanks primarily to redundant equipment.

Plans include staffing up to one full-time engineer per mine for the monitoring system. Although the system initially gave frequency "nuisance" alarms, those problems have largely been solved, with the occasional exception of false alarms associated with the monthly calibration procedure. They also conduct a weekly inspection. Where alarms are displayed at the surface, the appropriate site is notified by telephone.

Future plans include monitoring of methane and airflow in returns. They have a methane drainage research project for which they have currently purchased methane and airflow monitors. During a 6-week period in the winter of 1981, they lost 10 shifts of longwall production as a result of gas outs, shutdowns that are sometimes mine wide and are the motivation for their ventilation monitoring and control plans.

Adjustment and deployment of the monitoring system hardware, including sensors, is a nuisance factor. There have also been incidents of either willful or careless destruction of equipment, particularly sensors.

They also monitor bearing temperature and water gage on their main ventilation fans, using a FSK audio band telemetry scheme.

The software for the S.R. Smith system was written by a software specialist. The costs for software were viewed as substantial.

Mine D

Coal producer D has made a very substantial commitment to its mine-wide monitoring, data acquisition, and control. Its mines are deep, with typically more than 2,000-foot overburden, are very gassy, and have difficult roof control problems. As a result, the producer has received permission to use the belt passageway for inlet air, provided that carbon monoxide is monitored. Currently two mines are equipped with belt fire monitoring equipment and two more are being outfitted. The two that are presently on-line have been operating for about 6 months. The system consists of Ecolyzer carbon monoxide sensors, with up to 40 monitors per mine, a Giangarlo transmission system, and Niagra Scientific computational and display equipment. There is no maintenance contract. The software was provided by Giangarlo. The system scans stations at a rate of about 1 per second. The cabling for the system is military surplus wire that is four-conductor twisted No. 19 wire with steel armor, which mine personnel purchased inexpensively. It has been found that the digital (frequency shift) signals can be transmitted up to about 3 miles with virtually no problems. The alarm algorithm at present is simply a level exceedance alarm. There have been four cable failures in the last 6 months, two failed open and two failed shorted, owing to accidents with large boulders on the belt. In the case of cables failing open, the system continued to operate up to the cable break, and in the case of cabling failing shorted, the entire system was faulted until repaired.

It is estimated that maintenance of the system requires about two man-shifts per week, including daily, weekly, and monthly inspections. The daily inspection is a physical inspection by the fire boss, the weekly inspection involves electrical tests, and the monthly inspection involves span calibration. The maintenance effort was estimated to be approximately one-half inspections and calibrations and one-half repair functions.

Ac power tends to be unreliable and intermittent. As a result, a gel-cell power has been installed for each sensor with a 48-hour capacity and continuous trickle charge. In the event of inadvertent disconnect and resultant battery discharge, the Ecolyzer indicates a false alarm.

All four systems were expected to be operating by 1982. Following completion of this carbon monoxide fire monitoring system, the system will be extended to monitor belt operation. In the No. 3 mine, there are 25 belts, each typically 4,000 feet long. The intent of the belt monitoring is to display remotely information about which belts are down and possibly, diagnostics as to failure mode.

Because the seam being mined is extremely gassy, the required amount of air is very high. This demand, combined with the extreme depth, results in very high water gage and very high ventilation costs. As a result, variable pitch ventilation fans have been installed, and methane and airflow will be monitored in the returns and the fan pitch modified accordingly to reduce ventilation costs. When a 2,000-hp fan was increased to a larger 7,000-hp variable-pitch fan, the power costs increased $1,900 per day at that mine. Plans also exist to monitor the temperature and vibration of fan bearings.

In addition, the producer is also automating its billing, inventory control, and maintenance functions, such as maintenance history, equipment inventory, lubrication histories, preventive maintenance, etc., as well as automating some mapping and plotter routines. These computational facilities will use their own computers and programs and *not* piggyback on the fire monitoring system.

Other monitoring plans include production tonnage monitoring, by section and shift, as well as power center monitoring, particularly on longwall sections.

Mine E

Mine monitoring at operation E has the following three distinct functions:

Trapped miner location-roof fall monitoring.

Ventilation monitoring at 11 stations.

Fan monitoring.

Trapped Miner-Roof Fall Detection

The trapped miner system was originally installed several years ago as a Bureau-funded research project. Six commercial, 40-Hz resonance, moving coil geophones are implanted about 2,000 feet apart in 50-ft-deep holes backfilled with sand. Their seismic output is fed to a Texas Instruments 980A computer that computes the epicenter of any event observed by three or more geophones. The software package includes graphics that plot the trapped miner-roof fall location with a triangle if three geophones received the signal, a square if four were activated, and an asterisk if five or more sensed the disturbance. The coordinates and computed confidence margin (error) are printed. Triangulation in the southern mine sections where the equipment is located is to within 50 to 100 feet. A disturbance count is also recorded. The trapped miner equipment is all located on the surface.

Ventilation Monitoring

Mine personnel at operation E were interested in upgrading mine technology and therefore were receptive to a Bureau of Mines request for a cooperative development. An electrical engineer from research was assigned to design and supervise the fabrication and installation of a ventilation monitoring (methane, carbon monoxide, air velocity, temperature) system and to assist in the development of a trapped miner location system. The telemetry system he designed is an audio frequency, FSK serial transmission system. It has a capacity for 16 stations and a capability for up to eight analog inputs at each station (0-5 volts dc). Data are telemetered in an audio band. The system is powered with a converter that uses power from the trolley wire,

converting -345 volts dc trolley power to 13 volts dc. At each station this 13-volt power is again converted to ±15 and ±5 for logic and control circuits. Methane is detected by mounting a Bacharach cell directly on top of the explosion-proof container that houses the electronics. Access to the box is via multipin Amphenol environmental connectors.

Carbon monoxide is detected with an Ecolyzer 4000 device, from which the 110-volt converter has been removed. Air velocity is measured with a J-Tec anemometer, mounted on a 3-ft-long pole near the center of the passageway. Flow calibration is accomplished with a Davis anemometer.

The processing display package prints hourly summaries of the low reading, high reading, and hourly average at each station.

Manual cross-checks of the system by the fire boss on his round are used to verify system accuracy and reliability. Each station is interrogated electronically every 5 min. The system has a capacity for 16 stations and a maximum cycle rate of 2.5 seconds per station.

Telemetry cables (unshielded twisted pairs) are strung adjacent to the trolley wires. The operation is gradually relocating these cables, since the most frequent failure mode for the system is a loss of telemetry because of a cable cut by a derailed trolley pantograph. Because of line losses, the sensors must be within 500 feet of the power supply and telemetry system.

Data are processed at the surface (thresholding, time averaging, high and low peak) and stored on a Phillips cassette. The cassettes can be processed with a print routine to generate hard copy.

A problem encountered during development of the wire power-to-12-volt dc converter was that there are massive transients on the trolley wire that the converter could not handle. The solution was to use a high wattage voltage divider with a zener limit, then dc-to-dc convert the voltage-divided, filtered dc.

The operation has asked for extension of the ventilation monitoring system to the north to cover the other half of the mine. However, the research staff is now committed to other projects.

All maintenance and operation is performed in-house. Spare boards are stocked for the TI 980 and the computer is maintained by swapping out defective boards. Normal maintenance and record keeping takes about 45 min per day. The system costs a little over $100,000. Individual stations cost $2,000 to $2,500. The biggest maintenance cost, by far, is line repair.

Fan Monitoring

The primary ventilation fans are continuously monitored. Local system dc power and fan head, in inches of water, are reported hourly with a low, average, and high reading. Alarm status is, of course, immediately printed.

Mine F

Operator F has three mines that share a power distribution system and that have very substantial monitoring instrumentation. Mine personnel have also begun development of a data base acquisition system. The system consists of several layers, developed sequentially.

The initial installation was a surface system for fans and circuit breakers. Later, haulage monitoring and underground fire detection were added. A large data base supervisory control system is now being installed that will be used to upgrade the fan monitoring to include vibration and temperature

monitoring so as to (1) anticipate failure, (2) detect smoldering fires by using carbon monoxide monitors, (3) control utility costs by power shedding when desirable, (4) extend haulage monitoring and control, and/or (5) acquire and store maintenance data on machines for preventive maintenance and failure analysis.

Quotations for this system are being solicited from mine monitoring system vendors and particularly from process control and energy management equipment vendors. A brief summary of the equipment to date follows.

Surface System

The surface system monitors ventilation fans and the status of circuit breakers. At present, there are 13 fans in the complex and 28 monitoring substations. The system was developed in-house in 1973 and uses a hard-wired FSK technique, with a 40-channel capacity.

Underground Haulage and Fire Detection

At present there are about six sections of instrumented haulage. A CRT display at the dispatcher indicates the number of available empty cars at each station, an estimated time of depletion of cars (a function of whether the mine is cutting), the number of loaded cars, a count of loaded cars for the shift, and whether the belt is running.

Heat sensor fire detection outputs are also displayed. Data acquisition is accomplished with a Westinghouse neumalogic system. A deluge system is controlled by the output.

Power Monitoring

The three mines have a monthly utility bill of several hundred thousand dollars. As a result, attention is being

ing given to power center control and load shedding. At present, overall power drain data are provided to dispatchers, so that they can shed "unnecessary" or lower priority loads; however, shedding rarely happens because of production pressures and the overwhelming complexity of the problem. Effective control requires mine-wide information, analysis, and synthesis of the data.

The operation buys power from the local utility at 69 kV, then distributes and transforms the power for the operations. Power billing is in proportion to the highest 30-min average, using sequential time windows (not a floating window).

Methane Monitoring

Methane is continuously monitored in one abandoned area.

Mine G

Operator G has a Motorola Intract 2000, UHF high-band transmitter-receiver system that is used at three mines. Personnel at this mine monitor ventilation fan operation, sensing water gage, and measuring bearing temperature and vibration. In each instance, the alarm level exceedance is the only data transmitted. In the case of circuit breakers, they have the capability to reset, trip, and monitor each of these.

Each mine typically has several fans and perhaps 20 circuit breakers physically distributed over the countryside, perhaps up to 4 or 5 miles distant from the portal. Electrical power is either 7,200 volts ac three-phase or 300-volt dc trolley power. In the case of circuit breakers, the system is used primarily for control and for resetting after interruptions. They reset as a test, and, if there is a second interruption, they dispatch a man to the site. Since fan

monitoring is required by law, the system saves personnel assignment to monitor the remote fans.

At the central station, located in the maintenance shop, data are displayed on a console with eight status lights, designating the presence or absence of threshold exceedance of any one of eight sensed variables at a site. There is also a hard-copy printout on a TI printer of twice-a-day status, plus alarms. One-third spares are maintained, and Motorola gives a 3-to-8-week turnaround time for repairs. The system has been on-line for 15 months, with many initial problems that have evidently been worked out.

Two fully qualified technicians with FCC licenses are on the staff and a third is being sought. Testing and qualification certification is contracted out.

Monitoring of this sort dates to 1969 when it began with a FEMCO hardware system. In 1975, an intermediate radio system was added and, later, the Intract 2000.

The parent research organization has also experimented with the feasibility of monitoring cars, as well as production activity, on each section, to improve the efficiency of the dispatch of cars to operating sections. This was a test of instrumentation and technique, using one section. They measured

1. Is the section operating?

    a. Continuous miner off.

    b. Continuous miner tramming.

    c. Continuous miner cutting.

2. At the section, how many--

    a. Cars at ramp.

    b. Empty cars waiting.

c. Full cars.

d. Empty--full conversions.

3. How many cars available at the dump site?

The goal was to reduce the "no empty" delays at the section.

The dispatcher has voice communication with the locomotive engineer and the loading supervisor at each section. Development of the design began with the following constraints:

1. Commercial sensors to be used, perhaps repackaged.

2. Existing phone lines to be used (Gaitronics) [but not same wires, i.e., use phone-quality wiring. Cable is figure 8, wire-supported, with 40 conductors in pairs.].

The sensors tested were

1. Infrared photocell (car count).

2. In-track magnetic proximity (count).

3. Sonic level (full-empty).

4. Current sensor at load center.

    a. Off

    b. Tramming

    c. Cutting

5. Traffic switch positions.

All data were telemetered to the dispatcher. There are local displays for debugging purposes. Intel microprocessors were used in remote stations.

A test of the sensing system was conducted by stationing an observer to note visually car passage, operating

time, empty-full status, and switch position. The test results were

	Visual	Automatic	Error
Direction......	582	599	3%
Empty-full.....	230	233	1%
Operating time.....min..	820	813	
Switch position	49	49	0

It was concluded that sensing reliability was good and quite adequate.

The most difficult problems were (1) the deployment-redeployment of sensors, and (2) cost-complexity of the system.

It was concluded that this type of rail haulage monitoring is technically feasible; however, the economic viability is probabilistic. There is economic payback only if all sections are instrumented, since intersection coordination is the goal. The operator opted for a computer simulation at this point to evaluate the economics, using a modified version of the Penn State RailSim program. The results indicated substantial incremental improvement in productivity, but since the operation is market limited, the economics for such a system were not quite attractive; i.e., it cannot easily sell more coal per year and cannot capitalize on the potential to run less days per year because of large capital costs and institutional factors.

A simpler less costly system might be viable. For example, a system that reported

1. Whether the section is operating (power center).

2. What the car count is at the dump site.

3. Other data manually input by the dispatcher.

Since use of longwall sections is expected soon, problems with haulage

coordination will be intensified. "Intangibles" (safety, morale, health, labor resistance, sabotage, etc.) are hard to evaluate.

A "smart sensor" standalone is being considered that--

1. Obtains power off rail line.

2. Senses a parameter, converts data to a secure format.

3. Transmits wireless.

Passive (unpowered) sensors are used wherever possible, and sensors are minimized (more manual input).

Power Monitoring

Billing of power used by energy-intensive industrial users is based on a base rate plus a peak load factor. Mine G's local utility expects to go to a peak factor based on the highest 5-min average, perhaps highest floating 5-min average. Although the potential savings are *very* substantial, an automatic power management system is clearly required to react within 5-min windows.

A very ambitious computerized maintenance management program has also been begun. There seems to be a likelihood that haulage and ventilation monitoring and/or control will eventually be attempted.

Mine H, Federal No. 2

Sensors for carbon monoxide and methane were placed so as to compare methane concentrations entering and leaving each section. Differential pressures were also measured to highlight ventilation problems owing to partial blockages, etc. Temperature, humidity, and air velocity were also measured at dozens of sensor stations. Computer control was performed at West Virginia University. These early tests served to prove that the task of underground monitoring was technologically feasible (2).

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More recently, a similar system has been used to test the concept of ventilation control (1). Ventilation parameters, including methane, carbon monoxide, temperature, humidity, airflow, and differential pressure, were measured. Ventilation regulators (louver door design) were operated electronically, and the resultant ventilation redistribution was monitored.

Mine I

Drainage of methane in advance of mining is an effective way of minimizing methane content at the working face. Since most coal mining countries have enacted safety regulations that require that face equipment be shut down if the methane content in the air reaches a predetermined level, methane drainage has production as well as safety benefits. Because methane liberation increases with rate of coal production, methane drainage is more desirable in highly mechanized longwall operations where production rates are relatively high. As a result, methane drainage is used extensively in Europe where longwall mining has become very common. In 1975, approximately 7.5 billion cubic feet of methane was drained in Polish mines, and over 21 billion cubic feet were drained from mines in the Federal Republic of Germany (7). Recently, methane drainage has also become more important as the production rates in U.S. mines have increased.

Because of the inherent design that roof falls, bottom heaving, etc., may rupture the methane drainage piping, the Bureau of Mines has specified that drainage systems be equipped with a "fail-safe" monitoring and control system (22). Basically, the system should be able to shut off the flow of methane into the drainage pipe in the event of unsafe conditions such as a power failure or break in the drainage piping.

One such system has been successfully employed in the Bethlehem Mines, Marianna No. 58, located in Marianna, Pa. This system consists of MSA methane sensors located at 500-foot intervals in the airway containing the methane drainage pipe. The output from these intrinsically safe sensors is transmitted to a control panel located in a nearby fresh air entry. Also located in the fresh air entry is a small (1.05-cfm) air compressor that supplies air through PVC tubing strapped to the drainage pipe, to the pneumatically actuated shutoff valves located at each borehole. The valves are spring loaded and held open by the air from the compressor.

The system can also incorporate a "receiving" station (located above ground) that contains meters that indicate the methane content measured by the sensors and recorders that provide a continuous log of the sensor output.

In the event of a power failure, the compressor would cease to function, the air pressure in the PVC tubing (normally 55 psig) would drop, and the valves would close. If the methane content in the airway containing the drainage pipe exceeds 1% (due to a leak in the pipe), the PVC tubing is vented by solenoids located on the control panel and the valves again shut down the methane flow. In addition, if a roof fall ruptures the drainage pipe, it will also rupture the other PVC tubing that is strapped to the top of the pipe, automatically dropping the pressure and closing the valves. Finally, if a sensor fails to operate or a cable is severed, the solenoids will vent the PVC tubing and again close the borehole valves.

References 10 and 18 discuss this system in more detail.

A summary of the monitoring systems reviewed is presented in table 4-6.

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TABLE 4-6. – Summary of monitoring systems surveyed in U.S. underground coal mines

	A	B	C
Function.............	Production, maintenance, communication.	Belt monitoring..........	Belt fire monitor, equipment status.
Parameters monitored.	Input from section foremen.	Belt operation, belt sequencing, motor temperature and power, CO.	CO, fan temperature and pressure, degasification pumps, fire suppression operation.
Size:			
Remote stations....	6..........................	40........................	15 to 20.
Input per station..	NA.........................	10........................	16 maximum.
Telemetry:			
Cables.............	2-conductor...............	2- and 4-conductor........	2-conductor and multi-conductor, shielded.
Format.............	Voice and digital.........	Digital...................	Digital.
Data display.........	Line printer, CRT's above and below ground.	Line printer, light panel.	Line printer, CRT.
Alarm................	No.........................	Yes.......................	2-level.
Year installed.......	1978......................	1978......................	1978.
Comments.............	Production reports, manpower planning.	Planned expansion—air velocity, CH_4 monitoring.	Allowed 75.326 variance.

	D	E	F
Function.............	Belt fire monitor.........	Environmental, fan operation, roof falls.	Fan operation, haulage, fire, environmental.
Parameters monitored.	CO........................	CO, CH_4, air velocity, fan power and pressure, seismic activity, battery voltage.	Fan operation, haulage, heat-CO, CH_4.
Size:			
Remote stations....	13.........................	11........................	26.
Input per station..	1.........................	4.........................	16 maximum.
Telemetry:			
Cables.............	4-conductor, shielded.....	5-conductor...............	2- and 4-conductor, shielded.
Format.............	Digital...................	Digital...................	Digital.
Data display.........	Line printer..............	Line printer, plotter, CRT, light panel.	Line printer, CRT, light panel.
Alarm................	At station and aboveground	Yes.......................	Yes.
Year installed.......	1981......................	1974......................	1978.
Comments.............	Allowed 75.326 variance, planned expansion—belt monitor, ventilation monitor.	Result of cooperative agreement with Bureau of Mines.	Planned expansion—fan temperature, vibration, maintenance data.

	G	H	I
Function.............	Fan operation.............	Environmental monitoring..	Methane drainage.
Parameters monitored.	Fan operation, temperature, pressure, vibration.	CH_4, CO, temperature, relative humidity, airflow, differential pressure.	CH_4.
Size:			
Remote stations....	10.........................	12........................	>4.
Input per station..	8.........................	10 to 20..................	1.
Telemetry:			
Cables.............	Radio link................	2-conductor...............	4-conductor.
Format.............	FM........................	Digital...................	Analog.
Data display.........	Line printer, light panel.	Mine maps, CRT, teletype..	Strip chart, meter.
Alarm................	Yes.......................	2-level...................	2-level.
Year installed.......	1979......................	1972......................	1977.
Comments.............	Had prototype haulage monitor, planned expansion—maintenance data.	WVU experiment, Bureau of Mines sponsored.	Controls drainage valves, result of Bureau of Mines Research.

NA Not available.

NOTE.—Alphabetic designators are those used for mine designations in text.

4.6.2 U.S. Underground Metal-Nonmetal Mines

Mine J

Although mine J is not a coal mine, its physical layout and mining technique are very coal-like. It is a very extensive, single-level, room and pillar mine that extracts about 5 million tons per year, working about 7 feet of a 9-foot seam that is 1,200 feet deep. The mine is classified gassy because of the presence of oil shale above and below the seam. However, it is allowed use of the beltway for fresh air, since metal-nonmetal mines are governed by 30 CFR, Part 57, which is less restrictive than the sections governing coal.

Up to 10 continuous miner sections and a longwall are operated. Underground equipment is electric, with a combination of rail and belt haulage.

A very satisfactory 50-station haulage monitoring system has been installed, and an additional system is on order. There is about 20 miles of belt conveyors.

The system, which was built by Aquatrol Corp., monitors belt functions such as belt slip, plug up, sequencing, alignment, etc.

Mine K

Operator K operates a multilevel copper mine, and has an ambitious load-shedding program underway. The haulage is electric-powered track and belt. Face operation is with diesel-powered trackless vehicles. Sump pumps run up to 5,000 hp. The utility bill is based on a 15-min peak load factor, which is hoped to be reduced greatly by load shedding. The hardware and telemetry will be purchased from Harris Co. Enlargement to a mine-wide supervisory control and data acquisition system, including airflow, perhaps production monitoring data, etc.,

is anticipated. An example with rapid payback is automatic measurement of air quality following a large explosive shot. At present, a rescue team is dispatched to certify the work areas. The result is a 3- or 4-hour mine-wide shutdown, which is, of course, expensive.

4.6.3 Foreign Mines

Canada

As in many countries, mine monitoring in Canada has become more important in recent years. The Canadian Mining Research Laboratories (CANMET) has been working on carbon monoxide and methane monitoring in western Canada since 1976. One such monitoring system, which uses an electrochemical carbon monoxide analyzer, was installed in a Kaiser Resources mine to detect mine heating. Air samples were drawn through 1/2-inch OD polyethelene tubing from distances up to 7,000 feet (8). In 1978, this system detected a significant rise in the carbon monoxide levels in one return, indicating the potential onset of heating. This early indication of heating was credited with allowing the mine to alleviate the situation without interrupting the mining schedule.

CANMET began working on methane monitoring in the coal mines in western Canada in 1977. This work centered around the use of remote methane analyzers, again by drawing air samples through polyethelene tubing. In one mine with a history of sudden gas bursts, the system successfully documented the sudden methane liberations (8).

More recently, the Cape Breton Development Corp. has installed a computer-based mine monitoring system in its coal mine in Nova Scotia (6). The system, which monitors methane concentrations, air velocities, air pressures, fan vibration, machine temperatures, and methane pump pressure, was supplied by Transmitton Ltd.

Poland

As is true for much of Europe, the Polish coal mining regulations consider continuous methane monitoring in the return airways with automatic deenergizing as an adequate alternative to individual monitoring on each piece of face equipment (as is done in the United States). Furthermore, the methane threshold values permitted by the regulations are also increased in mines where continuous monitoring and automatic deenergizing are used (16). As discussed earlier, such regulations tend to encourage the use of remote mine monitoring systems.

The Polish Research and Development Center for Mining Mechanization, Electrotechnics and Automation Systems (EMAG) has been working on ventilation monitoring and control systems for Polish coal mines for a number of years. The methane monitoring systems currently consist of remote sensors, telemetering equipment, and a miniprocessor, located in a central station that receives and analyzes the data. The system has the capability of automatically switching off electric power if the methane concentrations exceed the specified level. The system also maintains permanent records of warnings and alarms and provides summary reports on methane liberation cycles, etc.

For fire monitoring, EMAG has also developed a carbon monoxide monitoring system based on a catalytic sensor and an ionization fume sensor. The system has been tested, experimentally, in Polish coal mines.

EMAG has also worked on developing automatically controlled air regulators for coal mines. The regulator, which has pneumatically or hydraulically actuated vanes, is intended to become part of an overall mine monitoring and control system.

Sweden

Since most of the mining in Sweden is metal mining in nongassy mines,

interest in methane monitoring and control is not great. The Swedish mines do use diesels, however, and an effort is underway to monitor carbon monoxide, nitrogen dioxide, etc. In addition, some work has been done on the development of automatic air regulation. Because methane liberation is not a problem in Swedish mines, mine air regulation, which would be based on the number of diesels operating and on their location, is currently being studied (19).

U.S.S.R.

Automatic monitoring and control of mine ventilation systems has been studied in the U.S.S.R. for a number of years. This work has resulted in the development of an automatic ventilation monitoring and control system called ATMOS. This computer-based system is reportedly (14) able to monitor ventilation parameters (such as methane concentration, airflow, etc.), calculate the required airflows, and provide the system operator with information on the appropriate fan and regulator settings. Ventilation corrections are made on a weekly basis.

The system has been operationally tested in two mines, and the Ministry of Coal Mining is currently in the process of commercial development of the ATMOS system.

United Kingdom

The development and use of remote mine monitoring systems is probably more advanced in the United Kingdom than in any other country, apparently for two reasons.

The first is that British mining regulations tend to encourage the use of such systems. For example, in contrast with U.S. regulations requiring that methane monitoring devices be installed on each piece of face equipment that can deenergize the equipment once the established methane threshold is exceeded, British regulations permit monitoring of the return airways for methane if the data are transmitted to a central control

station that can remotely deenergize the affected equipment.

The second, and probably the more important reason, is that the British coal industry is nationalized and is supported by a centralized research organization (the National Coal Board's Mining Research and Development Establishment-- MRDE). This arrangement has greatly facilitated the development, testing, and implementation of mine monitoring systems in the United Kingdom.

In the 1970's, the MRDE focused its attention on developing a universal monitoring and control system that could be used throughout the coal mining industry. The system, called MINOS (for Mine Operating System), is based on a common core of equipment that consists of a control console, central computer(s), and peripherals. The application software is also the result of MRDE development. The monitoring systems are supplied to the mine by several independent companies that are free to market a variety of transducers, data transmission equipment, and accessories. The concept of a universal computer-based operating system has permitted the MRDE to achieve certain economies in the development of the system and tends to reduce interface problems.

The applications of the MINOS monitoring/control systems can be divided into the following six basic categories:

1. Ventilation monitoring.

2. Coal face monitoring.

3. Coal clearance monitoring.

4. Coal conveying monitoring.

5. Fired plant monitoring.

6. Preparation plant monitoring.

Ventilation monitoring in the United Kingdom is currently being accomplished via tube bundle air sampling as well as telemetering of data from electromechanical transducers. In the former, air samples are drawn through tubes and analyzed by using a gas analyzer located in a surface lab facility. In the latter, the output of the transducers is fed to outstations that encode and transmit the data to the surface via a communications cable. In either case, the environmental data (methane, oxygen, carbon monoxide levels, airflow, differential pressure, etc.) are analyzed, stored, and displayed on video monitors located on the central control panel. The displays and hardcopy reports can consist of warnings, alarms, actual values, or graphs of long-term trends (9). As of 1980, there were approximately two such systems either in operation or scheduled for installation (3).

Development of a system for monitoring face equipment performance began in 1977. One version of the system, called FIDO (Face Information Digested On-Line) was installed and tested in four collieries by 1980. The National Coal Board plans to install the system in an additional 24 collieries that have approximately 100 active coal faces (20). Although the system originally monitored only face equipment operations, the NCB plans to expand the system to provide data on such parameters as roof height, pick force, and equipment orientation, and eventually to permit automatic control of such equipment as longwall shearers.

Monitoring and control of underground coal conveying systems is relatively advanced in the United Kingdom, with the first system in operation in 1972. The systems provide stop-start logic sequencing in addition to sensing of such parameters as bearing temperatures, blocked chutes, motor operation, etc. As of 1980, there were approximately 30 such systems in operation in the United Kingdom (20).

Monitoring and control of coal preparation plant operations (such as conveying, reagent mixing, etc.) is a relatively new application for the MINOS system. The system began development testing in the Lea Hall colliery in 1978.

A decision on expanding the use of the system will depend on the results of this inplant demonstration.

It should be pointed out that mine monitoring systems based on the MINOS concept are currently being manufactured in the United States.

Germany

In recent years, remote monitoring of methane and carbon monoxide has received increased attention in German coal mines. One reason is that the German Federal Regulations on mine health and safety make such systems desirable and, in some cases, necessary. For example, the German regulations permit higher methane threshold values if constant monitoring is carried out by permanently installed recording instruments that can telemeter the data to a remote control center that can automatically deenergize the electrical face equipment (16). Another example is the German requirement for automatic recording of carbon monoxide levels along all belt entries.

It has been estimated that as many as 1,400 methane and 1,200 carbon monoxide measuring devices were in use in the Ruhr district in 1978. Most of these provided remote transmission of the measurement data to a central control station. In addition to the methane and carbon monoxide sensors, some 500 fixed-point air velocity sensors were also estimated to be operating in Ruhr district mines as of 1978.

In addition, investigations have been conducted in Germany into the use of minicomputers as well as microcomputers to receive and process the data from the remote sensors. The primary purposes are (1) the reduction of false alarms through trend identification and signature

matching and (2) the manipulation, presentation, and storage of large amounts of monitoring data.

South Africa

Remote automatic detection of underground mine fires is a major concern for South African mining companies. This is particularly true for the deep level gold mines because of the large amount of timber required for roof support in these mines. Instances of spontaneous combustion in South African coal mines have also been reported in recent years. For example, between 1968 and 1973 more than 23 mine fires occurred in one South African mining district. Approximately 65% of these were attributed to spontaneous combustion (11).

Two basic approaches have been used in remote monitoring for underground mine fires. In coal mines, an infrared gas analyzer drawing air samples through polyethelene tubes has been used to sense carbon monoxide levels (11), and a combination of infrared gas analyzers and ionization chamber detectors has been used in the underground gold mines (23). In the latter case, the electrical signals from the transducers were telemetered to a control room located above ground. In the control room, data (carbon monoxide level for the gas analyzer and ionization level for the combustion and particle detector) are recorded in analog form on continuous logs. In addition, the system has the capacity to initiate alarms if specified levels are exceeded.

Although some difficulties were encountered with the ancillary equipment (such as recorders) in the tube system and dirt and condensation in the telemetry system, both have proven effective in detecting mine fires.

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CHAPTER 5.--COMMUNICATION SYSTEM DESIGN AND IMPROVEMENT

5.1 Introduction

This chapter analyses the parameters influencing initial design of communication systems for new mines and upgrading existing systems.

Paragraph 5.2 outlines those variables that must be taken into account during the design stages of a new wired phone system. Recommended features, general requirements, and how they can be implemented are treated in this section.

Paragraph 5.3 describes ways of improving or extending the range of trolley carrier phone systems and pager phone systems already installed in the mine.

5.2 New Phone System Design

The task of designing an adequate communication, control, and monitoring system for an underground mine must be addressed on a system basis. In addition to insuring that effective voice communication is established, any new system should take into account present and future requirements of remote control and monitoring functions. Chapter 4 illustrated the drastic savings in response time that can be realized when remote control and monitoring are integrated into the overall communication system. The importance of including control and monitoring in the overall design plan for any system cannot be overemphasized.

Because each mine is unique, and thus usually has its own special operating characteristics and communication requirements, there is no such thing as "the one best system" to meet the requirements of all mines. The optimum communication, control, and monitoring system for a mine must be one that has been tailored to meet the special requirements of that particular mine. Factors that must be considered during system design include--

a. Type of mine and mining methods (low- or high-seam coal, deep hardrock

mine, stope caving, longwall, room and pillar, etc.).

b. Maximum number of working sections.

c. Expected mine growth rate and eventual maximum size.

d. Haulage methods (tracked trolley, diesel, belt, etc.).

e. Underground power distribution system (dc, ac, or both).

f. Features desired (two-way radio paging, private line capability for emergency use, etc.).

g. Redundant or backup systems for use during outages of the normal system.

Although no two mines are alike, the following items have been established as the main characteristics desired for any underground communication system:

1. Multiple Communication Paths to Outside--the objective here is to give all telephones a second method of communicating with the surface.

2. Audible Emergency Signaling--the communication system provides the main means of alerting miners during emergencies. The system should include means to broadcast distinct audible signals for emergency signaling. Initiation of these signals should probably be controlled from a central outside point, such as a surface control room.

3. Emergency Override--provisions should be included to permit any conversation to be overridden with emergency communication.

4. Selective Area Page--as mines grow larger it is apparent that the entire telephone system paging mode need not be activated each time a call is initiated. When the general area of a

person to be paged is known, only the pagers in that area would be activated.

5. Simultaneous Conversation Capability—although the ultimate for this characteristic would be a private line for each telephone, this channel capacity may not be necessary in some mines. In general, each working section does not produce much communication activity. Haulage and maintenance activities dominate telephone use. Since these activities tend to originate on the basis of mine "areas," it appears that providing different areas of the mine with a separate communication circuit could meet the simultaneous conversation need and maintain circuit simplicity.

6. Manual or Automatic Connection Between Subsystems—provisions must be made for connecting telephones within the telephone system, and provisions should be made for connecting the telephone system into the other communication systems used at the mine.

7. Remote Signaling—the design of the telephone equipment and circuits should be compatible with frequency division multiplexed equipment so frequencies above 3,000 Hz can be used for control and monitoring applications.

5.2.1 Wired Phone Systems

The options open to a designer during planning stages for a hard-wired phone system include

Single-pair phone system

Multipair phone system

Multiplexed phone system

5.2.1a Single-Pair Systems

Many different types of wire can be used for single-pair (party-line) communication systems (table 5-1). Smaller gage wire may be satisfactory if the number of telephones in the system is small and the distance between them is short. However, for most applications, a larger

gage wire is chosen to improve the tensile strength of the wire, as well as to reduce the overall resistance of the run.

TABLE 5-1. - Single-pair cable

Description	Wire gage, AWG	Loop resistance, ohms per mile
Plastic-insulated nonjacketed building wire..........	18	67
Type SO, neoprene-jacketed portable cable.............	18	67
	16	42
	14	27
Buried distribution wire..............	19	83
Plastic drop wire (copper-clad steel)	18	223

An inexpensive wire used for interconnecting mine phones is vinyl-plastic-coated, 18-gage, two-wire, twisted-pair building wire. Unjacketed wire of this type provides little environmental protection for the copper conductors; therefore it must be located out of the way of the mining equipment and carefully suspended to avoid moisture penetration.

The 14-gage neoprene-jacketed type (see fig. 5-1) is recommended for most underground applications. The greater mechanical strength, reduced loop resistance, and superior moisture resistance of this cable makes it ideal for communication applications.

