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 16 14	67 42 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:

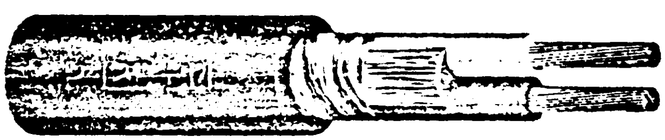


FIGURE 5-1. - Single-pair type SO neoprene cable.

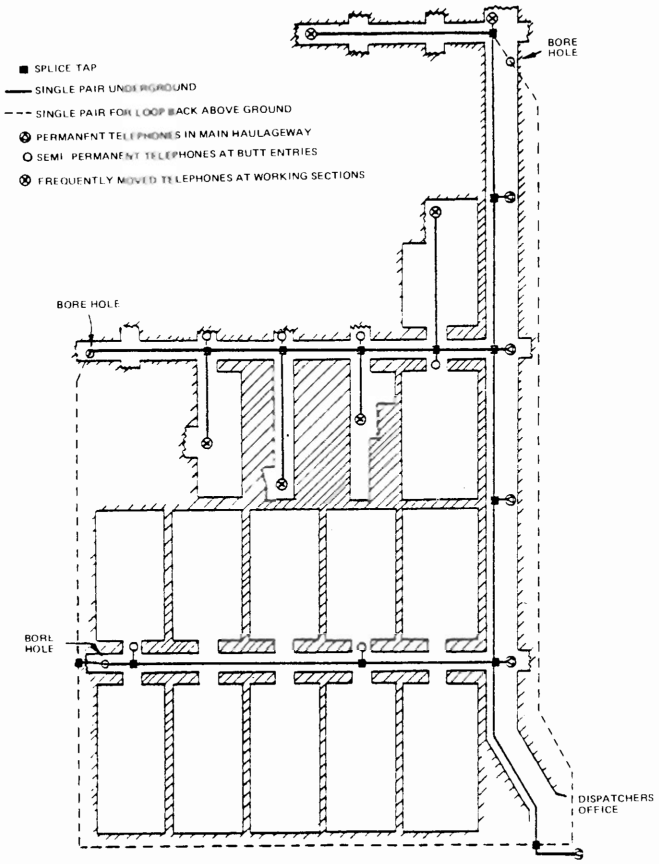


FIGURE 5-2. - Single-pair installation in typical mine.

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 nct 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.

$$54 \text{ lengths} \times 0.57 \text{ mile per length} = 30 \text{ miles of additional cable}$$

