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**TECHNICAL SERVICES FOR MINE
COMMUNICATIONS RESEARCH**

**APPLICABILITY OF AVAILABLE
MULTIPLEX CARRIER EQUIPMENT
FOR MINE TELEPHONE SYSTEMS**

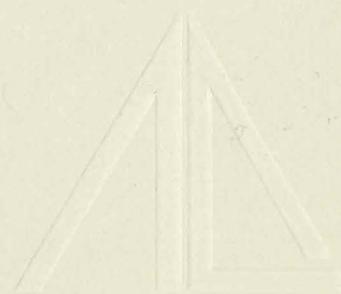
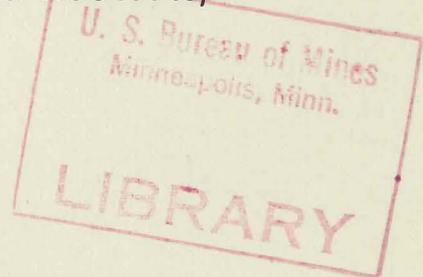
Robert L. Lagace - Task Leader
Warren G. Bender, John D. Foulkes, Paul F. O'Brien

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

USBM CONTRACT REPORT – TASK D (Contract No. HO346045)
TASK ORDER NO. 1

June 1975

ARTHUR D. LITTLE, INC.
Cambridge, Massachusetts



Arthur D. Little, Inc.

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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

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BUREAU OF MINES

FOREWORD

This report was prepared by Arthur D. Little, Inc., Cambridge, Massachusetts under USBM Contract No. HO346045. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Howard E. Parkinson acting as the technical project officer. Mr. Michael W. College was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period May 1974 to June 1975. This report was submitted by the authors in June 1975.

No inventions or patents were developed and no applications for inventions or patents are pending.

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I. EXECUTIVE SUMMARY

A. OBJECTIVE

The purpose of the work reported herein was to investigate whether available telephone multiplexing equipment offered a means to rapidly upgrade the traffic-handling capacity of present mine telephone systems and provide for selective calling for safer and more efficient mine operation.

Common sense was used to decide whether or not an item could be termed "available." Since conventional telephone gear is not designed to interface pager phones for example, existing shelf items would require adapters to compatibly interface these two types of gear for independent operation over the present single twisted pair used in mines. These and similar small items were allowed, but if a system required any extensive design work to adapt it for the mines, we ruled it "not available."

B. TASKS

The work was broken into three study areas, as follows:

1. Mine Topology and Existing Equipment

In order to establish the configuration of a mine multiplex telephone system, and the changes in configuration which such systems would face, we studied the topology of actual mines, and the mine telephone equipment used, and formulated a "Representative Mine" to use for cost comparison purposes. We developed for this representative mine the location of telephones as dictated by legal and practical considerations, the frequency with which different categories of telephones would be moved, the extent and type of wire for the twisted pair, and, lastly, the cost of the existing twisted pair. The results of these studies are presented in Section 2 of this report.

2. Available Multiplexing Equipment

We surveyed and examined available telephone multiplexing equipment (civilian and military), and such closely related equipment as subscriber line multiplexers, concentrators, and non-telephone multiplex systems. We studied the human factors involved in installing and maintaining such equipment in mines and the electromagnetic environment it would be subjected to. For cost comparison purposes, we chose a multiplex system which looked practical, the Anaconda S6A, and performed the exercise of defining and costing two alternative installations in the representative mine. In addition, we made a cursory examination of an experimental system proposed by Lee Engineering which, although not

available, appears to us to be practical, state of the art, and capable of being developed at a reasonable cost. The multiplex carrier equipment is discussed in Section 3 of this report.

3. Multipair Systems

Since multiplex systems are generally alternatives for copper pairs, we studied the practicality and cost of installing a multipair cable in underground mines to perform the same telecommunication functions as the multiplex systems. The results of this study are presented in Section 4 of this report.

C. FINDINGS

1. Mine Topology and Existing Equipment

Three significant items emerged from the first part of our study.

a. Telephone Locations

Looking at the permanence of a telephone installation, one can divide phone locations into three categories:

- | | |
|----------------------|--|
| (1) Permanent | These telephones stay in place for the life of the mine. (Most of them are in the main haulage-way.) |
| (2) Semi-Permanent | These have more than a year between moves. (These are in the submains.) |
| (3) Frequently Moved | These phones are moved weekly or monthly. (These are in the working sections.) |

b. Communication Requirements

Based on the limited data and survey results available, we estimate that 2 to 8 channels, depending on the activity of the mine, should be sufficient to provide efficient service for the working sections and the haulageways. (Very small mines should not need added channels.)

c. Single Pair Cable Costs

We found that the cost of the single pair represents a significant capital investment. When our typical mine had reached a stage of development having six submains, the wire costs could be:

(1) Using 14 AWG neoprene and not reusing any cable (a common practice)	\$59,800
(2) Using 14 AWG neoprene cable, and reusing section cable as needed	17,200
(3) Using 14 AWG for all mains, 18 AWG for sections and not reusing cable	25,100

2. Available Multiplexing Equipment

Our survey of existing equipment reveals that only two or three systems could even be considered as candidates for mine application. The following are some of the reasons why many available systems were judged unsuitable for mines:

- Most existing systems are large (24 channels), digital systems designed to operate over *two* specially conditioned pairs.
- Many systems are not designed to drop individual channels along the pair over which they operate. They demodulate the carrier channels at one point and wire pairs radiate from this point to individual telephones.
- Some of the systems demand 110 volt ac power at the channel drop and this limits their application at many mine locations.

Of the candidate systems, the Anaconda S6A was judged the most suitable for further study for the following reasons:

- It provides seven channels over a single pair.
- It can drop single channels along the carrier route.
- It is rugged and has good environmental specifications.
- It is inexpensive.
- It powers the remote, in-mine units by trickle charging batteries over the twisted pair and thus, although creating other problems listed below, eliminates problems associated with installation and maintenance.

For mine application, however, the system drawbacks are:

- The system is designed to operate with conventional telephones which are not permissible. It cannot, without extensive redesign, interface pager phones.
- If the existing pager phones are to be left in place on the mine telephone line, each pager phone must be provided with an expensive adapter (we estimate \$300 a copy) to allow the pager phones and the multiplex system to operate independently and without mutual interference over the twisted pair.
- The system puts high dc voltages on the twisted pair, up to 270 volts dc.
- Trolley phone interference will probably make two of its seven channels very noisy.

As stated previously, we went through the exercise of configuring an S6A for our representative mine. This exercise revealed the following costs:

- (1) Operating the S6A over the existing mine phone line, leaving the existing pager phones in place and providing adapters for them

Adapters	\$ 5,100
S6A Equipment	<u>6,210</u>
Total	\$11,310

- (2) As an alternative to providing adapters: operating the S6A over its own, separate pairs of wires

Wire	\$ 5,900
S6A Equipment	<u>6,210</u>
Total	\$12,110

It should be noted that the above costs compare favorably and are only for equipment. They do not include installation or the cost of the existing pair as given in Section C.1.c. above. Use of separate pairs dedicated to the multiplex units also avoids the proliferation of adapters, which will also need to be maintained, throughout the mine.

3. Multipair Systems

Our study of the hardware, the installation and maintenance techniques, and the costs of multipair systems reveals the following:

- The principal advantage of multipair cable is its ability to interface any type of equipment. Pager phones, conventional telephones, telemetry, and other special service channels can be provided at a surprisingly modest cost. Another advantage is that the cable hardware is rugged, well proven and designed to be installed and maintained by semi-skilled personnel working under adverse conditions.
- Its disadvantage is that, in the event of an accidental break, nonskilled, inexperienced personnel may have trouble, or may be unable to make a temporary splice.

Applying a steel messenger, figure eight, multipair system to our typical mine (with the numbers and gauges of the pairs tailored to the locations within the mine), resulted in the following costs:

- | | |
|--------------------------|----------|
| a) Reusing section cable | \$ 7,607 |
| b) No reuse of cable | 14,033 |

D. CONCLUSIONS

1. Costs

For our typical mine, at a growth stage when six submains are developed, the costs given previously can be summarized as follows:

Single Pair Cable

- | | |
|--|----------|
| (a) No reuse of 14 AWG neoprene section cable | \$59,800 |
| (b) Reusing 14 AWG neoprene section cable | 17,200 |
| (c) No reuse of 18 AWG plastic building wire section cable | 25,100 |

**Multiplex Carrier – S6A
(Add-on Capability)**

(a) Using present single pair* with pager phone adapters	\$11,310
(b) Using separate figure-eight 19 AWG single pair cable and no adapters	12,110

**Multipair Cable (Figure Eight)
(Substitute for Single Pair)**

(a) Reusing 18 AWG plastic copper-clad steel drop wire section cable	\$ 7,607
(b) No reuse of above 18 AWG section cable	14,033

The higher cost of the present single pair compared to multipair is caused by having to make the single pair a large gauge (AWG 14) in order to drive all pager phones throughout the mine. Any pair of the multipair cable is only asked to drive 2 to 4 pager phones, and hence smaller gauges can be used (AWG 19 and 22 multipair in the mains and submains, and 18 AWG drop wire in the sections). As far as cable costs are concerned, it would be cheaper by a factor of 2 to install multipair cable cases (a) and (b) as compared to single pair cable cases (b) and (c), respectively.

Comparing the costs of multipair versus multiplex, it can be seen that multiplex is marginally cheaper than multipair, but the numbers are so close that we must conclude that cost is not a significant decision criterion.

2. Practicality

Multiplex equipment has several practical disadvantages. The two most important are:

- The conventional telephones it uses have not been subjected to tests for permissibility. This restricts the location of the telephones and the use of the system during outages in the mine ventilation system.
- The pair used by the carrier system has a high dc voltage across it for charging the batteries of the remote units. This imposes additional safety problems.

*Costs of present single pair cable installations are listed above. For comparison purposes, the costs of the pager phones have been excluded in each case, because the objective was not to replace the existing pager phone system but to enlarge upon its flexibility and utility.

With these reservations, we conclude that it is possible and economic, but not necessarily advisable, to use certain presently available subscriber carrier multiplex equipment to obtain additional communication channels in mines.

A similar capability can also be obtained at comparable cost by using multipair cable with conventional pager phones. The most important practical disadvantage in this case is the slightly greater skill and additional tool needed to splice a severed cable, as opposed to what is required for the present single pair mine telephone cable.

E. RECOMMENDATIONS

1. Available Multiplex Systems

Until the practical disadvantages associated with presently available subscriber carrier multiplex equipment (namely, non-permissibility of equipment, high dc battery charging voltage on the pair, and pager phone adapters if used on the mine telephone line), are alleviated in a satisfactory manner, we recommend that this equipment not be used in mines, even on a trial basis. However, should the permissibility and high voltage problems be easily and economically resolved in the near future, we recommend, but with reservations, that any trial installation in a mine be made with the carrier equipment connected to a separate pair of wires independent of the mine phone line in order to avoid the need for pager phone adapters.

2. Multichannel Systems for Small-to-Moderate Sized Mines

We recommend that additional thought and study be given to identifying the types and features of multichannel systems best suited to small-to-moderate sized mine applications. The goals of such a study should be to:

- (a) Design the system to have such desirable features as call alert, privacy, mine monitoring and signaling, intrinsic safety, economy, and modular feature add-on capability.
- (b) Give equal consideration to multipair and multiplex techniques to implement such multichannel systems.

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II. THE PRESENT SINGLE PAIR SYSTEM

The mine telephone communication system used in underground coal mines consists of wall-mounted telephones, hereafter referred to as fixed phones, connected in parallel by a single twisted pair cable. The resulting configuration is a multiparty, single channel communication system providing two-way communication between the surface and working sections. The principal objective of this investigation is to examine ways to increase the number of voice channels on this single pair by using multiplexed carrier equipment.

A. EXISTING MINE COMMUNICATION EQUIPMENT

The fixed equipment, single pair mine telephone systems utilize primarily pager and magneto phones. With the exception of a few mines, conventional telecommunications products for home and business have not been installed underground.

1. Safety Codes

Some of the equipment available for single pair mine telephone systems is approved by various test groups or has been designed to meet specific safety standards. The principal code is the U.S. Bureau of Mines Schedule 9B, Part 23, which covers the testing of telephones for use in gassy or dust-laden atmospheres. Products tested and approved under this schedule by the Bureau of Mines are classified as "Permissible Equipment" and can be used in such areas. Other equipment has the approval of Underwriters Laboratories or is designed to meet the National Electrical Code Article 500 (Hazardous Locations). This latter equipment is used in the non-gassy or dusty areas of the mine with permission from the proper federal and state authorities.

2. Fixed Telephone Systems

The fixed telephone systems are defined here as all telephones that are hard wired into the mine. They are usually interconnected by a single twisted pair of wires. A 14 to 18 gauge copper pair with a neoprene jacket is most often used for this purpose.

Magneto phones were first used in these systems. Although many are still in use, they have been largely replaced by loudspeaking pager phones. In a few mines the conventional 500-type telephone with a rotary dial and ringer (mounted in an explosionproof housing) has been used. Systems using these dial phones are usually an extension of an above ground private automatic branch exchange (PABX) or a single-party independent system with a small switchboard. Even multipair cable has been used in at least one mine to connect individual phones to an above ground PABX.

The predominantly used pager telephone system was specifically designed for underground mining operations. It differs from a conventional telephone in the following ways:

- Instead of a ringer, a loudspeaker is used in each phone to alert the person being called.
- Each phone has its own batteries for power instead of being centrally powered.
- All phones must be placed across the single pair cable in order to have dc continuity for the paging relay.

3. Carrier (Trolley) Telephone Systems

Mobile carrier phone systems operate over the existing trolley wire dc power circuits to provide two-way voice communication between tracked vehicles powered via the trolley wire and a small number of fixed stations in the mine. In underground mining these carrier systems are used extensively for traffic control of the tracked haulage equipment and personnel carriers. The trolley wire and tracks serve as the carrier current path, hence the name trolley phone. These phones are FM push-to-talk transmitter/receiver units designed for common talk (party line) operation. Carrier frequency couplers consisting of by-pass capacitors are used to provide continuity of the RF signal path between sections of track served by different dc power centers. These carrier systems typically operate in the 60 to 200 kHz range.

4. Major Suppliers

The major manufacturers of pager and/or carrier wire phones, many of which are approved under Schedule 9B, of the U.S. Bureau of Mines, are:

- Femco, Division of Gulton Industries, Irwin, Pa.
- Gaitronics Corp., Reading, Pa.
- Mine Safety Appliances Co., Pittsburgh, Pa.
- Pyott-Boone, Inc., Tazewell, Va.

Major U.S. suppliers of explosionproof phones that have National Electrical Code approval under Article 500 are:

- Crouse-Hinds Co., Syracuse, N.Y.
- Northern Telcom Inc., Boston, Mass.