The best method of getting a feel for the design considerations of a single-pair system is to design a system for a representative moderate-sized mine. An example of such a mine is shown in figure 5-2. This mine has the following characteristics:

FIGURE 5-1. - Single-pair type SO neoprene cable.
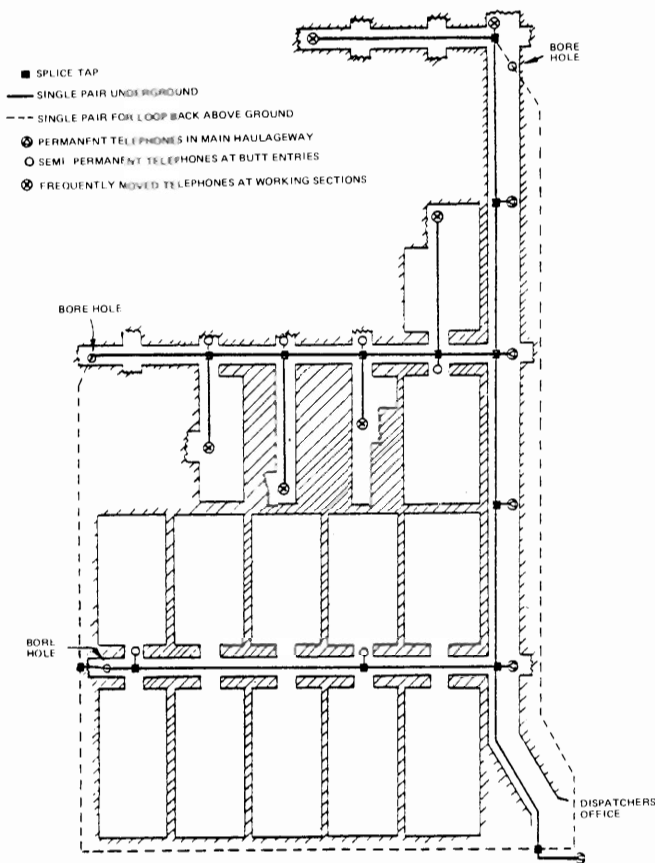
FIGURE 5-2. - Single-pair installation in typical mine.

Less than 2 years old

6 square miles in total area

3.5 miles of main haulageway

0.8-mile-long average submain

Average panel size of 800 feet by 2,100 feet

Average working section size of 300 feet by 400 feet

5 working sections per shift

A maximum of 6 active working sections

17 fixed mine pager phones presently installed

The fixed-telephone, single-pair communication system shown in figure 5-2 complies with the Federal Coal Mine Health and Safety Act of 1969, in that it provides two-way communication between the surface and each working section. Additional phones were installed at the intersections of the main haulageway and the submains, and at the intersections of the submains and the butt entries to all active sections.

Based on the physical characteristics of the mine, the total length of single-pair cable required can be calculated for this stage of development as follows:

	Miles
1 main haulageway.........	3.5
3 submains (0.8 mile each)....................	2.4
6 active sections (3,000 feet per section).	3.4
Total................	9.3

The 3.4 miles of section cable assumes the reuse of the cable as the working sections move from one panel to another. At this stage in the mine's development, 15 panels have been driven or are being driven which would have required 8.5 miles of section cable if reusing it had not been assumed. Therefore, the total cable miles needed are

9.3 if section cable reused

14.4 if section cable not reused

The least expensive wire for the above application is plastic-insulated, nonjacketed 18 AWG building wire. However, the high loop resistance (67 ohms per mile) of the 18-gage wire will make future expansion impractical; therefore we should consider a larger gage wire.

A more suitable cable due to its low loop resistance is 14 AWG, type SO, neoprene wire. The 14 AWG neoprene cable uses annealed copper conductors so that it can withstand severe mechanical abuse. (The cable is designed for use as power supply cable on portable equipment.) If the 3,000 feet of 14 AWG neoprene wire used for each active section is mounted

on a reel and travels with the working section phone into the panel, then we can plan on reusing this wire when developing future panels. The cost of expanding to 6 submains and 60 panels would involve only the additional wire for 3 submains, assuming we can reuse the section wire.

The economic importance of reusing section wire can be elaborated on by the following calculations for 54 lengths of additional section wire needed to reach the 6-submain development stage if the section wire is not reused. Each length is 3,000 feet, or 0.57 mile.

54 lengths × 0.57 mile per length
= 30 miles of additional cable

The cost of this additional cable can be a significant part of the total cost of the entire single-pair system. Although material costs are greatly reduced if section wire is reused, some additional labor costs are involved in the removal of cable once a panel has been completed.

Another alternative that can be employed is to use high-quality 14 AWG wire for the main and submains, and then use a less expensive lighter gage wire for the panels and not reuse this wire. A low-cost 18-gage building wire may be acceptable as section wire, because its high resistance is not a problem for the short length involved.

5.2.1b Multipair Systems

A single-pair cable system restricts the mine communication system to a single-channel multiparty configuration. Introducing multipair cable into the mine communication system allows one to expand the number of channels to whatever is necessary for efficient voice traffic. In an existing mine, this would mean

replacing the single-pair cable in the main haulageway and the submains with multipair cable. In a new mine, it would mean calculating the maximum channel requirements expected during the life of the mine and specifying the proper multipair distribution system.

The hardware for a multipair system is of proven reliability and has stood the test of time. All of these materials have been used for aerial distribution systems in the telephone industry and were refined over the years to survive in any part of the world with a minimum of preventive maintenance. Because it was designed to be installed and maintained by linemen working in all kinds of weather while standing on ladders, on aerial platforms, or in manholes, multipair equipment can be handled by electricians in the underground environment. The only new skill that mine personnel may have to learn is the splicing of small-diameter wires. However, crimp-type splice connectors are available to simplify the splicing of multipair cables.

Table 5-2 shows the major characteristics of multipair cable available from telecommunication cable manufacturers. Figure-8 cable is recommended for the mine application because the messenger wire adds considerable tensile strength to the cable, and the installation is similar to that of trolley wire.

The previous section described a single-pair cable system using a representative moderate-size fictitious mine. The same mine will be used to analyze a multipair cable system (fig. 5-3).

Using a cable distribution and loading plan that will allow the servicing of no more than two sections per twisted pair, a minimum of three pairs is

TABLE 5-2. - Range of multipair cables commercially available

Number of pairs......................................	3-400
Messenger size (diameter).....................inch..	0.134-0.250
Conductor size................................AWG..	26-19
Conductor dc resistance at 68° F...ohms per mile..	43-220
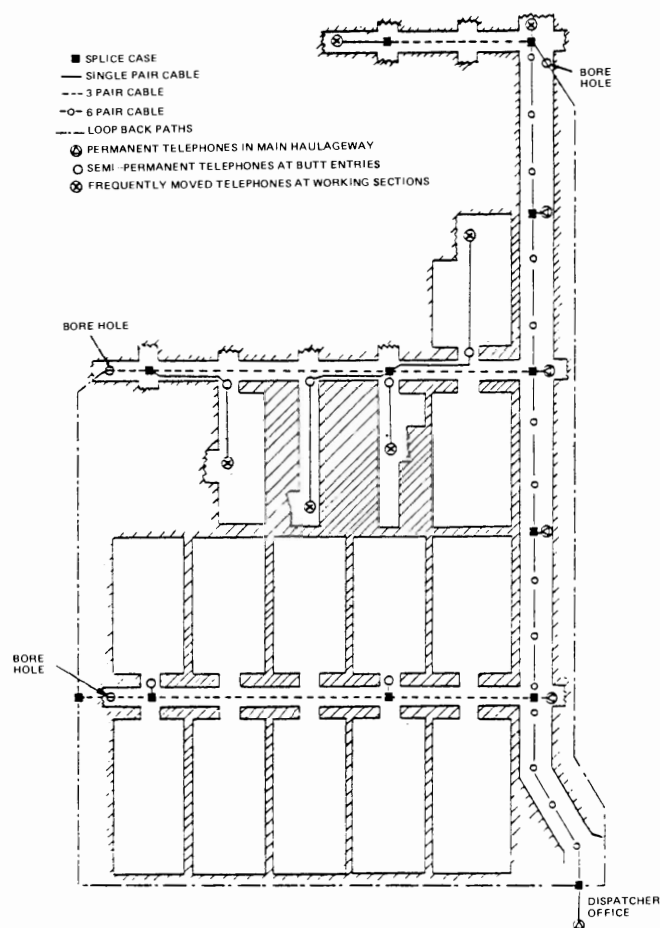
FIGURE 5-3. - Multipair installation in typical mine.

required to handle the six working sections. The main haulageway phones connected across a single party line require an additional pair for a total of four pairs, each of which extends back to a centralized location such as the dispatcher's office. A six-pair cable placed in the main haulageway will accommodate the above required pairs while leaving an extra two pairs for future expansion. Three-pair cable may be appropriate for the submains because no more than four sections will be active per submain at any one time. A single-pair cable can be used between the panel entry phone, located in the submain, and the section phone, which must move with the section crew.

Due to the 3.5-mile length of the main haulageway and assuming that a maximum of seven phones will be connected in parallel across one pair, a 19-gage

six-pair cable has been selected for the haulageway. The submains with only two phones per pair and run lengths of less than 1 mile can use 22-gage wire. A splice case at every third section entry should be sufficient in this application and will reduce labor costs.

The section cable can be a single pair but must be strong enough to withstand the wear caused by the almost constant phone relocating required in the working section. A 3,000-foot reel of wire that travels with the section phone would reach any location in an 800- by 2,100-foot panel. Plastic drop wire has been chosen for the section cable. This wire is made up of two 18 AWG copper-covered steel wires laid in parallel and coated with a black flame-resistant polyvinyl chloride insulation. The high strength of this cable allows for long spans which make for quick temporary installations and also reuse of the cable. A stainless steel drop wire clamp can be hooked to roof bolts or nailed to timbers for support.

In cost comparisons between single-pair and multipair systems $(\underline{2})$,[1] the wiring costs for multipair installations were less expensive because the smaller gage wire allowed in the multipair cable, due to fewer phones placed in parallel per pairs, kept the per-mile cost of multipair cable competitive with that of the larger gage single-pair cable.

Two questions worthy of consideration at this point are, How well does a multipair communication system meet the needs of the mine user? and What improvements can be incorporated into a multipair system that are not possible with the present day single-pair mine telephone system?

Advantages

More Channels.--Using multipair cable, a system can be designed with as

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[1]Underlined numbers in parentheses refer to items in the bibliography at the end of this chapter.

many channels as are deemed necessary for the particular application, the only limits being cost and complexity.

Private Channels.--Individual pairs can be assigned to each working section, thereby producing a private channel between the section and the mine communications center.

Zone Paging.--The communication center can page over an individual pair so that only the section of the mine concerned with the transmission need be disturbed. This would eliminate the present situation of requiring miners in all sections to listen to all pages.

Direct Dialing.--Pairs can be dedicated to connect underground dial phones directly to the company's private automatic branch exchange (PABX) or directly to a central office through an approved interface. This would allow key locations in the mine to dial each other, place outgoing calls, or receive incoming calls via the local exchange without relaying messages through the communication center. Provisions for preventing abuse of the latter two features could also be included.

Remote Monitoring.--Extra pairs in the cable may be used for monitoring the mine environment and/or equipment.

Disadvantages

Increased Operating Costs.--A multipair system incorporating all of the above advantages will cost more than a single-pair system, even though the multipair cable may cost less than the single-pair cable. This is due to the additional cost of a central switching equipment required for multipair systems. For a particular application, the increased efficiency and other benefits must be weighed against the added installation and maintenance costs in order to establish its true worth.

Training Costs.--The maintenance personnel assigned to install and maintain this equipment will have to be trained to use the different splicing techniques required and to troubleshoot this somewhat more complex system.

5.2.1c Multiplexed Phone Systems

Multiplex telephone systems achieve their private channel capability via electronic means on a single cable. Multiplexing can be via time division multiplexing (TDM) or frequency division multiplexing (FDM). Although TDM systems have been developed and provide certain advantages, a multitude of disadvantages tend to make this type of multiplexing unattractive for mine telephone systems.

FDM systems have been developed and tested in underground mines with considerable success. These systems can be divided into ones that require a central switching station for system control and those that do not. In a central switching system, most if not all of the system intelligence resides in the central unit which assigns frequencies, provides power for the phones, and generates ringing and busy signals. These systems are generally permitted only in nongassy mines. A serious disadvantage of such a system is that a failure in the central unit can render the entire system inoperative.

A system that does not rely on a central switching unit has been developed by the Bureau of Mines. The system is based upon microprocessor control, where intelligence is resident in each telephone. Eight-channel voice or data communications is possible. The system utilizes FDM at medium frequencies (340-650 kHz) and is designed for a 10-mile cable plant. A failure of any one phone normally affects the multiplex feature of that phone only. Each phone also includes a resident pager phone capability such that even a total failure of the microprocessor intelligence will not normally inhibit a user from making a call. This feature is essential in any modern telephone system for underground mines. Supervisory feedback and a visual message-leaving capability (as is required in several States) are also included.

5.2.2 Cable Selection

Telephone transmission is made over wires which represent a considerable fraction of the cost of any telephone system. As an example, figure 5-4 shows three broad categories of equipment in which telephone companies invest. The "transmission" category not only represents wires, but also includes multiplex systems, microwave systems, and other wire substitutes. Since transmission equipment accounts for about half of the total investment, telephone companies put considerable effort into planning the layout and the growth of their transmission facilities. Cable costs account for even a greater percent of the expense involved in an underground communication system. Therefore, mine planners should also carefully plan the network and revise the plan on a scheduled basis.

The general environment in an underground mine imposes severe physical requirements on communication cable. Insulation is required to withstand exposure to moisture, abrasion, and rough handling; to afford protection against some level of accidental contact with higher
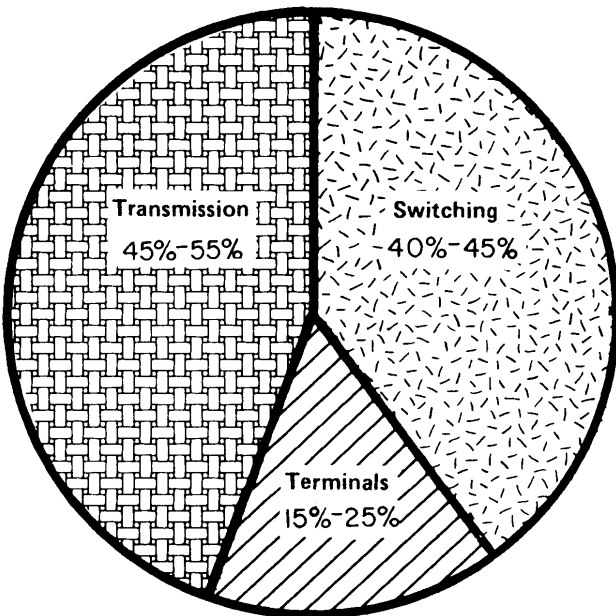
voltages; and to not support combustion in case of fire.

Twisted-pair construction is advised to reduce the effects of induced noise or interference. The 14 AWG solid-conductor twisted pair, with suitable insulation dielectric and outer protective jacket is very rugged, and will withstand the rough handling and stress imposed by abrasion against timbers or falling debris. For the smaller diameter wires, such as 19 AWG, a figure-8 cable is recommended. In this construction, a steel "messenger" or support wire is added to the twisted-pair bundle, so that the overall cross section resembles a figure 8. The steel messenger cable provides additional strength and support so that minimum strain is applied to the signal-carrying twisted pair.

Solid conductor is advised, rather than the more easily handled multistrand wire. The multistrand cable is subject to corrosion buildup on the surface of the individual conductor strands, which in time could reduce the conductivity of a splice or connection and become the source of added noise and reduced signal level. Conditions within an underground mine dictate the use of press-on or twist-on connectors as common practice to complete a splice. Such practices are not compatible with the use of multistrand wire.

The choice of wire size is determined by the configuration of the telephone system and the type of phone in use. Major factors to consider in the choice of wire size are the total length of cable run, the number of phones in the circuit, the average distance between the phones, and the characteristics of the ringing or calling circuit in each phone.

In pager phone systems, the paging relay circuit is one of the more critical parameters to consider in the choice of pager phone wire size. The normal audio signal imposed on the cable is about 1 to 2 MW; this signal level is sufficient to operate a phone receiver at satisfactory

FIGURE 5-4. - Telephone company investments.

volume over several miles of cable as small as 19 AWG. The limiting condition is the ability to reliably operate the paging relays. In this regard, the cable impedance, or resistance per unit length, as it affects the available dc voltage at the paging relay, is more influential than audio loss. Calculation of the minimum wire size that will insure reliable operation of all paging relays must take into account three major parameters: paging circuit impedance, battery voltage, and wire losses.

Some pager phones use electromechanical relays that have an impedance of about 2,500 ohms while other systems use electronic or semiconductor switching circuits that have an impedance of from 8,000 to 50,000 ohms. The minimum dc voltage required to operate any of these relays is about 1.5 to 4 volts. To insure a safety margin, it is recommended that at least 5 volts dc be available at all telephone paging relays. It is easier to obtain this minimum voltage with the higher impedance circuits.

Available battery voltage is a function of the condition of the battery and the load it must operate. In a 12-volt system, the battery is at the end of its useful life when the dc voltage under load condition approaches 8 volts. For a 24-volt system, a battery is at the end of its useful life when the available dc voltage under load approaches 16 volts. There is no specific time at which the battery can be identified as not usable. However, it is generally agreed that the levels just stated are typical of the end of a battery's useful life and indicate that it should be replaced.

In many pager phones, the internal circuit has been designed so that the total battery voltage is not available on the line for operation of paging relays. Circuitry in such phones can add a series dc resistance of from 10 to 100 ohms to limit the short-circuit drain to levels of operation that are intrinsically safe. A pager phone system can draw significant current from the battery in the "paging" phone. This causes an internal voltage drop which significantly reduces the effective voltage presented to the line. Estimates of this effect, for a variety of conditions, are shown in table 5-3.

Wire loss per unit length is a function of wire diameter and system configuration. These factors include total wire used, telephone spacing, number of phones, and input impedance. All of these factors must be considered together in view of the expected battery voltage at end of useful life (8 or 16 volts), the relay impedance (2,500 ohms or greater than 8,000 ohms), and the internal voltage drop because of circuit losses.

TABLE 5-3. - Effect of paging circuit impedance

(Electromechanical relays, 2,500 ohms)

Battery voltage, dc volts	Limiting resistance, ohms	Available battery voltage on the line, dc volts	
		10-phone system	20-phone system
24-volt battery:			
24 (new)...............	10	23.75	23.5
	100	19	18
16 (near end of life).	10	15.5	15.5
	100	13	12
12-volt battery:			
12 (new)..............	10	11.8	11.6
	100	10	8
8 (near end of life)..	10	7.8	7.6
	100	6.5	6

The simplest calculation is to assume a basic ladder configuration, where all phones are in parallel on the same single two-wire cable, strung the length of the installation (fig. 5-5). This basic installation is the one most normally considered when calculations are made to determine minimum wire size. Tables 5-4 and 5-5 indicate the minimum wire size for both electromechanical and electronic relays, with average phone spacing of 1/4 and 1/2 mile.

In a 12-volt system, with electromechanical 2,500-ohm relays, only 12 hones spaced 1/4 mile apart over 3 miles can be used with 19 AWG wire. However, 20 phones can be used over a 5-mile run if 14 AWG wire is used. If electronic 8,000-ohm relays were used, the 24-volt system could support 33 phones over 8 miles of cable using 19 AWG wire.

Tables 5-4 and 5-5 do not take into consideration line losses caused by poor splices, dampness, or defective phones. However, they do illustrate comparative conditions as a guide for system design and component selection.

Consideration of a topography that involves a multiple-branch system may result in a design that can use a smaller diameter wire. Conditions in mines normally degrade even the best of systems—moisture causes signal leakage; erratic

Rw = LINE IMPEDANCE
Rp = PHONE INPUT IMPEDANCE
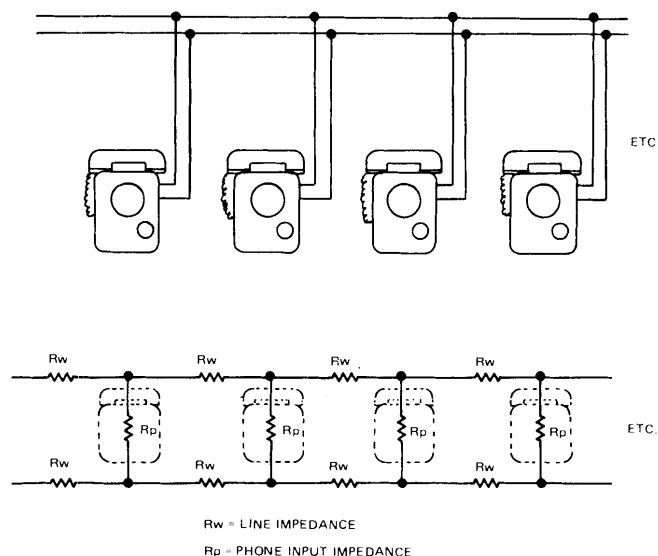
FIGURE 5-5. - Basic ladder configuration.

or incorrect branch connections and splices tend to reduce performance—so that using detailed calculations to determine marginally usable minimum wire size is not a recommended practice. It makes more sense to determine a minimum wire size for safe operating level and then use that size as a guide to select or recommend a wire that meets all the specifications. For multiple-branch configurations, the following rules of thumb can be used to estimate minimum wire size without extensive calculation:

1. Determine present telephone configuration.

TABLE 5-4. - 1/4-mile pager phone spacing

System	19 AWG	14 AWG
12-volt, 2,500-ohm relay	3 miles, 12 phones	5 miles, 20 phones
24-volt, 2,500-ohm relay	5 miles, 20 phones	9 miles, 36 phones
12-volt, 8,000-ohm relay	5 miles, 20 phones	9 miles, 36 phones
24-volt, 8,000-ohm relay	8 miles, 33 phones	>9 miles, >36 phones

TABLE 5-5. - 1/2-mile pager phone spacing

System	19 AWG	14 AWG
12-volt, 2,500-ohm relay	4.5 miles, 9 phones	7.5 miles, 15 phones
24-volt, 2,500-ohm relay	7 miles, 14 phones	13 miles, 26 phones
12-volt, 8,000-ohm relay	7.5 miles, 15 phones	13 miles, 26 phones
24-volt, 8,000-ohm relay	13 miles, 26 phones	>18 miles, >36 phones

2. Estimate probable growth of the telephone configuration.

3. Sketch the future telephone configuration.

4. Examine the sketch to determine the longest combined path that takes into account a majority of the telephones.

5. From table 5-2 or 5-3 determine the minimum wire size for the longest path needs.

6. The added loads of the other branches will not greatly affect the determination of minimum wire size and can be ignored for such an estimate.

The 21 pager phones shown in the top panel of figure 5-6, spaced an average of 1/4 mile apart, are connected in a branching system, which can be represented by the impedance diagram shown in the bottom panel. The longest path is E

to D to J, which includes 10 phones over about 2.5 miles of cable. If we examine table 5-2, we find that with 2,500-ohm mechanical relays in a 12-volt system, 19 AWG wire is adequate for the configuration.

This type of rule-of-thumb estimate is adequate to identify approximate requirements for wire size, but it does not replace necessary detailed calculations for a major installation with many branches. It must also be emphasized that calculation of minimum wire size identifies the bottom limit of a marginal condition and good engineering practice dictates some margin of reliability. The general manufacturers' recommendation of 14 to 16 AWG twisted pair for systems using 2,500-ohm electromechanical relays is sound, particularly for a 12-volt system.

For systems using semiconductor paging circuits (with impedances of 8,000 ohms or greater), 19 AWG is usually adequate. This is particularly true for 24-volt systems, but also applies to most 12-volt systems that have high-impedance switching circuits.

In summary, the cable wire size depends on a series of factors that include the total number of telephones in an installation, the total length of cable run (distance between the farthest phones), the configuration of branch lines, the available battery voltage, and the type of paging relay used. The preferred cable, regardless of wire size, is a twisted pair of solid conductor wires, with individual insulation around each wire in the pair and an outer abrasion-resistant covering of waterproof, flame-retardant material.

5.2.3 Summary

The basic system choices that may be selected when choosing an underground wired phone system consist of—

Single pair.—This is a party line system in which all phones are on the same channel.

(A) ¼—MILE PAGER PHONE SPACING

(B) EQUIVALENT CIRCUIT
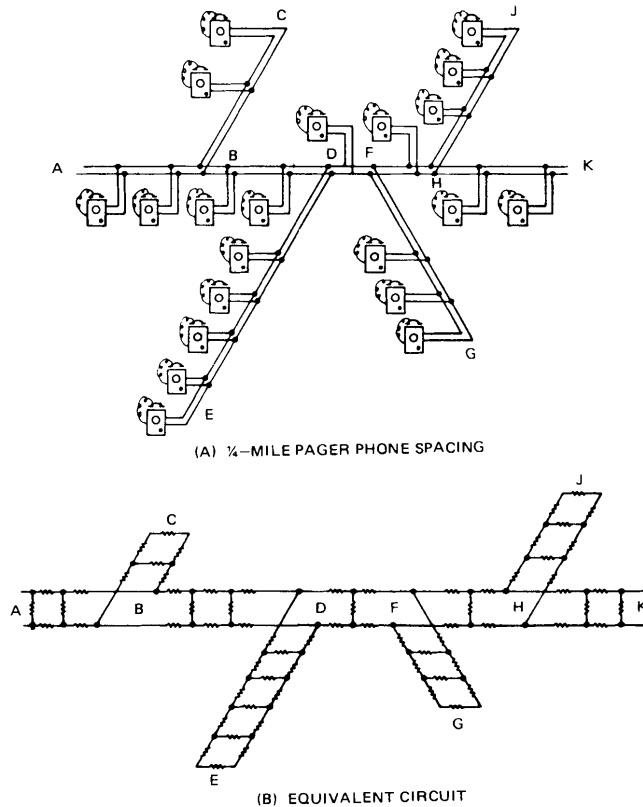
FIGURE 5-6. - Branching ladder network.

Multipair.--A private line system with each phone or group of phones connected to the system center by its own individual wire pair.

Multiplex.--A private line system using a single cable, with the audio to and from each phone multiplexed onto the common cable.

In all of these systems, telephone transmission is made over wires which represents a considerable fraction of the cost of the entire system. Since transmission equipment accounts for about half of total investment, companies should put considerable effort into planning the layout and growth of their transmission facilities.

In planning mine communication systems, the pairs or voice channels that will be needed in the future and the mobility of the telephones involved should be kept in mind. In addition, pairs that will be needed for purposes other than for telephones (telemetry, remote monitoring, etc.), which incidentally may exceed voice communication needs, should also be taken into account.[1]

5.3 Improving Existing (In-Place) Phone Systems

The two types of communication systems commonly used to date in underground mines are as follows:

Carrier current radio system using the trolley line.

Various types of telephone system.

Because these systems have gained such widespread usage, methods for upgrading and improving presently installed systems are presented in the following sections. The first deals with improving

[1]Approved and nonapproved equipment may not share the same cables; check with MSHA for details.

performance of a trolley carrier system, and the second treats telephone systems.

5.3.1 Trolley Carrier Phone Systems

WARNING

Some of these procedures are undertaken with the trolley wire energized; therefore, they are extremely hazardous. Extreme caution must be exercised to avoid potentially lethal shock. The fuses used in the test leads serve only to protect equipment and do not in any way reduce the shock hazard to personnel. Only personnel thoroughly familiar with electrical work on trolley wires should conduct these procedures. The permanent connection of components should be done with power removed. Care should also be taken to insure that components and equipment are suitable for use in the desired application.

The trolley carrier phones used for dispatch purposes in electrical rail haulage mines often show problems in providing coverage over the entire haulage system. Direct communication between the dispatcher and vehicles in certain areas of the mine is often difficult or impossible. The major reason for these difficulties is the effects that loads placed across the trolley wire or rail have on transmission.

Both theory and experiment show that the trolley wire-rail by itself is a relatively good transmission line for carrier phone frequencies. In fact, on an unloaded trolley wire-rail transmission line, a distance of 35 miles could be expected for communication range. Communications over a real trolley wire-rail can never achieve this range because the many loads across the trolley wire-rail absorb and reflect carrier signal power. The list of these loads is long and includes rectifiers, personnel heaters, signal lights, vehicle motors, vehicle lights, and the carrier phone itself. It is probable that the net signal attenuation

rate for a trolley wire-rail with typical loads placed across it yields a useful range as low as 3.5 miles. The problem of obtaining good signal propagation is further aggravated by branches of the trolley wire where the signal splits in a totally uncontrollable way. Lack of proper signal termination at the ends of the trolley wire-rail further degrades signal propagation. The vehicles represent moving loads on the transmission line and add a further complication to obtaining or predicting good signal propagation. Also, advancing the mine face means that the transmission network changes with time, yielding more uncertainty to the quality of transmission.

The seriousness of the bridging loads can be seen by reference to figure 5-7 where the losses for typical loads are tabulated. Using this chart, one can make an estimate of the total signal loss by adding the individual losses (in decibels).

In the past, whenever poor trolley carrier communications existed, attempts were made to remedy the problem using "Z-boxes," or signal couplers to the phone line. Z-boxes are not permissible, are usually not the best solution, and may actually introduce more problems then they solve. Mines are full of Z-boxes that have been disconnected and abandoned

because of poor performance. It is recommended that solutions other than Z-boxes be used to improve the performance of trolley carrier phone systems.

The most straightforward way of treating the trolley wire-rail to make it into a functional carrier signal transmission line is to physically remove from the trolley wire-rail all of the bridging loads that impede carrier signal propagation. The steps in this process follow:

1. Identify the bridging loads. List all the bridging loads across the trolley wire-rail. Consult figure 5-7 to estimate the seriousness of the impediment to carrier signal propagation that each load represents.

2. Determine which loads can be removed from the trolley wire-rail and be operated from mine ac power.

For practical reasons, physical removal of bridging loads has severe limitations. Certain critical loads, including rectifiers, vehicles, lights, motors, and carrier phones themselves, cannot be removed from the trolley wire-rail. In some instances, none of the loads can be removed from the trolley wire-rail, and efforts to improve signal propagation must involve other methods.

Studies conducted have revealed alternative ways of increasing the range and quality of existing trolley carrier phone systems. These methods include--

Isolated loads at the carrier frequency

Using a dedicated line

Using a remote transceiver

5.3.1a Isolating Loads at the Carrier Frequency

Figure 5-7 shows that as the bridging resistance is increased, the signal loss decreases. The "isolating loads" method involves adding passive circuit elements (inductors and capacitors) in

LOAD	OHMS
HEATERS	20-400
RECTIFIERS	2-10
VEHICLE MOTORS	50-500
VEHICLE LIGHTS	60-120
CARRIER PHONES	20-200
MINE LIGHTS	500-2000
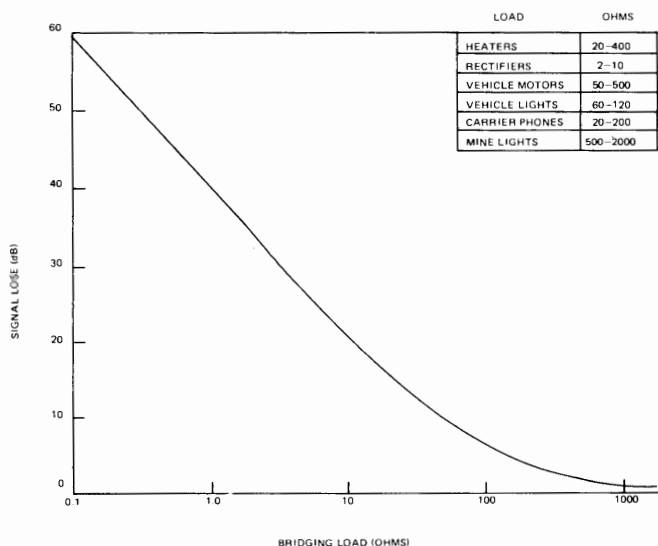
FIGURE 5-7. - Signal loss versus bridging load.

series with the particular load to reduce the effects of the bridging load. The circuit elements do not affect dc equipment (motors, lights, etc.) being powered from the trolley wire, but they do, if properly chosen, add high impedance at the carrier frequency. Rectifiers, heaters, and vehicle lights are the bridging loads that most seriously degrade received signal levels and should be treated first to improve received signal levels.

5.3.1a.i Rectifiers

There are three means of raising the effective carrier frequency impedance of a rectifier. The most practical method depends on where the rectifier is installed. If it is located relatively far from the rail (beyond 40 feet), the feed wires represent sufficient inductance that can be resonated, thereby raising the effective impedance as seen by the trolley wire-rail (fig. 5-8A). If the rectifier setback is short (less than 40 feet), two techniques can be used to raise the effective impedance: (1) A fixed high-current inductor can be added in series with the rectifier and that inductor can then be tuned to raise the effective impedance (fig. 5-8B); or (2) the inductance of the trolley wire-rail can be used to resonate short sections of the trolley wire-rail near the bridging load to raise the effective bridging impedance (fig. 5-8C). The ways of applying each of these means are described below.

a. Resonating the Feed Wire Inductance

The following steps are required to tune the rectifier feed wires:

1. Attach a 1,000-volt (some systems may require even higher voltage components), 1-µF or larger, oil-filled capacitor directly across the plus and minus terminals inside the rectifier. (This capacitor serves to reject rectifier-generated interference in the carrier frequency band.)

2. At the far end of the feeder wires, as near to the trolley wire-rail

A. RESONATING THE FEED WIRE INDUCTANCE

B. RESONATING AN ADDED FIXED INDUCTANCE

C. RESONATING THE TROLLEY WIRE/RAIL INDUCTANCE
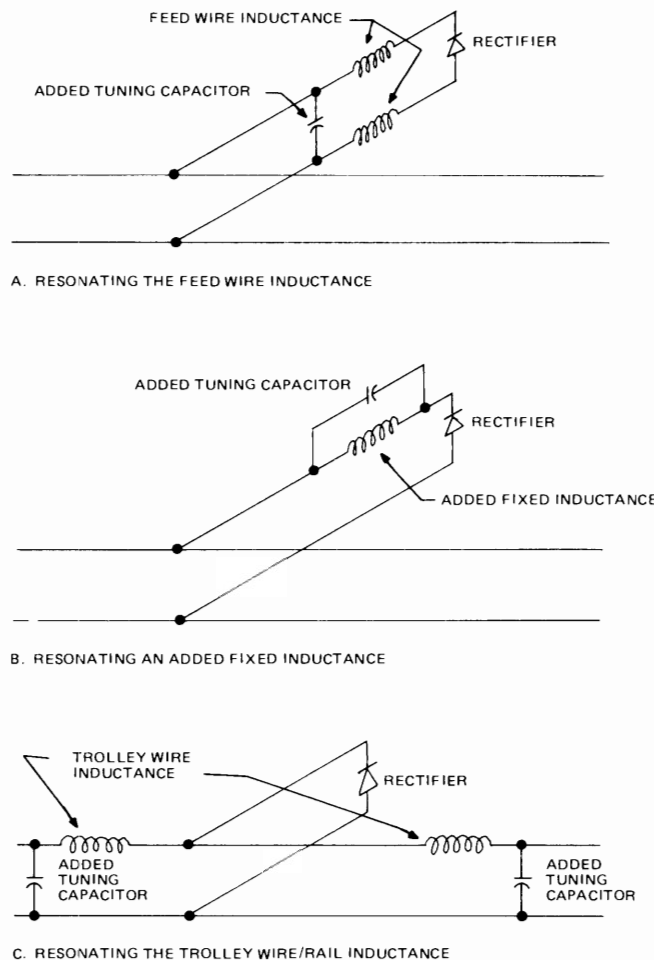
FIGURE 5-8. - Ways of raising the impedance of a rectifier.

as practical, install the temporary test set shown in figure 5-9. This test set comprises a decade capacitor, isolating and protection devices, and a tuned voltmeter. Usually two feed wires are run from the rectifier to this point. Only one need be treated.