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

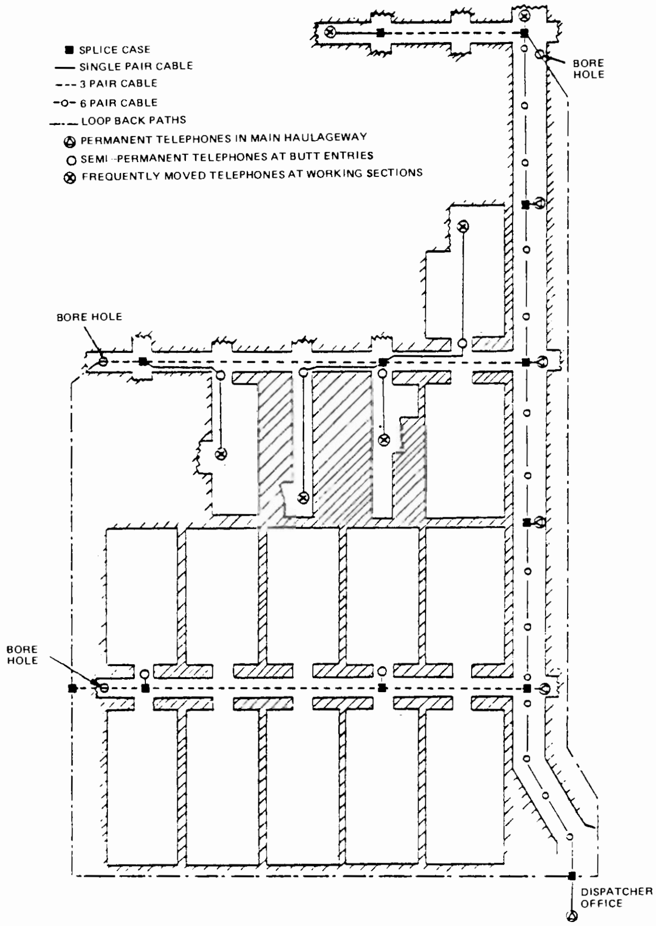


FIGURE 5-3. - Multipair installation in typical mine.

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 (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

[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.

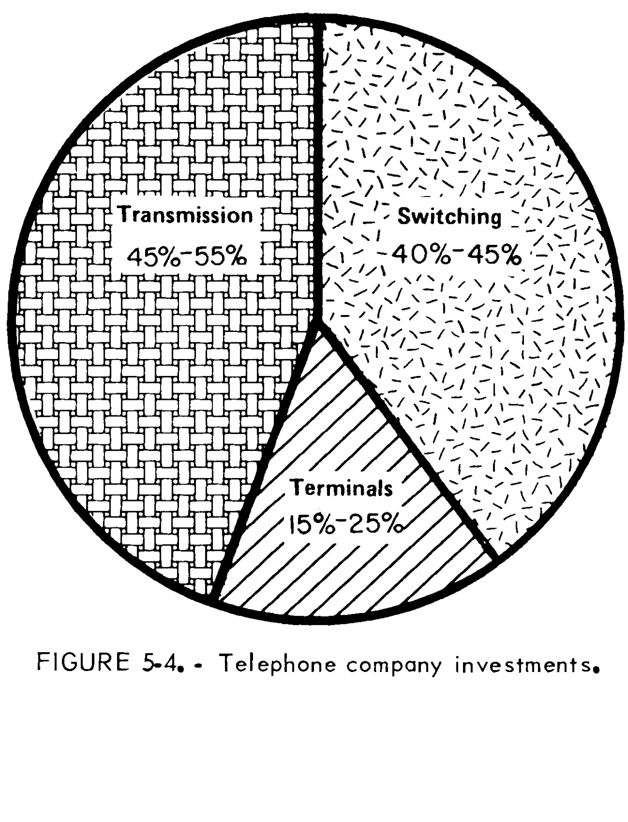


FIGURE 5-4. - Telephone company investments.

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 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 i/2 mile.

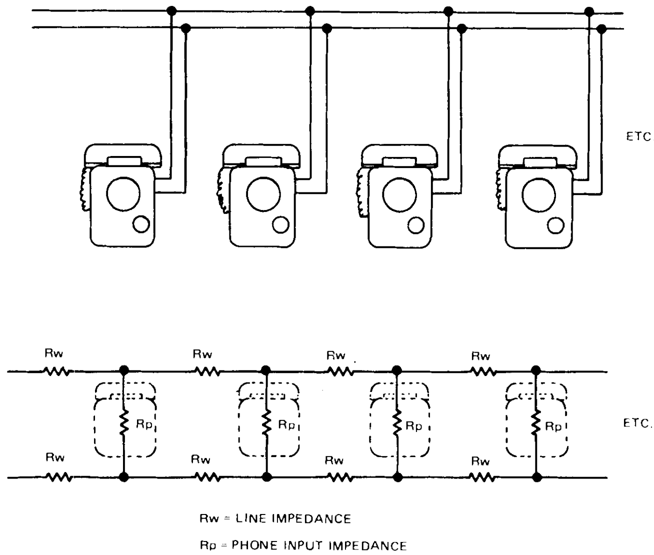


FIGURE 5-5. - Basic ladder configuration.

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 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.