B. MINE TOPOLOGY AND TELEPHONE LOCATIONS

The topology of a coal mine is established as part of an overall plan for extracting the maximum amount of coal from a given area of a seam for the least cost.

1. Effects on Topology

The life of a mine can be as long as 50 years, and the overall mining plan is modified over the years as the structure and quality of the seam varies from one area to another. Over these years, technological changes, in both mining and hauling equipment also affect the overall topology. For example, the increased mechanization of coal mining that has occurred during the transition from conventional to continuous and longwall mining and the use of both track and belt haulage systems has resulted in an essentially rectangular mining topology.

2. Development of a Mine

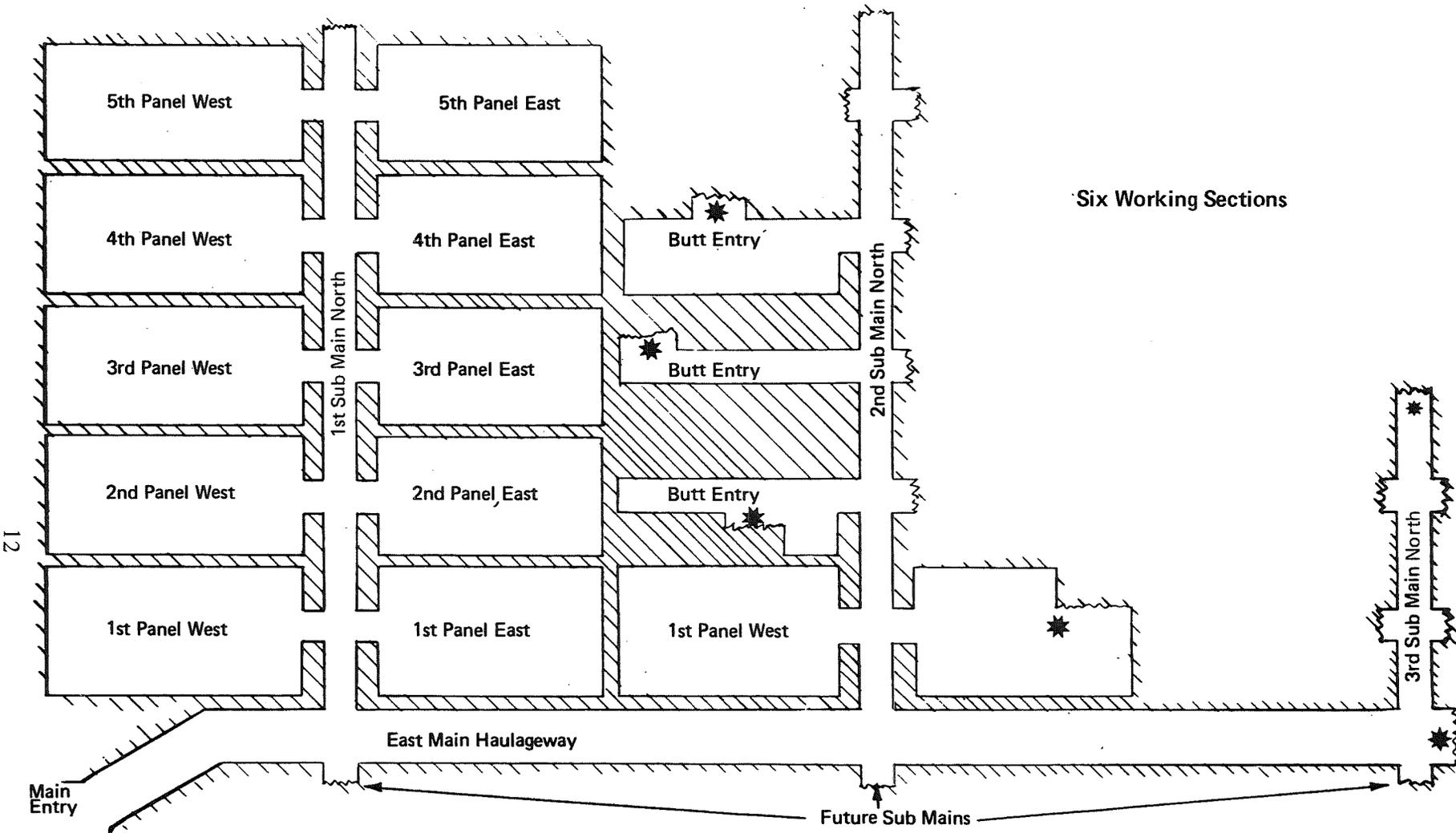
The first step in the development of a mine is to drive a vertical or inclined (sloped) shaft, called the main entry, to the coal seam. Next the main haulage and ventilation ways are driven. These consist of 2 to 6 parallel tunnels on 50 to 100 foot centers, which are cross connected every 100 to 200 feet. These are the major routes for the transportation of air, coal, men, and supplies to and from working sections of the mine. They can be anywhere from 1 to 8 miles in length and are used during the whole life of the mine.

At right angles to the main haulageway, submains are driven dividing the coal seam into panels. The submains are spaced approximately every 4000 feet along the main haulageway. About every 600 to 800 feet along the submains, butt entries are driven into a panel for a distance of 2000 to 3000 feet. The panels are further subdivided along the butt entries into working sections of approximately 300 feet by 450 feet. The sections are developed by driving 3 to 5 headings on approximately 60-foot centers some 300 feet into the panel at right angles to the butt entries. The headings are cross connected every 60 to 100 feet producing a system of pillars to support the roof. This method of mining is called "room and pillar mining," and is the most commonly used in the United States. Figure 2-1 shows the topology for a typical coal mine.

3. Location of Fixed Telephones

Federal* and State regulations as well as operating conditions determine the location of telephones in a working mine. There are basically three types of fixed

*Public Law 91-173 Section 315 "Federal Coal Mine Health and Safety Act of 1969."



Six Working Sections

* Working section locations.
 Note: Fine detail, such as pillars, not shown.
 Source: Arthur D. Little, Inc.

FIGURE 2-1 TOPOLOGY OF TYPICAL COAL MINE

location telephones used in the coal mining industry, the pager phone, magneto phone, and the explosionproof rotary dial phone.

a. Main Haulageway

A common practice in the coal mining industry is to locate telephones at the intersections of all main and submains, and at the head and tail of all working conveyer belts. (Belt fires most often occur at these points.) Belt haulage mines also usually locate phones approximately every 600 feet along the belts, due to the absence of trolley (carrier) phones. The above phones are installed for the life of the mine and are seldom moved.

b. Submains

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 6, due 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 would have to be installed as in the case of the main haulageway.

c. Working Section

Per the Bureau of Mines Safety Regulations*, a communication link must be established within 500 feet of the working face. The butt entry port 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.

4. Location of Special Function Telephones

Special function telephones are also used as part of an overall mine communication system. Three common types in this category are trolley wire, longwall, and hoist telephones. These special function telephone systems are independent of the fixed, single pair party-line phone system.

The trolley wire or carrier telephone located in each tracked vehicle is primarily used for control of haulage vehicle traffic. All vehicles are kept in communication with each other and the dispatcher by a common party line that uses the overhead trolley wire. This system is sometimes electrically coupled to

*Bureau of Mines Safety Notice, John B. Rigg, DOC 73-12923 Filed 6/26/73 @8:45 A.M.

the fixed telephone system in order to overcome nulls or dead spots along the haulageway. The dispatcher can also be used to relay messages between the two systems by means of the fixed pager phone located at his station. For safety and productivity, any mine with a track haulage system uses this type of carrier phone system as well as a fixed mine phone system.

Longwall telephones are generally loudspeaking (paging) mine phones and are located approximately every 70 feet along the face of the longwall. This is a single party line used to keep the longwall crew members in continuous contact with each other. This system is not generally tied into any other communication system in the mine.

A hoist telephone system generally consists of two or three phones and is used to control the operation of the hoist. The hoist engineer is kept in contact with the skip, the bottom, and the top of the shaft with this system. In a small mine, with a single working section, the hoist engineer would act as the mine dispatcher and be located at the top or bottom of the main entry shaft. He would be able to contact the section foreman via the fixed phones and all motormen via the trolley phones.

5. Basic Types of Telephone Locations

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

- Permanent, life of the mine
- Semi-permanent, more than one year between moves
- Frequently moved, weekly to monthly

In the permanent category we must include all telephones installed in the main haulageway irrespective of the type of haulage used. All trolley wire phones should also be included in this category because the haulage system continuously expands over the lifetime of a mine. The longwall and hoist phones are also permanent installations due to their association with major subsystems of a mine.

Semi-permanent 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 of the mine. One or two phones would remain for use by roving inspectors. 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 move with the section foreman in order to keep him in close communication with the dispatcher, maintenance, and management personnel.

C. COMMUNICATION REQUIREMENTS OF THE UNDERGROUND PERSONNEL

By separating the underground personnel, in present-day coal mine operations, into four functional groups, their communication requirements are more readily defined. These groups are:

- Working section crew
- Maintenance crew
- Motormen
- Inspectors and management personnel

The position of dispatcher will be considered separately because he generally coordinates the communications as well as the haulage traffic. In small mines and belt haulage type mines the communication center is the responsibility of the hoist engineer, the supply man, or the maintenance foreman.

There are two conditions under which the user needs for a communication system must be efficiently met. These are normal (regular operating shift) and emergency conditions.

1. Communication Requirements of the Working Section Crew

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 delivers 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 conveyer 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.

2. Communication Requirements for the Maintenance Crew

Unlike a working section crew, the maintenance crew is spread throughout the mine. The maintenance foreman receives repair requests and dispatches his crew for both emergency and scheduled repair work. He must maintain communications with the individual crew members by any and all of the existing phone systems. The dispatcher routes messages for repair equipment and parts to the foreman from the maintenance crew. The dispatcher also arranges transportation for the maintenance crew.

Wireless mobile communication equipment, linking the maintenance foreman and his crew together, would be ideal for the above tasks except for the fact that the crew members already have much to carry.

3. Communication Requirements of the Motormen

The motormen are responsible for the coal haulage and the delivery of men and supplies to the working sections. Their activities are directed by the dispatcher via the trolley wire (carrier) phone system. This single-channel network keeps the dispatcher and all motormen in continuous contact with one another. Right-of-way and the disposition of haulage cars must be known to all motormen to avoid accidents. This phone system also allows the dispatcher to notify all motormen of any mine emergency. The two drawbacks to this system are:

- Dead zones, which are sections of track where the phone is inoperative due to excess electrical noise or excess attenuation of signal strength.
- Trolley wire power failures, which cause the phones to go dead unless back-up batteries are installed in each phone.

The motormen's communication requirements are the same as those for the maintenance crew except their direct link should be to the dispatcher. The present system meets these requirements, except for an emergency that severs the trolley wire or otherwise removes power from the wire.

4. Communication Requirements of the Inspectors and Management Personnel

These people are underground primarily to observe mine conditions and personnel. They would like 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.

Their requirements would be completely satisfied by an effective, extensive wireless mobile communication system. A vehicle-mounted system would be sufficient in most cases, such as the trolley phones in track haulage mines.

5. The Dispatcher

The dispatcher's location in most mines has developed into the communication center for all underground operations. He is in direct contact with all the 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. 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 include both vehicle and voice traffic control, and the monitoring of environmental conditions in the mine. The operating conditions of the haulage and mining equipment could also be monitored from the communications center in the future.

For safety and productivity reasons the voice traffic control and the monitoring functions of the dispatcher's job cannot interfere with his prime responsibility of vehicle traffic control. Therefore, these responsibilities in all likelihood will be transferred to other personnel or to automatic dialing and alarm equipment.

6. Channel Requirements

Present mine communication systems generally consist of two channels, the trolley wire and the fixed pager phones. The trolley wire channel must be a party line to keep motormen informed of one another's location. The pager phone channel is often divided into multiparty circuits which are controlled by the dispatcher. For example, U.S. Steel's Robena No. 4 Mine uses eight party-line phone circuits terminated at a simple switchboard in the dispatcher's office*. A logical partitioning of the pager phone traffic into a multichannel system would be to give each working section a separate channel, or at the most two sections per channel, and have one common channel for all haulageway phones. Individual section channels would eliminate peak traffic demand during production reporting time and provide the section foreman with a private channel for reporting

*USBM Contract No. HO232056 Research and Development Contract for Coal Mine Communications Systems Vol. 1, Collins Radio Co.

an emergency. Other channels could be used for monitoring the environment and equipment. Based on limited data and survey results to date, it appears that about 2 to 8 channels, depending on activity of the mine, would be sufficient to provide efficient service for the working sections and also provide a common channel for the haulageways.

D. SINGLE PAIR CABLE COSTS FOR A TYPICAL MINE

Many different types of wire are used for single pair communication systems (see Table 2-1). The wire gauge ranges from 18 to 14 AWG depending upon the number of telephones in parallel and the distance between them. In some applications a larger gauge wire is chosen to improve the tensile strength of the wire, as well as to reduce the overall resistance of the run.

TABLE 2-1
SINGLE PAIR CABLE COSTS

<u>Description</u>	<u>Wire Gauge AWG</u>	<u>Loop Resistance ohms/mile</u>	<u>Cost/Mile*</u>
Plastic insulated non-jacketed building wire	18	67	\$ 370
Type SO, neoprene jacketed portable cable	18	67	\$ 870
	16	42	\$ 980
	14	27	\$1500
Buried distribution wire	19	83	\$ 610
Plastic drop wire (copper-clad steel)	18	223	\$ 225

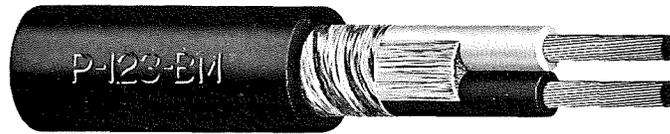
*Average price September, 1974

Source: Arthur D. Little, Inc.

An inexpensive wire used for interconnecting mine phones is the vinyl plastic coated, 18 gauge, 2 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 most expensive cable, the 14 gauge neoprene jacketed type (see Figure 2-2) is used in newer mines, such as Peabody Coal Company's Baldwin Number 1 located in Monissa, Illinois. The greater mechanical strength, reduced loop resistance, and superior moisture resistance of the neoprene jacketed cable make it ideal for communications applications. The two-conductor 14 gauge cable is indent marked with the number, P-123-BM, to indicate compliance with the

requirements of the U.S. Bureau of Mines and the Pennsylvania Department of Mines.



Source: Carol Cable Company.