3. The dispatcher is called from a jeep parked nearby and asked to key on his transmitter for 20 seconds or so. The decade capacitor box is switched through its range of operation and left at the position of maximum signal, as indicated by the tuned voltmeter. (The decade box should have enough range to peak the voltmeter.) This value of signal should be larger than when the decade capacitor is at its off position. The two values--the voltage when the decade capacitor is off and the maximum
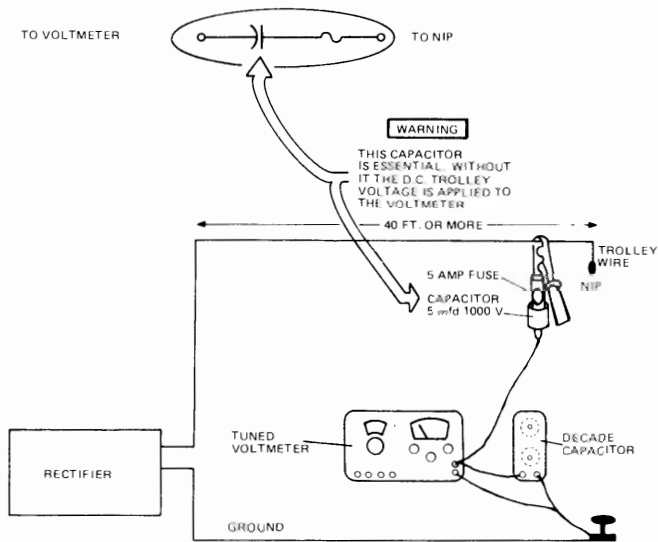
FIGURE 5-9. - Test configurations for tuning feeder wire.
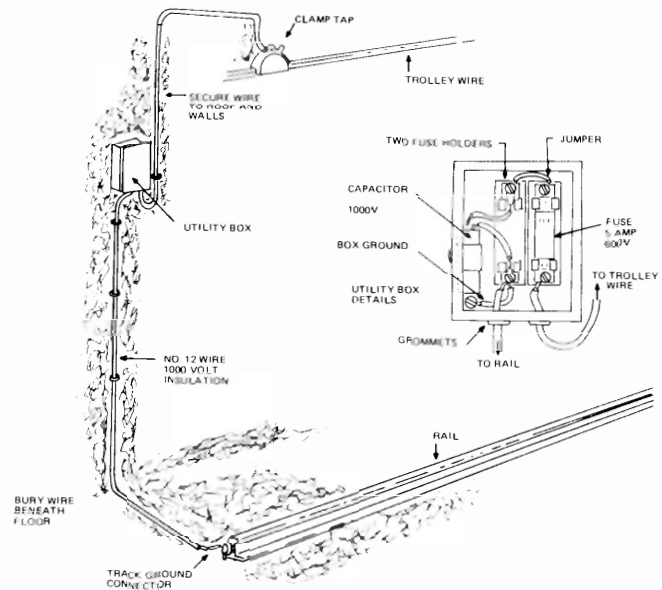
FIGURE 5-10. - Permanent installation of tuning elements for feeder wire.

WARNING

Some of these procedures are undertaken with the trolley wire energized; there-fore, they are extremely hazardous. Extreme caution must be exercised to avoid potentially lethal shock. The fuses used in the test leads serve only to protect equipment and do not in any way reduce the shock hazard to personnel. Only per-sonnel thoroughly familiar with electrical work on trolley wires should conduct these procedures. The permanent connection of components should be done with power removed. Care should also be taken to insure that components and equipment are suitable for use in the desired application.

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value--should be logged, preferably on a mine map. There should be an appreciable increase in voltage for this condition, at least 1 1/2 to 1, and in some in-stances up to 10 to 1. The value of the capacitance that produces the maximum voltage should be noted from the value indicated on the decade capacitor, and a suitable capacitor of that value should then be installed in a permanent fashion, as shown in figure 5-10. When this in-stallation has been made, a final check, using the tuned voltmeter, should be made to ascertain that the originally indi-cated increased voltage is obtained.

For this procedure, it is important that the tuned voltmeter be tuned to the precise transmission frequency of the dispatcher. A preliminary test can easily ascertain that this condition has been met by sweeping the tuning dial of the tuned voltmeter through the region near the transmitted frequency and leav-ing it at the position where maximum response is indicated.

b. Resonating an Added Fixed Inductance

When the setback is short, an added inductor made of a coil of feeder wire may be used to provide a series induct-ance that can be tuned. Because feeder wire is expensive, a coil in the so-called Brooks form, which yields the max-imum inductance per length of wire, should be used. See Appendix A (Mine E) for an actual installation example.

The approximate form is shown in figure 5-11. A reasonable bending radius for the typical thousand-circular-mils cable used for such feeder wires is 2 feet; therefore this dimension is approximately fixed. Four turns at this diameter yield an inductance of approximately 25)H, which is adequate for tuning most rectifiers. The coil should be installed in the room in which the rectifier is located and should be kept a few feet away from the coal to prevent added losses at the carrier frequency. The exact value of inductance is unknown, so the coil will have to be tuned in much the same manner as discussed previously for resonating the feeder wires.

Figure 5-12 illustrates the test setup. The dispatcher is called and asked for a 20-second transmission. The decade capacitor is switched through its positions and left at the position that yields the maximum voltage. (The decade box should have enough range to peak the voltmeter.) The received voltage with the decade capacitor in the "off" position and the maximum voltage should be

noted, preferably on a mine map. When the best capacitor value has been found in this manner, the test set is removed and a suitable capacitor of the value found during the test is permanently attached to the coil, as shown in figure 5-13. When completed, a last test is made to verify that the improved signal reception is obtained.

c. Resonating the Trolley Wire-Rail Inductance

A method that can be applied if the rectifier setback is short, and it would be impractical to install a fixed inductor in series with the rectifier feed wires, is to tune the trolley wire-rail
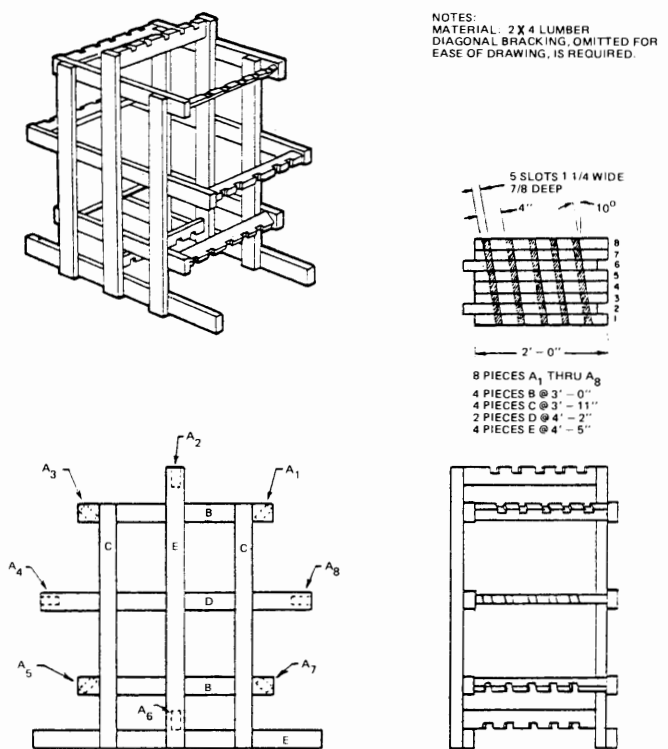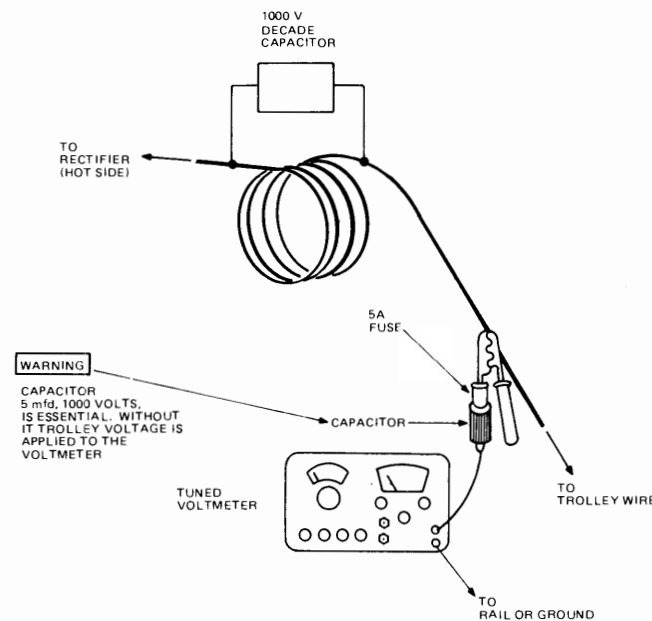
FIGURE 5-12. - Test setup for tuning fixed inductance.
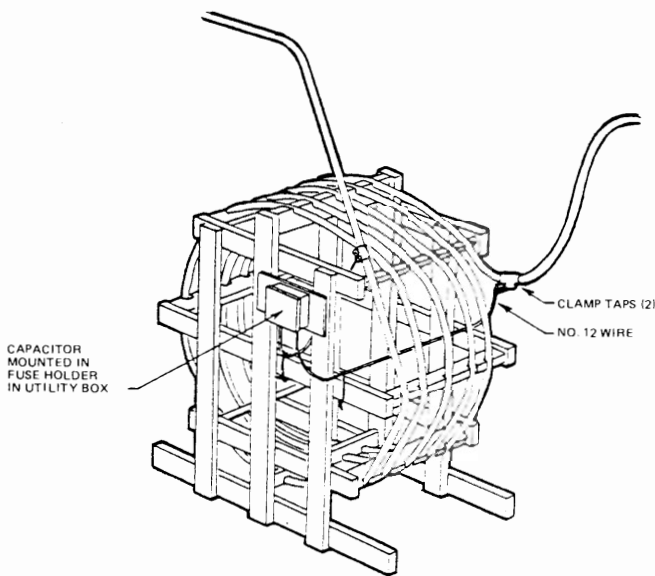
WARNING

Some of these procedures are undertaken with the trolley wire energized; therefore, they are extremely hazardous. Extreme caution must be exercised to avoid potentially lethal shock. The fuses used in the test leads serve only to protect equipment and do not in any way reduce the shock hazard to personnel. Only personnel thoroughly familiar with electrical work on trolley wires should conduct these procedures. The permanent connection of components should be done with power removed. Care should also be taken to insure that components and equipment are suitable for use in the desired application.

FIGURE 5-11. - Coil form.

NOTES:
MATERIAL: 2 X 4 LUMBER
DIAGONAL BRACKING, OMITTED FOR EASE OF DRAWING, IS REQUIRED.

5 SLOTS 1 1/4 WIDE 7/8 DEEP

8 PIECES A₁ THRU A₈
4 PIECES B @ 3' – 0"
4 PIECES C @ 3' – 11"
2 PIECES D @ 4' – 2"
4 PIECES E @ 4' – 5"

CAPACITOR
MOUNTED IN
FUSE HOLDER
IN UTILITY BOX

CLAMP TAPS (2)
NO. 12 WIRE

WARNING

Some of these procedures are undertaken with the trolley wire energized; therefore, they are extremely hazardous. Extreme caution must be exercised to avoid potentially lethal shock. The fuses used in the test leads serve only to protect equipment and do not in any way reduce the shock hazard to personnel. Only personnel thoroughly familiar with electrical work on trolley wires should conduct these procedures. The permanent connection of components should be done with power removed. Care should also be taken to insure that components and equipment are suitable for use in the desired application.

FIGURE 5-13. - Permanent attachment of tuning capacitor to fixed inductor.

as shown in figure 5-8C. The steps are described below:

1. Locate a position about 80 feet along the trolley wire-rail from the place where the rectifier feed wires attach to the trolley wire-rail. Install the test set as illustrated in figure 5-9 between the trolley wire and rail. Request the dispatcher to transmit for about 20 seconds. Switch the capacitor box through its values to find a maximum signal level, as indicated on the tuned voltmeter. (The decade box should have enough range to peak the voltage level.) Note the value with the decade capacitor in the "off" position and the value to maximum signal, and list these values on

a mine map. Remove the test fixture, and install permanently a suitable capacitor of the indicated value. Request another transmission to verify that the signal improvement observed during the test was maintained after permanent installation.

2. Repeat the same procedure as in step 1, but at a place in the opposite direction along the trolley wire-rail; that is, 80 feet or so on the other side of the feed point. Keep records as before.

3. Return to the first point and measure and record the signal level for a dispatcher's transmission.

5.3.1a.ii   Heaters

Personnel heaters with a wide range of wattage ratings are used; however, 1,000 watts is likely to be the lowest, and each heater of this rating or higher poses a significant signal loss to the carrier system. Such heaters will range in resistance from 360 ohms for a 1-kW unit on a 600-volt line to 18 ohms for a 5-kW unit on a 300-volt line. Current will range from 1.5 to 17 amperes for corresponding conditions. Unlike rectifier currents, these heater currents are sufficiently low that commercial inductors can be used untuned to provide isolation of heaters, thereby avoiding the step of individually tuning each isolator.

To raise the impedance level to 300 ohms at 100 kHz using an untuned inductance requires an inductor of 500 µH. While it would be convenient to find a single inductor usable for all such loads, the wide range of direct currents that must be handled (1.5 to 17 amperes) makes it necessary to select each inductor on an individual basis.

The procedure for treating personnel heaters follows: Locate the heater element. Measure the carrier frequency voltage at this load, using the tuned voltmeter and a dispatcher's transmission. Note this value on a mine map. Disconnect the heater and permanently

attach a 500-μH inductor in series with the element. Reconnect the heater and measure the voltage produced across the heater and inductor in series, using the tuned voltmeter and a dispatcher's transmission. An improvement in voltage of up to 10 to 1 can be expected. Note the new received voltage on the mine map. Repeat this procedure for each personnel heater.

5.3.1a.iii Vehicle Lights

Mine vehicles, including locomotives, jeeps, and portal buses, all draw substantial power from the trolley wire. Much of this power is used for motive purposes. Motors represent a relatively high impedance at trolley carrier frequencies, particularly for jeeps and portal buses and to a lesser extent for locomotives. However, a part of the power is used for headlights on the vehicles. Most conventional vehicles use 150-watt, 32-volt, PAR-type lights for this purpose. The difference between 32 volts and the trolley voltage is taken up with a ballast resistor. A single light circuit of this type presents a resistance of about 50 ohms on a 300-volt circuit and about 110 ohms on a 600-volt circuit. Because some vehicles use two lights at a time, and some only one, the bridging loads represented by the vehicle lights range from 110 to 25 ohms per vehicle. These values are sufficiently low that treatment is desirable.

The procedure for treating vehicle lights follows: Insert a 10-ampere, 500-μH inductor in series with the light circuit of each vehicle. Make sure that the inductor is only in series with the light circuit and is not in series with the motor or trolley phone circuits. Because of the variable conditions faced by the vehicles, it is not of much utility to check the before and after carrier frequency voltages found on vehicles, but the tuned voltmeter could be used for this purpose if so desired.

5.3.1a.iv Other Loads

Other loads can also adversely affect propagation on the trolley wire-rail; for example, signal and illumination lights. As noted earlier, an individual light bulb, or a string of such lights, does not impose much insertion loss. However, if there are many lights, the total effect could be substantial. A way to estimate whether such lights affect propagation significantly is to count the number of lights on the trolley wire-rail between the dispatcher and the farthest place in the mine, and calculate the total bridging resistance. Approximate value of loss versus bridging load can be estimated from figure 5-7. If the toal loss is less than 6 dB, only marginal improvements will result from treating these lights. If the loss is more than 6 dB, consideration should be given to treating the lights. It would be a rather unusual situation to find lights that really represented a significant impediment to propagation of a trolley wire-rail. However, when marginal signal levels exist, the lights could well make the difference between marginal and fully usable signal levels.

The most effective way to treat such lights would be to take them off the line and operate them from the ac system. This practice is being used in some of the newer mines. In old mines, where ac power is not available, little can be done. In some instances, the power rating of the lights could be reduced, thereby raising the value of the bridging impedance. Fixed inductors could also be used but would only have small effects because the light strings (typically three 100-watt, 115-volt lights in series in a 300-volt system) already have a fairly high resistance (approximately 300 ohms for the example above).

Other loads are comprised of such equipment as pumps and other motor-driven devices. However, these devices

generally have high enough impedances and are placed so infrequently that they result in minimal loading effects.

5.3.1b Using a Dedicated Wire

As previously mentioned, the trolley wire-rail is an inefficient transmission path because of the many loads that exist on the line. In the dedicated-wire technique, an independent wire (called the "dedicated wire") is run down the entryway with the trolley line on the wide side, but not connected to the trolley line in any manner.

Such a wire, since it is unloaded, has a very low attenuation rate. Therefore, if a signal is transmitted on the dedicated wire, the signal strength remains high. Since the trolley line and dedicated wire are located in the same entry, there is a mutual electromagnetic coupling between them. (The effects of loads on the trolley line are transferred to the dedicated wire, and the high signal on the dedicated wire is transferred to the trolley line.) Fortunately, if the separation between the two is large enough (9 feet or more), the loading effects of the trolley line are only weakly transferred to the dedicated wire, so that the attenuation rate stays low. But at the same time, the high signal levels on the dedicated wire are strongly coupled to the trolley line. The net result is that communication is now possible in areas where it was not possible before. The procedure for developing a system based on a dedicated wire is divided into the following three steps:

1. Routing.--Ascertain from a mine map the area of coverage desired, considering that the dispatcher position is the key position. Mark out on this map a route for a single line that runs in the same entryway as the trolley wire-rail to which communication is desired. Avoid branches on this route. If necessary, use a second or third such route to cover all regions of the mine. Short sidetracks need not be covered initially. If a branch on the route will cover the desired region with less length of wire,

use a branch, but minimize the number of branches.

2. Installation.--Install the wire; No. 10 or No. 12 wire is well suited to the task. Copper-weld construction is recommended for strength and integrity. This wire must be insulated and also held away from the rib or roof for at least 3 inches. Installation must be on the wide side of the entry, and the wire should be located for least exposure to damage. At the far ends of each line, the wire is terminated by a 200-ohm, 10-watt resistor to the rail, as illustrated in figure 5-14. If branches are used, signal-splitting resistors must be included (fig. 5-15) to reduce signal attenuation.

3. Connection of Transmitter.--Upon completion of the installation of the
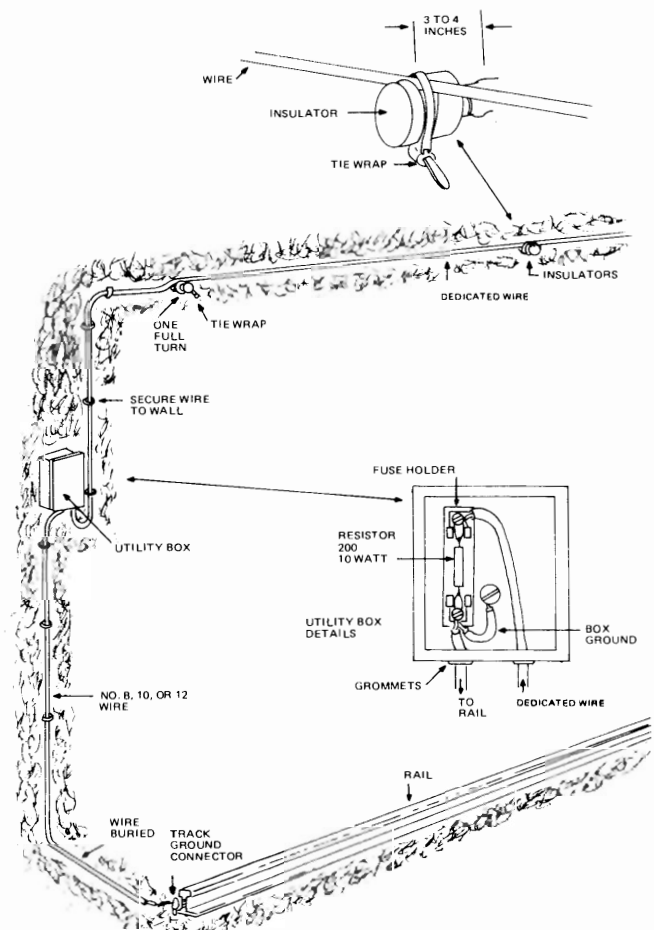
FIGURE 5-14. - Termination of the dedicated wire.
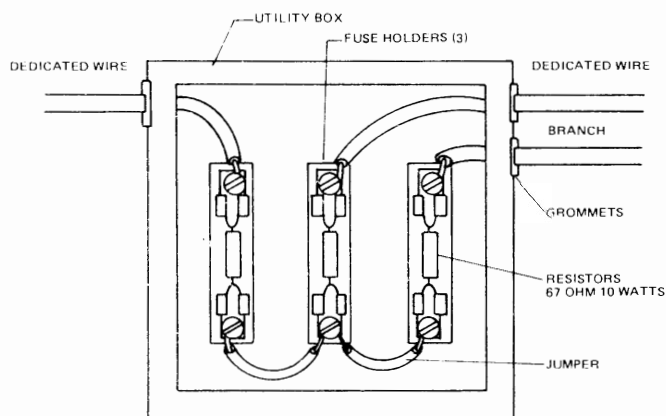
FIGURE 5-15. - Signal splitter.

special-purpose wire, the dispatcher's transmitter should be directly connected to the end or ends of the wire that converge on the dispatcher's station. The return wire of the transmitter should go to earth or to the rail.

As noted before, the use of branches should be minimized. When the routes are short, (considerably less than 10 miles), resort can be made to branches on a dedicated wire. When more than one wire is used, they should be run in separate entryways. The reason that branches are undesirable is that a branch reduces the signal level by 2 to 1 (6 dB). On short runs, such a loss can be tolerated, but on runs approaching 10 miles, such a loss may be too high.

5.3.1c Using a Remote Transceiver

Frequently the dispatcher is located at one edge of the mine complex. If this is the case, the communication range required must be extensive in order that the dispatcher be able to reach motormen on the opposite side of the mine. In some instances, a convenient way of solving the dispatcher's problem is to use a remote transceiver located at the most favorable place for reaching all parts of a mine complex. The location of such a remote transceiver is likely to be near the center of the rail haulage system of the mine, although in certain circumstances moving it somewhat away from such a center might produce more favorable results.

As an example of what might be achieved by this means, consider a dispatcher's position for which the signal attenuation is 80 dB from his position to the farthest reach of the mine. This attenuation means that an initial 25-volt rms signal provided by the dispatcher's transmitter would be reduced to 2.5 mV at the farthest reach of the mine. This level of signal is marginal, and thus the dispatcher would have poor communication to those motors on the far side of the mine. If the dispatcher's transceiver were moved to the center of such a mine, the signal attenuation should drop to one-half, or 40 dB, from this central position to the extremities of the mine. The 40 dB of attenuation would provide signal levels of 250 mV at the extremes of the mine, 100 times bigger than would result if the dispatcher's transmitter were located at one edge of the mine.

Such a substantial improvement in signal levels throughout the mine would change an otherwise marginal operation into a completely adequate communication system. Insofar as the ispatcher is concerned, his operation would remain the same. He would still have the carrier phone speaker and microphone located at his dispatching position; however, the control and audio signals would be transmitted from his position through a twisted shielded pair to the remote transceiver (fig. 5-16). Thus, it would be necessary to run an audio cable for whatever distance was necessary to reach the center of the mine. In mines where multipair telephone cable is used, a pair may be available for this purpose. If not, the expense and inconvenience of installing such a cable would be justified to assure adequate coverage for the dispatcher's communication system.
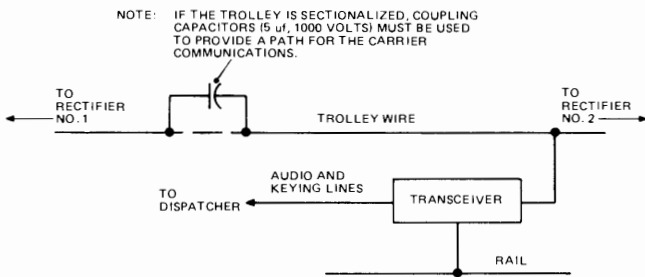
140

NOTE: IF THE TROLLEY IS SECTIONALIZED, COUPLING
CAPACITORS (5 uf, 1000 VOLTS) MUST BE USED
TO PROVIDE A PATH FOR THE CARRIER
COMMUNICATIONS.

TO
RECTIFIER
NO. 1

TROLLEY WIRE

TO
RECTIFIER
NO. 2

TO
DISPATCHER

AUDIO AND
KEYING LINES

TRANSCEIVER

RAIL

WARNING

Some of these procedures are undertaken with the trolley
wire energized; therefore, they are extremely hazardous.
Extreme caution must be exercised to avoid potentially
lethal shock. The fuses used in the test leads serve only
to protect equipment and do not in any way reduce the
shock hazard to personnel. Only personnel thoroughly
familiar with electrical work on trolley wires should con-
duct these procedures. The permanent connection of
components should be done with power removed. Care
should also be taken to insure that components and equip-
ment are suitable for use in the desired application.

FIGURE 5-16. - Dispatcher's remote transceiver.

5.3.1d Summary

A substantial number of the problems
associated with maintaining good trolley
communication systems can be avoided by
advanced planning. For those planning a
communication system for a new mine, the
following suggestions are offered to as-
sure optimum operation of the trolley
carrier phone system when installed:

1. If the trolley wire is section-
alized, make sure capacitors (5 µF,
1,000 volts) (some systems may require
even higher voltage components) tie the
sections together.

2. Plan to operate as many auxil-
iary loads as is practicable on mine ac
power rather than from the trolley wire
power.

3. Consider the use of a dedicated
wire to aid signal propagation.

4. Select carrier phone transceiv-
ers that show a high value of standby
impedance.

5. Insist that vehicle manufactur-
ers indicate the 88- to 100-kHz operating
impedance of their vehicles, and select
vehicles that show high operating imped-
ance at the carrier frequency.

6. If possible, use at least a 50-
foot setback for rectifiers that are to
be installed in the mine; this setback
will permit tuning of the rectifier leads
to raise the impedance of the rectifier.

7. Ask the rectifier manufacturers
to supply internal filters in series with
the voltage to raise the carrier fre-
quency impedance to a high level.

8. Plan and design isolators for
all other appreciable bridging loads
across the trolley wire rail.

5.3.2 Improving Telephone Systems

As mentioned earlier, hardwired
phone systems fall into three major cate-
gories: single pair (party-line), multi-
pair, and multiplex phone systems. A ma-
jor disadvantage of single-pair systems
is that each telephone must be used in a
party-line arrangement. This prevents
simultaneous conversations in the system
and reduces its usefulness for discussing
maintenance problems or other uses that
can tie up the system for long periods of
time. Multipair and multiplex systems
provide for many simultaneous conversa-
tions but until recently did not possess
the paging ability.

All three of these systems can usu-
ally be improved if the basic reasons for
poor performance or high noise levels are
understood. For instance:

Heavier gage wire presents less at-
tenuation to the signal and results in
better coverage over greater distance.

Splicing technique has a large ef-
fect on signal strength.

Twisted pair cable can reduce noise
pickup.

Even when proper precautions have been taken, all hardwired systems are inherently unreliable. For example, if a telephone line is broken or shorted by a roof fall, all telephones beyond that point are severed from communication to the outside. If the line is shorted, communications in the entire system may be severely affected or lost completely. These deficiencies can be corrected by the following methods:

Adding loopback to the phone line.

Sectionalizing the phone system.

5.3.2a Loopback Methods

A major disadvantage of any wired phone system is its dependence upon a continuous phone line running throughout the mine. If this phone line is broken, communication with all phones inby the break is lost. Alternate communication paths, or loopbacks, can be established as shown in figure 5-17 to overcome this deficiency. If a line break should occur, the loopback switch can be closed, allowing each and every phone to still communicate with all other phones in the system.

Another way to implement loopback is to return the phone line to the main shaft using a different underground path. No matter which method of loopback is used, the operation of the systems is similar. During normal operation the

FIGURE 5-17. - Phoneline loopback.

loopback switch is left in the open position. If a line break should occur anywhere in the underground phone line, the loopback switch can be closed and each phone will still be able to communicate with other phones. Depending upon the physical layout of the mine, forming an underground loop may actually require less wire than if a single line is strung with many branches running to the individual phones. It is imperative that the loopback switch be always left open under normal conditions to avoid "masking" line breaks.

Another method of establishing loopback is by using an overland radio link. In this type of system the mine telephone signals are returned from the end of the line to the surface through a ventilation shaft or borehole. At the surface a two-way radio base station establishes an overland radio link to a second station near the dispatcher or general mine foreman's office. Note that provisions must be made for dc paging.

Each of the loopback systems described above utilized a loopback switch that during normal operation (no line breaks) is left in the "open" position. This loopback switch serves an important function in any loopback system. For instance, consider what would happen in a loopbacked system with no loopback switch, or if the switch is normally left closed. No communication outages would be experienced when the first line break occurred because each phone would still be connected, through one or the other legs of the loop, to the system. The problem is that unless someone underground noticed the broken phone line, everyone would assume that the system was completely intact because no communication difficulties were being experienced. The system could operate in this mode for a long period of time. However, when a second line break occurred communications to and from all phones between the two breaks would be lost. Note also that each time the dispatcher talks he hears himself on the loopback phone. This feature alone assures that the phone line is intact.
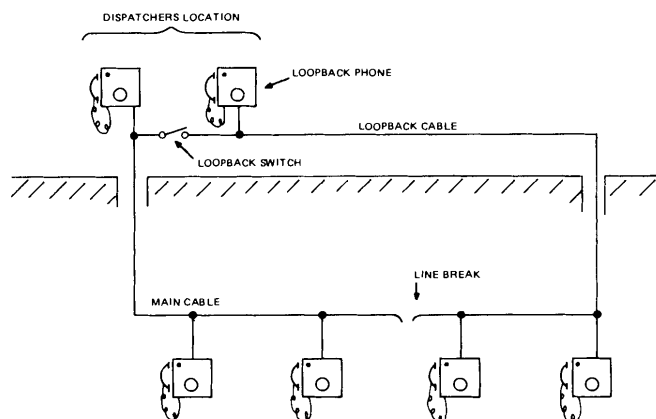
5.3.2b Sectionalizing the Underground Network

The desirability of selective area paging and simultaneous conversation capability along with the maximum possible use of two-wire transmission line makes the use of a zoning or sectionalization of the mine telephone system attractive. In this method, each zone or section in the underground complex is served by its own cable pair.

To see how the telephone sections would be interconnected, consider the simplified four-section system shown in figure 5-18. Within each area, the paging telephones would operate normally. That is, all phones in each area would operate on a party-line basis. When contact with a phone outside the local area is desired, connection to the area being called would be made at an outside central exchange. This type of system could also be made more reliable by having two different signal paths (loopbacks) available between each area and the central exchange.
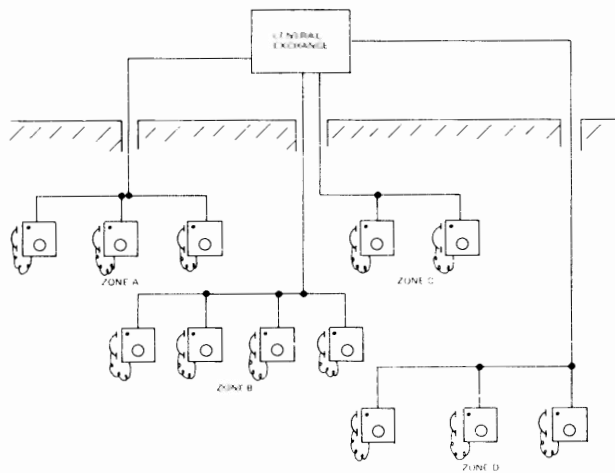
FIGURE 5-18. - Sectionalization of a phone system.

5.3.3 Summary

Advanced planning is essential to the successful design and installation of any communication system. The design plan should take into consideration changes in system requirements to meet communication demands throughout the entire life of the mine.

Single-pair, multipair, and multiplex systems are the basic choices available once it has been determined that a hardwired system will best meet the communication requirements. A considerable percentage of the expense involved in each of these systems is due to the distribution (cable) network, and advance planning is especially critical in this area. Wire lines to meet telemetry requirements for remote control and monitoring of equipment and atmospheric conditions should also be recognized. Note that MSHA regulations may prohibit running two systems in a single cable.

Methods also exist that allow improvement of systems already installed. The performance of trolley carrier systems can be improved by removing or isolating bridging loads on the trolley wire that cause signal attenuation. Dedicated lines or remote transceivers can also be used to improve the quality of these systems.

General maintenance and splicing technique can have a large effect on the quality of voice service over wire phone systems. These systems can also be made more reliable by providing loopback paths so that each phone will remain connected to the system in case of a line break.

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CHAPTER 6.--INSTALLATION TECHNIQUES

6.1 The Basic Philosophy

The investment involved in any communication system represents a considerable sum. Even though it is desirable that the system work properly each and every time it is called into use, some failures are bound to occur. Most failures, however, and especially those that occur most frequently, are due to poor installation techniques. An extra hour spent at an installation site can save many maintenance trips and many frustrating hours of system troubleshooting.

Typical faults likely to cause communication outrage are

Pager phone systems

Poor splices aggravated by corrosion.

Strain relief not provided.

Drip loop not provided.

Incorrect branch connections.

Overloading the circuit.

Poor battery connections.

Improper wire size or type.

Lightning strikes.

Improper placement of wire runs.

Carrier phones

Mounting transceiver near load resistors or other sources of heat.

Tracks not electrically bonded.

Cable abrasion due to poor mounting location.

Disconnected battery.

Poor mechanical installation.

Each installation should be well planned. After an installation is completed, the technician should ask the question, "What can go wrong with this unit or line?" Remember the adage, "Whatever can go wrong, will." Preventive measures taken during installation will pay off in the long run.

6.2 Pager Phone Installation

The pager phones used in many underground coal mines are battery-operated, party-line telephones with provisions for loudspeaker paging. The system is usually two-wire, nonpolarized, and operated by self-contained batteries. Many of the individual units are certified as permissible.

6.2.1 Mounting

Pager phones are designed to be mounted on an upright support at the desired location. For convenience, the phone should be mounted 5 feet above the floor where there is no obstruction to using the handset or removing the cabinet front cover for servicing or battery replacement. In low-coal situations, a suitable height for installation should be selected convenient to the normal operator's position at the site selected. About 12 inches of free space on each side of the phone should be provided for cabinet access. The phone should be protected against direct exposure to dripping water and should not be allowed to rest in a puddle of water. The mounting location should be convenient to a work location and have a safe, unobstructed area for a worker to stand and use the phone. The phone must be in a location where the worker will not be in the path of moving vehicles or falling debris. Each telephone is normally well insulated, but it is still good practice to provide an insulating mat or dry planking for the user to stand on.

6.2.2 Connections

For handling convenience, the branch line or connecting cable to each individual telephone can be a lighter wire gage than the main cable. Each connection to the main line should be a good electrical and mechanical joint, protected by a careful double wrap of plastic electrical tape.