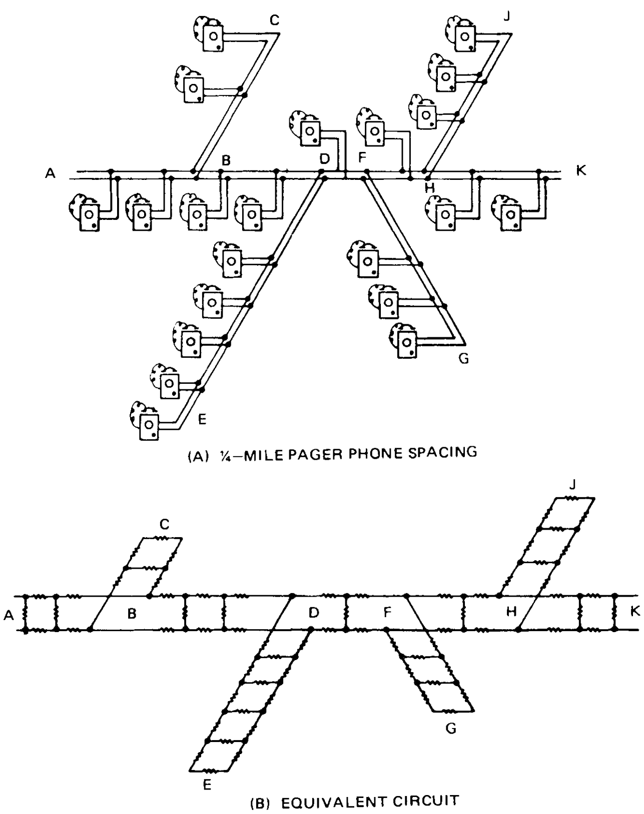


FIGURE 5-6. - Branching ladder network.

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.

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 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

[1] Approved and nonapproved equipment may not share the same cables; check with MSHA for details.

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.

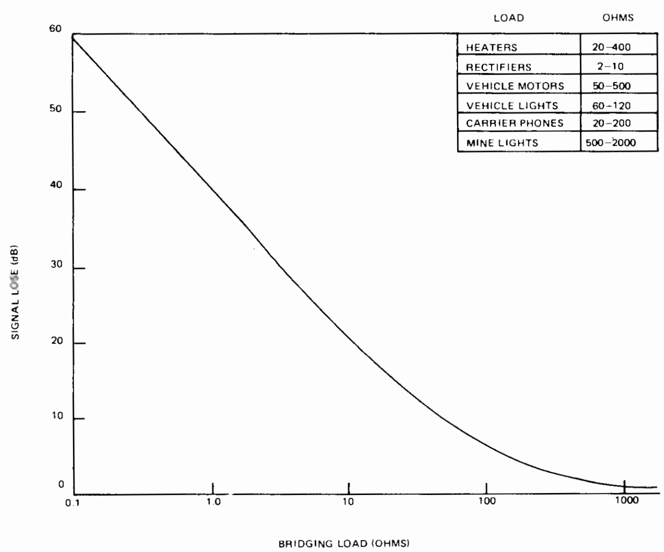


FIGURE 5-7. - Signal loss versus bridging load.

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 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. 5-8*A*). 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. 5-8*B*); 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. 5-8*C*). 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