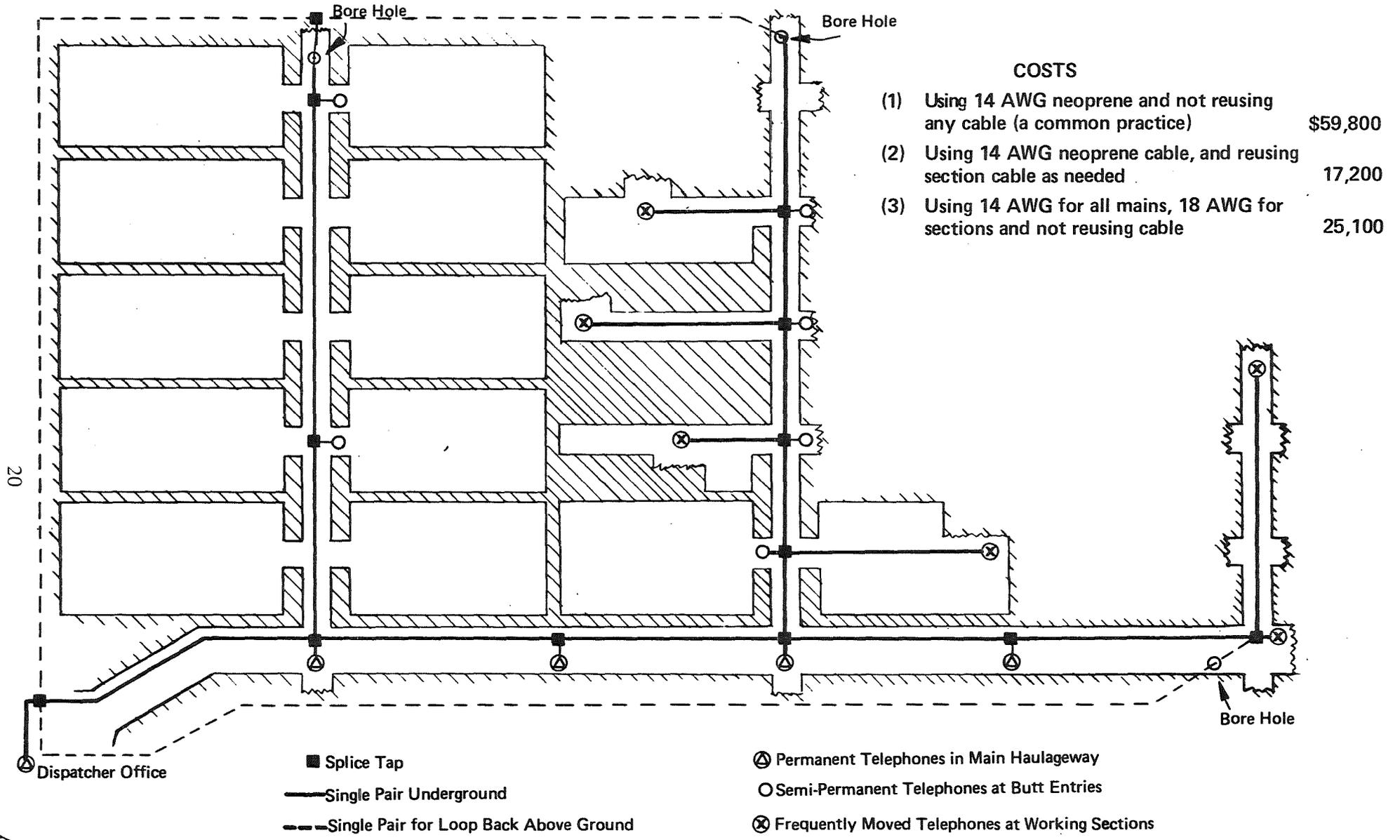
FIGURE 2-2 SINGLE PAIR TYPE SO NEOPRENE CABLE

1. Description of a Representative Mine

The best method of getting a feel for the cost of the single pair hardware is to cost out a representative moderate-sized fictitious mine. An example of such a mine is shown in Figure 2-3. The Peabody Coal Company's Baldwin Number 1 has characteristics similar to our representative mine. Our mine's chosen major characteristics are as follows:

- 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 2100 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 chosen for our representative mine 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.



Source: Arthur D. Little, Inc.

FIGURE 2-3 SINGLE PAIR INSTALLATION IN TYPICAL MINE

2. Single Pair Cost Calculations

Based on the above planning and the physical characteristics of the mine, the total length of single pair cable required can be calculated for this stage of development as follows:

● 1 main haulageway	3.5 miles
● 3 submains (0.8 mile each)	2.4 miles
● 6 active sections (3000 feet per section)	<u>3.4 miles</u>
	9.3 miles

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, from Table 2-1 is the plastic-insulated, nonjacketed 18 AWG building wire at \$370 per mile.

Total cable cost if section wire is reused
 $\$370/\text{mile} \times 9.3 \text{ miles} = \3440

Total cable cost if section wire is not reused
 $\$370/\text{mile} \times 14.4 \text{ miles} = \5330

Future expansion of the mine will increase the total cable length and the number of pager phones in the system. The high loop resistance (67 ohms/mile) of the 18 gauge wire will make future expansion impractical, therefore we should consider a larger gauge wire.

A *more suitable cable* due to its low loop resistance is the 14 AWG neoprene wire, type SO, at a cost of \$1500 per mile.

Total cable cost if section wire is reused
 $\$1500/\text{mile} \times 9.3 \text{ miles} = \$13,600$

Total cable cost if section wire is not reused
 $\$1500/\text{mile} \times 14.4 \text{ miles} = \$21,600$

The 14 AWG neoprene cable uses annealed stranded 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 3000 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. Three submains require 2.4 miles of wire at \$1500 per mile or \$3600.

3 submain development stage cost	\$13,600
3 additional submains cost	<u>3,600</u>
6 submain development stage	\$17,200

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 3000 feet or 0.57 mile.

(Additional cost if 14 AWG section wire not reused.)

$$54 \text{ lengths} \times 0.57 \text{ mile/length} \times \$1500/\text{mile} = \$46,170$$

The above cost is added to the 6 submain development stage costs for a total cable cost of \$59,800 for a cable plan using 14 AWG neoprene wire that is not reused. This cost can be reduced by using the 18 gauge building wire as section wire, because its high loop resistance is not a problem for the short length involved.

The 14 AWG neoprene cable length would be:

● 1 main haulageway	3.5 miles
● 6 submains (0.8 mile each)	<u>4.8 miles</u>
Total 14 AWG required	8.3 miles
$\$1500/\text{mile} \times 8.3 \text{ miles} = \$12,450$	

Plus the cost of 18 AWG building wire:

● 60 lengths x 0.57 mile/length x \$370/mile =	\$12,650
Cost of 14 AWG neoprene cable	12,450
Cost of 18 AWG building wire	<u>12,650</u>
Total cable costs	\$25,100

The above cost is the least expensive cable plan if one does not wish to reuse cable. Furthermore, it is a saving of \$34,700 when compared to an all 14 AWG neoprene cable plan in which none of the cable is reused.

3. Summary of Cable Plans for 6 Submain Development Stage

<u>Type of Plan</u>	<u>Total Cable Cost</u>
A. 14 AWG neoprene cable, reusing section cable	\$17,200
B. 14 AWG neoprene cable, not reusing section cable	\$59,800
C. 14 AWG neoprene cable for all mains, 18 AWG building wire for sections and no reuse of cable	\$25,100

Plan A also involves an additional labor cost for removing the section cable so that it may be reused. Therefore, the material cost saving of plan A could be offset by this additional labor cost over that of plan C.

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III. AVAILABLE TELEPHONE MULTIPLEXING EQUIPMENT

A. TRADITIONAL MULTIPLEX CARRIER SYSTEMS

Many manufacturers offer multiplex telephone carrier systems. They are designed to accommodate conventional telephone transmission, signaling, and supervision and to work in the framework of conventional telephone plant.

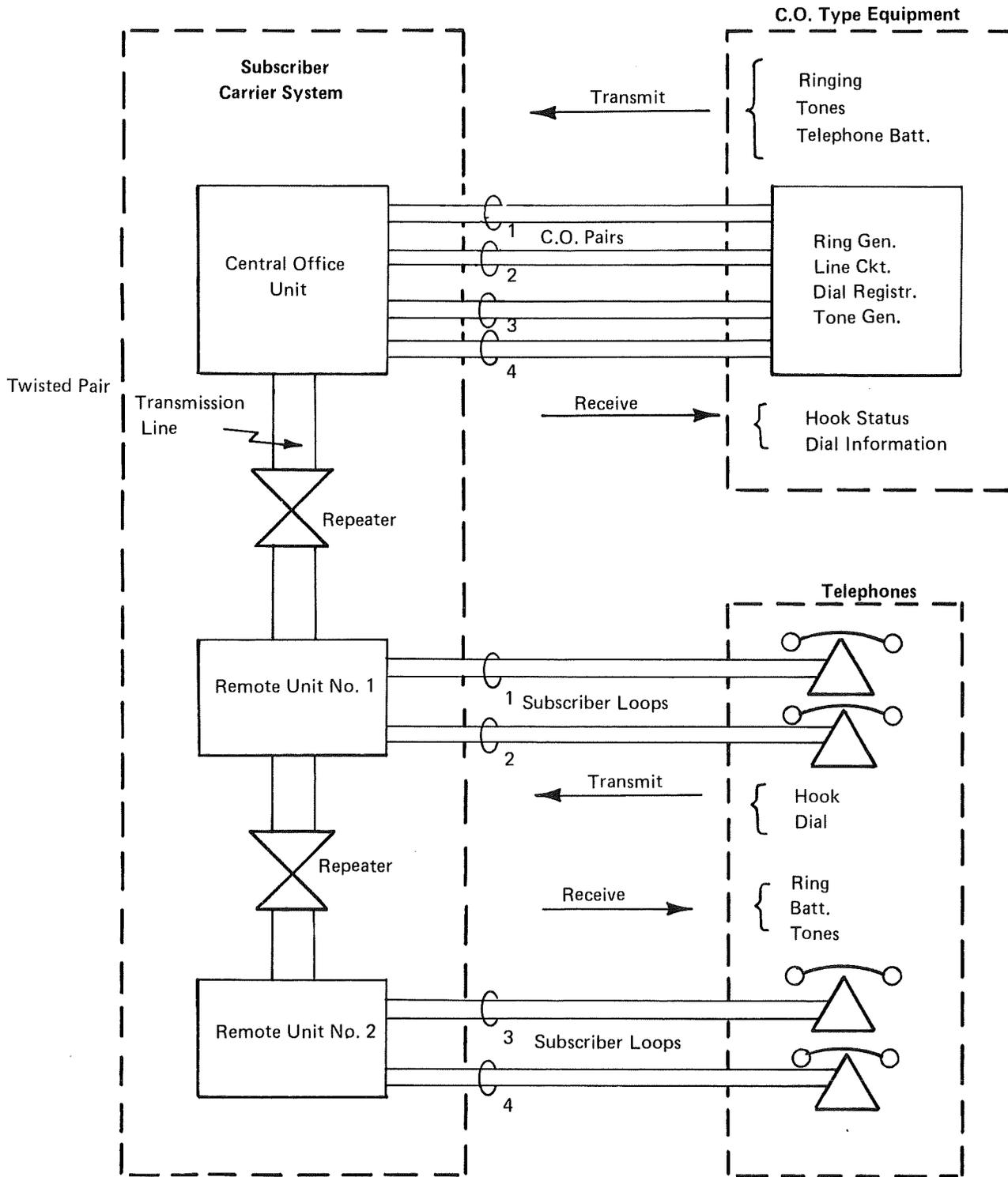
These carrier systems fall into two broad categories:

- Interoffice trunk carrier systems are designed to provide from 12 to tens of thousands of paths between central offices. Their objectives, terminal arrangements, and signaling make them unsuitable for mine communication.
- Subscriber carrier systems are designed to connect the end user (customer) with his nearest serving central office. They compete economically with pairs of copper wire contained in cables and provide circuits which make them interchangeable with these pairs.

Figure 3-1 illustrates the application of a typical subscriber carrier system. The system shown multiplexes four telephone channels on a single pair. At the central office (C.O.) end, it presents an installer with four pairs of wires, the C.O. pairs in the upper half of Figure 3-1. At each phone location, it presents the installer with a pair of wires to attach to a telephone, the subscriber loops of Figure 3-1. As far as the C.O. and the telephones are concerned, neither can tell whether they are connected by a carrier system or four copper pairs. It is important to note, though, that both ends expect to see an appropriate equipment interface. The C.O. end, for example, is equipped to recognize a ringing signal. When it does, it alerts the remote unit, which locally generates ringing (usually 80 volts rms at 20 Hz) and rings the telephone. It is not designed to expect, or cope with, a ringing signal applied at the subscriber end. At the C.O. end, it expects to interface C.O.-type equipment which transmits and receives the control signals listed in Figure 3-1. At the remote end, it expects to interface a 500-type telephone which transmits and receives the signals listed in the figure.

The main components of the subscriber carrier system are:

- The C.O. unit interfaces the C.O. pairs to the carrier transmission line. The system shown has four C.O. pairs, and voice signals on these pairs are multiplexed onto a single pair, the transmission line. Control signals are usually transmitted by in-band tones and dc signaling by relay closures. For example, when the telephone



Source: Arthur D. Little, Inc.

FIGURE 3-1 A SUBSCRIBER CARRIER SYSTEM

comes off-hook, the remote unit informs the C.O. unit of this fact, and the C.O. unit puts a dc short on the C.O. pair. Drawing current on a pair is the conventional way a telephone informs a C.O. that it is requesting service.

- The transmission line is a twisted pair whose gauge depends on the system size and can vary from 19 to 24 gauge.
- Repeaters can be inserted in the line to compensate for its attenuation.
- The remote units interface telephones. Unlike the system depicted in Figure 3-1, most systems have only one remote unit; they are designed to “drop” all telephones at one location. This is a matter of economics. Each remote unit has circuits and other hardware which could be shared among several demultiplex circuits, the power supplies, batteries, the housing, etc. Dropping all the telephones at one point allows this overhead to be centralized, and this reduces the cost of the system. The system shown in Figure 3-1 is representative of many small systems which allow the installer to distribute remote units along the transmission line. The figure shows two remote units, each equipped to drop two telephones.
- The subscriber loops are usually restricted in length to be around 200 ohms. Hence, if 19 gauge cable were used, the drop could be about two and one-half miles.