Special care should be taken to insure that each splice is a good electrical and mechanical connection. Connections that are of poor or marginal quality, or that are not adequately protected from moisture, will contribute to poor performance. During periods when humidity levels are high, especially during the summer months, corrosion will form on all exposed splices. As this corrosion builds, audio levels decrease and line noise increases until eventually the entire system becomes useless.

Connections at the phone depend on each manufacturer's design and on individual state or local requirements. A majority of the phones provide two exposed spring-loaded terminals for attaching the wires. For proper connection, it is necessary to strip the installation away from each conductor in the pair, seal off the exposed area of the cable with plastic electrical tape to keep out moisture, and then insert one of the exposed conductors into each of the cabinet terminals. Some states, such as Pennsylvania, do not allow the use of exposed terminals at the face area of gassy mines. For these applications, some phones are equipped with twist-lock connectors at the end of a short cable. Each connector is mated with a similar connector on the drop or branch line to complete the installation. In either type of installation, there should be a drip loop below the cabinet to prevent condensate from running down the cable into the cabinet.

6.2.3 Batteries

Pager phones are usually operated by one (or two) 12-volt, dry-cell batteries,

NEDA No. 923 or No. 926 (National Electronic Distributors Association). To install batteries, it is necessary to open the pager phone cabinet and inspect the battery compartment. Remove the old battery by loosening the retaining clamp, and either unscrew the battery terminals to release the battery wires or remove the battery plug, depending on the battery type. Remove the battery, and carefully wipe out the battery compartment to remove dirt and moisture. Place a fresh battery in the compartment, and secure the retaining clamps tight enough to restrain the battery without crushing or bending the battery case. Reconnect the battery wires, being careful to observe the polarity markings noted on the case. If the plug-connector type is used, do not force the connector. Correct polarity is maintained when the larger connector pin fits in the larger hole. The difference in pin sizes is not great, so a mismatch can be forced. If the connector does not mate easily, reverse it and try again without forcing. After replacing the battery, close the cabinet and mark the date of battery replacement either on the outside of the cabinet or in a log book.

CAUTION

Pager phone circuits are normally designed to provide sufficient current limiting with the specified battery. If other battery types are used, such as the nickel-cadmium rechargeable type or one of the alkaline, long-life, high-current varieties, the circuit may not be able to limit the available current to a safe value. REPLACE WITH RECOMMENDED BATTERY ONLY.

Battery life is not easy to predict, because of the many operating variables that affect the average current drain. In general, the batteries in a telephone system that is used many times a day may have to be replaced every 4 to 6 weeks, while a telephone system that is seldom used may keep its batteries at usable strength for 4 to 6 months.

Each battery change should be recorded, either on the telephone cabinet or in a central log. Experience gained over a period of time will help predict when a battery in a particular phone is reaching the end of its useful life. Periodic verification of battery status at each phone should be made with a voltmeter and recorded in the log. (Measure battery voltage while under load; that is, during paging.) When the battery voltage drops to a value that is 75% to 80% of the installed level, it should be replaced. For example, for a 12-volt battery, the replacement level is about 8 to 9 volts.

6.2.4 Fuses

Fuses are provided in pager telephones as an added precaution against excessive current in the external circuit. Current-limiting circuitry is normally provided in the telephone, but the fuse is an additional safeguard. No provision is made in most phones to store a spare fuse. It is good practice to tape two additional spare fuses to the inside of the cabinet when the phone is first installed. Then, the correct fuse will be available at the phone if it is needed. Make sure the fuses do not and cannot short circuit any circuitry.

6.2.5 Amplifier Loudness

Each pager phone has a loudspeaker, powered by its own internal amplifier, that is switched on by the dc paging signal. The available audio power is about 5 watts, which is adequate to be heard above most mine noises. Many telephones have a volume control for the speaker. During installation, the speaker should be oriented, and the volume set, to insure adequate coverage in the area.

During setup, someone should page from another location to the phone being installed. The volume control should be set to the desired level during the paging. The telephone cabinet should be positioned to direct maximum sound to the work area.

6.3 Phone Lines and Transmission Cables

6.3.1 Phone Lines

The cable used to interconnect underground pager phones must be rugged enough to withstand the underground environment and also have the proper electrical characteristics for requirements of the pager system. Generally, the cable used for this purpose is a twisted pair of solid-conductor wires that has a nonwater-absorbing, flame-retardant insulation with a rating of 600 volts dc and an outer abrasion-resistant covering. The conductor used depends on the installation; recommended sizes are 19 AWG to 14 AWG.

Many telephones used underground, particularly those used at the working face, are subject to periodic relocation. To allow for this, and to reduce the problems associated with repeated cable splicing, some convenient length of wire (say, 500 feet) can be included as part of the branch line. This extra wire can be kept reeled, or neatly coiled in a bundle and secured with a few wraps of plastic electrical tape. The extra wire should be hung near the telephone in a place free of dripping water or water accumulation, and should be supported by an insulated hanger that is isolated from power or trolley wires. The practice of coiling the cable is recommended, but with certain restrictions. If the cable is used to transmit monitor signals via an RF (radio frequency) carrier imposed on the two-wire pager phone line, the coiled cable becomes an inductor that will impede the proper transmission of the RF signal.[1]

Methods and recommended techniques for the permanent installation of phone lines are presented in a Bureau of Mines

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[1] The addition of equipment to a phone system could violate intrinsic safety standards; check with MSHA for detailed application information.

handbook (2),[2] including installation, lightning protection, cable selection, and splicing methods. Note that 30 CFR specifies certain requirements for cable installation.

6.3.2 Leaky Feeder Cable

Installation of leaky feeder cable requires some special techniques. A typical installation of leaky feeder cable is shown in figure 6-1. For installation of the repeaters, refer to the manufacturer's installation guide. Hanging the leaky feeder cable requires clamps such as those used for conduits or other power cables. In areas where corrosion may be a problem, stainless steel or plastic clamps should be used. Typical hangers are shown in figure 6-2. The type of insulated hanger shown supports the leaky feeder cable from the messenger cable. Leaky feeder cable should be supported at intervals of 5 feet and is usually terminated with an antenna.

6.4 Carrier Phone Installation

The primary function of the carrier phone system is to provide a reliable communication network over which the dispatcher can direct all tracked vehicle

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[2]Underlined numbers in parentheses refer to items in the bibliography at the end of this chapter.
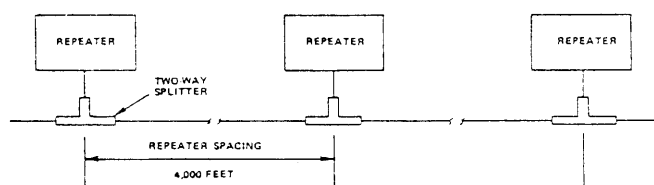
FIGURE 6-1. - Typical installation.

METAL HANGER
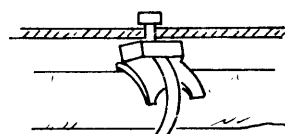
INSULATED MESSENGER CABLE HANGER

FIGURE 6-2. - Hanger hardware.

traffic in the mine. The safety and productivity of the mine depend, to a large measure, on the ability of the dispatcher to maintain direct contact with all motormen via the carrier phone system. For this reason, the carrier phone installation should be carefully thought out, and the workmanship should be of the highest caliber.

```
CAUTION

    Installation procedures in this
section are guidelines and not com-
prehensive  technical  instructions.
Procedures described in  this section
must be performed by people thorough-
ly  qualified  to do  such work.  In-
stallations should comply with manu-
facturer's    recommendations,    good
safety procedures, and all applicable
codes and regulations.
```

6.4.1 The Dispatcher Location

The trend in modern coal mining is to locate the dispatcher aboveground in a separate building or a separate room in the mine office complex. This location provides a continuously manned communications center even if the mine must be evacuated owing to emergencies or ventilation failures. Since 1974 the mining laws of West Virginia have required that the dispatcher be located on the surface in all new mines and for existing mines if the dispatcher is relocated (Article 22-2-37, Part T5).

Underground dispatchers' locations vary greatly, depending on the mine layout and growth. The two most common locations chosen are at the bottom of the main shaft or near the physical center of the mine.

The carrier phone equipment is usually installed on a panel which is mounted on a wall adjacent to the dispatchers' desk. This panel provides one convenient location for all the subassemblies that make up a carrier phone and protects the interconnecting cables from unnecessary flexing and stretching. The panel should be made from at least

1/8-inch-thick steel plate if the carrier phone uses a power-conditioning unit or resistor box that contains series-dropping resistors.

```
┌─────────────────────────────────────┐
│              CAUTION                 │
│                                      │
│    Remove the  electronic subassem-  │
│ blies from the mounting  plate during│
│ welding operations.  Keep all  elec- │
│ trical cables  and  other nonmetallic│
│ materials away from the welding area.│
│ This  will prevent the  carrier phone│
│ components from being damaged by heat │
│ during welding operations.           │
└─────────────────────────────────────┘
```

The microphone-speaker assembly is the only part of the carrier phone that interfaces directly with the dispatcher; therefore, it must be located within easy reach. The speaker volume control should also be within easy reach.

Locate the transceiver on the panel at either side of the speaker assembly, taking into consideration the location of the interconnecting cables. Leave room for the excess cable to be coiled up and secured to the panel.

Temperature-sensitive electronic circuits are located inside the transceiver assembly. Therefore, it should be protected from the temperature extremes produced by load resistor banks and room heaters. For reliable operation, the ambient operating temperature range that the transceiver is exposed to should be restricted to -40° to +140° F.

Approximately 6 inches of clearance should be left around all surfaces on which the connectors and/or fuses are mounted. If possible, the connector-mounting surfaces should be protected from dirt and moisture. Sufficient clearance should be allowed to remove access covers and open-hinged panels so that adjustments can be reached and plug-in modules can be changed.

The power-conditioning unit is used to convert the trolley voltage (typically 300 or 600 volts dc) or the local ac power to 12-volt dc power for the transceiver electronics and to recharge the battery. The circuit generally used in this unit contains a large series-dropping resistor that under normal operating conditions dissipates several hundred watts. The high temperature associated with this power dissipation would be harmful to the sensitive transceiver circuitry; therefore, it is a separate unit that can be located where it will not heat up the transceiver. When only the series-dropping resistor is contained in this unit, it is called a resistor box. It is also referred to as the battery charger by some manufacturers; in this case, it would contain the dropping resistors and the charging circuits.

The main consideration when locating this unit is its heat dissipation and its relationship to the heat-sensitive transceiver. The heat is dissipated into the ambient air and into the structure on which it is fastened; therefore, it is important to follow the manufacturer's mounting instructions carefully.

The power unit should never be mounted below the transceiver (heat rises) or the speaker enclosure. Keep the power unit a minimum of 6 inches away from either side or the top of the transceiver. If mine personnel can come in contact with the hot surfaces of the power-conditioning unit, a protective grille should be added. This grille should be open at the top and bottom to allow for proper air circulation.

A 12-volt lead-acid automotive-type storage battery is most often used as an external emergency power source with carrier phones. When locating this type of battery, the prime considerations should be the accessibility of the fill caps for servicing and proper room ventilation to handle the outgassing of hydrogen. The battery should also be kept away from materials that are susceptible to corrosion by sulfuric acid.

The ideal temperature range for the battery is 60° to 80° F. Low temperatures reduce capacity but prolong battery

life; high temperatures give some additional capacity but reduce total battery life. Temperatures above 125° F can actually damage some of the battery components and cause early failure.

Once the various subassemblies have been physically mounted to the panel, the final installation task is to make the electrical interconnections. This procedure consists primarily of inserting cable-mounted connectors into the proper receptacles on the subassemblies and connecting the signal and power cords into the proper mine ectrical systems.

A block diagram of a typical carrier phone interconnecting cable system is shown in figure 6-3. The cable connected to the trolley power and/or building power should be installed last. The other cables may be installed in any order that is convenient.

```
┌─────────────────────────────────────┐
│             CAUTION                  │
│                                      │
│    Clean and inspect all connectors  │
│  before mating.  Study the keying ar-│
│  rangement or  polarization to prevent│
│  jamming and misalinement.           │
└─────────────────────────────────────┘
```

Before connecting power, verify that the RF signal common and the case and chassis grounds are all connected. The RF signal common should be an all-metallic connection to the rail system, even if the dispatcher is located above-ground. Often the rails are bonded to the steel structural members of the main shaft to help establish a good earth
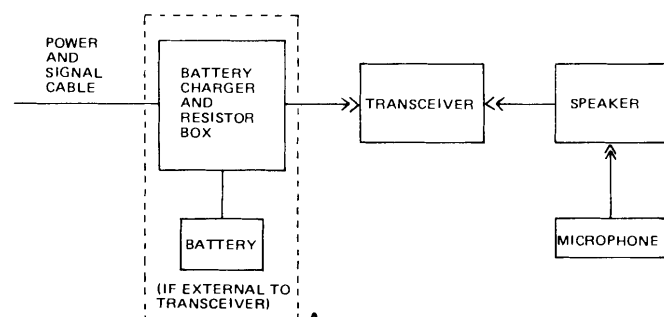
FIGURE 6-3. - Typical carrier phone interconnecting cable system.

ground for the mine. If this is the case, the RF signal common can be wired to the shaft structure at the surface or the hoist house structure. A minimum 14 AWG insulated copper wire should be used for this purpose. If the input power is supplied by the trolley wire, then the RF signal common and the power common should be jumpered together.

Connect all chassis and case grounds from the lugs or studs provided by the manufacturer to earth ground. Do not rely on the mechanical mounting of the case for a ground connection; always run a separate ground wire to the earth ground. Refer to the Code of Federal Regulations, Title 30, Part 75, Subpart H, for explicit grounding requirements.

The earth ground connection or building is generally made to a metallic water supply pipe or to the structural ironwork of the building. In either case, the connection should be made close to where the pipe or structure enters the earth to insure a minimum resistance between the connection and the earth.

The input power to the dispatcher's phone is supplied from either the trolley wire (typically 300 to 600 volts dc) or the local 115-volt ac power. If trolley wire input power is to be used with the dedicated line coupling method, then the in-line fuse holder cable is connected to only the hot input power terminal on the phone. The other end of the cable is connected to the trolley wire. Whenever trolley wire input power is used, the common power connection and the common signal connection are jumpered together and wired to the rails.

If the carrier phone is not located adjacent to the haulageway, then a wall-mounted fuse box should be used instead of the in-line fuse. Terminate the wire on the line side of the fuse block. Using the same type of wire, make a welded connection to the rail and run this back to the fuse box. Now, two-wire neoprene-jacketed-type portable cable may be used to supply power to the dispatcher's phone.

```
┌─────────────────────────────────┐
│             NOTE                │
│                                 │
│   The manufacturer's detailed in- │
│ stallation instructions   should be │
│ carefully followed to make certain │
│ the carrier phone is  compatible with │
│ the polarity of the mine trolley │
│ power.                          │
└─────────────────────────────────┘
```

The 12-volt power fuse and the trolley power fuse should be removed to permit making the battery connections without a load immediately being placed across the battery. The grounded side of the battery should be connected first. If the mine has a positive trolley system, then the negative side of the battery should be grounded. The battery post is made of lead, as are the internal connections between the post and the battery plates. If too great a torque is applied to the clamping bolt, the internal connections can develop hairline fractures that can cause an intermittent connection. To avoid this condition, a second wrench should be used to steady the bolthead while tightening the nut.

Fuses provide an intentionally weakened part of an electric circuit and thereby act as a safety valve in the event of dangerous overloads. This protects both personnel and equipment from potential fire hazards due to overheating of the carrier phone.

```
┌─────────────────────────────────┐
│             NOTE                │
│                                 │
│   Fuses do not provide protection │
│ from dangerous high-voltage shocks. │
└─────────────────────────────────┘
```

Fuses come in many sizes, types, and electrical ratings. Always use a replacement fuse that has the same rating as specified by the carrier phone manufacturers.

The last step in installation is to connect the power wire. Two commonly used installation methods are direct coupling to the trolley wire, and single dedicated line coupling. For the installer's safety, the input power should be connected last.

Direct coupling involves wiring the hot RF signal connecting point directly to the trolley wire with the in-line holder cable provided with the phone. If the dispatcher's office is remotely located, then a fuse box adjacent to the trolley wire should be used. If the input power to the phone is to be supplied by the trolley wire typically (300 to 600 volts dc), then the hot power connection is jumpered to the hot RF signal connection with a length of 14 AWG insulated copper wire. Do not install the 3-ampere in-line power fuse until all ground connections are made up.

A second method of signal coupling is to connect the dispatcher's phone to a single conductor dedicated wire. This wire would originate at the hot RF signal connecting point.

6.4.2 Vehicle Installations

The carrier phone typically consists of a transceiver assembly, a microphone-speaker assembly, and power conditioning units; these are sometimes an integral part of the transceivers (fig. 6-4). Carrier phone equipment is installed on all types of tracked vehicles. Three commonly used vehicles found on coal haulage systems are locomotives, portal buses, and utility cars. Each of these vehicles has a different seating arrangement for the driver (fig. 6-5).

The microphone-speaker assembly is the only part of the carrier phone that interfaces directly with the vehicle operator. Thus, it must be located so that it can be easily reached. If the microphone hanger is not conveniently located, it will not be used by the operator, and the microphone and cord will suffer unnecessary damage from mistreatment. The speaker volume control should also be within easy reach, and the speaker should be pointed directly at the operator to provide the best reception.

Vehicles without dual controls require the operator to assume two different positions in front of the same
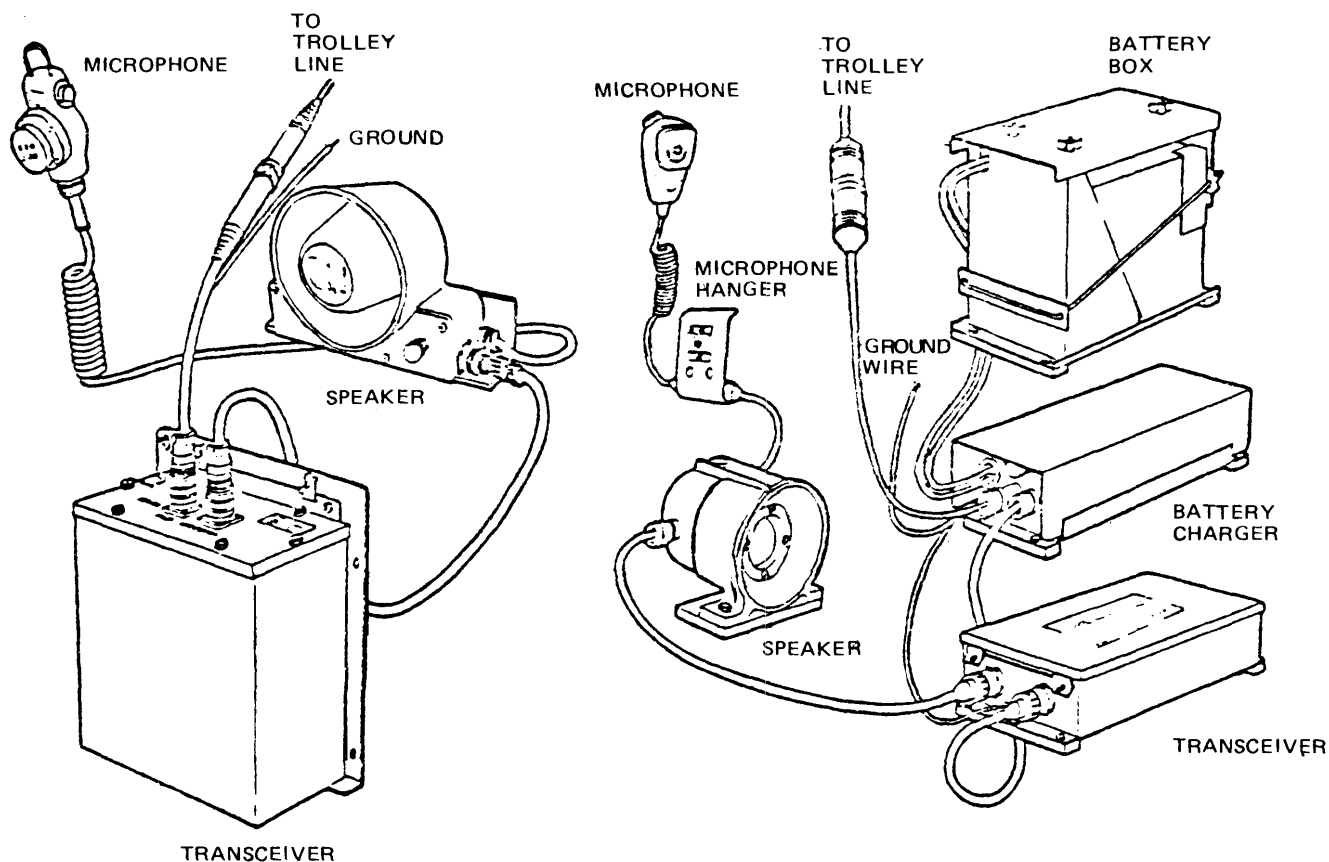
FIGURE 6-4. - Typical carrier phones.

controls so that he can observe the track ahead of him. This further complicates the positioning of the microphone-speaker assembly. It is sometimes helpful to use two microphone hangers for this type of installation so that the microphone is convenient no matter which way the vehicle is traveling.

Entanglement of the microphone cord with other vehicle controls, causing an unsafe operating condition, should also be considered when locating the microphone-speaker assembly. The microphone should also be mounted in an area that will protect it from falling debris and/or dripping water.

Once a suitable place for the microphone-speaker assembly has been determined, the transceiver location can be considered. The first restriction on its location is the length of the cables running between the different assemblies. Temperature-sensitive electronic circuits

are located inside the transceiver assembly. Therefore, it should be protected from temperature extremes such as those produced by load resistor banks and the vehicle's drive motors.

It is important that installation of the transceiver does not reduce the minimum roof clearance of the vehicle. Approximately 6 inches of clearance should be left between the vehicle and the surfaces on which the connectors and/or fuses are mounted. If possible, the connectors should be protected from dirt and moisture. Sufficient clearance should be allowed to permit removal of access covers and open-hinged panels so that adjustments can be reached and plug-in modules can be changed.

The main consideration when locating the power conditioning unit is its heat dissipation and its relationship to the heat-sensitive transceiver. The heat is dissipated into the ambient air and into

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TRANSCEIVER
SPEAKER
MICROPHONE

(A) LOCOMOTIVE

SPEAKER
MICROPHONE
TRANSCEIVER

(B) UTILITY CAR

SPEAKER
MICROPHONE
(ROOF REMOVED
TO SHOW INTERIOR)

TRANSCEIVER
MICROPHONE
SPEAKER

(C) PORTAL BUS
WITH DUAL CONTROLS
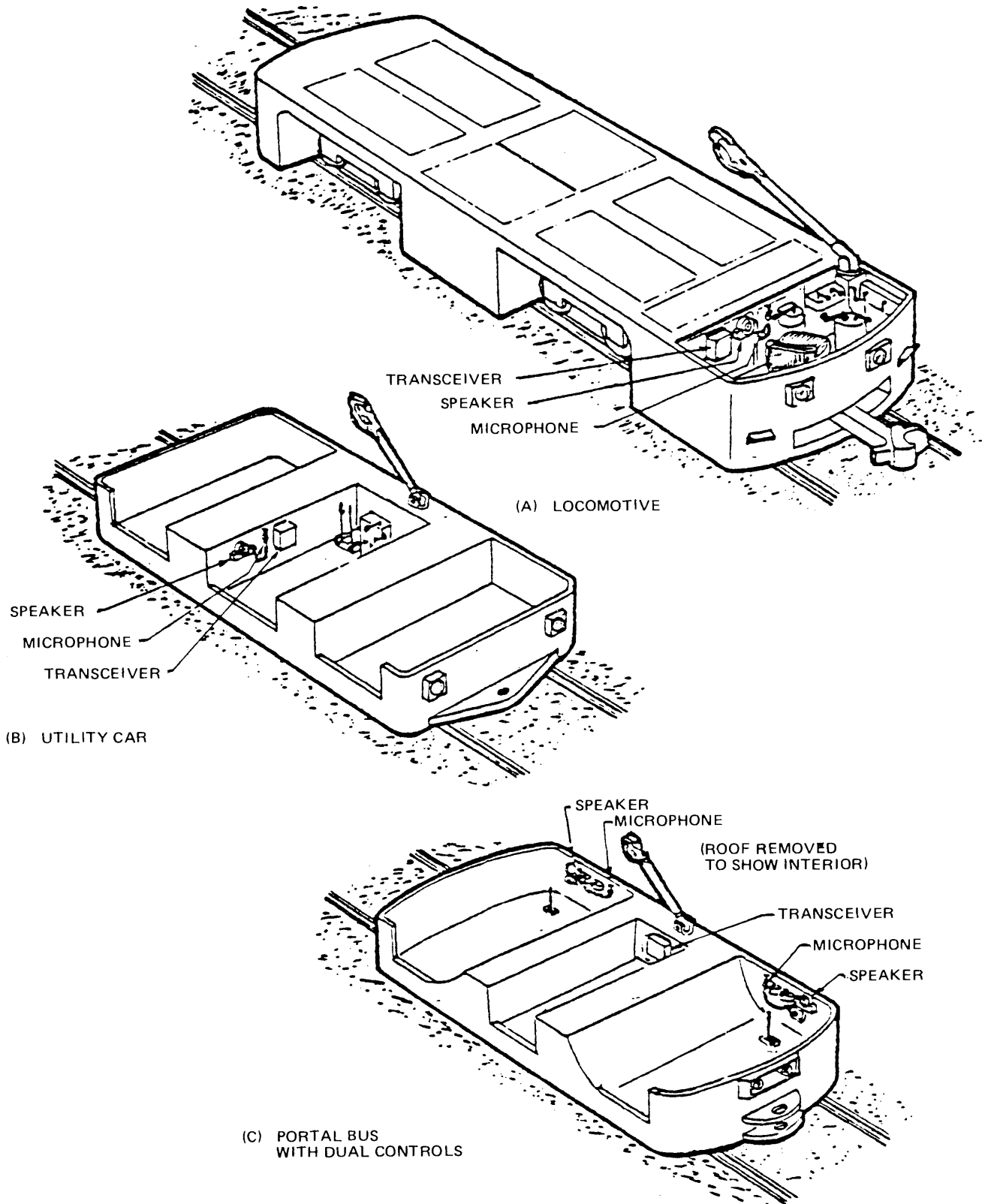
FIGURE 6-5. - Typical mine vehicles.

the structure on which it is fastened; therefore, it is important to follow the manufacturer's mounting instructions carefully. The mounting surface should be a massive structural part of the vehicle that can absorb the heat transferred from the unit.

If it is a horizontal surface, a minimum of 3 inches should be allowed on all sides; if possible, nothing should be mounted above the unit. If it is a verticle surface, a minimum clearance of 3 inches above and below the unit should be provided for proper air circulation. The power unit should never be mounted below the transceiver; if possible, a minimum separation of 1 foot in all other directions should be provided.

A 12-volt lead-acid automotive-type storage battery is most often used as an external emergency power source with carrier phones. When locating this type of battery, the prime considerations should be the accessibility of the fill caps for servicing and proper room ventilation to handle the outgassing of hydrogen. The battery should also be kept away from materials that are susceptible to corrosion by sulfuric acid.

The ideal temperature range for the battery is 60° to 80° F. Low temperatures reduce capacity but prolong battery life; high temperatures give some additional capacity but reduce total battery life. Temperatures above 125° F can actually damage some of the battery components and cause early failure.

Most carrier phone components are supplied with mounting plates that can be tack-welded to the vehicle. This provides a permanent mounting surface with tapped holes or threaded studs onto which the subassemblies are fastened. This arrangement also provides an easy means of interchanging subassemblies for maintenance purposes.

CAUTION

Remove the subassembly from the mounting plate during the welding operation. Keep all electrical cables and other nonmetallic materials away from the welding area. This will prevent the carrier phone components from being damaged by the heat generated from the welding operation.

Procedures for making the electrical connections between carrier system components are similar to those for the dispatcher's installation (paragraph 6.4.1). For the installer's safety, the trolley shoe should be removed from the trolley line.

Proper cable protection will reduce the downtime of the communication system and prevent accidents, such as loose cables tripping up mine personnel when entering or leaving the vehicle. The interconnecting cables should be located, if possible, away from areas occupied by mine personnel or supplies. This will prevent cutting and crushing of the cables caused by shifting loads.

Heavy-duty plastic ties or cable clamps should be used to lash the cord to the frame of the vehicle. If possible, the cable should be run under overhanging parts of the frame to protect it from falling debris and/or dripping water. Enough slack should be left to form a drip loop to prevent condensate from running down the cord and into the rear of the connector. All holes in the frame through which the cable runs should be grommeted. The cable should not be run over sharp edges that might abrade it. Excess cable should be neatly coiled and secured with plastic electrical tape or cable ties and then clamped to the frame. The cable should never be stretched between clamps; this will leave it in tension, causing an elongation of the insulation and the conductor. In addition,

the jacket will lose a considerable part of its resistance to mechanical damage, making it vulnerable to cutting, tearing, and abrasion.

6.5 Carrier Current Hoist Phone

Carrier current hoist phones utilize existing physical conductors (the hoist rope) for a transmission medium. Typical hoist radio hardware is shown in figure 6-6.

6.5.1 Cage

The cage equipment consists of the transceiver, which contains a speaker, microphone, and push-to-talk switch, a battery, generally of the lead-acid type, a cage coupler, and the connecting cables. The transceiver is the only unit that must be mounted within the cage, where space is usually at a premium. For that reason, it should be recessed in the cage wall. The battery must be mounted
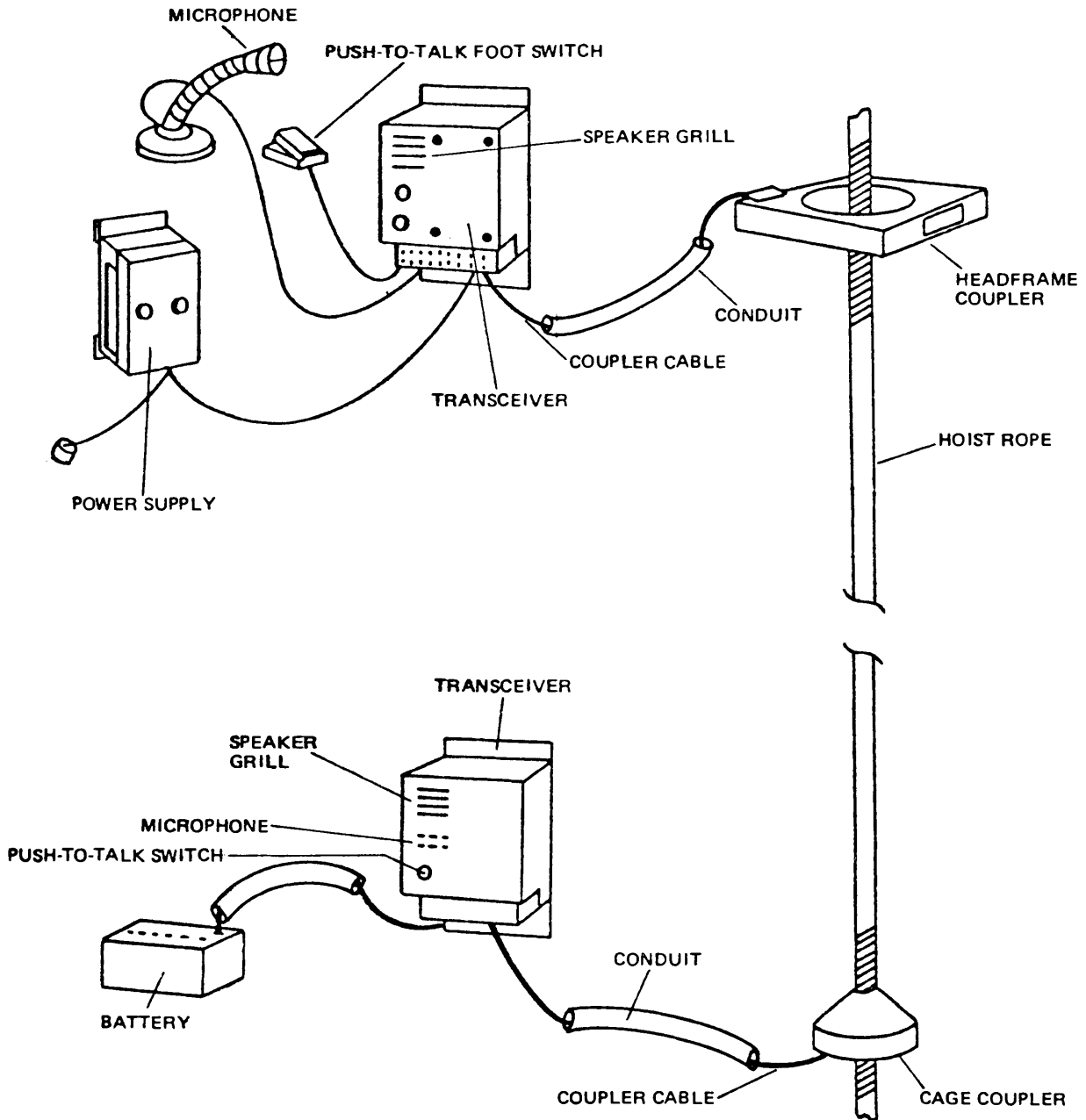
FIGURE 6-6. - Hoist radio hardware.

in an upright position either inside the cage or on top. Mounting the battery on the top of the cage provides early access for charging or replacement. The cage coupler is bolted to the hoist rope above the cage with the conical section up to act as a rock shield. It is suggested that the battery be placed within a protective enclosure to prevent a short circuit which could be caused by debris. Be sure the cable and unit connectors are clean before mating them. Conductive dust in a connector interface may cause the equipment to malfunction. Cables between the battery, transceiver, and coupler should be strategically placed to avoid damage. Cable clamps should be used to take up slack; a loose cable is a hazard to personnel and equipment. It is suggested that cables be run through heavy-gage conduit.

6.5.2 Hoistroom and Headframe

The hoistroom equipment is shown in the upper part of figure 6-6. The hoistroom will contain the power supply, transceiver, push-to-talk foot switch, and microphone. The power supply and transceiver may be wall mounted. It is best to leave at least 6 inches between the power supply and transceiver, and the power supply should not be mounted below the transceiver. The microphone should be placed so that it can be within 2 inches of the operator's mouth while the operator has both hands on the hoist conrols. The foot switch should be in easy reach of the operator's foot while the operator is at the controls.

The headframe coupler is located at the top of the shaft. It may be clamped to or suspended from the headframe structure. The coupler cable from the headframe coupler to the transceiver should be run through conduit.

6.6 Summary

Tables 6-1 through 6-4 are basic checklists for four types of installation: Pager phone, carrier phone, hoist phone, and cable. It is evident that not all criteria are covered in these basic checklists. Additional items that are peculiar to a specific installation may be added.

There are some procedures associated with any installation. They are

READ INSTRUCTIONS BEFORE STARTING!

DO IT SAFELY!

DO IT CAREFULLY!

CHECK IT THOROUGHLY!

SEEK HELP IF NECESSARY!

Short cuts in installation will probably lead to equipment malfunction or damage. All communications equipment should be tested with transmissions to and from another unit after installation.