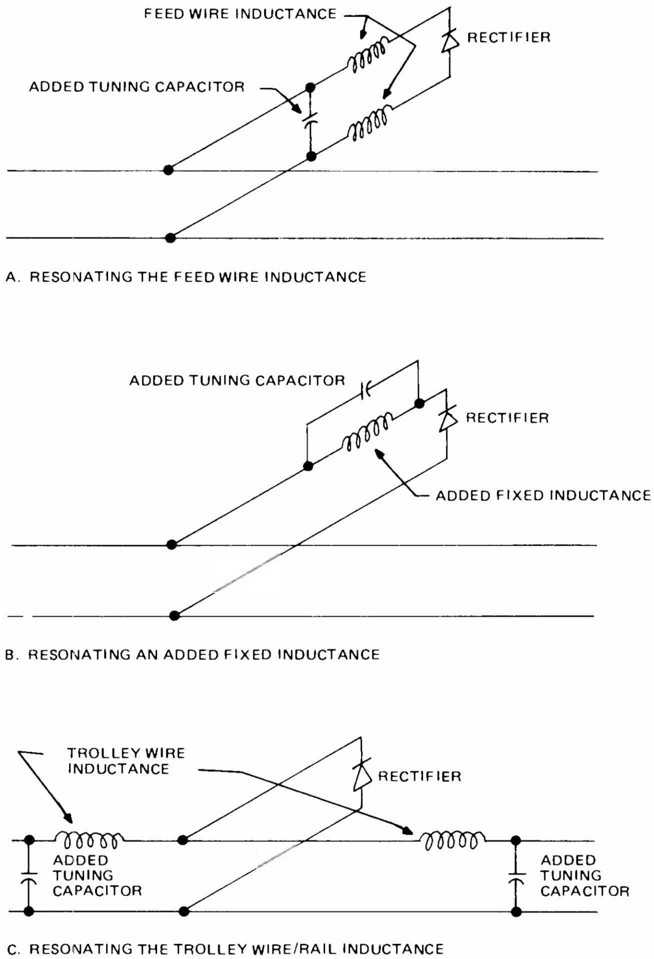


FIGURE 5-8. - Ways of raising the impedance of a rectifier.

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

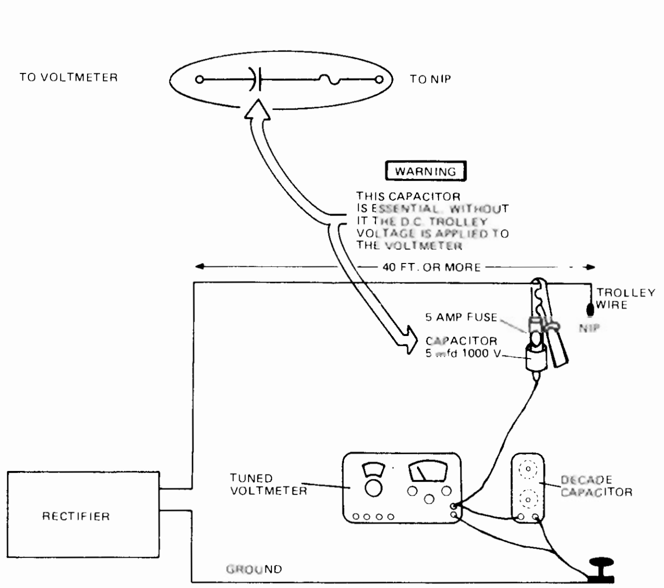


FIGURE 5-9. - Test configurations for tuning feeder wire.

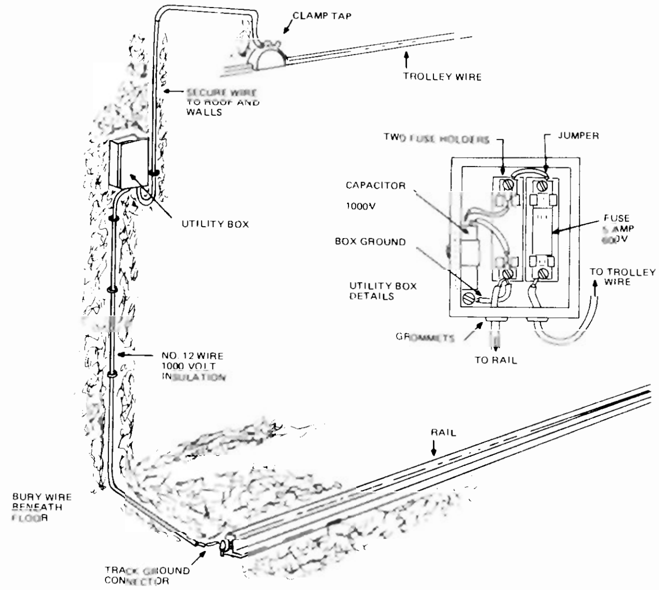


FIGURE 5-10. - Permanent installation of tuning elements for feeder wire.