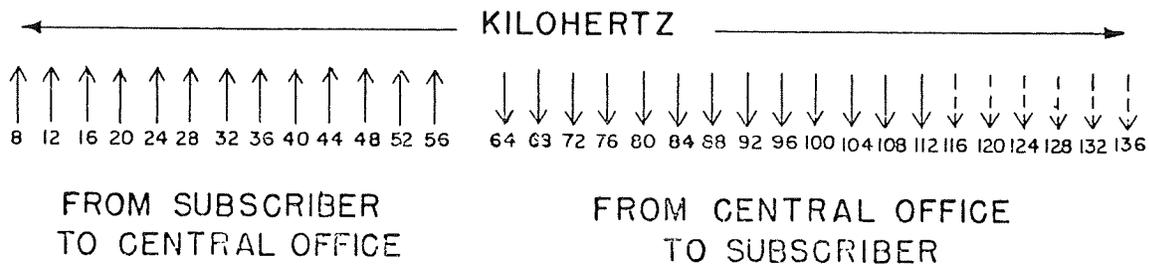
One of the most difficult problems faced by subscriber carrier systems concerns the powering of the remote unit. Most systems use commercial 110-volt power at the remote unit and provide rechargeable batteries for standby during power outages. In the mine environment, 110 volts is not readily available at some telephone locations. Many small systems (six channels or less) power the remote units by dc voltages applied to the transmission pair. This would make the underground system freestanding and would centralize power problems at the C.O. unit. For mine applications, it has two disadvantages. First, this use of the dc link on the twisted pair by the carrier system interferes with the operation of existing pager phones. This problem can be solved by designing and using special adapters to interface pager phones, see Section E below. The second disadvantage is that existing systems put high voltages on the pair to power the remote units — as high as 270 volts. At the very least, this is a maintenance hazard.

1. Typical Specifications

The Rural Electrification Administration (REA), a part of the U.S. Department of Agriculture, makes money available at attractive interest rates to small rural telephone companies. To be eligible to borrow this money, the companies must buy equipment from an REA-approved list. REA specifications, consequently, are extremely influential in the design of subscriber carriers; REA approval is like the "Good Housekeeping Seal" and all independent telephone companies tend to look for it whether they are REA borrowers or not.

Almost all subscriber carrier manufacturers, therefore, meet REA specifications. The following selected items from the specifications are of interest in mine use:*

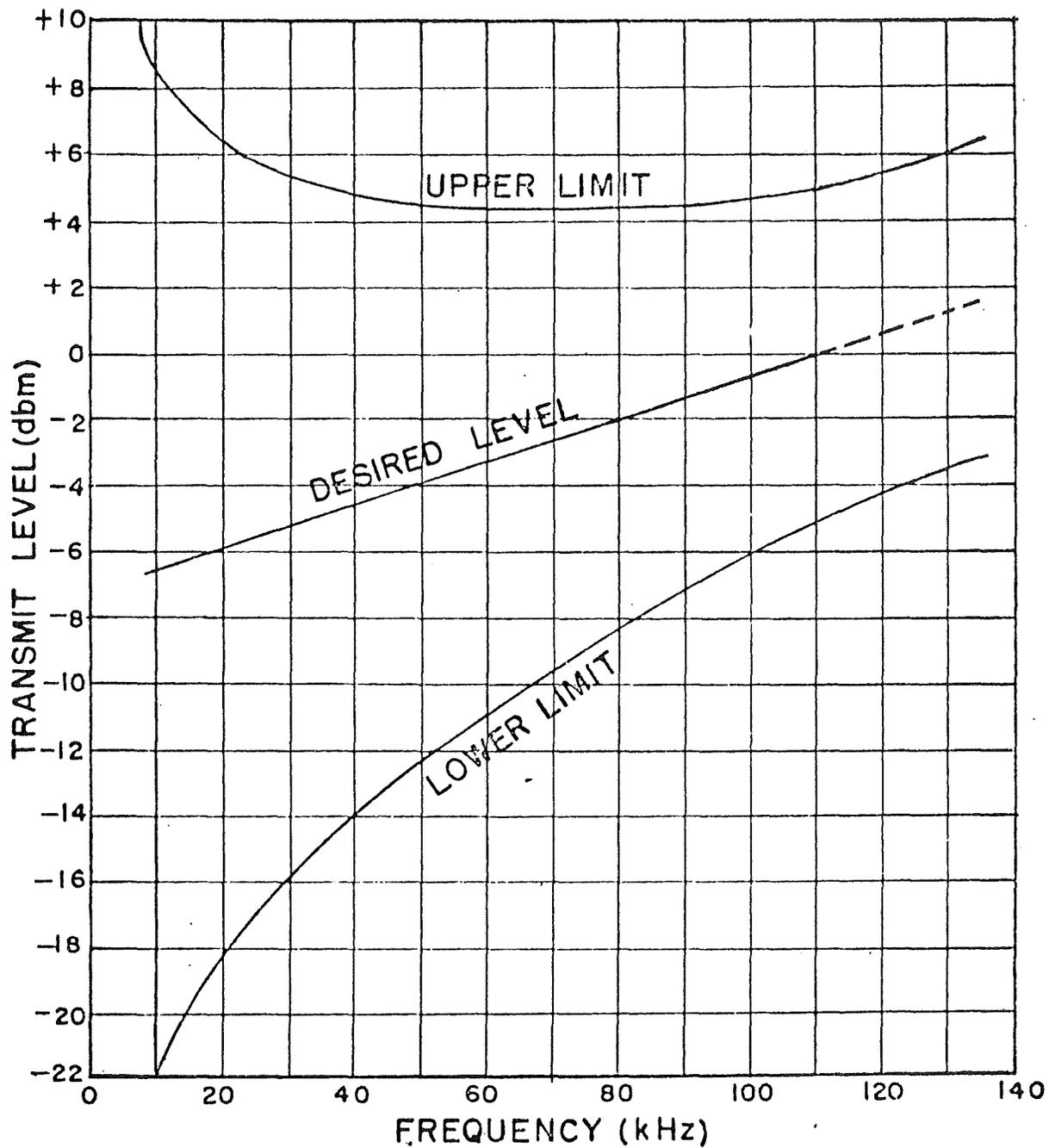
- Frequency assignment and minimum power (frequency division multiplex only). Figure 3-2 indicates standard frequency assignments, any sets of which may be used as long as the general pattern is maintained. The curve (Figure 3-3) shows the maximum carrier power allowable. Note that:
 - (a) even with a single channel carrier, one frequency is at least 64 kHz; and
 - (b) the power levels, which are expressed in dB, referred to one milliwatt, are on the order of a few milliwatts at most.



Source: REA Specifications.

FIGURE 3-2 FREQUENCY STANDARD FOR STATION CARRIER EQUIPMENT

*Source: REA Specification PE-62.



Source: REA Specifications.

FIGURE 3-3 LEVEL REQUIREMENTS FOR STATION CARRIER EQUIPMENT

- *Power.* To the maximum extent possible, the C.O. terminal and repeaters must be powered from a C.O. power source that is not subject to outage with the loss of 110-volt power. All equipment powered from a 110-volt power source must have the capability of providing standby power during the loss of 110-volt power. With the charging current removed, the standby power source must provide power for a minimum of eight hours. (Computations must be made available to show that the equipment meets this requirement under moderate traffic conditions.)

- *Life.* Excluding occasional catastrophic failures, the majority of the equipment is expected to be repairable and serviceable for 20 years. Unless stated otherwise by the manufacturer, design objectives for subscriber carrier equipment and accessories must be based on at least 20-year life.

- *Adjustments.* It is intended that field installation and maintenance adjustments on the equipment be kept to a minimum. Instructions for these adjustments must be clear and concise. Periodic maintenance adjustments on terminal equipment must be written in simple instructional form and either be permanently attached to, or capable of being attached to, the terminal equipment for ready reference.

- *Party-Line Use.* Single party and/or multiparty signaling are acceptable as stated by the carrier equipment manufacturer.

- *Dialing.* The received dial pulses measured at the voice frequency drop of the C.O. terminal shall be within 45% to 70% break with 8, 10, and 12 pulses per second when 60% break is applied to the subscriber terminal voice frequency drop through each of the following networks:

- (a) zero loop (direct);
- (b) maximum loop (a resistor equal to the maximum loop resistance of the drop plus 200 ohms); and
- (c) "A" leak (shunt networks at zero loop consisting of (1) 10,000 ohms, and (2) 5000 ohms in series with 2 μ F).

- *Ringling.* Carrier systems work with normal telephone sets. The carrier ringing system shall provide sufficient ringing on a bridged basis over the voltage and temperature limits of this specification and over subscriber drops within the limits stated by the manufacturer. The carrier ringing system shall be without operational problems, such as bell tapping during dialing. The manufacturer shall state the minimum number (not less than two) of main station ringers that can be used for each ringing option available. If conventional ringers (almost always the

case) are used, the subscriber terminals must ring at least the number of standard REA-accepted main station ringers at the end of the maximum subscriber loop as stated in the manufacturer's literature to an acoustic level of at least 75 dB rap at one meter distance when mounted in the telephone set.

- *Current for Telephone Set.* A minimum of 20 milliamperes dc shall be provided for the transmitter of the telephone set at the subscriber station under the maximum loop conditions of each signaling option. The minimum of 20 milliamperes shall be measured at the "end of service conditions" or minimum battery voltages at the end of the 8-hour standby power period.

- *Noise.* When the channels are aligned for a 2 dB net loss, the idle channel noise measured drop-to-drop on a two-wire basis, with carrier terminals connected back-to-back, shall not exceed:

- (a) 22 dBrnc0 on analog system channels (20 dBrnc @ 2 dB loss).

- (b) 26 dBrnc0 on digital system channels (24 dBrnc @ 2 dB loss).

The above requirements shall be met when the received carrier power is in the manufacturer's recommended range for proper system regulation. All channels of the system, except the one under test, are transmitting signal tones (if used) at normal idle levels in both directions of transmission.

- *Stability and Loss.* The equipment shall operate satisfactorily with respect to voice and carrier frequency levels, signaling, idle channel noise, and synchronization (where applicable) without adjustment over a minimum interval of three months under normal operating conditions. (The voice frequency drop level shall not vary more than ± 0.5 dB during this period for systems with channel net loss adjustments. For systems without channel net loss adjustments, the voice frequency drop level shall not vary more than ± 1.0 dB over a long-term period.)

For systems not containing voice frequency net loss adjustments, the net loss shall be 2 dB \pm 1 dB at 1000 Hz or at another specific net loss as stated by the manufacturer \pm 1 dB.

- *Temperature and Power.* Compliance with specification requirements shall be determined at nominal room and outside temperatures and powering voltage. At extremes of temperature and voltage, some tolerances will be allowed so long as the transmission and signaling functions are adequate for proper operation.

Equipment mounted indoors shall operate satisfactorily within the ambient temperature range (external to cabinet) of 30°F to 120°F at 95% relative humidity.

Equipment mounted outdoors in normal operation (with cabinet doors closed) shall operate satisfactorily within the ambient temperature range (external to cabinet) of -40°F to 140°F at 95% relative humidity. As an alternative to this requirement, an upper temperature of 120°F ambient with equipment (cabinet) exposed to direct sunlight may be substituted.

Where equipment is dc powered, it must operate satisfactorily over a range of 50 volts \pm 6 volts dc.

Where equipment is ac powered, it must operate satisfactorily over a range of 117 volts \pm 12 volts ac.

● *Voltages on Lines.* Voltages applied to wire facilities external to subscribers' buildings shall not exceed the following open circuit values:

Paired Exchange Cable (Limited Access Facility):

- 300 volts dc, tip-to-ring or between any combination of conductors.
- 270 volts dc, tip- or ring-to-ground.
- 90 volts rms, ac, tip-to-ring or between any combination of conductors.
- 75 volts rms, ac, tip- or ring-to-ground.

Open Wire:

- 200 volts dc, tip-to-ring or between any combination of conductors.
- 180 volts dc, tip- or ring-to-ground.
- 55 volts rms, ac, tip-to-ring or between any combination of conductors.
- 50 volts rms, ac, tip- or ring-to-ground.

2. Summary of Available Carrier Systems

The following two tables list all presently available subscriber carrier systems. It may be assumed that all systems meet the REA requirements enumerated above. Frequency division systems are listed in Table 3-1 and digital systems in Table 3-2.

It can be seen that the digital systems of Table 3-2 have two characteristics which make them of marginal interest for mine applications:

- They are designed to accommodate a large number of channels, 24 and up. Most mine applications need only around six channels, and to use these systems to accommodate a few channels makes their per channel cost very expensive. A digital system has a high overhead cost associated with its digital encoders, decoders, and housekeeping functions. This overhead must be spread over a large number of channels to keep the per channel cost competitive with copper pairs.
- With the exception of the Wescom unit, they are designed to drop all the channels at one location. They are not designed to serve telephones distributed along the transmission path. The Wescom unit is capable of dropping 12 channels at one location and then, further down the path, dropping the other 12.

The smaller systems of Table 3-1 are of more interest. Nineteen are listed and 14 of them can be eliminated as candidates for mine applications for the following reasons:

- The ITT K245 and the K31 are too big and have the same disadvantages as the digital systems.
- The four AML-type systems (AML, 83A, 84A, ITT Pair-Saver) only provide a single carrier channel (with retained use of the baseband channel) and are too small.
- Seven systems (SSC-5A, CM-8, EDS, 82A, 82B, 821B, and SC8) use unfiltered carriers sufficiently close to the baseband that they would probably interfere with existing pager phones (see Section E below).
- The S6 is the original Anaconda six-channel system, in which a seventh channel, although present, does not meet REA specifications and is designated a maintenance channel. The S6A (still up for consideration) provides the seventh channel within specifications at virtually no extra cost.