A little extra time spent in the installation phase of a communication system can mean the difference between a reliable, well-managed system and an undependable system requiring frequent maintenance.

TABLE 6-1. - Pager phone installation basic checklist

Item	Yes	No	Comments
1. Has the exposed area of the cable been sealed with electrical tape to keep out moisture?			
2. Is the drip loop positioned properly to keep condensate from getting into phone?			
3. Is the tension in the spring terminals sufficient for a good connection between the wire and phone?			
4. Is the twist-to-lock connector in the locked position?			
5. Has the battery been tested?			
6. Have spare fuses been provided?			
7. Has the phone been called from a distant phone and been found operable?			
8. Is the volume satisfactory or has the amplifier been adjusted for proper loudness?			
9. Is the phone mounted at a proper height for convenience?			
10. Is an insulating mat or dry planking provided on which the user may stand?			
11. Is all cabling secured and protected from passing machinery?			
12. Are all splices QUALITY splices?			
13. Are the cables heavy enough?			

TABLE 6-2. - Carrier phone installation basic checklist

Item	Yes	No	Comments
1. Is the microphone-speaker assembly within easy reach?			
2. Is the transceiver protected from temperature extremes (away from power conditioning unit)?			
3. Is the power conditioning unit mounted so personnel will not come in contact with it?			
4. Is the power conditioning unit covered by a protective grille?			
5. Has the battery been tested under load?			
6. Have mating surfaces of connectors been inspected and cleaned?			
7. Have all cable connectors been firmly joined to the units?			
8. Are threaded connectors tightened?			
9. Have all chassis and case grounds been wired to earth ground?			
10. Can the microphone cord become entangled in the vehicle controls?			
11. Are cables protected from abrasion?			
12. Are all components mounted low enough so that minimum roof clearance has not increased?			
13. Has sufficient clearance been given to allow easy removal of access covers, hinged panels, etc.?			
14. Are the bridging capacitors in place on all sectionalized trolley lines?			

TABLE 6-3. - Hoist phone installation basic checklist

Item	Yes	No	Comments
1. Is the microphone of the transceiver at a proper height (mouth level) for average person?			
2. Is the battery accessible for charging or replacement?			
3. Is the cage coupler firmly mounted?			
4. Have mating surfaces of connectors been inspected and cleaned?			
5. Have cable connectors been firmly joined to the units?			
6. Are threaded connectors tightened?			
7. Are cables protected from damage?			
8. Have any slack cables been tied down (clamped)?			
9. Is headframe coupler firmly connected to or suspended from headframe?			
10. Are microphone and push-to-talk switch near hoist controls?			
11. Is the transceiver frame firmly attached to the cage?			
12. Have all completed connections been sprayed with silicone or other moisture-inhibiting spray?			

TABLE 6-4. - Telephone cable installation basic checklist

Item	Yes	No	Comments
1. Has proper cable been selected according to system plan (type and gage)?			
2. Is the cable supported at the proper interval (approximately 10 feet for twisted pair or figure-8 cable and 5 feet for leaky feeder)?			
3. Do droplines have strain relief on main line and tap line?			
4. Are splices mechanically sound and protected from moisture?			
5. Is strain relief used at splices?			
6. Have lightning arrestors been used according to code?			
7. Has extra insullation been provided where the cable crosses the trolley or other high-voltage lines?			
8. Is the cable positioned out of the way of machinery and secured in place?			
9. Are all splices QUALITY splices?			

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CHAPTER 7.--MAINTENANCE

7.1 General

Preventive maintenance practices are listed in the manufacturers' instruction books. In general, equipment that requires frequent and extensive preventive maintenance is generally the most costly. The manpower spent on these frequent trips to remote areas is such that it is usually better to invest in a more costly system which requires little preventive maintenance. The best preventive maintenance for the system is a good installation.

7.2 Preventive Maintenance and Inspections

With any system, periodic inspection is required because of the corrosive atmosphere and adverse conditions that exist in underground mines. These inspections can spot potential trouble in the system. Repair or replacement at that time averts the possibility of losing effectiveness of all or part of the system.

7.2.1 Cables

Approximately once per month all cables in the communications system should be inspected for kinking, chafing, cracking, wear, stretching, or other signs of physical abuse. Particular attention should be paid to cable glands at the entry or exit points to the various units in the system, where the cable goes around sharp corners, in the vicinity of holding cleats which may be clamping the cable too tightly causing potential damage, and across the areas where the cable is exposed to physical damage from outside sources, such as equipment or falling objects. If a cable is damaged, it should be replaced as soon as possible.

It is mandatory that the ground leads and connections to carrier current phones be thoroughly inspected and maintained in good condition, since considerable hazard may exist to the operator or equipment if a ground connection is broken.

7.2.2 Pager Phones

The most readily available test set to determine if a pager telephone is operating correctly is the pager phone itself. The following physical check of the system can be performed at any phone station.

7.2.2a Listen Circuit

Remove the handset from its cradle and listen to determine if the circuit is functional, as indicated by the presence of noise or conversation on the line. If no noise or voice signals are present at the handset receiver, take the following corrective action:

1. Operate the handset press-to-talk switch several times. Any corrosion on the contacts of this switch may cause a receiver to be temporarily inoperative. Repeated operation may clear the condition.

2. Open the cabinet and see if the battery cables are properly connected and are making firm contact. Check the handset cable and its connections in the cabinet of the pager phone, and see if there is any evidence of a break in the cable, corroded contacts, or poor connections.

3. Remove the handset receiver earpiece by unscrewing it counterclockwise (to the left), and remove the receiver from the socket. Examine the handset cavity; in some units, a patch of cotton batting or floss is used as a barrier to reduce acoustic feedback in the handset. If the cotton patch has absorbed moisture, remove it and replace with a crumpled ball of soft rubber, stuffed just far enough into the handset so it will not touch the receiver or switch terminals.

7.2.2b Page Circuit and Talk Circuit

Push the page switch, squeeze the handset press-to-talk switch, and call any other phone. Release the page switch

and listen for a reply. If the background noise is too high, or if the received signal is either too weak or too garbled to be understood, then repairs should be initiated to improve that particular telephone. The phone should be replaced by an operable unit and repaired by qualified personnel. Ask the answering party if the paging signal could be understood, and also check the quality of your received signal. Have the other party page you to verify that your speaker works. Some of the most common problems with the pager phone system that can be remedied by good installation and maintenance practics are: very low voice levels and very high noise levels.

Often, the sources of these problems are--

1. Poor placement of the phone line (near rectifiers, motors, etc.).

2. Using too light a gage phone line.

3. Using the wrong kind of wire for the phone line. The line should be of the twisted two-wire type. Nontwisted line of any gage is not acceptable. It is the *twist* that provides a great deal of noise immunity.

4. Poorly made splices. These cause high resistance and leaky joints in the line that lower the signal and increase the noise. (Note that the phone systems always are worst in the summer months. This is because the high humidity is affecting the splices.)

7.2.2c General Comments

If any of the signals is erratic, low in signal level, has exceptionally high noise levels, or is unintelligible, check whether other phones in the system are having similar problems. If not, replace the defective phone with a good one. If the other phones are not operating properly, it is possible that the problem is in the line. A cable may be short-circuited, improperly spliced, or running too close to noise-producing power or trolley lines. Such conditions should be corrected.

In the environment of underground mines, switch contacts are particularly susceptible to erratic operation because of corrosion or oxidation of the switching contacts. This is particularly true of contacts that are used infrequently. Repeated operation of each of the switches in the telephone may aid in clearing some of the corrosion and restoring the phone to more reliable operating condition. Cleaning individual contacts should not be attempted with a phone in service; it should only be done by trained or experienced repair personnel, who have approved burnishing tools specifically designed for use on switch contacts.

7.2.2d Battery Condition

The battery condition of a pager phone can be approximately checked by pushing the page button and calling some other phone to determine whether or not the paging signal is sufficiently strong to energize all relays within the system. Of particular importance is whether or not the battery has sufficient voltage to energize the paging relay of the telephone farthest from the phone being tested. Therefore, one of the most distant phones should be called. Batteries can also be checked with a voltmeter to judge if they are near the end of their life or in a marginal state. There are several methods of measuring the available battery voltage as noted in the following section.

7.2.2e Battery Testing

Most pager phones are powered by one or two 12-volt batteries of the NEDA 923 or 926 drycell type. These are 12-volt, metal-cased batteries that measure 2-3/4 inches wide, 5-1/4 inches long, and 4-3/8 inches high. The difference between the two types is that the 926 has two screw terminals for lead attachment and the 923 has a two-prong connector system for lead attachment. For those phones using a 24-volt system, two batteries are connected in a series. In consideration of intrinsic safety, it is common to find some means of current limiting, such as a 50- to 100-ohm resistor and a fuse in series with the battery system, to limit

the maximum current flow. Batteries are approaching the end of their useful life in a system when the available voltage at the terminals has dropped 25% from the rated value measured under load conditions. In a 12-volt system, this is approximately 8 to 9 volts; in a 24-volt system, it is 16 to 18 volts.

Measurement of the battery voltage can be made by connecting a dc voltmeter across the battery terminals, pressing the page switch, and reading the battery voltage. Measurement of battery voltage on the line will not give a true measure of the battery condition, because of the added voltage drop in the current-limiting resistor.

Remember that it is useless to measure the output of a battery not under load. Under these conditions, even the poorest battery will still maintain its rated terminal voltage.

It is not always practical to carry a voltmeter into all sections of a mine, and checking a battery requires that the phone enclosure be opened. The following scheme can minimize such difficulties.

A voltmeter can be permanently installed at some convenient location aboveground, such as in a repair or maintenance shop.[1] The meter is connected across the line so that it continuously indicates any dc voltage on the line. A listing of voltage readings is made from each remote phone at this reference station, when the individual phones are paging with new batteries installed. A chart is then made of the allowable reduction in voltage for each phone by estimating a 20% to 25% reduction from the new battery condition. Reference to this chart can give advance warning of the approximate condition of each battery and will provide guidance for planned prelacement. A periodic check can be made of each phone by requesting a page from each of the phones and maintaining a

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[1]This could violate MSHA intrinsic safety standards; check with MSHA for application details.

log of the voltage readings. This will assist in maintaining an up-to-date status of the battery condition at individual phones. This procedure will remain valid as long as the phone system is configured as it was when the original listing was made. Substantial change in the phone system could require making a new chart.

7.2.3 Carrier Phones

```
CAUTION

    Some of the procedures discussed
in this manual are undertaken with
the in-mine trolley wire energized
and are therefore very hazardous.
Extreme caution must be exercised
to avoid accidental electrocution.
Fuses used in test leads protect only
the equipment and do not provide any
protection from shock hazard for the
operator. Do not attempt any of the
electrical tests or installations de-
scribed in this manual unless you are
qualified for such work and are thor-
oughly familiar with electrical work
on trolley wires.
```

Each of the carrier phone units should be examined for any external physical damage. All fixing screws must be tight. All connectors and externally accessible fuses should be checked for proper seating.

7.2.3a Microphone

The carrier phone microphone is a delicate piece of equipment and is most prone to abuse by handling or dropping. The microphone should be examined for evidence of physical abuse. The action of the transmit relay can be observed by pressing the transmit button and listening for the transmit relay inside the transmitter (in units where such a relay is used) to produce a sharp click. The microphone quality can then be assessed by transmitting a test count to a remote unit; the operator of the remote unit will judge the quality of the voice he receives and report back to the unit being tested so that the receiving

quality of the unit being tested may also be assessed.

7.2.3b Batteries

Two different types of battery systems are used in carrier phones. One is a conventional car battery type or wet lead-acid cell, and the other is a gelled electrolyte battery. Both types should be tested once a month to insure a proper state of charge, and the electrolyte should be checked in wet lead-acid batteries, if possible. The gelled electrolyte battery is also of a lead-acid construction; however, its so-called dry electrolyte system cannot be changed since the cell is sealed to prevent any electrolyte loss. Overcharging of either of the battery types causes considerable electrolyte loss, and both types of battery can be ruined if overcharged for a long period of time.

CAUTION

Electrolyte loss also happens to a lesser extent during a normal charge cycle and results in the emission of hydrogen and oxygen from the cells in a ratio which is explosive. Slow emission of this hydrogen and oxygen gas mixture in the enclosures using a gelled electrolytic battery can create a hazardous mixture of gases inside the units. Some units are vented to prevent a pressure buildup inside the enclosure, but this is insufficient ventilation to prevent the possible buildup of a hazardous atmosphere inside the box. Thus, transceivers using a gelled electrolyte battery should only be opened in a well-ventilated area where there are no possible sources of ignition of the hydrogen and oxygen mixture before it is sufficiently diluted by the surrounding air to become harmless. Wet lead-acid batteries should be placed in a well-ventilated area in the vehicle to prevent buildup of pockets of dangerous hydrogen-oxygen mixture.

7.2.3c Wet Cell Maintenance

If a car-type wet cell lead-acid battery is used, it should be installed in a well ventilated area easily accessible for routine maintenance. Each week the level of the electrolyte in each cell should be checked and restored to its proper level by the addition of distilled water. The electrolyte should read a specific gravity of approximately 1.275 on a battery-testing hydrometer when the battery is fully charged. The voltage for each cell should be between 2.2 and 2.4 volts. Since in normal operation the battery is under continuous charge, the specific gravity and voltage of a battery in good condition should be around the stated values. Values significantly less are symptoms of problems with either the battery or the battery charger and should be investigated. If electrolyte is lost from the battery due to spillage, then electrolyte premixed to the same specific gravity should be used to refill the battery to its normal level.

Terminal posts on lead-acid batteries should be examined and cleaned each month. Petroleum jelly may be used to coat these posts to prevent corrosion. Also, any corrosion of the battery box should be scraped clean, and petroleum jelly should be applied to prevent any further corrosion.

If a vehicle equipped with a carrier phone is to be taken out of service for some time, then both battery leads should be disconnected to prevent discharge of the battery while the unit remains in standby mode. Again, petroleum jelly should be applied to the battery posts and the terminals to prevent any corrosion.

Any battery found to be in a weak condition should be removed for recharging and replaced by a fully charged battery. If a particular vehicle has repeated battery problems, the battery charger in that vehicle should be removed for checkout.

7.2.3d Gelled Electrolyte Battery

It is not possible to service the electrolyte in a gelled electrolyte battery since it is sealed at the factory. However, these batteries do vent small amounts of hydrogen and oxygen during the charging process, which will increase to larger amounts if the battery is overcharged. Normally, the battery should be charged by a taper-charge process. This means that when the battery is in a discharged condition, the battery charger can apply a comparatively large amount of current to build the charge up in the battery quickly. However, as the battery charge increases, the charging rate should decrease. When the battery is almost fully charged, the charging current should fall to zero or maintain a very small charge. Each of the two types of carrier phones using batteries of this type have a taper-charge-type battery charger built in to maintain the cells at a fully charged state, without the hazard of overcharging.

The important parameter to measure for proper gelled electrolyte battery maintenance is the battery voltage. A nominal 12-volt gelled electrolyte battery is fully charged when it reads 13.8 volts across the terminals. This should be the voltage reading when the battery has been fully charged by the operation of its battery charger. Any voltage higher than 13.8 is an indication that the battery is being overcharged, thereby suffering a considerable loss of life due to the drying out of the electrolyte. This also causes generation of dangerous quantities of hydrogen and oxygen gas mixtures as the cell vents. If this is the case, the battery charger should be examined for malfunction.

Alternatively, if the carrier phone has been left on for an extended time without any battery charging from the trolley wire, it is possible for the battery to become moderately or deeply discharged. A moderately discharged battery can be removed for recharging and generally will not suffer any significant harm. However, if the battery is deeply discharged and stored in this condition without being recharged, the battery may develop a condition where it cannot be recharged and should be replaced.

7.2.3e Troubleshooting on the Vehicle

When an operator reports a malfunction carrier phone, initial diagnosis of a problem can be carried out using only the equipment suggested in table 7-1. The repairman may either take his equipment to the faulty vehicle, or the faulty vehicle may be returned to the test and maintenance area.

First, the battery voltage should be checked to make sure it has not become discharged. If it is found to be good, all external fuses in the unit should be checked. If a faulty fuse is found, it should only be replaced with a fuse of the proper rating. If the fuse blows again, then the unit is probably faulty. It is possible that replacing the blown fuse with a new one will cause the unit to operate properly since a momentary overload could have caused the original fuse to blow.

Sometimes the phone itself can provide valuable information on the nature of a problem. Use of the carrier phone will generally isolate the problem into one of the following three categories.

1. Cannot transmit to others or receive from others:

    a. Check the main fuse.

    b. Check the ground connection.

    c. Check all connectors for corroded contacts.

    d. Check all cables for breaks.

    e. Check the battery condition.

    f. If cause cannot be readily located, replace with spare unit and take the malfunctioning unit in for bench maintenance.

TABLE 7-1. - Suggested test equipment

Item	Type	Use
Multimeter.......	Various............	Meter can be used for measuring voltages in and around the unit, power consumption, power output, and fuse checking. In order to give useful results for transmitter power output measurements, the meter should be capable of operating with frequencies of at least 100 kHz.
Fuses............	...do.............	Fuses provide an intentionally weakened part of an electric circuit, and thereby act as a safety valve in the event of dangerous overloads. This protects both personnel and equipment from potential fire hazards due to overheating of the carrier phone.
		A blown fuse generally indicates that some part of the circuit of the carrier phone has become defective. Occasionally a temporary external overload condition can cause a fuse to blow; hence it is a useful practice to change a blown fuse one time to see if the unit can be brought back into service. Should the fuse blow again, then a more detailed trouble-shooting process should be attempted.
Substitute units.	Same as used in the mine.	Each carrier phone consists of a number of different units interconnected by cables. To facilitate troubleshooting on the vehicle, a fully operational spare set of the type used in the mine should be maintained so that initial trouble-shooting can be performed by substitution of the individual units.
Hydrometer.......	Battery type.......	The hydrometer measures the charge-discharge condition of the battery electrolyte.
Distilled water..		A battery with a low level of electrolyte will require an addition of distilled water.
Petroleum jelly..	Any..............	Coating the battery terminals with petroleum jelly aids in preventing corrosion.
Battery charger..	Any applicable (for wet battery) or special battery charger for gelled electrolyte battery.	The battery charger is used to recharge batteries that have become discharged.

NOTE.--Insure equipment is suitable for desired application.

2. Can hear others but cannot apparently transmit:

    a. Check cables and connectors (especially the microphone for corroded contacts or breaks).

    b. Replace the microphone.

    c. If neither the above is at fault, the problem is probably in the transmitter; take the malfunctioning unit in for bench maintenance.

3. Cannot hear others but they can hear your transmission:

    a. Check the volume control setting.

    b. Check the cables and connectors for breaks and corrosion.

    c. Replace the speaker assembly by substitution.

    d. Check the squelch setting.

    e. If none of these measures solve the problem, it is probably in the receiver; replace the transceiver with a spare unit and take the malfunctioning unit in for bench maintenance.

If all these steps fail to make the unit operational, then repair by substitution is usually the quickest way of getting the unit into operation again. Substitution should be in the order of items considered to be more or less vulnerable. Unless it is obvious which unit is faulty, the process should be carried out in the following order:

1. Change the microphone assembly and test for normal operation.

2. Change the transceiver assembly and check for normal operation.

3. Change the loudspeaker unit and check for normal operation.

4. Where relevant, change the battery charger box and check for normal operation.

When the faulty unit has been isolated and replaced, it should be returned to the repair area for a more detailed examination, including an overall performance checkout after the fault has been isolated and repaired.

CAUTION

The following procedure is undertaken with the trolley wire energized; therefore, it is extremely hazardous. Extreme caution must be exercised to avoid potentially lethal shock. Only personnel thoroughly familiar with electrical work on trolley wires should conduct the test procedures. Equipment used must be appropriate for this application.

On 300-volt systems, a test can be made of the transmitter power output onto the trolley line. A simple method of measurement in the field makes use of the multimeter with the range selector switch set to the 50-volt-ac scale. The black meter lead should be plugged into the column (-) terminal of the meter and the free end connected to the ground. The red lead must be plugged into the meter output jack and connected to the trolley wire. The trolley pole must be in contact with the wire. A reading of 15-volts or more when the transmitter is keyed indicates normal operation provided the test is made at least 200 feet from the nearest power rectifier that supplies the trolley wire. This test cannot be performed on 600-volt dc systems since this voltage will overstress some components inside the multimeter. In this case, the unit should be returned to the repair shop for a standard bench test. It should be noted that the meter will respond to ripple present on the trolley wire; thus a base reading of up to 10 volts will be shown even with the transmitter off.

7.2.3f Mapping Signal Levels

The maintenance of trolley carrier phone systems requires not only the maintenance of the equipment involved, but the maintenance of the transmission line (trolley wire-rail) used to transmit the signals (refer to paragraph 5.3.1). Evidence accumulated over the years indicates that this signal path is subject to many loads that impede the propagation of carrier signals.

One of the most useful ways of determining the state of the overall transmission system is to map the signal and noise strengths at various points throughout the mine. Such mapping requires a tuned signal-measuring device.

The mapping is preferably carried out by measuring the signal produced by the dispatcher's transmitter at various points along the rail haulage system where vehicles operate. A satisfactory way of conducting the measurements is to place a suitable tuned voltmeter aboard a mine vehicle (such as a jeep), and at appropriate places along the rail haulage--for example, at 2,000- or 3,000-foot intervals--measure the received dispatcher's signal and background noise. These values should be noted on a mine map for future reference as the mine expands, or as carrier phone problems occur. Except under extremely unusual conditions, the signal-strength map produced in this manner will also indicate the level of signal that a vehicle transmitter at the measuring position would produce at the dispatcher's place. A portion of a mine map with signal and noise readings is shown in figure 7-1.

The equipment for making such a signal-strength map must be battery operated, easily portable, and easy to use and read. Two such units commercially available are shown in figure 7-2. These tuned voltmeters are general-purpose, battery-operated instruments appropriate
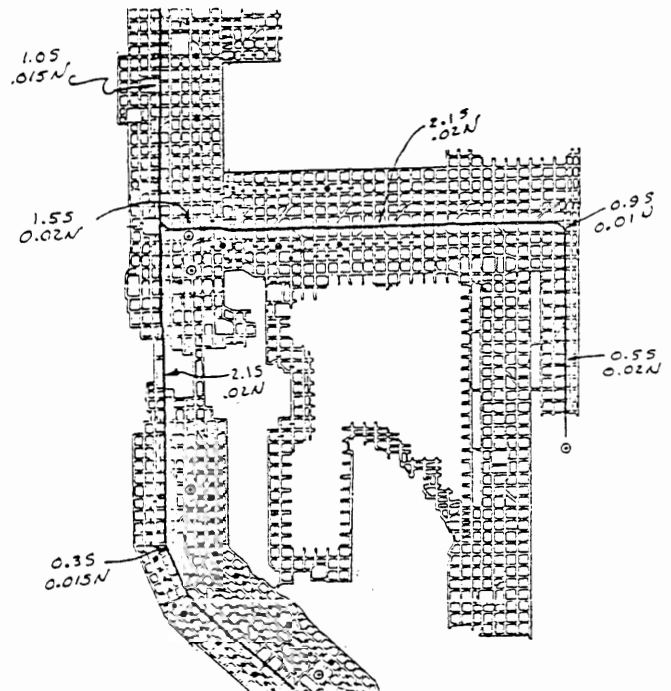
FIGURE 7-1. - Example of signal level map.

for many tasks other than the mapping of trolley carrier signal levels. For this reason careful attention must be paid to the tuning of the instrument to the precise frequency, attenuator settings, and meter indications. Table 7-2 gives specifications for these tuned voltmeters.

The simple straightforward procedure of measuring the dispatcher's signal level from a jeep or vehicle moving about the mine can best be accomplished by connecting the trolley wire voltage on board the vehicle to the input of the tuned voltmeter. Because of the hazards associated with the high voltage of the trolley wire, either voltmeter has to be properly isolated so that personnel operating the instrument are not subjected to this voltage through error in operation. Therefore, it is important that a capacitor and a fuse be connected in the series with the instrument to insure that the potentially lethal voltage of the trolley wire does not inadvertently reach an operator. Figure 7-3 shows a possible way of connecting the instruments.

TABLE 7-2. - Key specifications of tuned voltmeters

Specification	Sierra 127C	Rycom 3115
Frequency range...................kHz..	2-350	3-200
Accuracy:		
Frequency.......................kHz..	±1	±1
Level............................dB..	±1	±1
Selectivity (standard 250 Hz), Hz:		
3-dB bandwidth......................	250	1,000
35-dB bandwidth.....................	600	NAp
60-dB bandwidth.....................	1,000	4,000
Ranges (full scale)....................	1 mV to 10 V	-37 to +13 dB (3.7 mV to 1.65 V)
Intermediate frequencies, kHz:		
1st.................................	1,305	NAp
2nd.................................	330	NAp
Power requirements....................	6 zinc-carbon or 7 NiCd rechargeable D-size cells	2 gel cells Globe 610
Voltage................................	9 (nominal)	12
Battery life (zinc carbon)....hours..	100	5 (continuous)
Temperature range..................°C..	-10-50	-10-55
Dimensions, inches:		
Width...............................	12	7-1/4
Height..............................	7-1/2	5-1/4
Depth...............................	7-1/2	7-3/4
Weight.......................pounds..	15	6

NAp   Not applicable.

WARNING

Disconnect the instrument when the vehicle is moving. Transients from the vehicle motor can cause damage.

CAUTION

The following procedure is undertaken with the trolley wire energized; therefore, it is extremely hazardous. Extreme caution must be exercised to avoid potentially lethal shock. The fuses used in the test leads serve only to protect equipment and do not in any way reduce the shock hazard to personnel. Only personnel thoroughly familiar with electrical work on trolley wires should conduct the test procedures. Equipment used must be appropriate for this application.

To make a measurement, the vehicle is moved to the desired location in the mine and stopped. The operator then asks the dispatcher to "key" his transmitter for a 5-second transmission of unmodulated carrier. The response on the indicating meter is noted, together with any attenuator setting, so that an absolute value of voltage (in volts rms) can be noted on the corresponding position on the mine map. It may be necessary when starting measurements to switch the range knobs of the instruments to make sure that the instrument's response is on scale rather than high and off the scale. In this event, perhaps two transmissions will be required before on-scale readings are obtained. After the transmission from the dispatcher is recorded, the sensitivity of the instrument should be increased and the noise level at the particular position noted again in volts or millivolts rms.

The signal-level map will reveal regions of the mine where the dispatcher signals are weak which may cause difficulties in carrier communication. The mine map will also reveal regions where

RYCOM 3115

SIERRA 127C

FIGURE 7-2. - Tuned voltmeters.

TROLLEY WIRE

FUSE AND CAPACITOR

SIGNAL LEAD

GROUND TO NEAREST NUT OR BOLT HEAD

METER
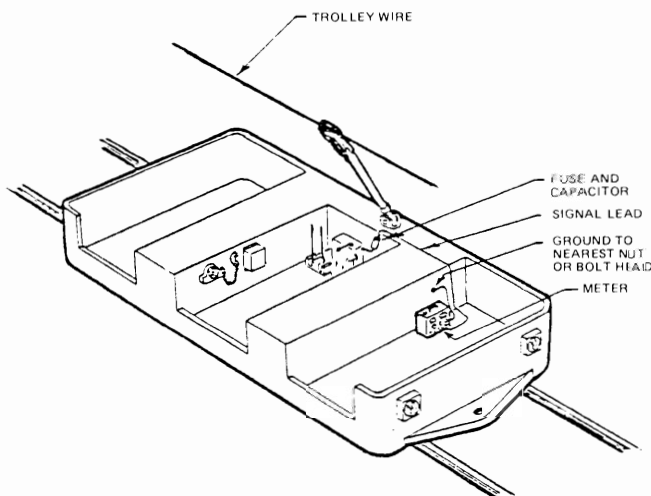
FIGURE 7-3. - Instrument connections.

excessive noise is the main cause of poor communications. In this event, it is important to locate the source of the offending noise and to take measures to alleviate the problem.

The signal-level map will also be extremely useful should carrier communications deteriorate with time, with the installation of new equipment, or with the advancement of the mine. Reference can be made back to the original signal levels to determine if and why communications have been degraded.

7.3 Summary

Good preventive maintenance and periodic inspection practices are the key to successfully maintaining any communication system. Common problems that can affect communications include:

Corrosion or conductive dust on battery terminals.

Cable abrasion and line breaks.

Corrosion on switch contacts or in cable splices.

Weak batteries.

Blown fuses.

Weak or broken springs on spring-loaded connectors.

Poor splicing techniques.

In addition to problems that develop owing to normal system usage and environmental conditions, trolley carrier systems may be affected by characteristics of the trolley wire and rail itself. Poor signal strength may result because of bringing loads across the trolley wire-rail or high signal attenuation rates in the trolley wire. Methods of compensating for the effect of bridging across the wire-rail are given in section 5.3.1.

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APPENDIX A.--COMMUNICATION SYSTEM EXAMPLES[1]

A.1   INTRODUCTION

Because no two mines are identical, there is no "one best system" that can be defined to meet the requirements of all mines. The following examples of system installations are presented to indicate how some mines have adapted available equipment to meet their particular requirements. Selection of examples were based on the goal of obtaining the widest possible range and cross section of the following characteristics:

Type of mine

Age and size of mine

Electrical power usage

Haulage methods

Existing communications

Usefulness of present communications

Examples A through F are of coal mines utilizing various combinations of magneto, pager, and conventional trolley-carrier-type phone systems. Example G is of a magnetite ore block-caving operation where a radiating cable and radio system is used. Example H indicates how a dial-page phone system can be utilized in a coal mine. Example I presents a multi-channel (multiplexed carrier) system presently in use in a deep metal mine.

A.2   MINE A

Mine Description

Mine A is part of a connected four-mine complex. This particular mine is approximately 20 years old, and although there are some new working sections, the major coal extraction is from retreat mining where pillars are being pulled. Personnel entry is achieved through a

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[1]Use of company names is for identification purposes only and does not imply endorsement by the Bureau of Mines.

vertical shaft approximately 545 feet deep. Coal is removed from the face area by shuttle cars and placed in a set of six tracked haulage cars. When full, the sets of cars are combined into trains and brought to the surface through a slope entry. Average coal production is 4,000 to 5,000 tons per day for 240 working days, setting yearly production at approximately 1 million tons.

The mine size is currently 2.4 miles north and south by 3.9 miles east and west with overburden from 545 feet to 1,000 feet. All tunnels and haulageways are typically 6.5 feet high by 14 to 15 feet wide. An average working section is 425 feet by 300 feet long, and 10-foot roof bolts are used. The mine has only one borehole, which is used to supply the mine with water.

Currently the mine has six working sections of which five are worked every shift. The shifts run from 8 a.m. to 4 p.m., 4 p.m. to 12 p.m., and 12 p.m. to 8. a.m. A typical working section cycle starts with the continuous miner cutting coal and filling a shuttle car. When the shuttle car is full, the driver moves the coal load to the tracks and transfers the coal to one of the six haulage cars positioned on the side track. The shuttle car then returns to the continuous miner to repeat the cycle. Excluding mechanical trouble, the continuous miner will cut a block of coal 5 feet high, 15 feet wide, and 16 feet long in 1 hour, and a section can mine five blocks this size in an 8-hour shift. The mine typically has 100 men underground per shift.

Mine Equipment and Power

The prime power for the mine is 550 volts brought in on a feeder cable. In the mine the trolley wire is run parallel to the feeder cable. At the working section the continuous miner, shuttle cars, and car pull are run off the 550-volt-dc trolley line fed at nip stations. Compressed air is used to run the roof-bolting machine.

The equipment at each working section includes one continuous miner, two shuttle cars, one roof-bolting machine, and one car pull. Other equipment includes 3 bottom-loading machines, 2 minor-type cutting machines, and 12 pumps.

The tracked vehicles include 3 dual locomotives or tandems, 24 Jeeps, and 3 portal buses.

Present Mine Communications

The present communication consists of a carrier phone system and a magnetophone system. All vehicles are equipped with FEMCO carrier phones, and all active working sections, along with selected underground positions, have Western Electric magnetophones.

Telephone System

The heart of this mine's communication system is a central dispatcher located at the bottom of the main shaft.

Eight party-line magnetophone circuits terminate at a simple switchboard in the dispatcher's office. Each of these 8 circuits has several of the 41 telephones wired in parallel. Calls between circuits must be made through the dispatcher and his or her switchboard, whereas calls within a circuit need not. The dispatcher can connect any two phone circuits together and can make two of these connections, generating two independent phone circuits for two-channel operation.

Since this magnetophone system operates with a bell ringer rather than a loudspeaker, the rings are coded to indicate certain places or individuals. The dispatcher communicates through a single headset, and selection of either the mine phone or the carrier phone is made using a two-position switch. Other switches connect and disconnect the various mine telephone circuits.

This dispatcher controls all vehicle traffic and serves as a telephone operator. Operator duties include answering phone calls, switching phone circuits, personnel calling and location, and taking and relaying messages.

Because the dispatcher is more likely to contact a working section through the motor and an associated carrier phone in that section, the mine phone is used relatively little compared with the carrier phone.

Based on the observed traffic density and on the number of phones in the system, the probability of a busy signal on the magnetophone system is 5%.

Trolley Carrier Phone System

Vehicle-mounted carrier phone usage during a typical shift is shown in figure A-1.

During a first shift survey, there were 182 dispatching calls, 20 calls relating to personnel location, and 58 calls relating to placing empty and loaded cars.

Communications Requirements—Users' Viewpoint

Evidence of this mine's interest in communications is shown by the expression of one foreman that "their production would be cut in half if they lost either telephone or carrier phone communications." An important communications requirement as defined by the management of this mine concerned safety. They strongly felt that a secure channel was needed where only the persons calling and called could hear the conversation. There are two reasons for this: First, anyone seeking aid for an injured miner tends to belittle the seriousness of the injury because he knows that friends and relatives of the injured miner, and those just curious, will be listening to the conversation. The problem is not unique to this mine. Secondly, the phones of these eavesdroppers load the line to the extent that the emergency communications are impaired.