WARNING

Some of these procedures are undertaken with the trolley wire energized; 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.

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 instances 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 installation has been made, a final check, using the tuned voltmeter, should be made to ascertain that the originally indicated 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 leaving 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 inductance that can be tuned. Because feeder wire is expensive, a coil in the so-called Brooks form, which yields the maximum 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

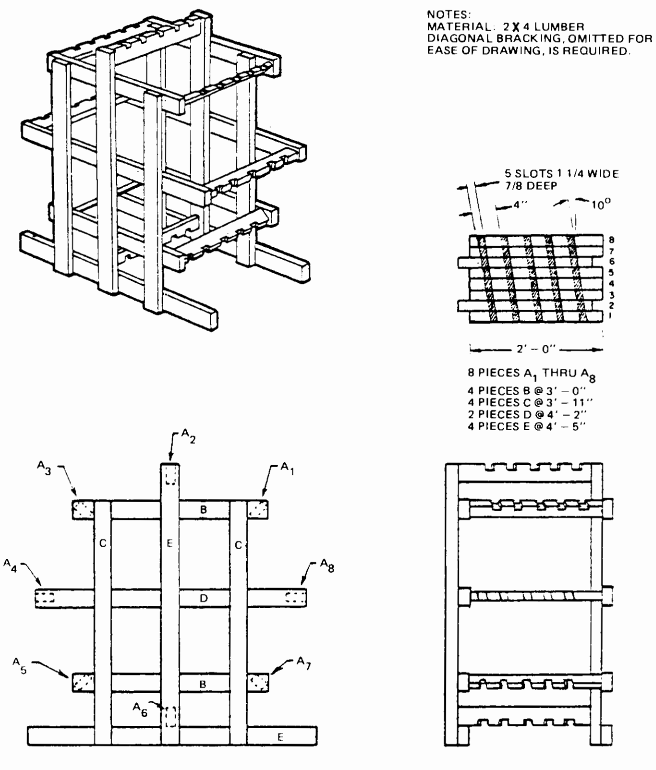
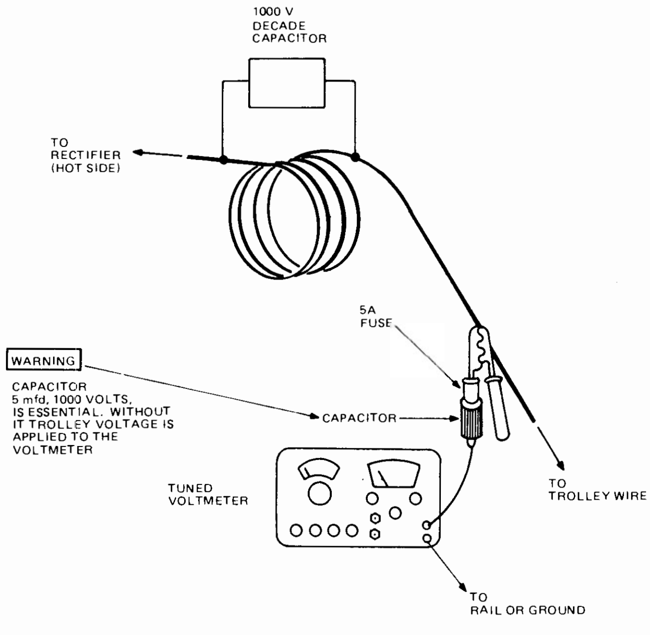