TABLE 3-1

FREQUENCY DIVISION MULTIPLEX STATION CARRIER SYSTEM SPECIFICATIONS

Station Carrier System	S-6	S6A	SSC-5A	CM-4	CM-8	AML	EDS	Centralier 48	Sx*5
Manufacturer	ANACONDA	ANACONDA	SEISMOGRAPH	Continental Tel. Electronic Co.	Continental Tel. Electronic Co.	Continental Tel. Electronic Co.	Continental Tel. Electronic Co.	Continental Tel. Electronic Co.	ESSEX
No. of Channels Per System	6	7	5	8	4	2*	4	5	6
Method of Transmission	AM-DSBTC	AM-DSBTC	AM-DSB	AM-DSB	AM-DSBTC	AM-DSB	AM-DSBTC	AM-DSBTC	AM-DSB
Powering of Equipment	Entire System D.C. from C.O. - MSES ground return	Entire System D.C. from C.O. (135 Vdc)	System Powered from C.O. (48 Vdc)	Entire System D.C. from C.O. (130 Vdc)	Entire System D.C. from C.O. - uses ground return (130 Vdc)	C.O. Term - 48 Vdc, 35 M.A. Subterm Powered from C.O.	C.O. Term AC - RPTR and Subterm AC from C.O.	120 Vac	C.O. Term DC Sub term AC on Premises
System Length	22.6 miles, 19 gauge 033 Cable		Not Specified	Not Specified	22 miles, 19 gauge 083 Cable	40 dB @ 76 kHz	22 miles, 19 gauge 083 Cable	30 miles, 19 gauge 083 Cable	Not Specified
D.C. Loop Limit	3000 Ω	3000 Ω	2450 Ω	2700 Ω	2400 Ω	Not Specified	2400 Ω	3000 Ω	Not Specified
Frequency	12-120 kHz	16 kHz to 116 kHz	12 kHz to 124 kHz	8 kHz to 144 kHz	16 kHz to 116 kHz	28 to 76 kHz	13 - 119 kHz	16 kHz - 116 kHz	16-108 kHz
VF Impedance	900 Ω + 2 mfd	900 Ω + 2 mfd	500 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd
Line Loss	7.1 dB @ 11 kHz	35 dB @ 112 kHz	35 dB @ 112 kHz	35 dB @ 112 kHz	35 dB @ 112 kHz	Not Specified	35 dB @ 116 kHz	Not Specified	Not Specified
Number of Repeaters	3	4	3	Yes - Not Specified	3	0	3	Yes - Not Specified 4	Not Specified
Subscriber Drop Length (excl. inst.)	300 Ω	200 Ω	250 Ω	400 Ω	200 Ω	200 Ω	200 Ω	Not Specified 200 Ω	Not Specified
Minimum Channel Freq. Response	H.S. - 2.5 dB Ref. 1kHz 300-3000 Hz	+ 1.5, - 2.5 dB Ref. 1kHz 300-3000 Hz	+1, - 3 dB Ref. 1kHz 300-3000 Hz	+1, - 4 dB Ref. 1kHz 300-3000 Hz	+1, - 3 dB Ref. 1kHz 300-3000 Hz	+1, - 3 dB Ref. 1kHz 300-3000 Hz	+1, - 3 dB Ref. 1kHz 250 Hz-3000 Hz	+1, - 3 dB Ref. 1kHz 250-3000 Hz	+1, - 3 dB Ref. 1kHz 300-3000 Hz
VF Net Loss	- 4± 2dB w/no Adj.	4± 2dB	- 4 dB	4± 2dB	- 5 dB	2dB	- 5 dB w/no Adjust.	- 5dB	0dB
Idle Channel Noise	20 dBrnc	20 dBrnc	Not Specified	20 dBrnc	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
Compandored	Yes	Yes	Not Specified	Yes	Yes	Not Specified	Yes	Yes	Not Specified
Facilities	19, 22, 24, 26 gauge also Open Wire	19, 22, 24, 26 gauge Plastic or Paper or any Combination also open wire	19, 22, 24, 26 gauge or any Combination thereof	19, 22, 24, 26 gauge Plastic or Paper or Combination thereof	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
Subscriber Term, Location	0 to 40 dB from C.O. term or 0 to 35 dB from a Repeater	0 to 40 dB from C.O. term or 0 to 35 dB from Repeaters	0 to 35 dB from C.O. or Repeater	Not Specified	Anywhere along Cable Route or on Bridged Tap	Anywhere Along Cable Route	Not Specified	Not Specified	Not Specified
Repeater Spacing	Nominal 35 dB 25 to 40 dB or ± 3 KI any gauge	Nominal 35 dB (28 to 42 dB) or ± 3KI any gauge	Nominal 35 dB @ 112 kHz	35 dB ± 10% @ 112 kHz	Nominal 35 dB (30 to 40 dB)	Not Specified	Nominal 35 dB	Nominal 35 dB (30-40 dB)	Not Specified
Ambient Temp. Limits	CO: - 12 to + 60°C SUBSC: - 40 to + 60°C	CO: - 1°C to + 50°C SUBSC: - 40°C to + 60°C	CO: - 1°C to + 49°C SUBSC: - 40°C to 60°C	CO: - 12°C to 60°C SUBSC: - 40°C to + 60°C	CO: - 7°C to + 50°C SUBSC: - 40°C to + 60°C	CO: - 7°C to + 50°C SUBSC: - 40°C to + 60°C	CO: - 7°C to + 50°C SUBS: - 40°C to + 60°C	CO: - 7°C to + 60°C SUBS: - 40°C to 60°C	Not Specified
Protection	Built-in Gas Tubes and Zeners	Built-in Gas Tubes and Zeners	Built-in Gas Tubes	Not Specified	Built-in Rare Gas Tube Protectors and Zeners	Not Specified	Built-in Gas Tube and Zeners	Built-in Rare Gas Tube Protectors and Zeners	Normal Station Protection

*One carrier channel plus retained use of baseband channel.

**TABLE 3-1
(Continued)**

861	82A	83A	84A	82B	821B	SC-8	ITT	ITT	ITT
STROMBERG-CARLSON	LENKURT	LENKURT	LENKURT	LENKURT	LENKURT	JDC COMMUNICATIONS	K24S	PAIR-SAVER	K31
5	6	2*	2*	6	6	8	24	2*	12: Cable 24: Radio
AM-DSBTC	AM-DSBTC	FM	AM-DSBTC	AM-DSB	AM-DSB	AM-DSB	AM-DSB	AM-DSB	AM-DSB
Entire System D.C. from C.O. — use ground return (60 mAdc)	Entire System D.C. from C.O. — uses ground return	C.O. Office Batt. Sub-local 117 vac	C.O. Term — 48 Vdc 50 m.a. battery charge units 40 vdc 35 m.a.	C.O. Term — 48 Vdc	48 Vdc 1.3A (All channels idle) 100 co 130 Vac 60 Hz 2A max.	C.O. Term 48 Vdc Sta Term Ac	C.O. Term 52 Vdc @ 2.0 Subterm from Login Sup.	33 m.a. moon per channel from C.O. battery	120 m.a. st — 48 Vdc SUBS: 95-160 m.a. @ 22.5 V
20 miles, 19 gauge 083 Cable	20 miles, 19 gauge 083 Cable	40 dB @ 70 kHz	43 dB @ 76 kHz w/o Repeaters	205 dB @ 112 kHz (with 5 repeaters)	Not Specified	Not Specified	Not Specified	430 dB @ 76 kHz	Not Specified
N/A	1600 Ω	Not Specified	800 Ω	1200 Ω for 23 mA loop current	1200 Ω for 23 mA loop current	1000 Ω	1500 Ω incl. inst.	Not Specified	1200 Ω
20-112 kHz	12-136 kHz	16-70 kHz	28-76 kHz	8-140 kHz	8-140 kHz	12-160 kHz	64-480 kHz	28-76 kHz	14-35 kHz
CO: 900 Ω + 2 mfd Sub 600 Ω	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd
35 dB @ 112 kHz	35 dB @ 112 kHz	—	Not Specified	40 dB @ 112 kHz	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
3	3	0	Yes — Not Specified	5	Yes — Not Specified	Yes — Not Specified	Yes — Not Specified	0	Yes — Not Specified
400 Ω	240 Ω	800 Ω	25 Ω	Not Specified	Not Specified	Not Specified	Not Specified	25 Ω	Not Specified
+1, — 3 dB Ref. 1kHz 300-3000 Hz	+1, — 3 dB Ref. 1kHz 300-3000 Hz	+1, — 3 300-3000 Hz	+1, — 3 dB Ref. 1kHz 300-3000 Hz	+1, — 3 dB Ref. 1kHz 300-3000 Hz	Not Specified	+1.0, — 3 dB Ref. 1kHz 300-3000 kHz	+1.0, — 3 dB Ref. 1kHz 300-3000 kHz	+1.0, — 3 dB Ref. 1kHz 300-3000 Hz	1.0, — 3 dB Ref. 1kHz 300-3000 Hz
N/A	N/A	2dB	5dB	Not Specified	Not Specified	2± 1dB	2± 1dBm	2dB	Not Specified
19 dBrc	20 dBrc	20 dBrc	< 20 dBrc	< 20 dBrc	Not Specified	< 20 dBrc	< 20 dBrc	< 20 dBrc	< 20 dBrc
Uses a Squelch Circuit	Yes	No	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
19, 22, 24, 26 gauge mixed or matched	19, 22, 24, 26 gauge or any combination also open wire	19, 22, 24, 26 or mix	Not Specified	19, 22, 24, 26 gauge or any combination thereof	19, 22, 24, 26 gauge or any combination thereof	Not Specified	Yes	Not Specified	Yes
Not Specified	0 to 40 dB from C.O. 0 to 35 dB from repeater	0 to 40 dB from C.O.	Not Specified	Not Specified	Not Specified	19, 22, 24, 26 gauge or any combination thereof	19, 22, 24, 26 gauge or any combination thereof	19, 22, 24, 26 gauge or any combination thereof	Not Specified
25 to 35 dB @ 112 kHz	Nominal 35 dB (20 to 40 dB)	—	Not Specified	Nominal 35 dB	Not Specified	Not Specified	25 dBm max. @ 4801 Hz	Not Specified	Not Specified
CO: — 10°C to + 55°C SUBS: — 40°C to + 55°C	CO: — 12 to + 50°C SUBS: — 40°C to + 60°C	7°C to 50°C	CO: — 7°C to + 50°C SUBS: — 7°C to + 50°C	CO: — 10°C to 50°C SUBS: — 10°C to + 50°C	— 10°C to 50°C	CO: — 40°C to + 60°C SUBS: — 40°C to + 60°C	Subterm w Heaters 0°C to 50°C	CO: — 10°C to + 50°C SUBS: 0°C to + 50°C	Not Specified
Yes — Not Specified	Built-in Gas Tubes and Zeners	Normal Station Protection	Grounded Station Protector must be added between the line and station term.	Not Specified	Gas Tube Surge Protection	Built-in Gas Tubes and Zeners	Built-in Gas Tubes and Zeners	Built-in Gas Tube Protectors.	Not Specified

(Essentially identical to AML)

**TABLE 3-2
DIGITAL SUBSCRIBER CARRIER SYSTEMS**

System	910A	B3215	T124S	T324S
Manufacturer	LENKURT	LYNCH	ITT	ITT
Method of Transmission	PCM	PCM	PCM	PCM
No. of Channels Per System	24	24-48	24-48	24
VF Impedance	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd
VF Subscriber Loops	1600 Ω	1700 Ω Incl. Inst.	1700 Ω	1900 Ω Incl. Inst.
VF Stability	Not Specified	\pm 5dB	\pm .5dB	\pm .5dB
VF Response	- 30 B Ref. 1KHz 225-3400 Hz	0, - 3dB Ref. 1KHz 300-3400 Hz	+1, - 3dB 300-3400 Hz	+1, - 3dB Ref. 1KHz 300-3200 Hz
VF Drop Level	- 2dBm	- 2dBm0	- 2dBm	- 2dBm
System Adjustments	None	None	None	None
Idle Channel Noise	23 dBrcnO Max.	23 dBrcnO	24 dBrcn	21 dBrcn
Subset is Ignallino	Rotary Dial or Touchtone	Rotary Dial or Touchtone	Rotary Dial or Touchtone	Rotary Dial or Touchtone
Alarm Monitoring	Yes	Yes	Yes	Yes
Protection	Gas Tubes	Gas Tubes	Gas Tubes	Gas Tubes
Ambient Temp Limits	CO: 0° to + 50°C SUBSC: - 40°C to + 60°C	CO: 0° to + 50°C SUBSC: - 40°C to + 60°C	CO: 0° to + 60°C SUBSC: - 40°C to + 60°C	CO: 0° to + 55°C SUBSC: - 40°C to + 60°C
Repeater Line	Standard T1	Standard T1	Standard T1	Standard T1
Power Req.	C.O. Term 4 amps @ - 48 Vdc Remote Term 6 amps @ - 48 Vdc	C.O. Term - 42 to - 56 Vdc @ 5 amps max. SUBSC. Term 117 Vac \pm 12 Vac @ 4 amps Max.	C.O. Term 44-56 V @ 2 amps Max. Sub Term 117 V @ 15 amps Max.	C.O. Term - 44 to -56 Vdc @ lamp - 44 to - 56 Vdc @ 2 amps or 117 Vac, 15 amps

*This unit is not comparable to others. It is a combination 24 channel pcar carrier + 24:96 remote switch (concentrator)

**Not comparable. Only unit with Delta Mod rather than PCM - Not U.S. Industry Standard

**TABLE 3-2
(Continued)**

320	TCS-28	TCS-30	PSB 10005	D960*	DM325**
WESCOM	G.E.	G.E.	VICOM	Digital Telephone	ITT
PCM	PCM	PCM	PCM	PCM Equivalent	DELTA
24	36	24-48	24	96	32
900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	900 Ω + 2 mfd	Not Specified	900 Ω + 2.16 mfd
1800 Ω Incl. Inst.	1500 Ω Incl. Inst.	1500 Ω excl. Inst.	1500 Ω excl. Inst.	1200 Ω Incl. Inst.	1800 Ω Incl. Inst.
Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	± 5dB
+1, - 3dB Ref. 1KHz 300-3250 Hz	+1, - 3dB Ref. 1KHz 300-3400 Hz	+1, - 3dB Ref. 1KHz 300-3400 Hz	0.5dB, - 3dB Ref. 1KHz	Not Specified	+1, - 3dB 300-3200 Hz
- 2dBm	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
Set Transmit and Receive Levels	Not Specified	Not Specified	Set Transmit and Receive Levels	Not Specified	None
26dBrcO Max.	26 d BrncO Max.	26 dBrcO Max.	25dBrc Max.	Not Specified	8 dBrc
Rotary Dial or Touchtone	Rotary Dial or Touchtone	Rotary Dial or Touchtone	Rotary Dial or Touchtone	Rotary Dial or Touchtone	Rotary Dial or Touchtone
Yes	Yes	Yes	Yes	Yes	Yes
Gas Tubes	Not Specified	Not Specified	Gas Tubes	Gas Tubes	Gas Tubes
CO: - 0° to + 50°C SUBSC: - 40°C to + 60°C	CO: - 1°C to + 50°C SUBSC: - 4°C to + 50 C	CO: - 1°C to + 50°C SUBSC: - 4°C to + 50°C	CO: - 1°C to + 49°C SUBSC: - 40°C to + 60°C	CO: - 35°C to + 55°C SUBSC: - 40°C to + 60°C	CO: 0°C to + 60°C SUBSC: - 40°C to + 60°C
Standard T1	Standard T1	Standard T1	Standard T1	Standard T1	Standard T1 or equivalent
C.O. Term 44-56 Vdc @ 2 amps Sub Term 117 Vac ± 10%, 60 Hz	C.O. Term - 42 to -57 Vdc Sub Term 117 Vac	C.O. Term - 42 to -57 Vdc Sub Term 117 Vac	C.O. Term - 48 V @ 2.0 amps Subs Term 117 Vac ± 15% @ 2.5 amps 1.5 amps Max.	C.O. Term - 44-56 Vdc @ 1 amp Sub Term -44 -56 Vdc @ 2 amps Max. @ 2 amps Max. or 117 Vac 15 amps	Multiplex Shelf: - 44 to -56 Vdc @ 3.5 a SUBSC: -44 to -56 Vdc @ 35 @ or 117 Vac, 15 amp

Of the remaining five systems, three – the CM-4 (four channels) and the 4B and 861 (five channels) – are sufficiently similar to the larger Anaconda S6A (seven channels), that a separate discussion of them is not necessary.