Based on this realistic situation, a basic communications requirement is a
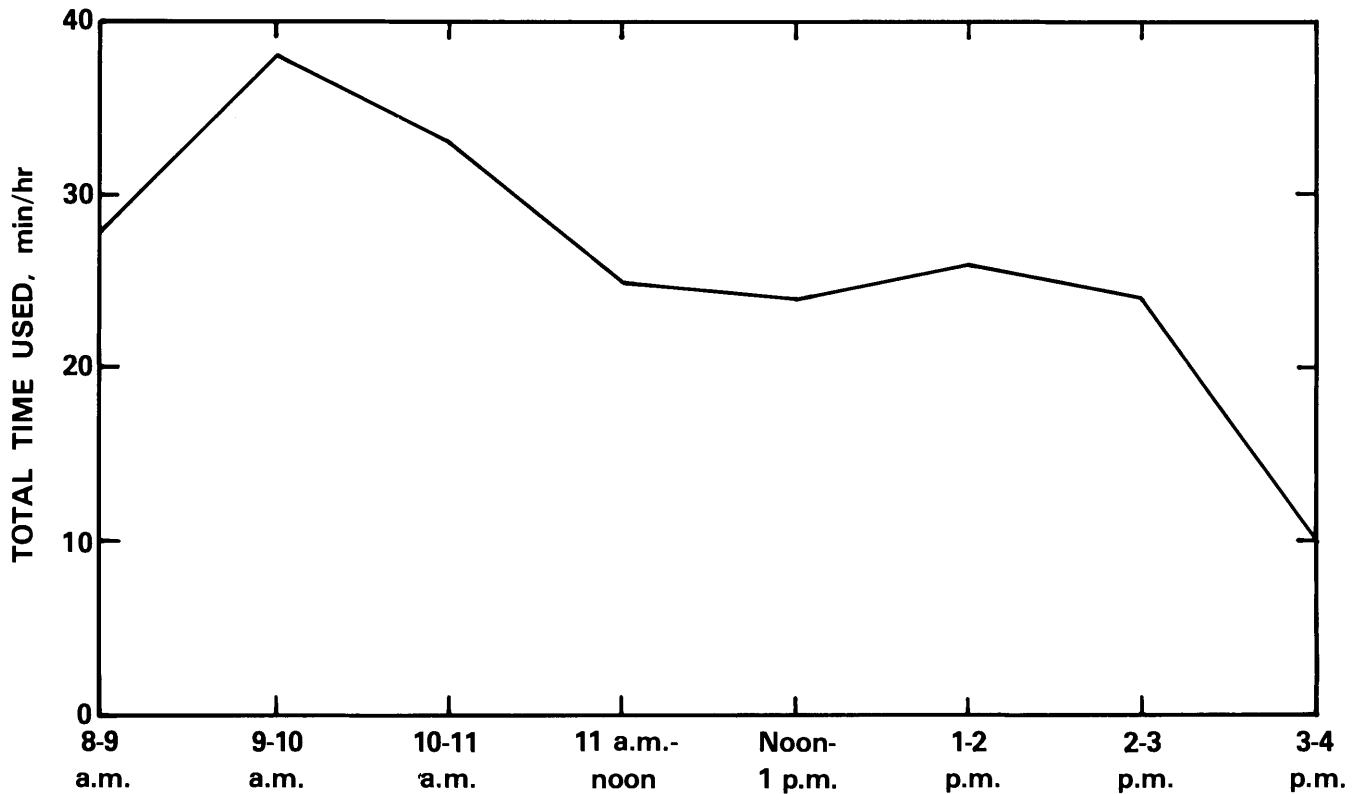
FIGURE A-1. - Vehicle-mounted carrier phone use in typical shift.

private line, selective calling channel over which the person attending an injured person can privately call, at his or her discretion, the mine foreman, the dispatcher, the safety foreman, or the nearest hospital or ambulance service. Note that a conventional private dial system meets this requirement. Mine C (described in section A-4) has a dial phone adjacent to each pager phone. This met the need for a secure channel for both management and emergency communications.

Communications Requirements—Based on Survey Analysis

Although the personnel interviewed felt the quality of their communications was adequate, analysis indicates that excessive noise and distortion were present. Therefore, a requirement that applies to this mine as well as to all communication systems is that of reasonable signal-to-noise ratio for good intelligibility.

The fact that the chance of getting a busy signal is 5% is proof that additional channel capacity is needed. Adding additional channels to a wired system appears to be an acceptable solution since these extra channels will minimize the telephone duties the dispatcher now performs and will eliminate the communication system blocking problem. Calculations indicate that a minimum of five communication channels are needed for this mine. Furthermore, making one of the five channels a private line will fulfill the requirement for private communications.

Also, from observing the mine operation and talking to various personnel it appears that section foremen, like the foremen in most industrial operations, are overworked, and yet are the key to improving productivity. Therefore, wireless communication is needed for at least the section foremen along with various other supervisors and maintenance personnel.

From this brief analysis of the mine and its current communications, the following is a list of minimum communication requirements for Mine A.

a. Reasonable communication channel signal-to-noise level.

b. At least five independent voice channels.

c. At least one secure voice channel, which may be included in the five voice channels.

d. Some form of wireless communication to select individuals on the working section or roving in haulageways.

A.3 MINE B

Mine Description

Mine B consists of adjacent (No. 1 and No. 2) low-coal mines. The No. 1 Mine employs longwall and continuous mining. The No. 2 Mine employs conventional and continuous mining and is preparing for its first longwall operation. Both mines employ belt coal haulage to closely located drift entrances. Men and supplies enter the No. 1 Mine by a 400-foot shaft remotely located from the No. 2 Mine drift entrance. From the two mines, 8,000 tons of coal per day are mined by about 600 union men under the supervision of about 60 officials.

The No. 1 and No. 2 Mines each currently employ one longwall mining unit and conventional working sections of Lee Norse continuous miners. For the No. 1 Mine's longwall mining, coal is moved by an armored face conveyor to a stage loader at one end of the longwall, to an extendable belt, and finally to a conventional belt.

In addition to longwall mining, the No. 2 Mine employs a full-dimension unit, a conventional mining unit, and continuous miners for seven working sections per shift.

The equipment used in conventional mining consists of a cutting machine, a loader, and two shuttle cars. With a full-dimension system, the shuttle cars are replaced by an extendable belt.

Coal is brought out of the two mines by conveyor belt, and men and supplies are moved by track. The coal is moved by belt from the two mines to a screening house having 1,250 tons of storage capacity. To cope with slacks and overflows, coal can be automatically diverted to a 12,000-ton-capacity storage pile.

Ac power is brought into the mines at 12,470 volts. Two rectifiers are positioned at every 6,000 feet of track, each with a capability of 300 kW, to supply 300-volt-dc power to the trolley wires and their feeders. In addition to supplying locomotives with power, the trolley lines supply power, at nip points along the line, for the operation of the 300-volt-dc shuttle cars. Where needed, the 12,470 volts ac is transformed to 600 volts to provide ac power for rock dusters, conveyor belt drives, miners, roof bolters, and belt feeders.

Present Mine Communications

The equipment used in each of the two mines includes paging-type party line telephones, trolley carrier phones, the fire sensor tape recording that would automatically be patched into the phone system should there be a belt fire, and the fan sensors that utilize the phone lines.

The No. 1 Mine's communications systems are independent of the No. 2 Mine's, but generally of the same size and equipment types. The No. 2 Mine's chief electrician's office has a No. 1 Mine phone, as does the No. 2 Mine's foreman's office.

Telephone System

Since both mines have similar communication equipment, only the No. 2 Mine will be described. The No. 2 Mine has 31 underground loudspeaking telephones. The underground phones are all in a single network. The following seven surface phones are also in this network:

Outside mechanics shanty--1

Outside shop--1

Auditorium--1

Chief electrician--1

Cleaning plant--2

Double breaker switchhouse--1

The paging phones used in these mines use 6 volts for normal phone use and 22.5 volts during paging. With these phones, pressing the paging button at any station permits the operator to broadcast through the loudspeakers on the remaining 37 telephones. On releasing the paging button the operator can converse with anyone who picks up the handset on any other phone.

Tape recordings were taken of both the No. 1 and the No. 2 Mine's party line pager phone system and the No. 1 Mine's carrier phone system. Analysis of these recordings revealed that for the No. 2 Mine, based on hour intervals, the most the system is used is about 50% of the time, between 9 and 10 a.m. But, based on 15-minute intervals, the phones are used nearly 90% of the time around 3:30 in the afternoon.

This heavy usage occurs during the last hour of the shift when section foremen are making their end-of-shift reports on production status, supplies on hand, supply requests, and maintenance work requests. The fact that the phone system is used 90% of the time signifies that other calls that could improve production efficiency must either be delayed or not made at all.

Carrier Phone System

A second means of voice communications is the carrier phone system that uses the dc trolley wire as a carrier of 88-kHz (No. 2 Mine) and 100-kHz (No. 1 Mine) FM. In each mine five carrier phones are used: One as a base station

at the inside mechanics shanty, two on utility jeeps, and two on motors.

One shortcoming of the present carrier system is that there is no way for personnel with carrier phones to communicate with working sections. Mine personnel would like some way of patching the carrier and pager phone systems together.

Longwall Communications

Five permissible loudspeaking telephones are spaced at 125-foot intervals along the 500-foot longwall system. These five phones are connected together to form an independent communications system. Near the phones at either end of the longwall system are phones of the overall telephone network. Though not interconnected, the two phone networks are physically close to each other.

The five phones are identical to those of the main telephone system except that the paging mode is permanently wired into all five phones as a safety measure. Anything said into any one of the five handsets will be broadcast over all five loudspeakers, thus alerting all nearby personnel of activity on the longwall section.

Belt Maintenance Communications

Along the belt lines (every 2,000 feet) and at the belt heads are located phones of the telephone communications system. The belt heads are the only spots where belt mechanism fires are likely to occur.

Belt Fire Alarm System

Although these mines have never had a belt fire, their fire alarm system is better than required by law. A tape player is positioned underground and when activated will broadcast a warning over all telephone and carrier phone loudspeakers. The recorded message warns all personnel of the alarm condition, specifies the location of the tripped

alarms, and advises personnel of safety precautions to be taken.

Fan-Stop Alarm

In the event a fan stops, provision is made for utilizing the phone systems to insure that proper action is taken. At the No. 1 Mine, where there is a phone at the fan site and where personnel are within earshot of an audible alarm, the person responding to the alarm can use the normal telephone system in seeking help. The fans for the No. 2 Mine are remote from any mine personnel so the alarm is automatically sent over a commercial phone line to No. 2 Mine's lamphouse.

Communications Requirements--User's Viewpoint

Through interviews and discussions with those who use, plan, and maintain the communications systems, communications requirements were determined that would aid production at these mines. These requirements dealt directly with mine operations not using a dispatcher, with operations where coal haulage is by belt only, and with operations involving low-coal and longwall mining.

The first suggestion made by mine personnel was that they needed someone to perform the communications and information center tasks often performed by the dispatcher in other mines. Presently they have no way of relaying messages between, or interlinking, the independent telephone and carrier phone systems. They also would like someone to monitor belt line sensors, from a center, in order to coordinate troubleshooting, maintenance, and repair of all belt lines. Thus, a requirement for a communications center operator (communications coordinator) would resolve the two immediate problems as well as many others.

Low coal and longwall mining combine in determining a requirement for fixed communications terminals to be close to all classes of foremen, and a

requirement for personal hands-off-operation radios of insignificant weight and bulk. Coordinating the operation and and repair of a 500-foot longwall miner is difficult, especially in low coal.

Mine personnel felt that having nothing would be better than having a simple radio pager where a section foreman might have to crawl 700 feet to the nearest phone to find out that it really wasn't that important. If the section foremen are given anything for mobile communications, it must be small, light, and two-way. In this mine they would like the section foremen to be able to easily contact a general assistant foreman for supplies and repairs. The need for small portable two-way communications is shown by the case where someone at the mine, on his own initiative, tried some two-way units he had borrowed from a local hospital.

Communication Requirements--Based on Survey Analysis

An analysis of both the No. 1 and the No. 2 Mine survey indicates that the communications systems noise levels were unacceptably high and that communications capability is on the verge of becoming unacceptable. Improved communication and improved mining operation would result merely by improving the signal-to-noise ratio of the present communications systems.

Since the current phone traffic makes the chance of getting a busy signal between 350 and 450 times greater than most industries find acceptable, additional channel capacity is needed to reduce the chance of blocking to the 1% level. Although blocking is still 10 times greater than industrial standards, it appears to be a reasonable selection for mine communications.

Also, from observing the mine operation and talking to various personnel, it appears that section foremen and select longwall personnel need some form of two-way wireless communication of minimum size and weight. All personnel expressed

a negative attitude toward any one-way type of communication.

Furthermore, the mine personnel felt they needed a location where the daily production activity could be monitored. This location can evolve into a communication center, since as the mine expands and more vehicles are equipped with trolley carrier phones, a combination dispatcher, call monitor, and production monitor can be financially justified.

Specifically for these mines, the following represents a minimum for future communication requirements:

a. Reasonable communication channel signal-to-noise ratio.

b. At least five independent voice channels to replace the present one channel.

c. Small, lightweight wireless two-way communicator units for foremen and select personnel.

d. A communication center.

A.4 Mine C

Mine Description

Mine C has been operational since 1903 with production originally estimated for 100 years. Coal is being mined in the B and C seams, and there is 36 to 60 feet of vertical displacement between these seams. The mine employs continuous mining techniques, and personnel enter the mine through a slope entry. Coal production is approximately 1 million tons per year and is removed by a combination of belt and haulage cars. The B seam has two active working sections, and each section transfers coal from shuttle cars to a small feeder belt. A longer mother belt then takes the coal to a main loader head. This loader head has the capacity for 18 cars; when 12 cars are filled, these cars are assembled into a 12-car train 240 feet in length for main line haulage. The C seam has only 1 working section, and coal is

transferred by shuttle cars to a set of 6 haulage cars; 2 of these combinations of 6 cars are attached to make a 12-car train, which removes the coal from the mine.

The B seam is currently 1.7 miles north and south by 3.2 miles east and west; the C seam is 0.35 mile north and south by 0.45 mile east and west. The overburden ranges from 0 at the slope entry to 2,000 feet. All tunnels are typically 18 feet wide. The average C seam tunnel is 9 feet high, and the typical B seam height is 15 feet. Since the B seam has coal 22 feet thick in some places, the top level is mined first; they return to mine the bottom coal for maximum yield. Roof bolt length is typically 6 feet with variations from 4 to 12 feet. These bolts are positioned on 5-foot centers in the B seam and on 4-foot centers in the C seam.

The mine has one borehole into the B seam, which was used at one time for a phone line and another time for pumping water out of the mine. A second borehole in the C seam is used to pump methane out of the mine.

Currently the mine has two coal-producing sections in the B seam and one coalproducing section in the C seam. Furthermore, the B seam has one large cleanup section and two smaller cleanup or rehabilitation sections. A typical working section is 320 feet square. The mine has two production shifts and one maintenance shift, and they run from 8 a.m. to 4 p.m., 4 p.m. to 12 p.m., and 12 p.m. to 8 a.m. The mine has 71 men underground for the first production shift, 55 men underground for the second production shift, and 45 men underground for the last or maintenance shift.

Mine personnel typically require 20 minutes to get from the portal to their working sections, and they take 30 minutes for lunch some time between 11 a.m. and 1 p.m. These lunch periods are staggered between working sections. On the B seam the work cycle starts with the continuous miner cutting coal and

filling a shuttle car. When the shuttle car is full, the driver transfers the coal load to one of the 36-inch 550-fpm belts run to the section. The belts then remove the coal to the south loader head, where it is loaded into cars that will make up the main line haulage train. The shuttle car round trip takes approximately 7 minutes to complete a work cycle on the B seam. Except for the shuttle cars dumping directly into haulage cars, the C seam has the same type of work cycle. Furthermore, the C seam has no belt haulage and uses tracked haulage for coal removal.

Mine Equipment and Power

Three surface substations convert 44,000 volts three-phase to 4,160 volts three-phase, the 4,160 volts is carried underground to various 440-volt-ac and 275- to 300-volt-dc power stations.

At the working sections, the shuttle cars are powered either by 440 volts ac or 275 to 300 volts dc; the continuous miner is powered by 440 volts ac, and the roof bolting machines are powered by 275 to 300 volts dc. The dc voltage can be obtained by either a trolley nip point or an ac-dc load center.

All trolleys are powered by a 275- to 300-volt-dc trolley line, which is a common ring bus fed by 300-kW rectifiers and two 500-kW rectifiers. The quantity and type of trolleys or vehicles follow:

Man-trip cars--7

Mechanics' jeeps--2

27-ton motor--6

13-ton motor--2 ·

Present Mine Communications

This mine utilizes a combination of loudspeaking paging phones, dial telephones, and 88-kHz vehicle-mounted carrier phones. The carrier phone system is tied electrically to the loudspeaking

paging phones by a trolley coupler. This type application should not be used with intrinsically safe phones. To improve communication coverage, auxiliary speakers are sometimes used with the loudspeaking paging phones. The following tabulation shows the number of phones and their general location:

Phone type	B seam	C seam	Sur-face	Stor-age	Vehi-cle
Dial telephone...	12	1	16	0	0
Loudspeaking pager phone.	5	1	1	1	0
Carrier phone	1	0	1	0	17

In general, vehicle operators and supervisory personnel use the trolley carrier phones, and mine section foremen, maintenance personnel, and supervisory personnel use the dial telephones and pager phones.

Dial Telephone System

The mine has purchased from the telephone company dial telephones, telephone environmental enclosures, associated PABX, and 25-pair telephone cable with wire size No. 19. All underground telephone equipment and wire was installed by mine personnel and has been in service for the last 10 years. Standard dial telephones are mounted in environmental enclosures.

The biggest problem the mine has had with the dial telephones was dust and moisture getting into the dial mechanism. This was understandable since it was found that the majority of the underground telephone enclosures had been left wide open and were liberally rock dusted. Of the eight underground telephones checked, seven were in good working order and one had rock dust in its dial mechanism contacts. Another problem, not related directly to the telephone equipment, was that of acoustic noise from mine machinery. For example, a telephone is required near the 3d south loader head, and mine personnel find communication difficult when the loader head is in operation. Mine officials have

considered building a telephone enclosure that will shield this telephone from external acoustic noise.

Other than leaving the door to the environmental enclosures open, the mine personnel appeared to operate the telephone system properly. The telephone was mostly used to call from underground stations to surface stations or call out of the mine. Most calls were for supplies, maintenance, and location of personnel. This telephone system was also used as a backup system when communications were bad. For example, once personnel were contacted using the trolley carrier phone or pager phone and extended conversation was needed, the person would be instructed to go to the nearest dial extension telephone and reestablish contact to complete the communication.

Over the history of the mine, only one major emergency has occurred, a destructive fire. This fire destroyed the telephone cable, and the underground dial telephone system could not be used for emergency personnel evacuation. This points out the basic weakness that telephone systems without loopback paths have during a real disaster situation.

Loudspeaking Paging Phone—Carrier Phone System

Carrier phones installed at the mine include six 10-year-old units and thirteen 14-month-old units, all with 88-kHz center frequency. The mine personnel plan to replace the older carrier models with new models in the near future. The carrier phone to paging phone coupler (<u>an application that cannot be used with an intrinsically safe phone system</u>) is of standard manufacture, and auxiliary speakers are used with the paging phones where the need arises. The loudspeaking paging phones communicate through a pair of wires from the 25-pair telephone cable, and the carrier phones use the dc trolley wires for their signal paths.

With the exception of service problems with the older carrier phones, all carrier and paging phones are of good quality, are holding up well, and are apparently being properly used by working personnel. However, there is a problem associated with the carrier phones communicating from certain dead zones in the mine to the surface. Another problem with the carrier phones was that the battery had to be serviced every 30 days and mine personnel said this was excessive. Also, the mine officials indicated that the ringfed trolley rectifiers added receiver noise and that additional rectifier line filtering helped but did not eliminate the local problem when the trolley was near the rectifier stations.

External audio noise and replacing the internal battery approximately every 90 days were the most annoying problems associated with the loudspeaking paging phones.

Although the two systems are electrically tied together, the loudspeaking paging phone was primarily used to reach the working section and the carrier phone was used for right of way, placing loads and empties, personnel location, and requesting supplies. When the trolley-mounted carrier phone was used for self-traffic control, the operator would twice give his location and destination and then proceed to his final destination. Although this method of traffic control worked for this mine, an improvement could be seen using a dispatcher.

Tape recordings for a first 8-hour work shift survey show that the most frequent call made was concerned with right of way. Also, it was noted that out of the total 296 calls on the trolley and pager system, only 8 were on the pager. By listening to tape recordings of both the pager and the carrier phone simultaneously, it was discovered that 78 calls out of the 296 were not heard on the outside trolley carrier phone. It was also found that the trolley-to-pager hookup failed on 12 occasions. The actual failure of the coupler to function on some signals and the propagation dead zones were major problems associated with this system.

During the fire previously mentioned, the carrier phones were the only communication that worked through the evacuation. The telephone wire was fused, and communication was not possible using the dial system. However, the carrier phones could and did operate, using their internal batteries, through the fire. Although the loudspeaking phones were not in widespread service at the time of the fire, their line would have also been fused, making them inoperative if and when needed.

Communications Requirements--User's Viewpoint

Mine personnel indicated that the most urgent communication requirement was the elimination of dead zones in their trolley carrier phone system.

Communication between the shuttle cars and from the shuttle cars to the continuous miner was also thought to be useful. However, there was apparently no great need or requirement for this type of communication.

Portable two-way wireless communication for the maintenance foreman, fire boss, miners on the weekend inspection, and working section foreman was noted as a possible requirement. If portable two-way wireless equipment costs were high, the maintenance foreman, roving supervisors, and key personnel could use a one-way pager. However, mine personnel did not consider equipping a working section with a one-way pager since a working section foreman mostly communicates out from his location and is seldom called from other sections or surface locations.

A requirement existed for battery-operated portable emergency communications that could be moved with the miners as the working section moved. This requirement became evident during the fire, when it would have been useful during the emergency and recovery efforts. Also noted was the fact that if the number of working sections increased,

the mine may economically justify a dispatcher.

Communication Requirements--Based on Survey Analysis

This mine is unique in that it has a dial telephone system, a pager system, and a carrier phone system. The mine, as configured, has no need for additional channels, private channels, or the capability to interconnect to the public phone since the dial telephone has all these capabilities.

From the traffic density seen on the pager phone and trolley carrier phone system, only two additional channels can be justified to get the probability of blocking to the 1% level. However, only 3% of this communications is from the pager phone system, and the vehicle communication system must be single-channel operation for safety reasons. Therefore, there exists no justification for additional channels for the pager phone. Using this analysis and the needs generated by the mine personnel, the following list was developed to represent communication requirements for this mine.

a. Reliable two-way vehicle communication.

b. A dispatcher with communication center if the mine increases appreciably in size.

c. Portable two-way wireless communication for working section foreman, maintenance foreman, and key personnel.

d. Portable battery-operated communication equipment for mine-to-surface emergency two-way communication.

A.5 Mine D

Mine Description

Mine D was opened in 1892. Even though the mine is old, they are still developing in some areas. At present they have eight sections on development

and five on retreat. It is estimated that there are 15 years of mining left.

The mine is entered through one of two drift mouths. A vertical shaft is available but is seldom used. The mine produces approximately 4,500 tons of coal a day by the conventional, continuous, and longwall mining methods in the following percentages:

First shift:
  Conventional................. 18
  Continuous................... 35
  Longwall..................... 10
  Other shifts................. _37_
        Total................... 100

The coal is removed from the mine by track to the cleaning plant about 2 miles from the mine. The mine has an annual production of about 1,300,000 tons.

The mine is 7 miles by 5 miles and has overburden from 300 feet to 800 feet. All haulage tunnels are at least 6 feet high by 18 feet. There is no average size for a working section; some are as much as 3,000 feet in length. This requires that coal be removed from the working face to the track by belt. The belt is 36 inches in width, and the mine has approximately 25,000 feet of belt. If the distance is short (less than 500 feet), it is possible to dump coal from the shuttle car directly into the coal car.

Eight 37-ton locomotives are used to remove the coal. The mine has 30 miles of track underground at present. Eight boreholes are used to provide access for 13,800-volt-ac, three-phase, cables to the mine. Roof control is obtained by the use of roof bolts ranging in length from 42 inches to 8 or 9 feet.

Owing to the amount of track and layout of the mine, it is necessary to have two dispatchers. This mine is also engaged in strip mining at various locations directly above the mine. This coal is taken to the same cleaning plant as is the coal mined underground. This requires that dispatcher 1 dispatch right-of-way outside as well as underground.

The mine employs a total of 675 men and works three 8-hour shifts each day, with the major production done on the first shift. The start and end of each shift and the total men working follow:

First shift: 6:45 a.m. to 3 p.m.--
               308 men

Second shift: 3:30 p.m. to
               11:45 p.m.--216 men

Third shift: 12:15 a.m. to
               8:30 a.m.--151 men

Mine Equipment and Power

Power is provided by the power company at 138,000 volts ac. This is then stepped down to 13,800 volts ac and distributed to eight boreholes, where it is taken underground. At some point underground it is converted to 250 volts dc, 550 volts dc, or 440 volts ac three-phase, depending on the equipment being used on the section and location in the mine. One of the reasons for this is that from the outside to dispatcher 2, the mine uses 550 volts dc on the trolley. Then branching out from dispatcher 2, the mine uses 250 volts dc on the trolley. The 440 volts ac is used in both areas.

The power provided to sections varies according to the type of equipment used. There are cases where, on the same section, 250 volts dc or 550 volts dc must be provided for the shuttle cars, and 440 volts ac provided for the miner. Both longwalls require 440 volts ac, as do some of the newer continuous miners. There are also battery-powered scoops on some sections. They are used for cleaning the section and hauling supplies.

The mine at present uses the following equipment:

Continuous miners—8

Loading machines—5

Longwalls (1 plow, 1 shear)—2

Cutting machines—3

Shuttle cars—29

Present Mine Communications

At present, the mine communication system consists of a magnetophone system, carrier phone system, and loudspeaking phones.

The loudspeaking phones are used only on the longwalls. Carrier phones are placed on most of the track vehicles. At the cleaning plant a 60-watt amplifier is used as a public address system calling 14 stations, each of which has a microphone and speaker.

Each dispatcher is responsible for carrier phone and magnetophone control in his area of the mine. The two dispatchers must consult with each other when routing traffic toward each other. Typically, the telephone network having dispatcher 2 as its control point has heavier traffic of a more varied nature than that of dispatcher 1.

During the busiest period of the shift, the fourth hour, the busier trunk was used 70% of the time. This three-channel traffic intensity implies that there is a 30% chance of getting a busy signal on any given call. This is considerably worse than the one chance in a thousand of commercial telephone standards. A six-channel network would be required to bring the system to commercial standards.

There have been no major emergencies at the mine to test the existing system. It is possible that a roof fall could break the phone line and cut off communications to the outside for some areas of the mine. In the case of an accident the section notifies the dispatcher, who in turn calls mine management on the outside.

Telephone System

The mine has 77 magneto telephones, 60 of which are underground. These phones are approximately 30 years old. They use simple twisted-pair, No. 14 wire for the phone circuit.

The phones are usually mounted on wood that is connected, in some manner, to the roof. They are placed at locations along the main haulage. Phones on the section are located at the head and tailpiece of the belt. These phones are not permissible.

The dispatchers are the heart of the phone system. Dispatcher 1 is responsible for the outside phones and for underground phones 1 to 20. Dispatcher 2 has phones 20 to 60. If a person wished to call outside from say phone 57, he would have to ring dispatcher 2. Dispatcher 2 would then call dispatcher 1, who would ring outside, then connect the lines.

Since the phones are a ringer type, each station must have a certain ring. It should be kept in mind that the circuits for the two dispatchers are separated. Therefore, each dispatcher could use the same ring combinations.

Recordings and corresponding analysis of the traffic on the phone system shows that there are periods when the system is used 70% of the time and that the system is overloaded at times.

Trolley Carrier Phone System

The carrier phones are mounted on most of the track vehicles. The fact that the mine uses 250 volts dc and 550 volts dc on the trolley requires the use of two different carrier phones. They have twelve 250-volt, 163-kHz trolley phones and twenty-eight 550-volt, 100-kHz phones. Both tube and

transistorized versions are used. The tube type is 20 years old, and the transistorized type is 12 years old. The transistorized units are equipped with a 12-volt battery, so that they will still operate should the power in the mine go off.

Pager Phones

Pager phones are used on the longwalls and on the outside of the mine. The pager phones are mounted on J-hooks from the roof support jacks. Wires are hung from the roof supports for the phones. Rocks falling between the jacks have caused the line to break, causing a potential safety hazard due to interrupted communication. The reason for this is there is no way of hearing a ring on the pager system. There are 10 pagers on the plow and 5 on the shear. The phones are 10 years old. The mine personnel felt that the phones were mistreated by man and environment, and that was the reason for failures.

Fan Monitors

The size of the mines requires that the fans be located at great distances from the maintenance shop. The fans are monitored by sending a signal over the high-voltage lines, which is monitored at the outside shop. The five frequencies used (one for each fan) are 39, 116, 47, 61, and 33 kHz.

Communication Requirements--User's Viewpoint

The phone system performed very well considering its age. However, the changes in humidity caused some problems. There was also a problem with having to walk long distances. The phones are not permissible; this limits how close to the working face they can be placed and often requires that an individual walk as much as 500 feet to reach one.

Mine personnel felt that wireless communications of some type would be of help on a section. The foreman and the mechanic are the two most sought after individuals on the section. The mine personnel were of the opinion that communications to those two men would be desirable.

The maintenance foreman and master mechanic felt that portable two-way communications would decrease the time needed to locate them. Portable communications are also desired for the supervisory personnel (superintendent, mine foremen, and maintenance foremen). At the same time a private line was requested for the phone system for supervisory personnel.

The safety department personnel suggested that remote monitoring of the mine conditions would help increase safety for the entire mine. It was suggested that a private channel directly to the outside for emergency use would decrease the time required to get help from the outside. This private channel would also insure that the occurrence of an accident would not be heard by men on other sections.

There should be a secure channel open at all times, from any phone underground, to some central communications center aboveground. It is not necessary that this line be connected to the commercial phone system. Since the mine management are the first to be notified in case of an emergency, they in turn can call whomever is needed. In a mine this size the time saved by placing the call from underground to the commercial system for assistance, then notifying management, would be of little help.

Communications Requirements--Based on Survey Analysis

This mine has some communication problems that are related only to the extreme age of the equipment used. However, problems due to the large size of the mine may be typical of other large mines.

Signal-to-noise ratio (SNR) causes problems when talking great distances (5 to 10 miles). A new system must start by improving SNR on long-distance

converations, which may be typical of many large mines.

An analysis of the telephone traffic density indicates that three more channels (total six channels) would make the system comparable to an estimated mine standard of 1 in a 100 chances of getting a busy signal.

A dial system is recommended for this mine. A multipair or multiplex system would help to lessen the load of the dispatcher and could also provide the capability for conference calls. These systems also provide the channel privacy requested by mine management. For safety reasons, the trolley carrier phone system should remain one channel.

Using the above analysis and the suggestions of mine management, the following list of improvements was derived:

    a. Reliable two-way vehicle system.

    b. A total of at least six channels to meet minimum standards.

    c. At least one secure channel.

    d. Portable two-way wireless communications for certain key personnel.

    e. Battery-operated communications equipment that will work during an emergency.

    f. A communications center located at dispatcher.

A.6 Mine E

Mine Description

Mine E has a drift entry in a 5.5-foot soft coal seam. The working sections are presently 3.5 miles in from the entrance, with the possibility of eventually working at twice this distance. Mining at the present rate gives the mine a life of from 30 to 40 years. The mine operates two longwalls about 500 feet wide and will travel a range of 3,500 feet. New to mining in this area

is the "stall machine" used at the tail end of the plow longwall to give better roof control. This machine is a limited travel shear that leaves a cleaner end on the longwall than the plow. About one-third of the mining is by longwall, one-third is conventional, and the last third is continuous. The number of working sections for each type of mining follows:

	1st shift	2d shift
Conventional.......	2	2
Continuous.........	2	2
Longwall...........	1	1

Only a small amount of mining is done during the maintenance or third shift. The mine is small enough that there is no underground maintenance shop. Hence, repairs that cannot be made at the site of the failure must be made outside.

Coal is moved from the face by shuttle car except on the longwalls, where it goes directly to belt. Local belt haulage is used between the shuttle cars and tracked cars on the main line. The longest belt run is 4,500 feet.

During the first shift there are no idle sections so there is no need for maintenance crews when each section crew has its own mechanic. Extra mechanics work along the main line during this shift and help section mechanics when needed.

During the third shift, when few sections are working, there are three maintenance crews whose specific job is to work on equipment at the idle sections.

Mine Equipment and Power

Power is fed to the mainline trolley wire at 250 volts dc by four rectifiers. There are deadblocks between the four sections of trolley wire so that each rectifier supplies power to only one short length of wire. All face-mining equipment is ac operated so there is no

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need to have nip points from the trolley line.

Rather than utilizing power boreholes, 7,200-volt ac power is brought in along the mainline, up to transformers at the working sections. There the voltage is stepped down to 440 volts. Thus as the sections advance, the transformers must be moved to follow.

The only power outages have been due to storms or hunters shooting transformers on the power company's distribution system. Outside there are two high lines feeding the mine's single substation.

Should there be a power interruption within the mine, the substation attendant will check by telephone with the sections before reenergizing the distribution system.

Present Mine Communications

Telephone System

Pager phones are used in a network of 11 phones along the track throughout the mine, plus a phone in the dispatcher's outside office and one at the communication repair station in the shop. Tape recordings made during an 8-hour shift indicate that there were 160 discussions concerning the location and movement of empty and loaded coal cars. For the next most common topic, there were nearly 80 discussions concerned with the production of mined coal. Collectively the other subjects (reporting, personnel location, maintenance, etc.) add up to about 80, so no one of them is a significant user of channel capacity. Analysis showed that early in the shift, and just before the end, the phones are used as much as 50% of the time. This places the probability of a potential caller finding a busy line at one chance in two during these periods.

The loudspeaker telephones have an average age of about 4 years. Rock dust does seep in through their cases, but the users and maintenance men report there are few failures and these fall in no

consistent pattern. The people interviewed could give no suggestions on how the phone system--the one following the track--could be improved. There are several reasons that could be contributing to their satisfaction:

a. The phones are relatively new.

b. The phone network is not large.

c. The time and talent spent on maintaining the system are great.

d. The equipment supplier gave them much help in setting up their systems.

e. The characteristics of the phone lines are good.

The telephone network is such that anyone on a working section is never more than 350 feet from a phone. They feel this is adequate and that having a phone any closer would not really be of more value. Other phone locations are the boom and tailpiece of every belt, plus four in the escapeway. No allowance has been made for emergency usage in the sense that, should a telephone line be broken, there is no loopback to carry the signal.

Carrier Phone System

The carrier phone is a 72-kHz system that uses the trolley power line to carry the signals. Even though this is a fairly small mine, they did experience dead zones of unacceptably low signal strength in certain areas.

The dispatcher has an outside dial phone as well as a speaker phone, so he serves as a message relay center and information center as well as a dispatcher. The communications maintenance area of the shop also has a trolley carrier phone to aid the maintenance people in servicing the trolley carrier phone system. The carrier phones do not have storage battery backup. If there is a failure of trolley power, carrier phone communications are lost.

The mine has had a dispatcher for only the last 2 years. Before that, motor operators controlled the track for themselves. At that time the mine tried tying the telephone system in with the trolley phone system (this type application cannot be used with an intrinsically safe telephone system) but found it only added confusion to have those not near the main line hear all the discussions of the motormen.

To get the carrier signal around the deadblocks, 2-μF capacitors are used.

To keep rectifier "hash" out of the 72-kHz system, L-filters are used at each rectifier (paragraph 5.3.1a). The filter consists of a 50-μF capacitor across a rectifier's output, with a 10-turn, heavy-cable coil, the coil having an approximate diameter of 2 feet. The manufacturer tuned the filter to reject 72-kHz interference.

CAUTION

Installation of equipment in a mine should be done only by people thoroughly qualified to do such work. Installations should follow procedures recommended by the equipment manufacturer and should comply with good safety practices. All installations should also comply with applicable codes and regulations.