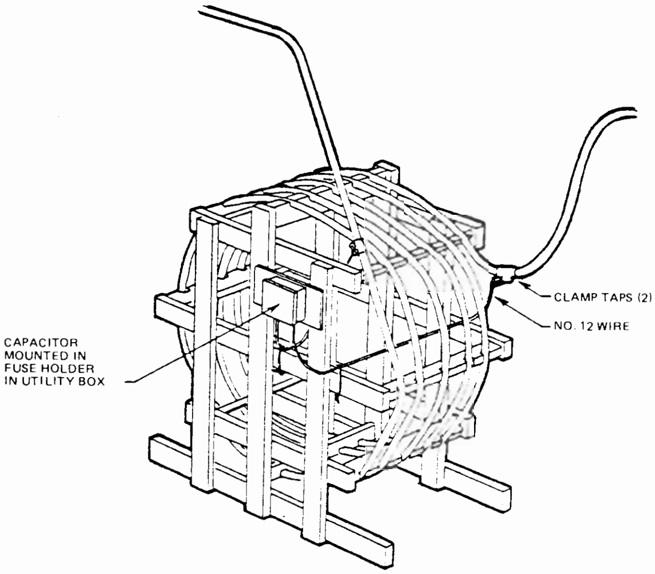
FIGURE 5-11. - Coil form.



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 5-12. - 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 5-13. - 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

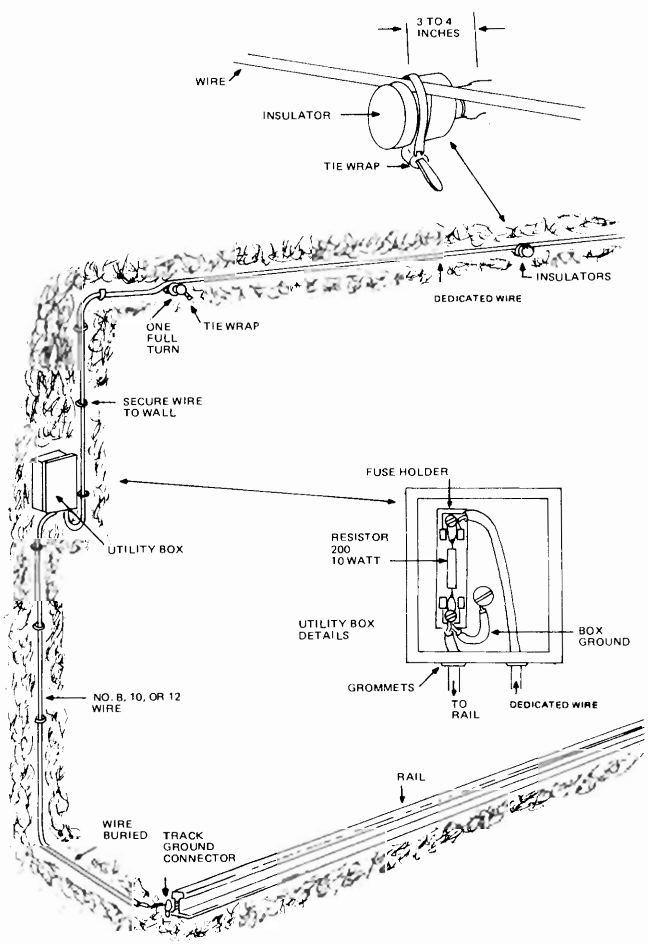


FIGURE 5-14. - Termination of the dedicated wire.

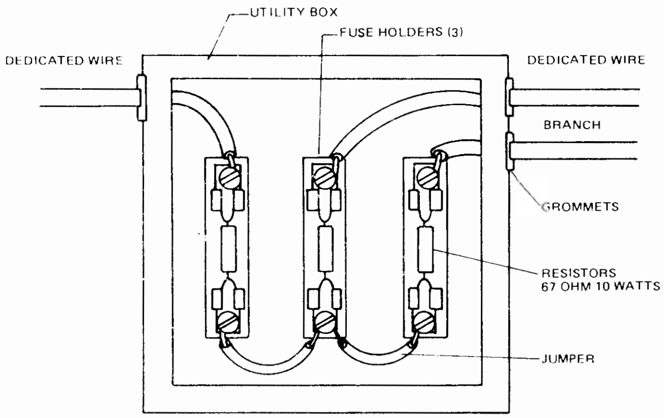


FIGURE 5-15. - Signal splitter.