One of the two remaining systems, the Essex SX+6, requires 110-volt ac power at the telephone unit. In most mines, this is not readily available underground at all telephone locations. The Anaconda S6A, on the other hand, powers the remote unit over the carrier path. Although this leads to the problem of providing an adapter for the pager phones, it makes the system freestanding and independent of power failures.

As far as commercially available telephone multiplexing equipment is concerned, the Anaconda S6A is the front runner.

B. SPECIAL SYSTEMS

1. Introduction

In addition to the traditional telephone multiplex equipment described in Section A above, there is a variety of equipment on the market which, at first glance, looks as if it might have some use in mine communications. Some of the telemetry equipment might be relevant but, as far as voice communications are concerned, in our judgment, none of the equipment in the next three sections has anything to offer the mine environment. Brief descriptions are included here for completeness.

2. Concentrators

Concentrators are small, remotely controlled switches which enable a number of telephones to access a smaller number of pairs. The idea is to take advantage of the statistics of user habits to reduce equipment cost. Suppose, for instance, we have a concentration of 100 telephones, such as in a mobile home park some distance out of town. They could be connected to the central office with 100 pairs of wires or their equivalent in subscriber channels. Alternatively, a switch could be located at the park which gives every telephone access to a smaller number of pairs. Statistics show that if each had access to 24 pairs, users would be blocked by the switch from gaining access to the central office only once in 100 attempts. This degree of blocking has been found, empirically, not to cause many complaints and; hence, in cases where the pair savings more than justifies the cost of the switch, concentrators are used. Representative equipment is:

- The Lynch Communication Systems Inc. B281 concentrates up to 112 telephones on 23 pairs. A 24th pair is used for monitoring and control.

- The Anaconda ES1 combines a switch with their subscriber carrier. It puts 24 subscribers on six subscriber carrier channels.
- The Digital Telephone System Inc. D960 puts 96 subscribers on 24 PCM carrier channels.

There are several reasons why concentrators have little to offer mine telecommunication needs. Mine topology is rarely characterized by groupings of large numbers of telephones at the end of long transmission lines; mine telephone traffic peaks at the shift changes, which is not the steady state pattern concentrators are designed to cope with; etc.

3. Subscriber Line Multiplexers

The large digital carrier systems of Table 3-2, use time division (as opposed to the frequency division schemes of Table 3-1), and pulse code modulation, PCM, to multiplex many channels (usually 24), onto two pairs. Concentrator systems, such as the D960 described above put a switch on the end of the carrier system and thereby serve 96 telephones, instead of 24, on two pairs. One disadvantage of all these large systems is that they drop all the telephones at one point; the telephones are connected to one remote unit, and the system then hauls the traffic into a central office unit.

Some ten years ago, the military began researching systems which used time division multiplexing but overcame this drawback. The two pairs used as the transmission line in PCM subscriber carrier systems are divided into a C.O. transmit and a receive pair. The new systems, now known as subscriber line multiplexers, SLMs, use one pair in the form of a loop. Remote units on this loop use the incoming pair to receive signals and the on-going pair to transmit. Time division multiplexing is used, but the digital encoding is Delta Modulation, Δ -mod, as opposed to PCM. With modern techniques, Δ -mod is cheaper to implement than PCM and also offers the designer an unusual tool. The quality of digitally encoded speech improves as the bit rate is increased. It is difficult to vary the bit rate in PCM systems. For Δ -mod, it is relatively easy, and so it is possible to design a system which has superb quality when the system carries a normal number of talkers; but as the system is loaded beyond this point, instead of rejecting new requests for service, the system accepts them and slowly degrades speech quality for everyone.

Some three years ago, Bell System developed a commercial SLM (the SLM-80) to accommodate 80 subscribers distributed along a loop. The SLM-80 is an example of the complexity of such time division, digital systems. A complete description of this type of system can be found on page 80 of the March 1972 issue of the *Bell Laboratories Record*. Very recently, Bell System announced the

development of a smaller system accommodating 40 subscribers. Proprietary information at Arthur D. Little, Inc., indicates that within a few months other small SLM systems accommodating in the neighborhood of 30 telephones will be announced.

In our judgment, none of these systems are, or will be, practical for mine applications because of their size and complexity.

4. Non-Telephone Systems

There are two military multiplex systems worth mentioning for completeness but which are not seen as suitable for mine applications. Both can work over a single pair and require 110-volt ac power at both ends. The Army TD660 is a 12-channel PCM system and hence requires repeaters on the line every mile or so. It is extremely rugged but costs in the neighborhood of \$8000. The Army TCC70 multiplexes four voice channels, an order wire channel, and two telex channels. It uses FDM on a single pair.

Outside of military and telephone technology, two-way, voice multiplex systems have been small, very specialized, and not constructed for durability or abuse. Single or two-channel systems have been designed for such applications as power line intercoms, low frequency, induction-coupled wireless systems, etc.

The only area where there is an emerging need and technology is in the field of large office building fire communication systems. Pending laws in large cities are about to impose standards on the emergency monitoring, reporting, and communication systems in large office buildings. At present, these systems do not incorporate multichannel, two-way, voice communications, but they will shortly. For mine telecommunications, the main interest is the way these systems integrate telemetry monitoring and control functions into systems operating over the power wiring. As yet, they are unripe for mine applications, but some systems such as the Codata Office Building Five Communications System are worth watching.

C. HUMAN FACTORS

To be practical and effective in mines, communication equipment must be capable of being installed, maintained, used, and, to some extent, abused by personnel of limited skill operating in the mine environment. Any assessment of the applicability of available equipment to mine communications must take these human factors into account, but the lack of any official guidelines or reference material makes this a difficult task. Fortunately, most of the available equipment of any relevance was designed for outdoor application in the telephone plant, where many problems are not all that different from those encountered in mines. Some points of similarity are:

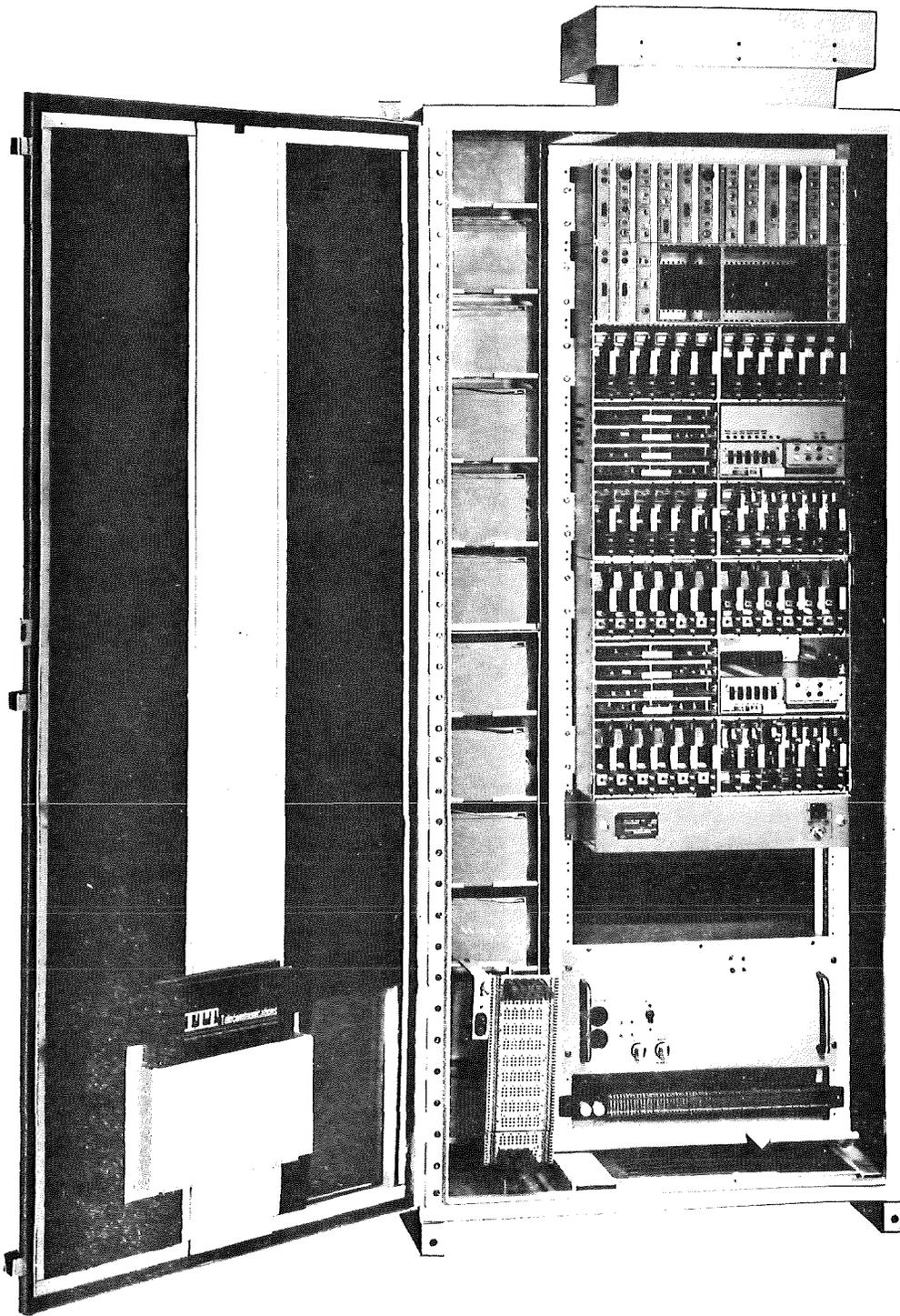
- For the outside telephone plant, craftsmen are relatively unskilled.
- They operate under the adverse circumstances of being either up a pole or in a confined manhole.
- Equipment is subjected to severe environmental conditions in temperature, humidity, dust, etc.
- Abuse is often severe. Rural housings seem to attract vandals, hunters looking for target practice, nesting birds, and even ram-paging bears (the theory is that the humming sounds like bees).

These considerations have resulted in the design of rugged equipment, and most of the practices used to install and maintain it are, in our judgment, practical for the mine environment. Using these and background knowledge, we formulated and used the following few general guidelines to assess the practicality of presently available multiplex equipment.

The weight of equipment to be installed underground is not an important factor. Communication equipment is nowhere near the weight of the power equipment currently moved around in the mine. In addition, the equipment is installed in increments. The cabinet and shelving are installed first, and then the cards, batteries, etc., are added. The size of the equipment is another matter. Figure 3-4, shows the subscriber terminal of one of the larger PCM systems. As shown, the system accommodates 48 channels, but the same box is used to house a 24-channel system. The box is 81 x 32 x 18 inches and is entirely impractical. Figure 3-5 shows a smaller packaged system but still one which would present problems in low coal. Systems, such as the CM-8 and S6A, shown in Figures 3-6 and 3-7, have several housing options. The single-system configurations which provide seven or eight channels and are of most interest here come in a few small packages. The single system remote cabinet of the S6A, for example, is some 24 x 18 x 13 inches. In general, to be practical, a system should probably not involve any box which could not be enveloped by a cube 36 x 36 x 36 inches.

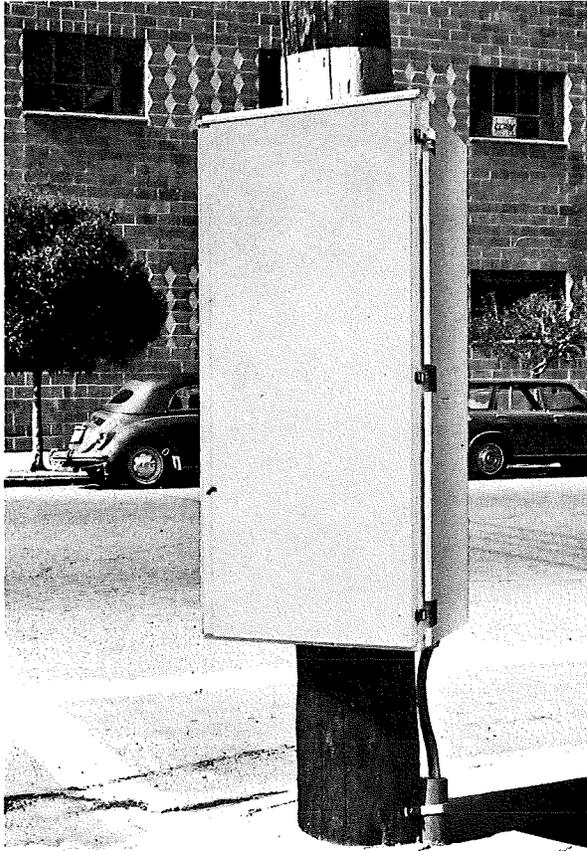
Concerning the ruggedness of equipment and the accessibility of circuit cards, etc., the existing telephone subscriber carriers should be adequate. Upgrading from this quality increases costs rapidly.

In the important area of wiring and splicing, we consider four techniques potentially acceptable for use in mines. One is stripping the wire and attaching it by means of a screw or bolt terminal, another is the scotchlok type of splice described in Section IV, and the third is the wire nut type of splice. Good quality, tape wrapped manual twist splices are also acceptable. We reject soldering and quick connect plugging with a 716 tool as being impractical.

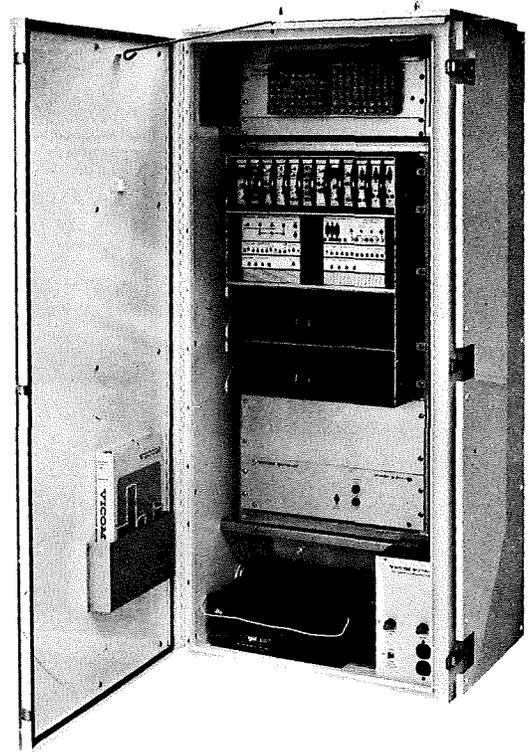


Source: ITT

FIGURE 3-4 ITT T324S PCM SUBSCRIBER CARRIER SYSTEM
(Subscriber Terminal E/W48 Channels)



The VICOM Subscriber Carrier remote terminal unit may be mounted on a pole or backboard. The subscriber terminal is designed to operate from -40°F to 140°F temperatures and up to 95% relative humidity at 100°F .