Longwall Communication System

The longwall miner has its own communications system consisting of seven loudspeaking telephones, one at each end and the other five equally spaced along the 500-foot longwall. These loudspeaking telephones have no handset and thus operate in the pager mode only, with the loudspeaker serving as a microphone when the push-to-talk button is pressed. The telephone lines lie in the troughs that carry the hydraulic lines. At one time the wires were hung under the top plate of the jacks, but slate falling between the jacks kept breaking the wires.

Signal lights are positioned along the longwall miner so the operators can coordinate their efforts if the phone system fails. The quality of speech reproduction for the phones was good, and the loudspeaker volume was adequate in spite of the high ambient noise of the miner.

The only complaint the personnel had was that the push-to-talk button failed often. This button is mounted on the recessed front face of the unit. The phones at the ends of the longwall are mounted horizontally so the recessed panel acts as a catch basin for the watered-down coal dust. Evidently the directional properties of the speaker are such that this mounting is necessary.

Communications Requirements-- User's View

Except for correction of the minor problems already presented, the mine personnel had little to suggest about new communications systems that would make their work safer and more effective. This may be due to their present system being new and seemingly adequate for this size mine, or due to their not having time to visualize how a higher capability system might profitably be utilized.

The one desire expressed at this mine was for a secure channel for seeking aid for an accident victim. As in other mines, when an accident is being reported, everyone who knows the phone is being used for this purpose will listen if he can. This lowers the productivity of the eavesdropper; takes his mind off his work, making him more accident prone; and worse, loads the telephone system so that the dispatcher can no longer clearly understand the report. It is not essential that the conversation cannot be listened to, just that personnel not become aware that someone in a panic is calling the dispatcher. Personnel seldom listen in on run-of-the-mill conversations.

Communications Requirements--Based on Survey Analysis

The exceptional high quality and the unusual amount of care given to the telephone and carrier phone systems leave little to suggest as to improving these communications means in mines similar to this one.

This mine, like some others visited, has a need for a secure channel as an aid in effectively handling injury problems, and it would be desirable to have a secure management channel.

Better communications capability would increase productivity in the longwall mining sections. Fast, effective hands-free communication is needed by operating personnel during both operation and repair of the miner. Because of its high production rate--and thus the high cost of downtime--and because of the almost impossible working conditions, it seems essential that all longwall workers have their own wireless communications network with each having small, lightweight equipment, including speakers and bone-conducting microphones mounted in helmets. The communication center operator should also be able to monitor this network.

A.7 Mine F

Mine Description

Mine F has been operational since 1963 with production originally estimated for 25 years. Coal is being mined from the Mammoth Seam in the Cherokee Group. Seam thickness is approximately 60 inches.

This mine is the only nonunion mine surveyed. As a result, some of the operations are notably different from those seen at the other mines examined.

The mine employs conventional mining techniques and employs tracked haulage to remove the coal. Personnel entry and coal removal are through a single shaft.

Coal production is approximately 250,000 tons per year. There is one mining section, operating one shift. Coal is mined via the room and pillar method with activity rotating through six active rooms.

The mine will ultimately be approximately 1-1/4 miles square. Mining activity is currently occurring about 3/4 mile from the shaft.

The overburden at the shaft is 157 feet, increasing gradually to the working face. Tunnels are typically 12 feet wide and range from 4 to 6 feet high. Four- and 6-foot roof bolts are installed on 5-foot centers.

There are no boreholes into the mine. The fresh air entrance serves as the emergency exit and is located about 500 feet from the main shaft. The main shaft serves as the air exhaust.

Mine Management

Since there is only one mining section, the mine operates with very few management personnel, as follows: General manager, chief engineer, superintendent, and foreman.

Management personnel do quite a bit of filling in as necessary; however, the chief engineer normally tends to topside operations while the superintendent stands by at the bottom of the shaft. The foreman remains at the face. The mine has 25 men underground during the shift.

There are five mining operations rotating continuously through the six active rooms at the face. A cycle starts with the cutter undercutting the coal face. This is followed by the coal driller drilling holes for the charges. After the driller moves on, the charges are set and fired by the shot firer. After a delay for the air to clear, the loader is moved in to begin loading shuttle cars, which transfer coal to the haulage cars. When a room has been

cleaned of the loose coal, the roof bolters move in to extend the supported section of the roof.

Loaded haulage trains are pulled to the shaft where the cars are dumped into a skip, one car to a skipload. The skip is lifted up the shaft and dumped into the crusher. Crushed coal is conveyed into semitrailer trucks that are used exclusively to haul the mine's output.

The maintenance philosophy of this mine results in a large amount of nonproductive machine time. There is a complete operating spare for each type of machine in the mine. As a result of this philosophy, however, there is virtually no downtime for equipment maintenance. A minor failure is repaired on the spot; in case of a major failure, the spare machine is placed in service while the broken one is fixed.

There is no fixed shop location. The maintenance personnel travel with the mining crew. The presence of spare machinery permits repairs and maintenance to be performed thoroughly without slowing production.

Supplies are delivered via the haulage cars. Just before the end of each working day the foreman calls his list of supplies to the hoisting engineer. These are placed at the top of the shaft and delivered to the face either at the end of the day or the beginning of the next one. Repair parts are delivered during the day via a return trip of the haulage cars.

The mine has a single man-trip car. This is sufficient to carry the entire crew, so only one man-trip is made, morning and evening. Administration of the mine operation is quite informal. The general manager oversees all operations and assists the topside personnel as necessary. All management personnel assist when and where needed.

Ventilation is via a single fan, blowing into the escape shaft and exhausting through the main shaft. Within the mine, water sprays are used to keep dust down. There has never been any problem with excessive water, so the only water-handling gear is that used to control dust.

Mine Equipment and Power

The following pieces of mining equipment are in use at the mine:

Shuttle cars--3	Roof bolter--1
Loader--1	Coal drill--1
Cutter--1	Locomotives--3

In addition to the equipment in use, there is one operating spare of each type of machine. In case of major breakdown the spare is placed in operation while the broken unit is repaired.

Primary power comes into the mine through the main shaft. A 2,300-volt, three-phase line is run to the two transformer-rectifier sets used. One transformer feeds the trolley for the haulage system; the other powers all machinery at the face. All machines in the mine run off 280 to 300 volts dc.

Present Mine Communications

The mine currently has a combination of three independent voice communication systems. The loudspeaking phone system uses two units, one located at the hoisting engineer's position, and the other at the working face. A two-station intercom connects the top and bottom of the shaft. Another intercom connects the hoisting engineer and the mine office. Two spare loudspeaking pagers serve as backup and permit a third station to be patched in if work is being done a long way from the face. The hoisting engineer serves as "communications central," tying the three systems together. In addition to the internal communication systems, an extension of the outside telephone line is

located at the chief engineer's desk. The pager at the face is kept mounted near the power sled, so the two are moved together. Nothing else is moved.

All equipment has been holding up well. Perhaps twice a year, one of the pagers will quit operating. Whenever this happens, the bad unit is removed and sent to a commercial repair station.

In normal system use, all calls are made from a remote point to the hoisting engineer "communication central." As long as calls are being made in this manner, the system functions well. A possible exception might occur in an emergency situation at the face. The pager at this point is 50 to 100 feet from the nearest working room, and on the other side of air-diverter flaps. It is conceivable that an accident could occur in which the phone would not be accessible. The other possibility involving an accident situation would involve the phone cable. There is a single run with no backup or loopback path. This cable is, however, protected in being mounted on vertical timbers and is of armored construction.

When calls are made from the "communication central" position to other parts of the mine, the system does not work so well. A complaint was made that if the superintendent leaves the bottom of the hoist it may take a half hour to get a message to him. It appears very unlikely that a call to the pager at the face would find anyone near enough to hear it. The fastest route to the face appears to involve relaying a message to a motorman at the hoist and having him deliver it to the face when he returns.

In this mine, communications efficiency would be improved by replacing the three independent two-station phone systems with a single multistation,

multichannel system. The system should have a minimum of seven stations.

Their locations would be as follows:

Mine office

Hoisting engineer's position

Shaft bottom

Working face

Bottom of emergency shaft

Midway between bottom and face along inbound haulageway

Midway between bottom and face along outbound haulageway.

Other stations that might be considered include--

Topside storage or shop area

Chief engineer's desk

Crusher

Most of the added stations would be concerned more with safety than with production. As things stand, it is possible to be blocked from a phone station or to be a long walk from one. In addition to the fixed stations, the management personnel should have radio communicators. This would eliminate the existing situation in which a critical man can be out of touch when others need a decision or information.

An expanded system needs no more than two general channels plus a private channel. Radio communicators operate best if they can access all three channels, but could operate with access only to one of the general channels.

The cable into the mine should be a continuous loop of armored wire for maximum reliability and protection. By using a multiplex system, all channels plus monitors could be included on a single cable.[1]

A.8 Mine G

Mines that do not employ rail haulage systems powered from a trolley wire face unique problems in establishing satisfactory communications between haulageway vehicles. Because common trolley carrier phones cannot be utilized, some other form of radio system must be used to establish the required voice link

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[1]Approved and nonapproved systems may not share the same cable; check with MSHA for details.

between motormen and/or motormen and a central dispatcher. This description illustrates how one mine in this category solved its haulageway communication requirements using a unique system of UHF and VHF repeaters combined with a "leaky coaxial" transmission line.

This mine was a magnetite ore block caving operation. Surface access to the Mine (fig. A-2) was by two vertical shafts to the No. 6 production level, 2,500 feet, with mining occurring at a depth of 2,500 to 2,800 feet. Diesel-powered, rubber-tired loading equipment was used to transport ore to the crushers. A conveyor belt ran between the crusher rooms and the ore skip storage bins where the ore was automatically loaded into 20-ton skip cars and hoisted to the surface.
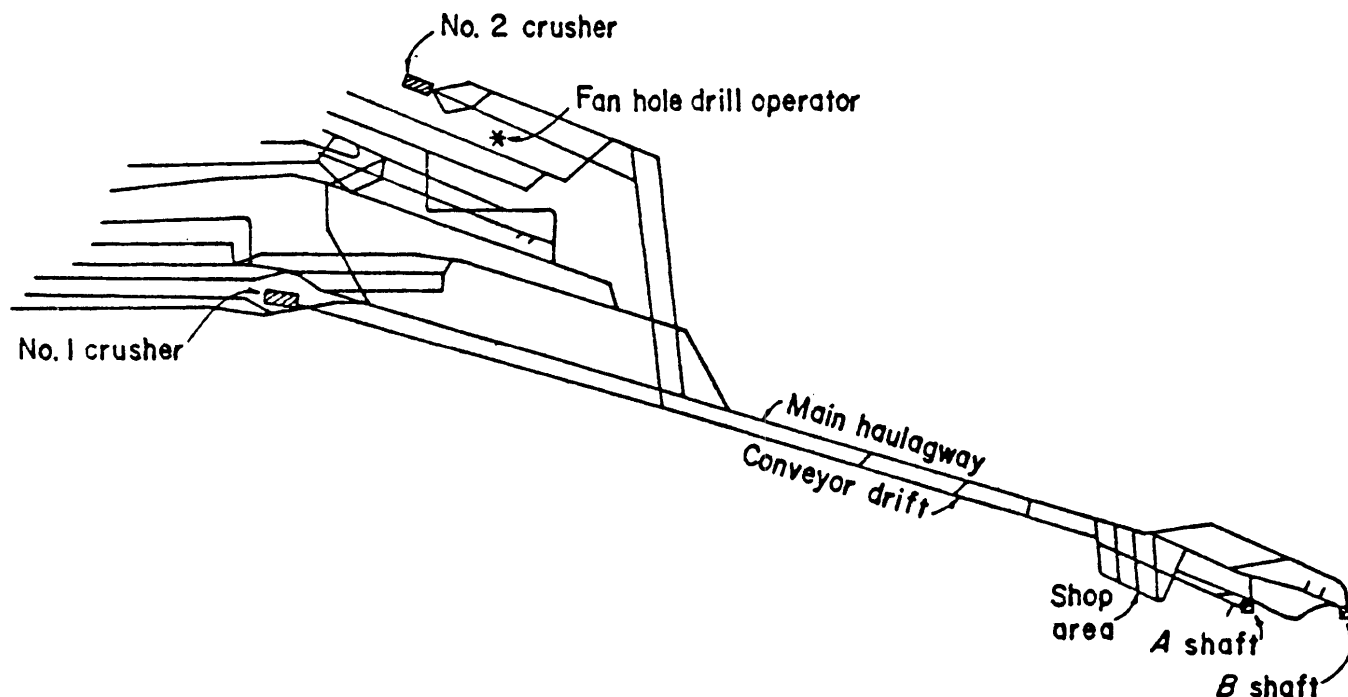

FIGURE A-2. - Underground map of mine, 6th level.

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Personnel underground included roving miners in production, haulage, and shop areas, fan-hole drill operators working alone, and maintenance vehicle and ambulance operators. To satisfy the objective to communicate between these personnel and the surface, a guided wireless communication system utilizing equipment available from Motorola, Inc., and Andrew Corp. was selected. Portable HT-220 radios and industrial dispatcher mobile transceivers were chosen for personnel and vehicles, respectively. Andrew Radiax cable, a special type of cable that allows for leakage of signals out of and into itself, was installed throughout the major areas of the mine. Because the total cable length exceeded 2 miles, it was necessary to install two repeaters. Although the system did not require a dispatcher or an operator, a communications center was established at an underground crusher room. Personnel could be selectively paged from the console, and an evacuation alarm could be activated from either the console or an alternate monitor station at the shaft bottom. The monitor station was wired to the surface where a remote control unit provided surface access to the system. During a power failure, the system would operate for 24 hours on backup battery power. A telltale beep in the system signaled that the system had reverted to emergency power. The communication system utilized off-the-shelf, readily available communications equipment and installation hardware. In addition, the system was compatible with the installation and maintenance capabilities of the mine personnel.

Figure A-3 shows the extent of the radiating cable installation. There was 11,000 feet of RX5-1R 7/8-inch Andrew Radiax in the system. The cable attenuation was 1.2 dB/100 ft; thus, two repeaters were required to compensate for signal loss as well as provide adequate power levels for future system expansion.

The cable specifications state that it must be supported every 5 feet. To avoid installing 2,000 anchors in the rock, a 3/16-inch steel messenger wire was attached at 20-foot intervals to roof-bolt-supported T-bars. The cable was then strapped to the messenger wire with standard cable ties.

Some areas were so far away from the installed cable that radio transmissions could not be established. This was overcome by inserting a stub cable with one
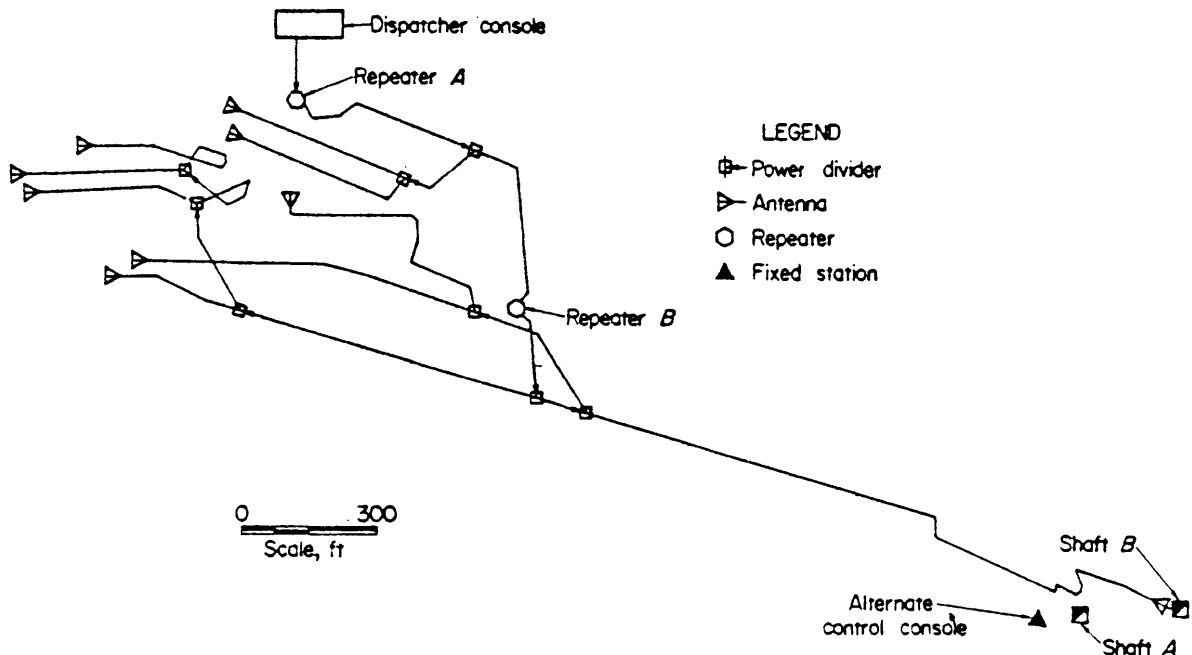

FIGURE A-3. - Leaky feeder cable layout.

end connected through a power divider to the main cable; the other end terminated in an antenna located within several hundred feet of the desired working area.

The repeaters, composed of a unique combination of UHF and VHF units, were bolted together and mounted on pallets for ease of transport within the mine. The UHF and VHF units were interconnected by a squelch and audio interface. Vehicular and personnel communications took place over the leaky coaxial cable on the UHF repeater frequencies, while the control between repeaters, located some 2,000 feet apart, used VHF over the same cable. A 5-MHz UHF transmit and receive frequency separation allowed connection to the common Radiax through a duplexer.

The repeaters were prewired, and the system was assembled on the surface where it underwent several months of burn-in. This procedure eliminated the frustrations of troubleshooting and testing the system underground.

The fan-hole drill operator, equipped with a portable radio attached either to his belt or to a chest pack as he preferred, was also equipped with an accessory noise-reducing earmuff and microphone. The receiver audio was routed to small loudspeakers inside his ear protectors, while the microphone and push-to-talk switch were installed in a similar earmuff which the fan hole drill operator placed over his mouth when he wished to make a radio transmission. All portable radios in the mine were equipped with the provision to use an external speaker microphone accessory so that the radio need not be detached from the operator's belt and raised to his ear or mouth. In noisy locations the use of a noise-reducing speaker-microphone is a necessity.

Two types of vehicular radios were used. The Industrial Dispatcher had all controls, the microphone plug, and speaker located on the transceiver package; this necessitated locating the transceiver within the vehicle operator's reach, which is nearly impossible on some

mining vehicles. A better radio for this application was the motorcycle version of the Industrial Dispatcher. All controls and the microphone plug were located on the small, rugged loudspeaker enclosure. The loudspeaker can be mounted in a convenient location, and the larger transceiver unit can be mounted in a more protected location. The antennas are either 1/4-wave whips or Sinclair low-profile blade antennas. The radome version of the blade antenna appears to be the most suitable for mining applications.

A dispatcher control console at the No. 2 crusher could be either manned or unmanned; no operator was necessary for system operation. Paging could be initiated from an encoder at the console to send private messages to pager-equipped radios. Equipping the fan-hole drill operator with a pager-encoded radio prevents the nuisance of his listening to general system traffic. He would only hear messages directed specifically to him. The console also had the provision for sending a warning signal to all radios in the mine. This wailing siren-like signal could be used for mine evacuation in an emergency.

The alternate control station provided an additional access point to the communications network. This station monitored the activity of the fan-hole drill operator. Also, this station was connected by wire line to an intercom unit in the surface guardhouse. The guard could access the system through remote control. This feature was especially desirable during maintenance periods when the underground stations are unmanned or during a mine emergency, to coordinate evacuation and rescue operations.

The mine had outfitted an underground radio shop with the necessary service equipment to maintain the communications system. A full-time Federal Communication Commission second-class licensed radioman was trained in system installation, operation, and maintenance. Reliability of the UHF-VHF system was

excellent with negligible downtime. This wireless communications system demonstrated that the objectives of personnel and vehicular underground mine communications can be satisfied. Worker and management acceptance of the system was excellent.

A.9 Mine H

To meet changing communication requirements in many of its mines, one utility company has installed a new multichannel mine dial-page phone system at its underground operations. The first of its type, this fully permissible communication system combines the paging capability of current mine page phones with the advantages of conventional telephones. Manufactured by GAI-Tronics Corp., the Mine Dial-Page Phone System (MDP) has the following features:

1. Each underground station is on a separate circuit ready for instant use depending upon the availability of an open channel in the central switch.

2. When connected to a telephone switchboard through a 12- to 48-volt interface circuitry card provided for each line, any underground station can call another underground station directly, or call any standard telephone at a surface location. Also, any underground station can be called from any aboveground standard telephone.

3. Selective paging capability to any single, specific underground station.

4. A dial-access, all-station paging capability to call personnel not at their normal location, or to alert all underground personnel.

5. Automatic switching to a pushbutton-operated, all-page-partyline mode in the event of a telephone switchboard power failure or severance of the cable interconnecting the switchboard and the interface cabinet, one of the key components of the MDP system.

6. Plug-in electronic assemblies, wherever possible, to facilitate

maintenance and adaptation to changes in mine operations.

The MDP system (fig. A-4) consists of individual phone stations placed at selected sites within the mine, one or more interface cabinets located on the surface, a telephone switchboard, and the necessary multiconductor interconnecting cable. (One pair of conductors is required for each private line.)

Each phone station is contained within a bright yellow, molded polyester-fiberglass-reinforced housing. This material, coupled with the use of stainless steel hardware, gives a corrosion-free enclosure. The station includes a handset, a telephone dial, a loudspeaker, an all-solid-state plug-in amplifier, and a self-contained battery of the standard 12-volt mine page phone type.

In addition, since some power for system operations is supplied from the surface, the mine phones are designed to have individual power to permit emergency communications in the event of a power cutoff. This is accomplished by a standard 12-volt phone battery, while the surface equipment is provided with a 12-volt rechargeable battery, required only in the event that voltage to the dc power supply should be lost.

Located outside each cable entry into the mine is an interface cabinet. The circuitry that converts the telephone switchboard voltages (ac and dc) to permissible levels is contained in this cabinet on a separate plug-in interface card for each telephone line. The cabinet also contains the 12-volt rechargeable battery. This battery automatically powers the system if there is a power failure at the switchboard or in the connecting cable between the switchboard and the cabinet.

The switchboard itself is an important link in the MDP operation.

This mine's initial installation uses a private automatic branch exchange provided and installed by the local
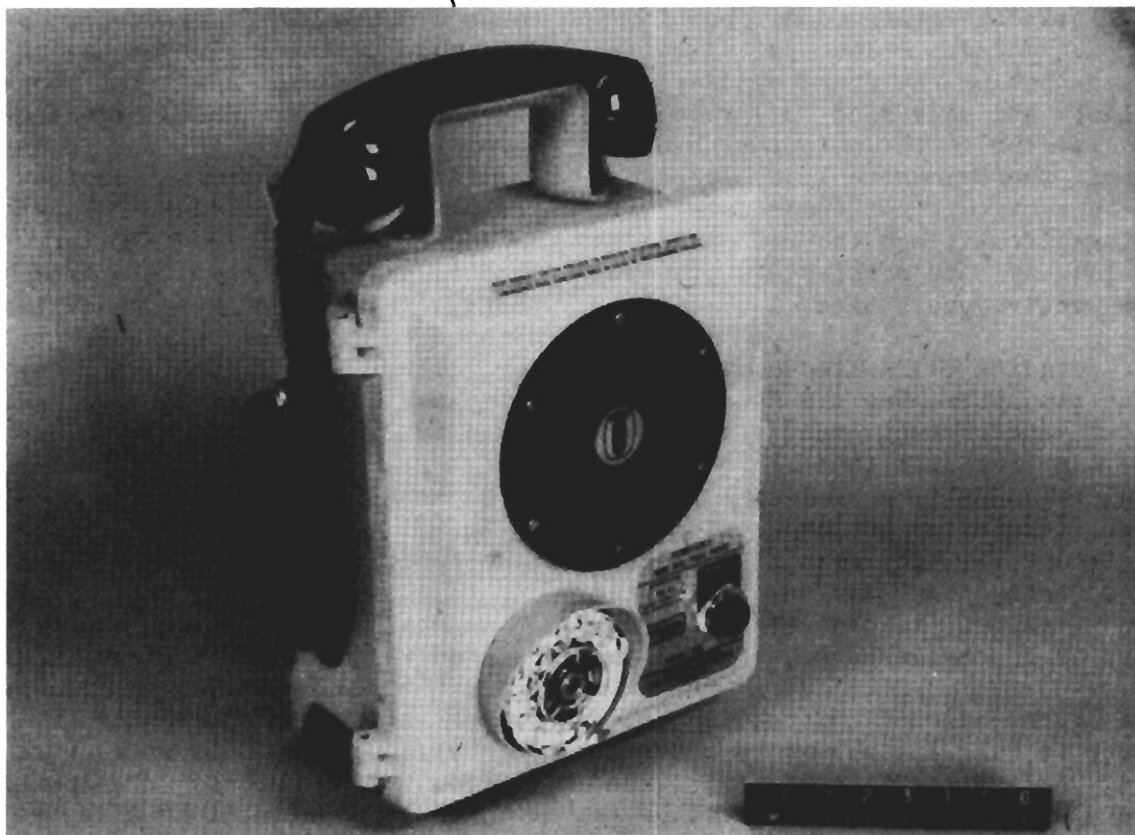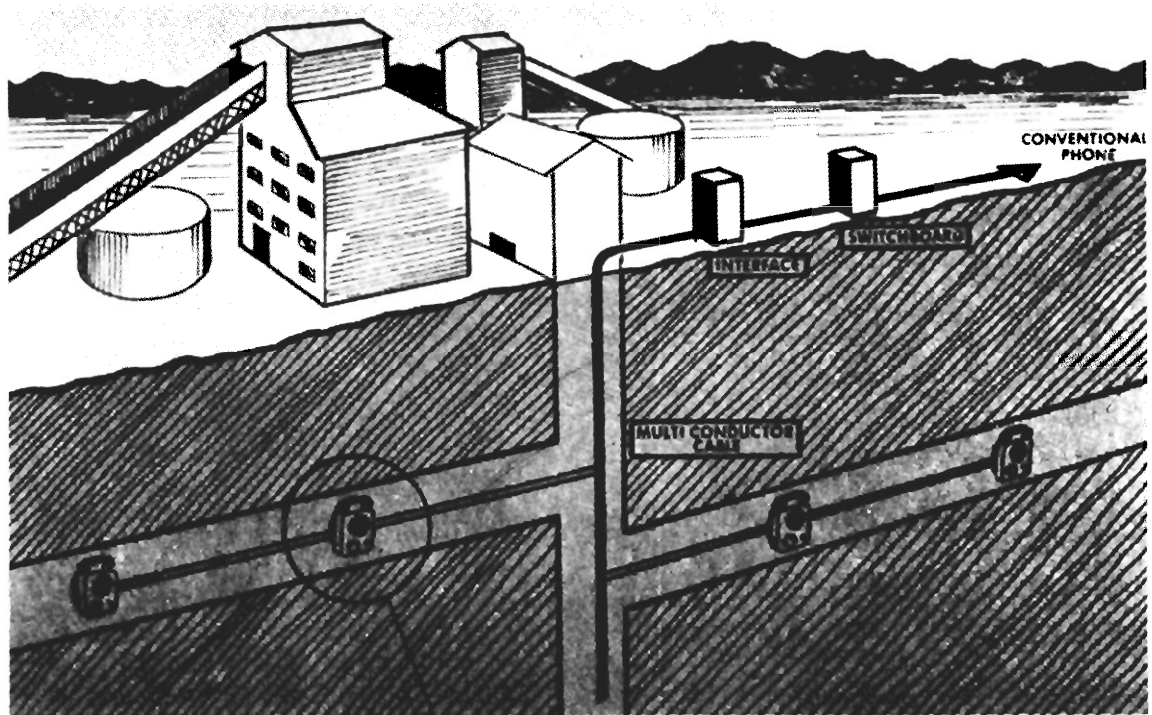
FIGURE A-4. - Typical mine dial-page phone system.

telephone company in the main office building at the mining operation.

An incoming call triggers the interface card circuitry in the cabinet, which begins with the activation of a timed holding circuit that completes the dc loop of the telephone line and halts the incoming ringing signal. The timing circuit holds the line for approximately 40 seconds and initiates additional circuitry which produces a distinctive warble ring tone on the appropriate MDP phone. The ring tone is applied for a 4-second period, and the balance of the 40 seconds is held for the calling party to page a specific person or make an announcement. At the end of this period, if the called station has not answered, the lines are automatically disconnected.

When the station answers before the end of the 40-second hold period, the timing circuitry is returned to its original standby state and the loudspeaker is muted. The party called responds by taking the phone handset from its holder and squeezing a press bar located in the center of the handle. Holding of the telephone line is accomplished by a circuit not associated with the timing circuit, and the connection is held as long as both parties are pressing their respective press bars.

For outgoing calls, the user of the MDP phone simply removes the handset from the holder and presses the press bar. When the familiar dial tone is heard, he can dial his call. Release of the press bar terminates the connection. A delay circuit is provided to maintain the line connection during any brief (2-second maximum) release of the press bar, such as to change hands.

The aforementioned procedures allow one party to call another at a specific location. A separate feature is provided to page a person when his location is unknown. By dialing a special number, a separate amplifier and electronic source within the interface cabinet activate the loudspeaker at each MDP station to provide one-way paging communication. Such

a page call will be heard in the handset receiver by all parties engaged in calls to, from, and between MDP phones, but it will not interrupt these conditions; the conversation can continue at the conclusion of the page. The person being paged, however, must dial the person initiating the page to carry on a regular conversation.

The interface cabinet contains a separate fail-safe system to maintain communications in the event of an accidental disconnection of the cable between the cabinet and the telephone switchboard, or if there is a failure of the switchboard's power. A second circuit network, controlled by a switchboard monitor, automatically ties all of the interface cards together in the event of such failure. In this mode, two-way paging and handset conversation can be carried out in a manner similar to that of presentday mine page phones. A push-to-page button is provided for paging in this mode, with each phone having its own battery to provide power for both normal and this alternate-mode operation.

Ability to dial outside calls—including direct-dial long-distance calls—and to receive similar calls is limited only by the telephone switchboard. That is, an MDP phone station can be used to dial any telephone or receive any incoming call that a conventional telephone connected to the same line could handle.

A.10 Mine I

Mine Description

Mine I is a silver mine centrally located in the Couer d'Alene mining district in Idaho. The mine was first opened in 1884 and presently employs over 500 persons, 400 of whom work underground. Main access to the mine is through a 200-foot-long adit to shaft A at the western edge of the mine. A miner proceeds down that shaft to the 3100 and 3700 levels and then eastward through 5,000-foot-long drifts to shaft B, which is collared at the 3,100-foot level.

Miners must then go down that shaft to the active working levels (fig. A-5).

Shaft B is bottomed just below the 6,000-foot level. Ore is being produced on the 4000, 4200, 4400, 4600, 4800, 4000, 5200, and 5400 levels. Level development is in progress on the 5600 level, and shaft station development is in progress on the 5800 level.

The A and B shafts are each provided with electric-powered double-drum hoists and electric-powered single-drum chippy hoists. The double-drum hoists on both shafts are used primarily for hauling ore and waste materials. The chippy hoist on shaft A is used for moving men and materials to all levels as far down as the 4000 level and for hoisting ore from the 4000 level to the 3100 level. The shaft B chippy hoist is on the 3700 level

and is equipped with a four-deck man cage with a total capacity of 48 men. It is used for servicing all levels below 3700.

Airflow for the mine is dependent upon pressures developed by fans located underground (series ventilation). All of the intake air for ventilation of the mine is coursed down shaft A to the 3100 and 3700 levels. The air is split between these two levels and travels laterally to shaft B. The air is then forced down the shaft B to the lower levels. The return air flows back through ventilation raises and exhaust airways to the surface.

The ore deposits occur as long, generally narrow veins containing sulfides of silver, copper, lead, and antimony in a carbonate quartz gangue. The vein dips range from 45° to 90° and are generally to the south. Strike lengths on the major ore shoots range up to a known maximum of 2,200 feet and are normally exceeded twofold or threefold vertically along the dip of the structure. The true vein width varies considerably but generally averages between 2 and 5 feet.

The steeply dipping fissure veins are mined by the horizontal cut and sand-fill method by either breasting down or back stoping. Stopes are developed a maximum of 100 feet along the strike of the vein. Level intervals are 200 feet. A raise climber is used to drive the 6- by 6-foot raises between levels.

All underground transportation is accomplished using either the hoists or battery-powered locomotives on narrow-gage tracks. The mined ore is transported to a muck pocket on the associated haulage level. This ore, or muck as it is called, is then dumped onto the shaft B hoist skips and transported to the 3100 level. The muck is then transported by locomotive to shaft A and hoisted 3,100 feet to the headframe storage bins.

Surface facilities include an office area, warehouse electric shop, machine shop, hoist and compressor house, garage,

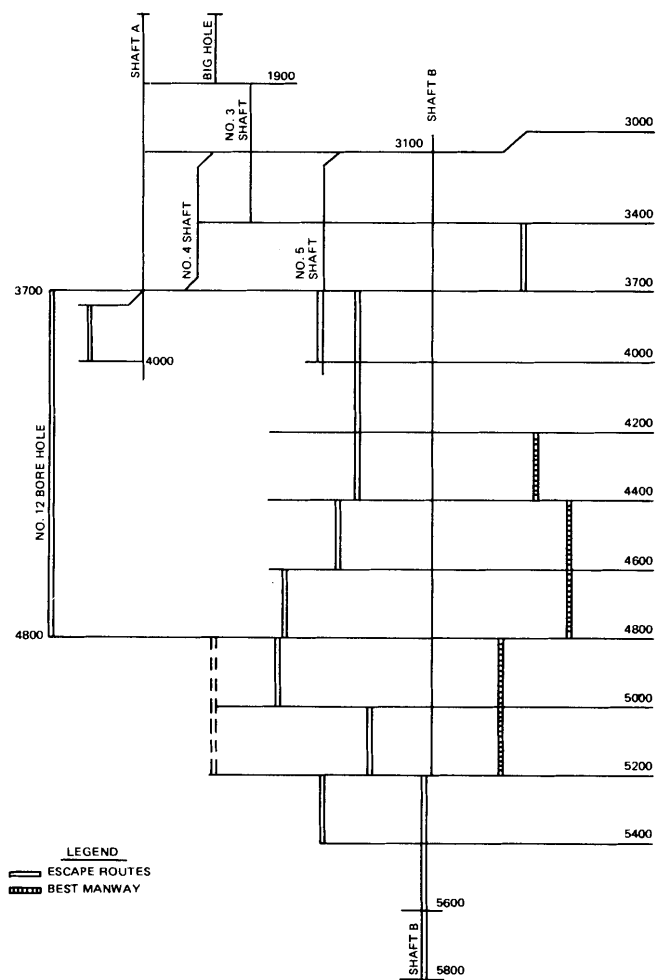

LEGEND
ESCAPE ROUTES
BEST MANWAY

FIGURE A-5. - Mine I, mine map.

carpenter shop, mine and mill changehouse for employees, dispensary, and tailing ponds. Engineering personnel are also located at the mine to provide facility planning and better control progress of the mining operations.