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.

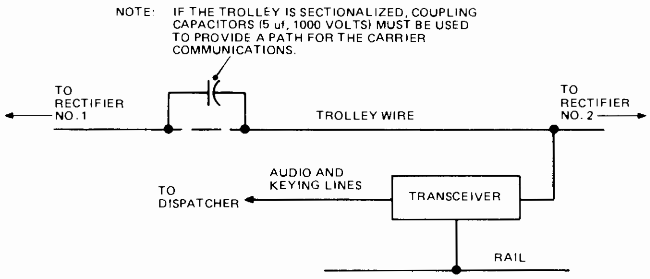
As noted before, the use of branches should be minimized. When the routes are short, (considerably less than 10 miles), resort can be made to branches on a dedicated wire. When more than one wire is used, they should be run in separate entryways. The reason that branches are undesirable is that a branch 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.



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 5-16. - 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 assure optimum operation of the trolley carrier phone system when installed:

1. If the trolley wire is sectionalized, 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 auxiliary 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 transceivers that show a high value of standby impedance.

5. Insist that vehicle manufacturers indicate the 88- to 100-kHz operating impedance of their vehicles, and select vehicles that show high operating impedance 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 frequency 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 categories: single pair (party-line), multipair, and multiplex phone systems. A major 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 conversations but until recently did not possess the paging ability.

All three of these systems can usually be improved if the basic reasons for poor performance or high noise levels are understood. For instance:

Heavier gage wire presents less attenuation to the signal and results in better coverage over greater distance.

Splicing technique has a large effect 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

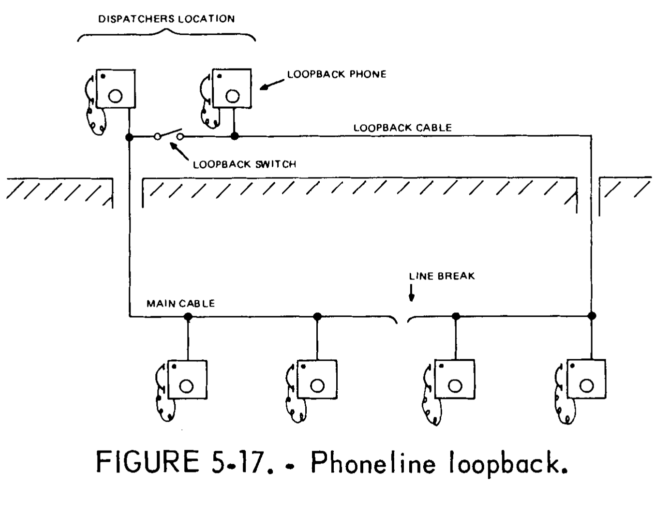


FIGURE 5-17. - Phoneline loopback.

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.

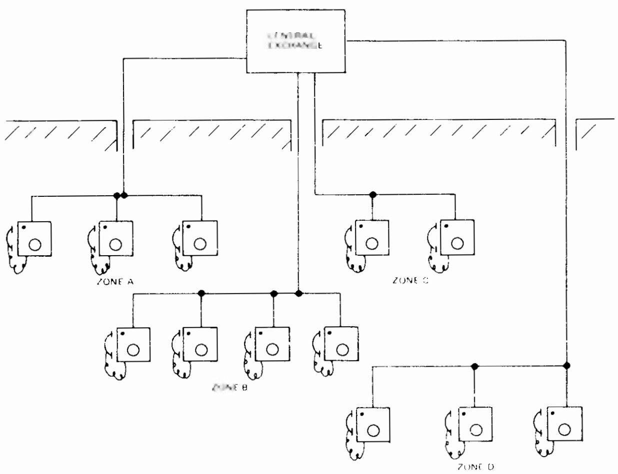


FIGURE 5-18. - Sectionalization of a phone system.

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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