The subscriber terminal is installed in a cabinet assembly. It includes (top to bottom): cable termination and protector block; terminal incorporating span termination equipment, common equipment, and channel units; power supply; standby batteries; and AC protection. The central office terminal is similar in appearance to the subscriber terminal.

Source: Vicom

FIGURE 3-5 VICOM T SUBSCRIBER CARRIER SYSTEM

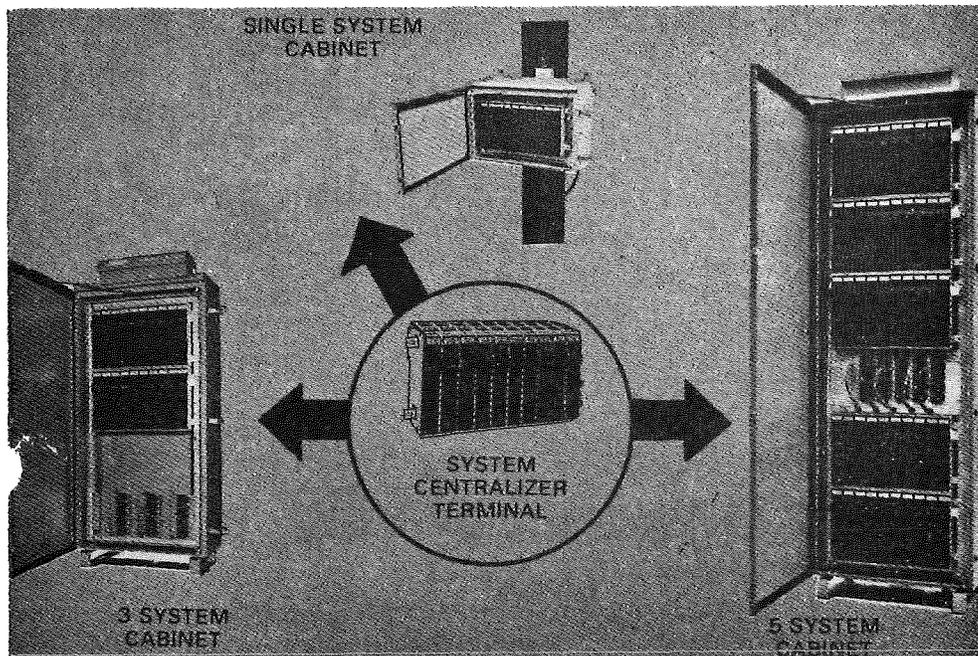


FIGURE 3-6 CONTINENTAL TELEPHONE CM-8 STATION CARRIER SYSTEM

For alignment and check-out during installations, most systems require a multimeter. This was judged to be reasonable, but no other test equipment was allowed. For maintenance purposes, simple P.C. card replacement cannot be avoided.

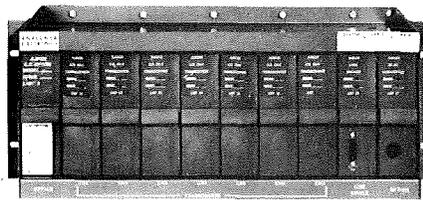
D. THE ELECTROMAGNETIC ENVIRONMENT

A carrier system operating over the existing twisted pair in a mine must contend with two phenomena which adversely affect its performance. One is the transmission loss caused by impedance discontinuities, and the other is the induced noise.

1. Effects of Impedance Discontinuities

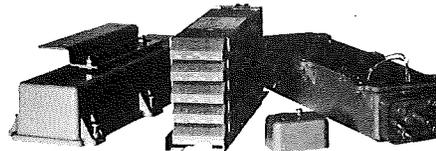
a. Propagation Constants of Twisted Pairs

Most available carrier systems operate between 10 kHz and 150 kHz. At these frequencies, the twisted pairs of interest – namely, 13, 16, and 19 gauge cable – have characteristic impedances with very small imaginary components – i.e., they are good, practical transmission lines. Table 3-3 shows the propagation



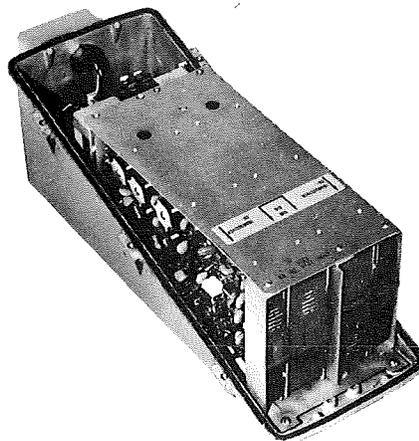
CENTRAL OFFICE TERMINAL

Complete C.O. Terminal with six channels plus a Channel X maintenance spare. Card at far left is the Ringing Option Card and card at the far right is the Powering Option card.



SINGLE REPEATER

Lightweight aluminum housing measures 4.8 inches by 5.5 inches by 16.6 inches, weighs 8 pounds. It will amplify all the signals for a complete system.



DUAL SUBSCRIBER TERMINAL

Save space and money—put two channels in one subscriber housing. Customer's home or business may be located several miles from the Subscriber Terminal.

Source: Anaconda Telecommunications.

FIGURE 3-7 ANACONDA S6A STATION CARRIER SYSTEM

constants of these pairs, and Figure 3-8 is an enlarged Smith Chart plot of their characteristic impedances, relative to 135 ohms.* It can be seen that in the range 50 to 100 kHz, our prime region of interest, we can treat the characteristic impedance, Z_o , as real. This enables us to use the standard transmission line equations and the Smith Chart to calculate the effects of bridging impedances.

TABLE 3-3

PROPAGATION CONSTANTS OF 13, 16, AND 19 GAUGE CABLE

Frequency (kHz)	Characteristic Impedance ($Z_o = R_o + jX_o$) (ohms)			Phase Shift (Rad/Mile) ($\beta=2\pi/\lambda$)			Attenuation (dB/Mile) (α)		
	Gauge			Gauge			Gauge		
	13	16	19	13	16	19	13	16	19
10	131-j23	142-j40	155-j73	0.50	0.52	0.59	0.80	1.32	2.43
20	128-j15	137-j25	141-j41	0.97	1.00	1.07	1.04	1.55	2.77
30	126-j12	135-j18	137-j30	1.43	1.48	1.57	1.27	1.78	3.02
50	124-j10	133-j13	134-j20	2.34	2.42	2.60	1.75	2.24	3.53
100	121-j7	130-j9	131-j13	4.54	4.71	5.00	2.72	3.31	4.80
150	119-j6	127-j7	129-j11	6.73	6.94	7.25	3.60	4.27	6.00

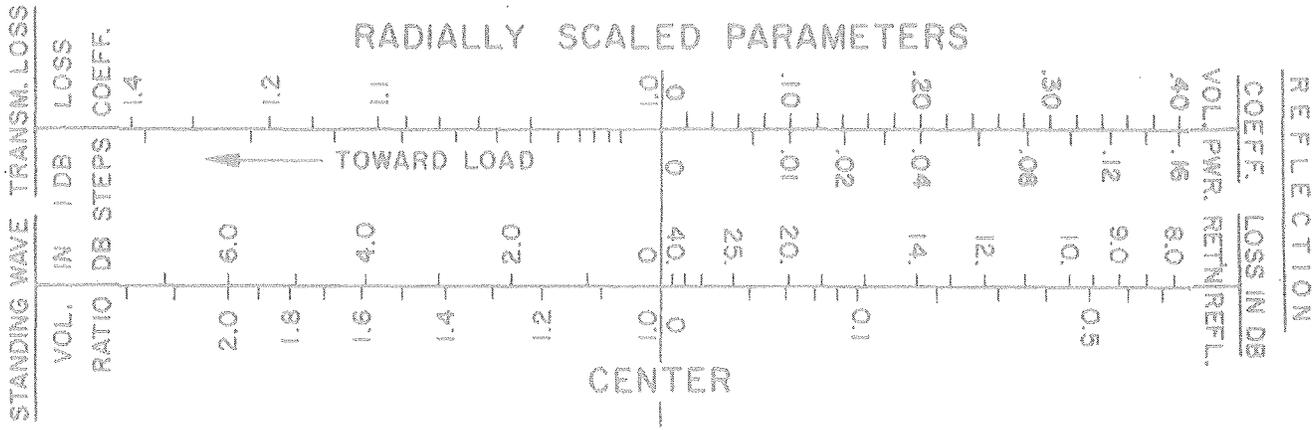
Source: ITT "Reference Data for Radio Engineers"

b. Impedances of Telephones

The telephones which now use the twisted pair would present a carrier system with mismatched terminating and bridging impedances. In the on-hook condition, most telephones have an input impedance of a few thousand ohms at frequencies in the range 30 to 150 kHz. In conventional phones, this is the ringer impedance; and in pager phones, the impedance is due to the de-energized input circuitry of the loudspeaker amplifier. At 50 kHz, for example, the Femco pager phone has an on-hook impedance of (25,000-j29,000),** and the Gaitronics unit an impedance of (3,200-j280).** In either case, the impedance is more than an order of magnitude greater than the characteristic impedance of the line (135 ohms), and hence can be regarded as an open circuit. An exception to this is the MSA Pager II phone which has a low on-hook impedance due to the transformer and capacitors it bridges across the line. Figure 3-9 is a Smith Chart plot showing the on-hook impedances of the Femco, Gaitronics, and MSA Pager I and Pager II telephones. It can be seen that, at carrier frequencies, the on-hook impedances of the Femco and Gaitronics telephones can be treated as open circuits, but the MSA Pager I and Pager II cannot.

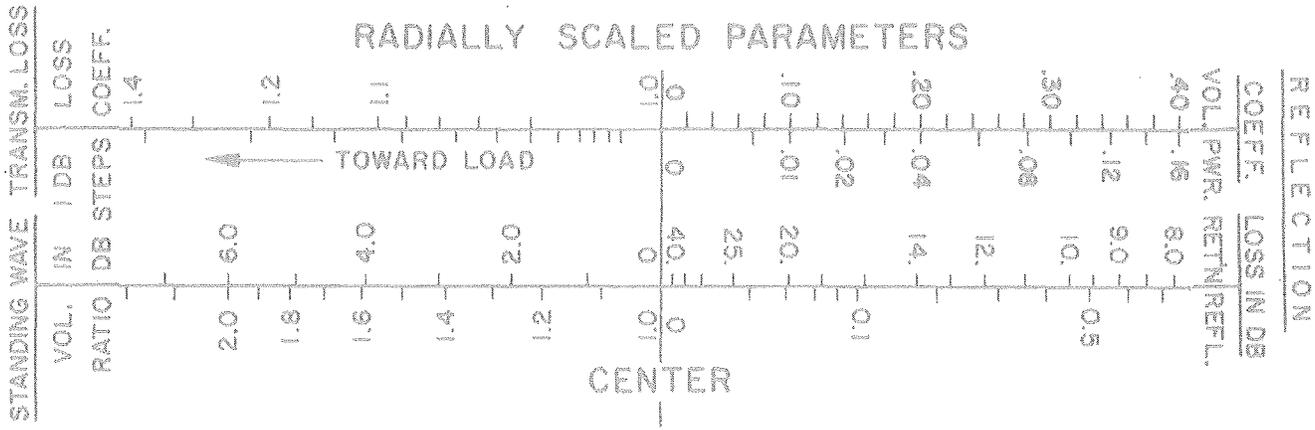
*135 ohms is the approximate characteristic impedance of 19 gauge cable at 50 kHz and will be used as Z_o in all subsequent calculations.

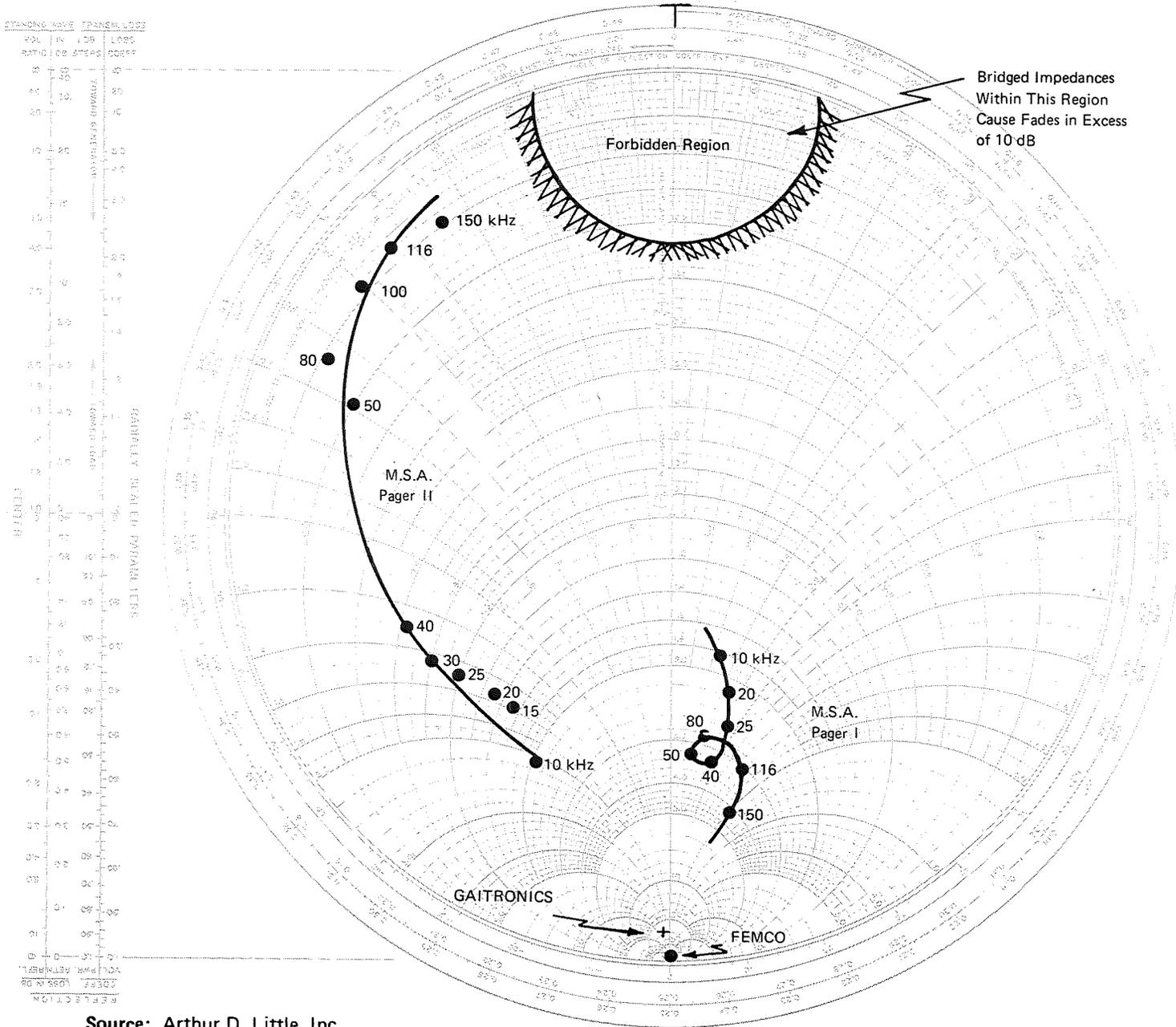
**Pager phone impedance data from Bureau of Mines, Pittsburgh Mining and Safety Research Center notebooks.