Present Mine Communications

The telephone permissibility requirements are not applicable to metal and nonmetal mines such as this mine. A high-dc voltage on the carrier pair, although a potential safety problem, is of much less severity in a metal or nonmetal mine. Therefore, an Anaconda S6A system was installed to provide telephone service underground.

The Anaconda S6A is a seven-channel, frequency division multiplex system. The following items are worth noting in regard to its suitability for mine applications:

1. The system provides a suitable number of channels (seven) on a single wire pair.

2. The mechanical and environmental specifications indicate the ability to operate under the severe conditions found in the mine.

3. The system allows branches to individual conventional dial telephones at any point on the system.

4. Remote units (at the telephones) have batteries that are trickle-charged over the wire pair. This enables the system to be freestanding and not connected to 110-volt power underground.

5. Carrier levels require no adjustment, as the system has automatic gain control circuitry.

The Anaconda S6A system is designed to interface a central office at one end and conventional telephones at the other. It was designed as a transparent substitute for copper pairs connecting the telephone company office to subscriber telephones. To perform its signaling functions, the system receives central office signals at one end (such as the ringing voltage generated by the central office to ring the telephones) and reproduces them at the other end (it remotely generates ringing voltages to ring the bells as needed). Conversely, the system can receive only dial pulses from the telephone end, which it passes to the central office. When used in this way, the system is a transparent substitute for copper pairs; that is, users cannot tell whether the S6A system or copper pairs are being used.

The central switching function of the phone system is handled by a small private branch exchange. System requirements were carefully examined before choosing a location for this PBX. A spare single twisted pair was available from the shaft A surface to deep within the mine. Any additional wiring in the shafts was to be avoided. An air-conditioned room was available in the shaft B area at the 3,700-foot level that met all environmental requirements of the PBX. Additionally, this location was approximately centered with respect to the number of telephones desired in the system. The single twisted pair was opened at this point, thereby forming two independent wire pairs. Carrier terminals were then installed on each pair, and these two independent carrier systems were then connected to the PBX circuits. This provided up to 14 private channels for communication within the mine. One channel in each carrier system was designated for use in a monitor-control system. Of the remaining 12 channels, 5 in each carrier system are used to connect phones to the PBX, and the additional channel is reserved as a spare. Additional phones for critical locations and functions in the 3700 level shaft B area are directly connected to PBX line circuits to provide them with private line service. This minimizes the possibility of getting a busy signal for these phones.

Each phone has battery backup that will allow operation for 24 hours.

APPENDIX B.--FEDERAL REGULATIONS

The following sections of the U.S. Code of Federal Regulations, Title 30, Mineral Resources, Chapter 1--Mine Safety and Health Administration are presented to assist planners of communication systems in insuring that all requirements are being satisfied.

It should be noted that some States have enacted laws that further regulate the use of communications, control, and monitoring equipment in underground mines. Check State and local regulations before proceeding with the installation of new or redesigned equipment.

PART 57—SAFETY AND HEALTH STANDARDS—METAL AND NON-METALLIC UNDERGROUND MINES

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§ 57.1 Purpose and scope.

The regulations in this part are promulgated pursuant to section 6 of the Federal Metal and Nonmetallic Mine Safety. Act (30 U.S.C. 725) and prescribe health and safety standards for the purpose of the protection of life, the promotion of health and safety, and the prevention of accidents in underground metal and nonmetallic mines which are subject to that Act. Each standard which is preceded by the word "Mandatory" is a mandatory standard. The violation of a mandatory standard will subject an operator to an order or notice under section 8 of the Act (30 U.S.C. 727). Those regulations in each subpart appearing under the heading "General—Surface and Underground" apply both to the underground and surface operations of underground mines; those appearing under the heading "Surface Only" apply only to the surface operations of underground mines: those appearing under the heading "Underground Only" apply only to the underground operations of underground mines.

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§ 57.11 Travelways and escapeways.

TRAVELWAYS

GENERAL—SURFACE AND UNDERGROUND

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57.11-54 *Mandatory.* Telephone or other voice communication shall be provided between the surface and refuge chambers and such systems shall be independent of the mine power supply.

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§ 57.18 Safety programs.

GENERAL—SURFACE AND UNDERGROUND

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57.18-12 *Mandatory.* Emergency telephone numbers shall be posted at appropriate telephones.

57.18-13 *Mandatory.* A suitable communication system shall be provided at the mine to obtain assistance in the event of an emergency.

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§ 57.19 Man hoisting.

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HOISTING PROCEDURES

57.19-55 *Mandatory.* When a manually operated hoist is used, a qualified hoistman shall remain within hearing of the telephone or signal device at all times while any person is underground.

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SIGNALING

57.19-90 *Mandatory.* There shall be at least two effective approved methods of signaling between each of the shaft stations and the hoist room, one of which shall be a telephone or speaking tube.

57.19-91 *Mandatory.* Hoist operators shall accept hoisting instructions only by the regular signaling system unless it is out of order. In such an event, and during other emergencies, the hoist operator shall accept instructions to direct movement of the conveyances only from authorized persons.

57.19-92 *Mandatory.* A method shall be provided to signal the hoist operator from cages or other conveyances at any point in the shaft.

57.19-93 *Mandatory.* A standard code of hoisting signals shall be adopted and used at each mine. The movement of a shaft conveyance on a "one bell" signal is prohibited.

57.19-94 *Mandatory.* A legible signal code shall be posted prominently in the hoist house within easy view of the hoistmen, and at each place where signals are given or received.

57.19-95 *Mandatory.* Hoisting signal devices shall be positioned within easy reach of persons on the shaft bottom or constantly attended by a person stationed on the lower deck of the sinking platform.

57.19-96 *Mandatory.* Any person responsible for receiving or giving signals for cages, skips, and mantrips when men or materials are being transported shall be familiar with the posted signaling code.

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§ 57.20 Miscellaneous.

GENERAL—SURFACE AND UNDERGROUND

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57.20-32 *Mandatory.* Telephones or other two-way communication equipment with instructions for their use shall be provided for communication from underground operations to the surface.

[34 FR 12517, July 31, 1969, as amended at 35 FR 3677, Feb. 25, 1970; 42 FR 29424, June 8, 1977; 42 FR 57044, Oct. 31, 1977; 44 FR 31919, June 1, 1979; 44 FR 48535, Aug. 17, 1979]

§ 57.21 Gassy mines.

Gassy mines shall be operated in accordance with all mandatory standards in this part. Such mines shall also be operated in accordance with the mandatory standards in this section. The standards in this section apply only to underground operations.

MINE CLASSIFICATION

57.21-1 *Mandatory.* A mine shall be deemed gassy, and thereafter operated as a gassy mine, if:

(a) The State in which the mine is located classifies the mine as gassy; or

(b) Flammable gas emanating from the orebody or the strata surrounding the orebody has been ignited in the mine; or

(c) A concentration of 0.25 percent or more, by air analysis, of flammable gas emanating only from the orebody or the strata surrounding the orebody has been detected not less than 12 inches from the back, face, or ribs in any open workings; or

(d) The mine is connected to a gassy mine.

57.21-2 *Mandatory.* Flammable gases detected only while unwatering mines or flooded sections of mines or during other mine reclamation operations shall not be used to permanently classify a mine gassy. During such periods that any flammable gas is present in the mine, the affected areas of the mine shall be operated in accordance with appropriate standards in this Section 57.21.

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VENTILATION

57.21-20 *Mandatory.* Main fans shall be:

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(f) Provided with an automatic signal device to give warning or alarm should the fan system malfunction. The signal device shall be so located that it can be seen or heard by a responsible person at all times when persons are underground.

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57.21-29 *Mandatory.* Booster fans shall be:

(a) Provided with an automatic signal device to give warning or alarm should the fan system malfunction. The signal device shall be so located that it can be seen or heard by a responsible person at all times when persons are underground.

(b) Equipped with a device that automatically deenergizes the power in affected active workings should the fan system malfunction.

(c) Provided with air locks, the doors of which open automatically should the fan stop.

(d) Equipped with two sets of controls capable of starting, stopping, and reversing the fans. One set of controls shall be located at the fans. A second set of controls shall be at another location remote from the fans.

PART 75—MANDATORY SAFETY STANDARDS—UNDERGROUND COAL MINES

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§ 75.321 Stoppage of fans, plans.

[STATUTORY PROVISIONS]

Each operator shall adopt a plan on or before May 29, 1970, which shall provide that when any mine fan stops, immediate action shall be taken by the operator or his agent (a) to withdraw all persons from the working sections, (b) to cut off the power in the mine in a timely manner, (c) to provide for restoration of power and resumption of work if ventilation is restored within a reasonable period as set forth in the plan after the working places and other active workings where methane is likely to accumulate are reexamined by a certified person to determine if methane in amounts of 1.0 volume per centum or more exists therein, and (d) to provide for withdrawal of all persons from the mine if ventilation cannot be restored within such reasonable time. The plan and revisions thereof approved by the Secretary shall be set out in printed form and a copy shall be furnished to the Secretary or his authorized representative.

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§ 75.508-1 Mine tracks.

When mine track is used as a conductor of a trolley system, the location of such track shall be shown on the map required by § 75.508, with a notation of the number of rails and the size of such track expressed in pounds per yard.

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§ 75.516-2 Communication wires and cables; installation; insulation; support.

(a) All communication wires shall be supported on insulated hangers or insulated J-hooks.

(b) All communication cables shall be insulated as required by § 75.517-1, and shall either be supported on insulated or uninsulated hangers or J-hooks, or securely attached to messenger wires, or buried, or otherwise protected against mechanical damage in a manner approved by the Secretary or his authorized representative.

(c) All communication wires and cables installed in track entries shall, except when a communication cable is buried in accordance with paragraph (b) of this section, be installed on the side of the entry opposite to trolley wires and trolley feeder wires. Additional insulation shall be provided for communication circuits at points where they pass over or under any power conductor.

(d) For purposes of this section, communication cable means two or more insulated conductors covered by an additional abrasion-resistant covering.

[38 FR 4975, Feb. 23, 1973]

§ 75.517 Power wires and cables; insulation and protection.

[STATUTORY PROVISIONS]

Power wires and cables, except trolley wires, trolley feeder wires, and bare signal wires, shall be insulated adequately and fully protected.

§ 75.517-1 Power wires and cables; insulation and protection.

Power wires and cables installed on or after March 30, 1970, shall have insulation with a dielectric strength at least equal to the voltage of the circuit.

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§ 75.521 Lightning arresters; ungrounded and exposed power conductors and telephone wires.

Each ungrounded, exposed power conductor and each ungrounded, exposed telephone wire that leads underground shall be equipped with suitable lightning arresters of approved type within 100 feet of the point where the circuit enters the mine. Lightning arresters shall be connected to a low resistance grounding medium on the surface which shall be separated from neutral grounds by a distance of not less than 25 feet.

[38 FR 4975, Feb. 23, 1973]

§ 75.701-4 Grounding wires; capacity of wires.

Where grounding wires are used to ground metallic sheaths, armors, conduits, frames, casings, and other metallic enclosures, such grounding wires will be approved if:

(a) The cross-sectional area (size) of the grounding wire is at least one-half the cross-sectional area (size) of the power conductor where the power conductor used is No. 6 A.W.G., or larger.

(b) Where the power conductor used is less than No. 6 A.W.G., the cross-sectional area (size) of the grounding wire is equal to the cross-sectional area (size) of the power conductor.

§ 75.1003-1 Other requirements for guarding of trolley wires and trolley feeder wires.

Adequate precaution shall be taken to insure that equipment being moved along haulageways will not come in contact with trolley wires or trolley feeder wires.

§ 75.1003-2 Requirements for movement of off-track mining equipment in areas of active workings where energized trolley wires or trolley feeder wires are present; pre-movement requirements; certified and qualified persons.

(f) A minimum vertical clearance of 12 inches shall be maintained between the farthest projection of the unit of equipment which is being moved and the energized trolley wires or trolley feeder wires at all times during the movement or transportation of such equipment; provided, however, that if the height of the coal seam does not permit 12 inches of vertical clearance to be so maintained, the following additional precautions shall be taken:

(1)(i) Except as provided in paragraph (f)(1)(ii) of this section electric power shall be supplied to the trolley wires or trolley feeder wires only from outby the unit of equipment being moved or transported. (ii) Where direct current electric power is used

and such electric power can be supplied only from inby the equipment being moved or transported, power may be supplied from inby such equipment provided a miner with the means to cut off the power, and in direct communication with persons actually engaged in the moving or transporting operation, is stationed outby the equipment being moved.

(2) The settings of automatic circuit interrupting devices used to provide short circuit protection for the trolley circuit shall be reduced to not more than one-half of the maximum current that could flow if the equipment being moved or transported were to come into contact with the trolley wire or trolley feeder wire;

(3) At all times the unit of equipment is being moved or transported, a miner shall be stationed at the first automatic circuit breaker outby the equipment being moved and such miner shall be: (i) In direct communication with persons actually engaged in the moving or transporting operation, and (ii) capable of communicating with the responsible person on the surface required to be on duty in accordance with § 75.1600-1 of this part;

(4) Where trolley phones are utilized to satisfy the requirements of paragraph (f)(3) of this section, telephones or other equivalent two-way communication devices that can readily be connected with the mine communication system shall be carried by the miner stationed at the first automatic circuit breaker outby the equipment being moved and by a miner actually engaged in the moving or transporting operation; and,

§ 75.1402 Communication between shaft stations and hoist room.

[STATUTORY PROVISIONS]

There shall be at least two effective methods approved by the Secretary of signaling between each of the shaft stations and the hoist room, one of which shall be a telephone or speaking tube.

§ 75.1402-1 Communication between shaft stations and hoist room.

One of the methods used to communicate between shaft stations and the hoist room shall give signals which can be heard by the hoisting engineer at all times while men are underground.

§ 75.1402-2 Tests of signaling systems.

Signaling systems used for communication between shaft stations and the hoist room shall be tested daily.

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Subpart Q—Communications

§ 75.1600 Communications.

[STATUTORY PROVISIONS]

Telephone service or equivalent two-way communication facilities, approved by the Secretary or his authorized representative, shall be provided between the surface and each landing of main shafts and slopes and between the surface and each working section of any coal mine that is more than 100 feet from a portal.

§ 75.1600-1 Communication facilities; main portals; installation requirements.

A telephone or equivalent two-way communication facility shall be located on the surface within 500 feet of all main portals, and shall be installed either in a building or in a box-like structure designed to protect the facilities from damage by inclement weather. At least one of these communication facilities shall be at a location where a responsible person who is always on duty when men are underground can hear the facility and respond immediately in the event of an emergency.

[38 FR 29999, Oct. 31, 1973]

§ 75.1600-2 Communication facilities; working sections; installation and maintenance requirements; audible or visual alarms.

(a) Telephones or equivalent two-way communication facilities provided at each working section shall be located not more than 500 feet outby the last open crosscut and not more than 800 feet from the farthest point of penetration of the working places on such section.

(b) The incoming communication signal shall activate an audible alarm, distinguishable from the surrounding noise level, or a visual alarm that can be seen by a miner regularly employed on the working section.

(c) If a communication system other than telephones is used and its operation depends entirely upon power from the mine electric system, means shall be provided to permit continued communication in the event the mine electric power fails or is cut off; provided, however, that where trolley phones and telephones are both used, an alternate source of power for the trolley phone system is not required.

(d) Trolley phones connected to the trolley wire shall be grounded in accordance with Subpart H of this part.

(e) Telephones or equivalent two-way communication facilities shall be maintained in good operating condition at all times. In the event of any failure in the system that results in loss of communication, repairs shall be started immediately, and the system restored to operating condition as soon as possible.

[38 FR 29999, Oct. 31, 1973]

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§ 75.1713-2 Emergency communications; requirements.

(a) Each operator of an underground coal mine shall establish and maintain a communication system from the mine to the nearest point of medical assistance for use in an emergency.

(b) The emergency communication system required to be maintained under paragraph (a) of this § 75.1713-2 may be established by telephone or radio transmission or by any other means of prompt communication to any facility (for example, the local sheriff, the State highway patrol, or local hospital) which has available the means of communication with the person or persons providing emergency medical assistance or transportation in accordance with the provisions of § 75.1713-1.

APPENDIX C.--EQUIPMENT SUPPLIERS

Pager Phones (And Associated Equipment)

Appalachian Electronics
801 West Monroe Ave.
Ronceverte, WV 24970

ComTrol Corp.
500 Penna. Ave.
Irwin, PA 15642

CSE Mine Service Co.
600 Seco Rd.
Monroeville, PA 15146

Fairmont Supply Co.
Box 501
Washington, PA 15301

FEMCO (See National Mine Service Co.)

Gai-Tronics Corp.
P.O. Box 31-T
Reading, PA 19603

Harrison R. Cooper Systems, Inc.
AME Box 22014
Salt Lake City, UT 84122

JABCO (See Schroeder Brothers Corp.)

Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA 15235

National Mine Service Co.
4900/600 Grant St.
Pittsburgh, PA 15219

Preiser/Mineco
Jones & Oliver Sts.
St. Albans, WV 25177

Pyott-Bonne, Inc.
P.O. Box 809
Tazewell, VA 24651

Schroeder Brothers Corp.
Nichol Ave.
Box 72
McKees Rocks, PA 15136

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

Carrier Phones

American Mine Research, Inc.
P.O. Box 1628
Bluefield, WV 24701

ComTrol Corp.
500 Penna. Ave.
Irwin, PA 15642

CSE Mine Service Co.
600 Seco Rd.
Monroeville, PA 15146

Fairmont Supply Co.
Box 501
Washington, PA 15301

FEMCO (See National Mine Service Co.)

Harrison R. Cooper Systems, Inc.
AMF Box 22014
Salt Lake, UT 84122

Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA 15235

National Mine Service Co.
4900/600 Grant St.
Pittsburgh, PA 15219

Hoist Communications

ComTrol Corp.
500 Penna. Ave.
Irwin, PA 15642

Fairmont Supply Co.
Box 501
Washington, PA 15301

FEMCO (See National Mine Service Co.)

Harrison R. Cooper Systems, Inc.
AMF Box 22014
Salt Lake City, UT   84122

Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA   15235

National Mine Service Co.
4900/600 Grant St.
Pittsburgh, PA   15219

Republic Wire and Cable
P.O. Box 352
Flushing, NY   11352

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

PABX and Multiplex Equipment

Anaconda Telecommunications
305 North Muller
Anaheim, CA   92801

Essex Group
800 East Garfield Ave.
Decatur, IL   62525

Executone, Inc.
Dept. TR-77
Long Island City, NY   11101

Phelps Dodge Communication Co.
5 Corporate Park Dr.
White Plains, NY   10604

Pulsecom Div.
Harvey Hubbell, Inc.
5714 Columbia Pike
Falls Church, VA   22041

Reliable Electric Co.
11333 West Addison
Franklin Park, IL   60131

TII Industries, Inc.
100 North Strong Ave.
Lindenhurst, NY   11757

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

Intercoms

ComTrol Corp.
500 Penna. Ave.
Irwin, PA   15642

Executone, Inc.
Dept. TR-77
Long Island City, NY   11101

FEMCO (See National Mine Service Co.).

Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA   15235

National Mine Service Co.
4900/600 Grant St.
Pittsburgh, PA   15219

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

Radio Pocket Pagers

Executone, Inc.
Dept. TR-77
Long Island City, NY   11101

FEMCO (See National Mine
  Service Co.)

General Electric Co., Mobile Radio Dept.
P.O. Box 4197
Lynchburg, VA   24502

National Mine Service Co.
4900/600 Grant St.
Pittsburgh, PA   15219

Leaky Feeder Equipment

Andrew Corp.
10500 West 153d St.
Orland Park, IL   60462

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

Mobile Radio Equipment

Fairmont Supply Co.
Box 501
Washington, PA   15301

General Electric Co., Mobile
 Radio Dept.
P.O. Box 4197
Lynchburg, VA   24502

Motorola Communications & Electronics
1301 East Algonquin Rd.
Schaumburg, IL   60196

Lee Engineering
2025 West Wisconsin Ave.
Milwaukee, WI   53201

Phelps Dodge Communication Co.
5 Corporate Park Dr.
White Plains, NY   10604

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

Closed Circuit Television

Midwest Telecommunications Div.,
Midwest Corp.
300 T First Ave.
Nitro, WV   25143

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

Remote Control and Monitor Equipment

American Mine Research, Inc.
P.O. Box 1628
Bluefield, WV   24701

BIF Accutel Inc.
1339 Lawrence Dr.
Newbury Park, CA   91320

ComTrol Corp.
500 Penna. Ave.
Irwin, PA   15642

FEMCO (See National Mine Service Co.)

General Electric Co., Mobile Radio Dept.
P.O. Box 4197
Lynchburg, VA   24502

General Equipment & Manufacturing
 Co., Inc.
3300 Fern Valley Rd.
P.O. Box 13226
Louisville, KY   40213

Mag-Con, Inc.
1626 Terrace Dr.
St. Paul, MN   55113

Mine Safety Appliances Co.
600 Penn Center Blvd.
Pittsburgh, PA   15235

National Mine Service Co.
4900/600 Grant St.
Pittsburgh, PA   15219

Notifier of Western Penn. Inc.
3460 Babcock Blvd.
Pittsburgh, PA   15237

Pace Transducer Co., Div. of
 C. J. Enterprises
P.O. Box 834
Tarzana, CA   91356

Pulsecom Div.
Harvey Hubbell, Inc.
5714 Columbia Pike
Falls Church, VA   22041

Pyott-Bonne, Inc.
P.O. Box 809
Taxewell, VA   24651

RFL Industries, Inc.
Boonton, NJ   07005

Stevens International Inc.
P.O. Box 619
Kennett Square, PA   19348

Winster Engineering Ltd.
Manners Ave.
Ilkeston, Derbyshire
United Kingdom

Environmental Sensors

Methane:

  Mine Safety Appliances Co.
  201 North Braddock Ave.
  Pittsburgh, PA 15208

  National Mine Service Co.
  300 Koppers Bldg.
  Pittsburgh, PA 15216

  Bacharach Instrument Co.
  625 Alpha Dr.
  Pittsburgh, PA 15238

  CSE Mine Service Co.
  2000 Eldo Rd.
  Monroeville, PA 15146

  Preiser/Mineco
  Jones and Oliver Sts.
  St. Albans, WV 25177

  Appalachian Electronics Instruments
  810 West Monroe Ave.
  Ronceverte, VA 24970

  American Mine Research, Inc.
  P.O. Box 1628
  Bluefield, WV 24701

Carbon monoxide:

  Mine Safety Appliances
  201 North Braddock Ave.
  Pittsburgh, PA 15208

  Energetics Sciences
  85 Executive Blvd.
  Elmsford, NY 10523

Oxygen:

  Beckman Instruments Inc.
  3900 River Rd.
  Schiller Park, IL 60176

Edmont-Wilson
1300 Walnut St.
Coshocton, OH 43812

Mine Safety Appliances Co.
201 North Braddock Ave.
Pittsburgh, PA 15208

Survivair Div. of U.S. Divers
3323 West Warner Ave.
Santa Ana, CA 91776

Teledyne Analytical Instruments
333 West Mission
San Gabriel, CA 91776

Oxides of nitrogen:

  Energetics Sciences
  85 Executive Blvd.
  Elmsford, NY 10523

Air flow sensors:

  Alnor Instrument Co.
  7301 North Caldwell Ave.
  Niles, IL 60648

  J-Tec Associates, Inc.
  317 Seventh Ave. SE
  Cedar Rapids, IA 52401

  Taylor Instrument
  Consumer Products Div.
  Arden, NC 28704

Atmospheric pressure:

  Pace Transducer Co., Div. of
  C. J. Enterprises
  P.O. Box 834
  Tarzana, CA 91356

  Leeds and Northrup Co.
  Dept. MD337
  North Wales, PA 19454

Seismic Equipment

Pace Transducer Co., Div. of
C. J. Enterprises
P. O. Box 834
Tarzana, CA   91356

Consultants

Arthur D. Little, Inc.
25 Acorn Park
Cambridge, MA   02140

Advance Mining Services
616 Beatty RD.   Industrial Court
Monroeville, PA   15146

ComTrol Corp.
500 Penna. Ave.
Irwin, PA   15642

CSE Mine Service Co.
600 Seco Rd.
Monroeville, PA   15146

Fairmont Supply Co.
Box 501
Washington, PA   15301

General Electric Co., Mobile Radio Dept.
P.O. Box 4197
Lynchburg, VA   24502

Midwest Telecommunications Div.,
 Midwest Corp.
300 T First Ave.
Nitro, WV   25143

Mineral Services Inc.
1276 West Third St.
Cleveland, OH   44113

National Coal Board
Mining Research and Development
 Establishment
Stanhope Bretby
Burton Upon Trent DEISOQD
United Kingdom

National Mine Service Co.
4900/600 Grant St.
Pittsburgh, PA   15219

Pyott-Bonne, Inc.
P.O. Box 809
Tazewell, VA   24651

Corma Resources
2857 Mount Vernon SE
Cedar Rapids, IA   52403

U.S. Bureau of Mines
4800 Forbes Avenue
Pittsburgh, PA   15213

Winster Engineering Ltd.
Manners Avenue
Ilkeston, Derbyshire
United Kingdom

Fire Detection Devices

ADT Co., Inc.
155 Sixth Ave.
New York, NY   10013

The Ansul Co.
One Stanton St.
Marinette, WI   54143

B. & B. Electric Manufacturing Co.
Seward, PA   15954

Gammaflex Corp.
821 Michael Faraday Dr.
Reston, VA   22070

JABCO
Schroeder Brothers Corp.
P.O. Box 72
Nichol Ave.
McKees Rocks, PA   15136

McJunkin Corp.
P.O. Boc 2473
1400 Hansford St.
Charleston, WV   25311

Mine Safety Appliances Co.
201 North Braddock Ave.
Pittsburgh, PA   15203

National Mine Service Co.
3000 Koppers Bldg.
436 Seventh Ave.
Pittsburgh, PA   15219

Notifier of Western Pennsylvania
3283 Babcock Blvd.
Pittsburgh, PA   15237

Prieser
Jones and Oliver Sts.
St. Albans, WV   25177

Pyott-Boone, Inc.
P.O. Box 809
Tazewell, VA   24651

Southern Engineering and Equipment Co.
P.O. Drawer 329
95 Third St., NE
Graysville, AL   35073

General Cable Corp.
600 Reed Rd.
Broomall, PA   19008

Industrial Component Inc.
342 Madison Ave.
Suite 702
New York, NY   10017

Okonite Co.
100 Hilltop Rd.
Ramsey, NJ   07446

Figure-8 Communication Cable

Delphi Wire & Cable
700 Carpenters Crossing
Folcroft, PA   19032

APPENDIX D.---GLOSSARY OF TERMS

Analog
A method of generating or transmitting information that is repre-sented by a continuous (as opposed to digital) voltage or current that is proportional to the information.

Angstrom
A unit of length. Usually used to measure the wavelength of light or other radiation. One angstrom is equal to one hundred-millionth of a centimeter.

AM
Abbreviation for "amplitude modulation." Modulation in which the amplitude of the information waveform modulates the amplitude of a carrier wave.

Attenuation
The decrease in signal strength during its transmission from one point to another. Attenuation is usually expressed in decibels.

Balance point
In an electronic bridge circuit, the point at which the electrical resistances in both branches of the network are the same.

Bandwidth
The difference (in cycles per second) between the highest and lowest frequency components required for the adequate transmission of information.

Baseband
The original frequency band (before modulation) of a signal. Usu-ally refers to the baseband of an audio or voice signal, which is approximately 300 to 5,000 Hz.

Binary
A digital numbering system with the base 2. In a binary system there are only two possibilities for each digit, selection, choice, or condition. For example, a simple switch is a binary device since it is either open or closed.

Bridge
An electrical bridge circuit is a network arranged so that voltage or current in one branch of the circuit may be measured by adjusting components in another branch of the circuit.

CATV
Abbreviation for "community antenna television," commonly known as cable television.

Characteristic impedance
Pertaining to transmission lines. For a uniform and infinitely long line, it is the ratio of applied voltage to current induced at a given frequency. It is measured in ohms and usually designated as Zo. For maximum signal transfer, the Zo of a line should equal the Zo of a source and load.

CO
Abbreviation for "central office." Refers to the telephone com-pany's central office.

Cross talk
Cross-coupling or interference between speech channels or wire pairs.

dB
Abbreviation of "decibel," a unit that represents the ratio between two amounts of power on a logarithmic scale. A value of +3 dB in-dicates a doubling of power, while -3 dB is a halving of power.

dBm	The normal signal level in a pager phone is about 1 milliwatt (1 mW). The designation 0 dBm is used to indicate this 1-mW reference level. Thus, +3 dBm is 3 dB above the reference (2 mW) and -3 dBm is 3 dB below the reference (0.5 mW).
Demodulation	A device that receives a carrier wave and recovers or "reconstructs" the original voice or information signal from the carrier wave.
DTMF	Abbreviation for "dual-tone multifrequency." A phone signaling method in which each digit dialed is converted to a dual-tone signal that will be recognized by the telephone office or PABX switching equipment. These control tones can be heard in the earpiece when dialing on many pushbutton phones.
Electromagnetic	Having both electric and magnetic properties.
Encoder	A unit that produces coded output combinations depending upon the specific input selected.
FDM	Abbreviation for "frequency-division multiplexing." A process in which two or more signals are sent over a common path by sending each one in a different frequency band.
Feedback	In a transmission system, or electrical device, the returning of a fraction of the output signal to the input.
FM	Abbreviation for "frequency modulation." Modulation in which the amplitude of the information waveform modulates the frequency of a carrier signal.
FSK	Abbreviation for "frequency-shift keying." A form of FM in which a binary code is transmitted by switching a carrier signal between two different frequencies.
Geophone	A device used to detect seismic vibrations or shockwaves in the earth.
Hall effect	In a conductor located in a magnetic field that is perpendicular to the direction of current, the production of a voltage perpendicular to both the current and the magnetic field.
Handset	A receiver-transmitter held by hand.
Headset	A receiver-transmitter that can be attached to the person to allow "hands-free" operation.
Hybrid	A circuit or communications system that is made up of two or more dissimilar systems.
Hz	Abbreviation for Hertz. A unit of frequency equal to 1 cycle per second.
Impedance	The total opposition (reactance plus resistance) that a circuit or transmission line offers to the flow of electrical current.

Inductively coupled	Method of inducing a signal into one conductor or wire from another conductor even though there may be no mechanical connection between the two conductors. (The magnetic field set up in the space around a conductor carrying alternating current will induce a signal in other nearby conductors.)
Joule heating	In an electrical circuit, the heat produced by the flow of current in the circuit.
Leaky feeder	A specially designed coaxial cable that allows radio signals to leak into or out of the cable so that they may be picked up by radio transceivers.
LED	Abbreviation for "light-emitting diode." A solid state electronic device that emits light when a current flows through it.
Magnetic field	The region surrounding a magnet or a conductor through which current is flowing.
Magneto	An ac generator for producing ringing signals.
Milliammeter	An electric current meter calibrated in milliamperes.
Modem	A device that is both a modulator and a demodulator. A modem is a two-way device that both modulates (transmits) and receives (demodulates) a signal.
Modulator	A device that modulates a voice or information signal and transmits the resulting carrier wave.
Monochromatic	A signal or beam of light consisting of a single wavelength or of a very small range of wavelengths.
Multiplexed	The simultaneous transmission of two or more signals using a single transmission path or wire.
PABX	Abbreviation for "private automatic branch exchange." A private branch exchange in which automatically controlled switches make connections between the phones in the system.
PAM	Abbreviation for "pulse amplitude modulation." Modulation in which the value or amplitude of each sample of the information waveform modulates the amplitude of a pulse carrier.
Parasitic coupling	The coupling of radio waves or electrical signals from one wire or medium to another with the result that the signal strength in the first conductor is decreased.
PBX	Abbreviation for "private branch exchange." A private manual telephone exchange requiring an operator at a switchboard to make connections between the phones.
PCM	Abbreviation for "pulse coded modulation." Modulation in which the value or amplitude of each sample of the information waveform is quantitized and transmitted as a digital binary code.

PDM	Abbreviation for "pulse duration modulation." Modulation in which the value or amplitude of each sample of the information waveform modulates the duration, or "width," of a pulse.
Piezoelectric	The property of certain crystals or materials that produce a voltage when subjected to mechanical stress.
Potentiometer	An electromechanical device with a sliding contact on a resistor. Movement of the sliding contact changes the electrical resistance of the circuit and allows the electronics to sense the position of the sliding contact.
PPM	Abbreviation for "pulse position modulation." Modulation in which the value or amplitude of each sample of the information waveform modulates the position in time of a pulse.
Propagation	The travel of electromagnetic (radio) or sound waves through a medium.
PSK	Abbreviation for "phase shift keying." A form of FM in which a binary code is transmitted by shifting the phase of a carrier signal.
Q	The "Q" of an ac circuit is the ratio of its reactance to its resistance. The voltage developed across the reactance is usable signal, but the voltage developed across the resistance subtracts from the signal. Thus, a high Q indicates an efficient, low-loss ac circuit.
Reactance	The opposition to the flow of alternating current (ac). Capacitive reactance (X_C) is the opposition offered by capacitors, and inductive reactance (X_L) is the opposition offered by a coil or other inductance.
rf	Abbreviation for radiofrequency. Any frequency at which electromagnetic radiation of energy (radio waves) is possible.
RFI	Radio frequency interference.
Reluctance	The resistance of a magnetic path to the flow of magnetic line of force. Aluminum has a high reluctance; iron has a low reluctance.
Repeater	A device that detects or receives a signal and rebroadcasts the same signal.
Resistance	The opposition to the flow of direct current (dc). The unit of resistance is the ohm.
Resonate	To bring to resonance; to tone.
Simplex	A communication system, or other device, that operates in only one direction (either transmit or receive) at a time.

Sine wave	The wave form corresponding to a pure, single-frequency oscillation.
SWR	Abbreviation for "standing wave ratio." On a transmission line or antenna element the current and voltage set up by waves traveling in the opposite direction are characterized by the presence of a number of stationary maximum and minimum points in the distribution curve. SWR is the ratio of the maximum to minimum current or voltage of these stationary waves.
Synchronize	To maintain one operation (or signal) in step with another.
TDM	Abbreviation for "time-division multiplexing." A process by which two or more channels of information are transmitted over the same link by allocating a different time interval for the transmission of each channel.
Transducer	A device that converts energy from one form to another. A seismic transducer, for instance, converts seismic shock waves into electrical signals.
Transceiver	A device that is both a transmitter and a receiver. A two-way CB radio is a transceiver.
Tuned voltmeter	A voltmeter that has been tuned to detect voltage levels or signal strengths at specific frequencies.
UHF	Ultra high frequency, 300 to 3,000 MHz
Ultrasonic	Having a frequency above that of audible sound.
vf	Abbreviation for voice frequency (same as audio frequency). The frequencies corresponding to speech or other audible sound wave.
VHF	Very high frequency, 30 to 300 MHz.
Vortex	A whirlpool or eddy caused by a fluid or gas moving past an obstruction.
Waveguide	A hollow, round or rectangular pipe (or tunnel), used as a transmission line for signaling.