Source: Arthur D. Little, Inc.

FIGURE 3-8 CHARACTERISTIC IMPEDANCE OF 13, 16 AND 19 GAUGE CABLE RELATIVE TO 135 OHMS FROM 10 kHz to 150 kHz





Source: Arthur D. Little, Inc.

FIGURE 3-9 ON-HOOK IMPEDANCES OF MINE PAGER PHONES

The off-hook impedance of a conventional telephone, at carrier frequencies, is a few tens of ohms and for analytic purposes, this can be treated as a short circuit. There is no data on the off-hook impedances of pager phones. Schematics of the MSA Pager I and Pager II phones suggest that their input impedances at carrier frequencies are chiefly due to the line transformers which in turn suggests that their off-hook impedances will not appreciably differ from their on-hook impedances. For other telephones, we could only guess at the off-hook impedances. This is not, in our judgment, a critical lack of data though. It will be seen in the next section that analysis of the available data gives results which are relatively insensitive in most cases to the impedance of the telephone. The exception is when the telephone presents a small real impedance, and for analytic purposes, this case will be covered by analyzing the extreme case of a short circuit.

The four impedances used in the analysis are:

- (a) An open circuit which is representative of the on-hook impedance of many telephones.
- (b) A short circuit which is the extreme case of the off-hook impedance of some telephones.
- (c) The on-hook impedance at 50 kHz of the MSA Pager I telephone. Normalized with respect to a characteristic impedance of 135 ohms, this is $(3.1 + j0.55)$.
- (d) The same impedance for the MSA Pager II, which is $(0.2 - j0.7)$.

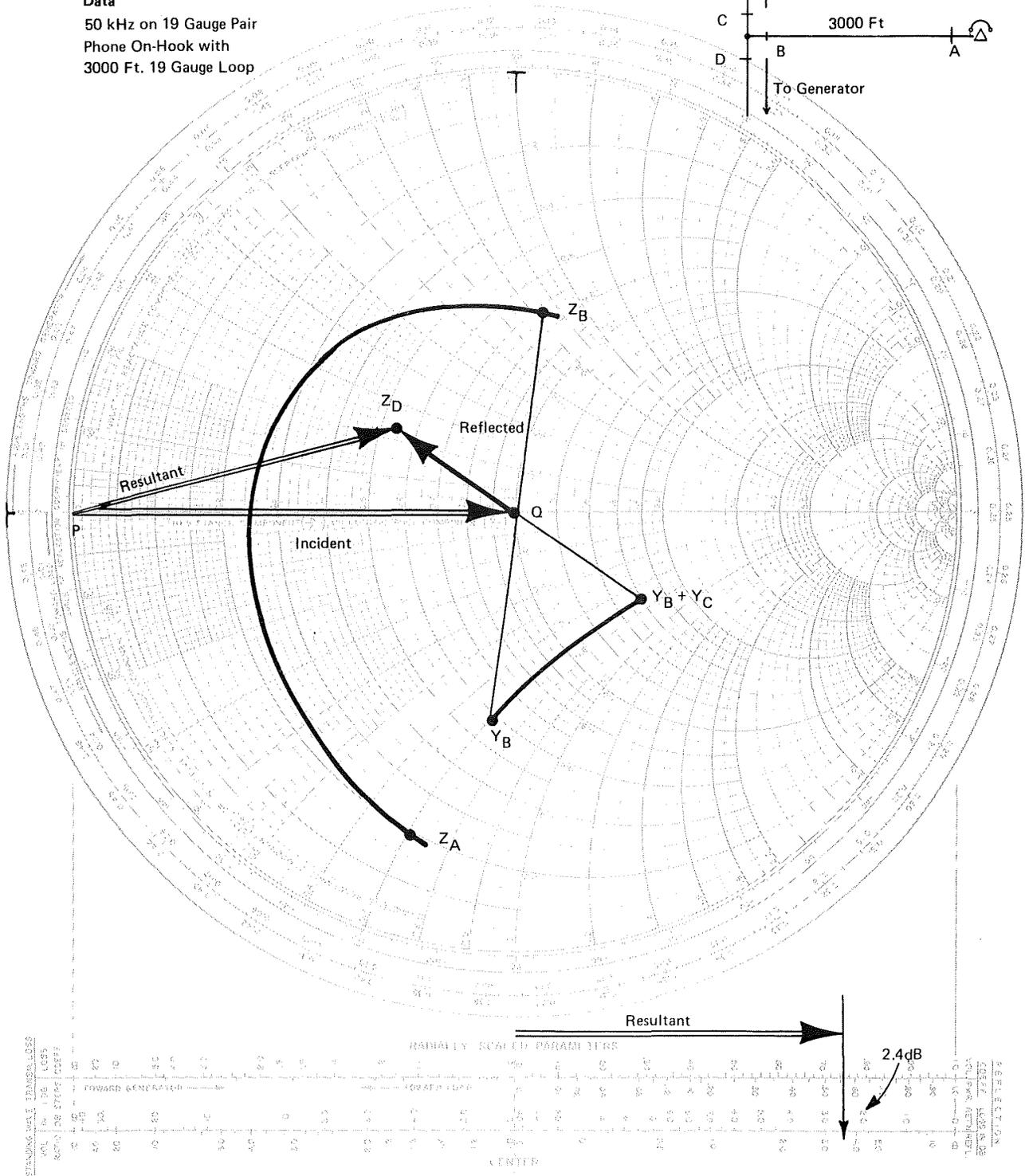
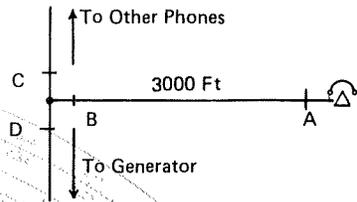
c. Power Loss Due to Bridging Telephones

A discontinuity in the impedance of a transmission line causes part of the incident wave traveling down the line to be reflected back to the source generator. This results in a power loss in the received signal. To quantify the phenomenon, a carrier operating at 50 kHz on 19 gauge cable will be examined. From Table 3-3, the cable can be treated as a transmission line having the following properties:

- Characteristic Impedance $Z_0 = 135$ ohms
- Wavelength ($\lambda = 2\pi/\beta$) $\lambda = 12,760$ feet
- Attenuation $\alpha = 0.6686$ dB per 1000 feet

Now consider what happens when a pager phone is bridged across the line at some point between the transmitter and the receiver of a carrier system operating at 50 kHz. Figure 3-10 illustrates a particular example. The carrier system uses the 19 gauge twisted pair to connect its transmitter (the generator in the sketch in the

Data
 50 kHz on 19 Gauge Pair
 Phone On-Hook with
 3000 Ft. 19 Gauge Loop



Source: Arthur D. Little, Inc.

FIGURE 3-10 IMPEDANCE VARIATIONS CAUSED BY AN MSA PAGER II BRIDGE TAP OF 3,000 FT.

upper right-hand corner of Figure 3-10) to its receivers — namely, the other phones indicated in the sketch. Between the two, a drop line, also of 19 gauge, is tapped onto the pair to serve an MSA Pager II telephone down a side entry 3000 feet away. The normalized on-hook impedance of the telephone is $(0.2-j0.7)$ and this is plotted as point Z_A on the Smith Chart. This is the impedance seen at point A in the sketch looking toward the telephone. The impedance at point B, the bridge tap, looking toward the telephone is point Z_B on the chart, obtained by moving circumferentially round the Chart a distance of 0.235λ ($= 3000$ feet) toward the generator and 2 dB radially toward the center, to allow for the attenuation of 3000 feet. The impedance seen by the generator at point D is Z_B in parallel with Z_C , the impedance looking down the remainder of the line. This analysis will assume that $Z_C = Z_0$, the characteristic impedance of the line. This will be true when either:

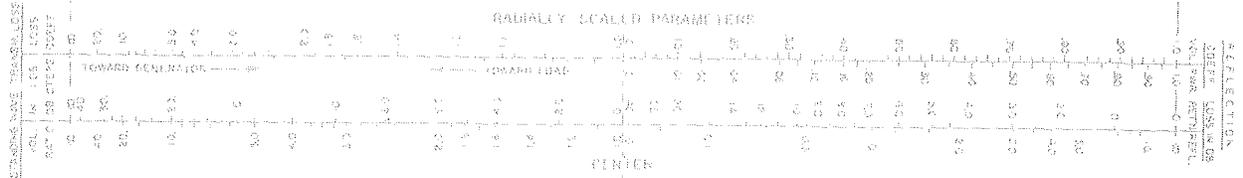
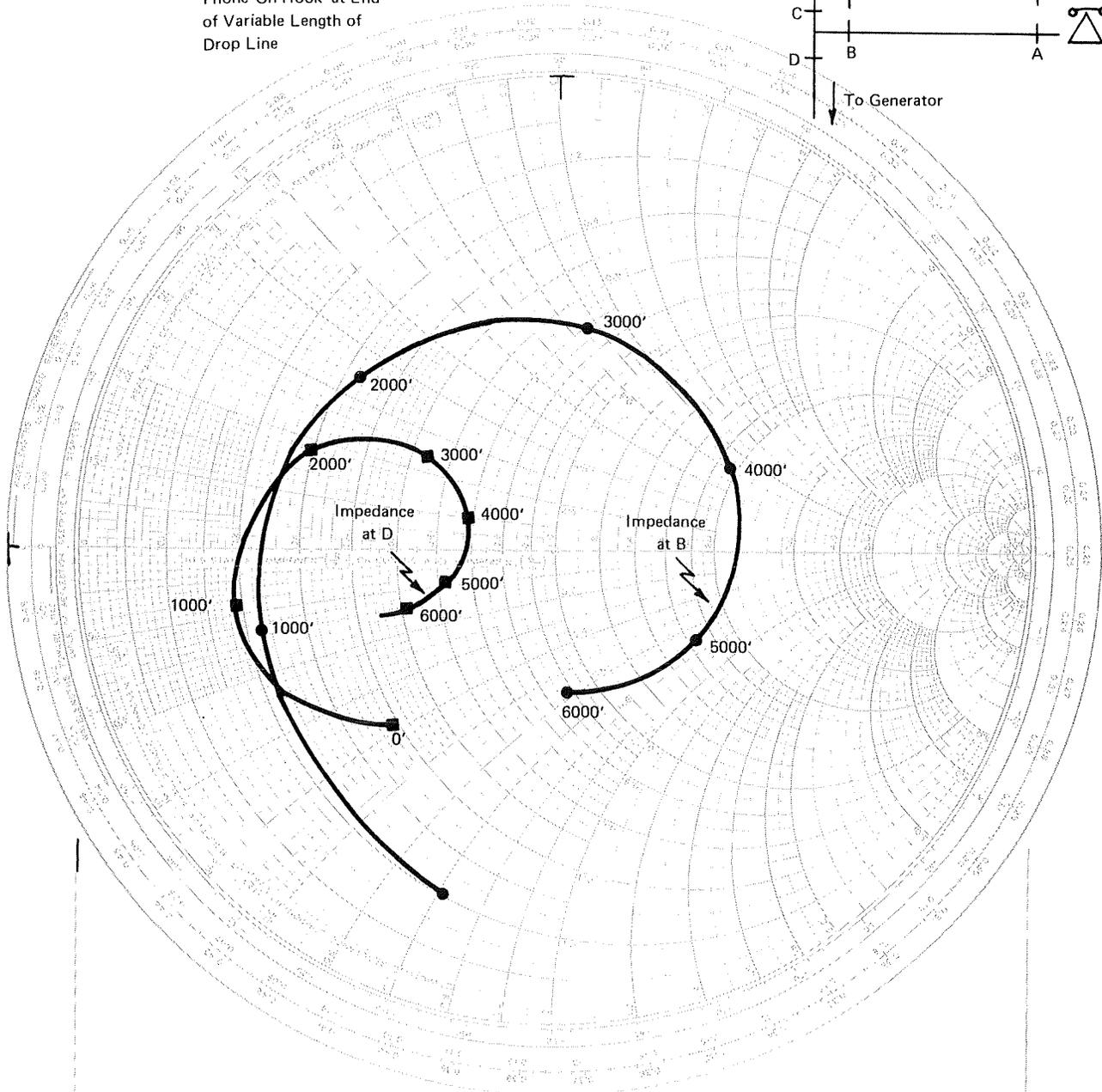
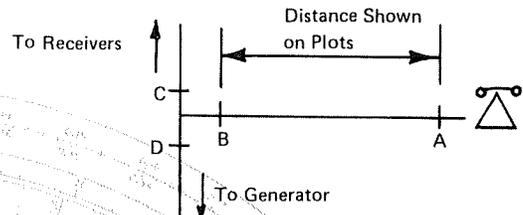
- (a) The equipment on branch C is entirely carrier equipment.
- (b) The distance along C to the nearest mismatch is large, and/or the mismatch is not severe.

The Smith Chart enables Z_D to be calculated graphically. Reflecting Z_B through the origin of Figure 3-10 to point Y_B gives a point whose chart coordinates are the reciprocal of Z_B — i.e., the admittance Y_B of the impedance Z_B . Adding the admittance of branch C ($Y_C = 1$) to Y_B moves the plot to point $(Y_B + Y_C)$ which is the admittance seen at point D. Reflecting through the origin again gives Z_D , the impedance at D. Now the nature of the Smith Chart is such that the position of point Z_D reveals all that one needs to know about the power loss caused by the bridged tap. If the vector PQ in Figure 3-10 is regarded as the Incident wave, QZ_D is the Reflected wave and, in consequence, PZ_D is the Resultant. PQ is the magnitude of the wave which would be on the line if the tap were not there; hence, the loss caused by the tap is the ratio of PZ_D to PQ. A scale associated with the chart allows this to be read directly as a power loss in dB. In this case, the loss is 2.4 dB, and this is the power loss experienced by the far end receiver as a result of the bridged tap.

Now consider what happens if the length of the bridge tap AB is something other than 3000 feet. Figure 3-11 plots the impedances Z_B and Z_D as the distance to the telephone varies from 0 to 6000 feet. The locus of Z_D enables the power loss experienced at the receiver to be determined. This loss in dB as a function of distance is shown in Figure 3-15.

If the telephone used in this example were an on-hook MSA Pager I instead of a Pager II, the plot would change to that of Figure 3-12. Again, Figure 3-15 shows the resulting power loss as a function of the length of the bridge tap.

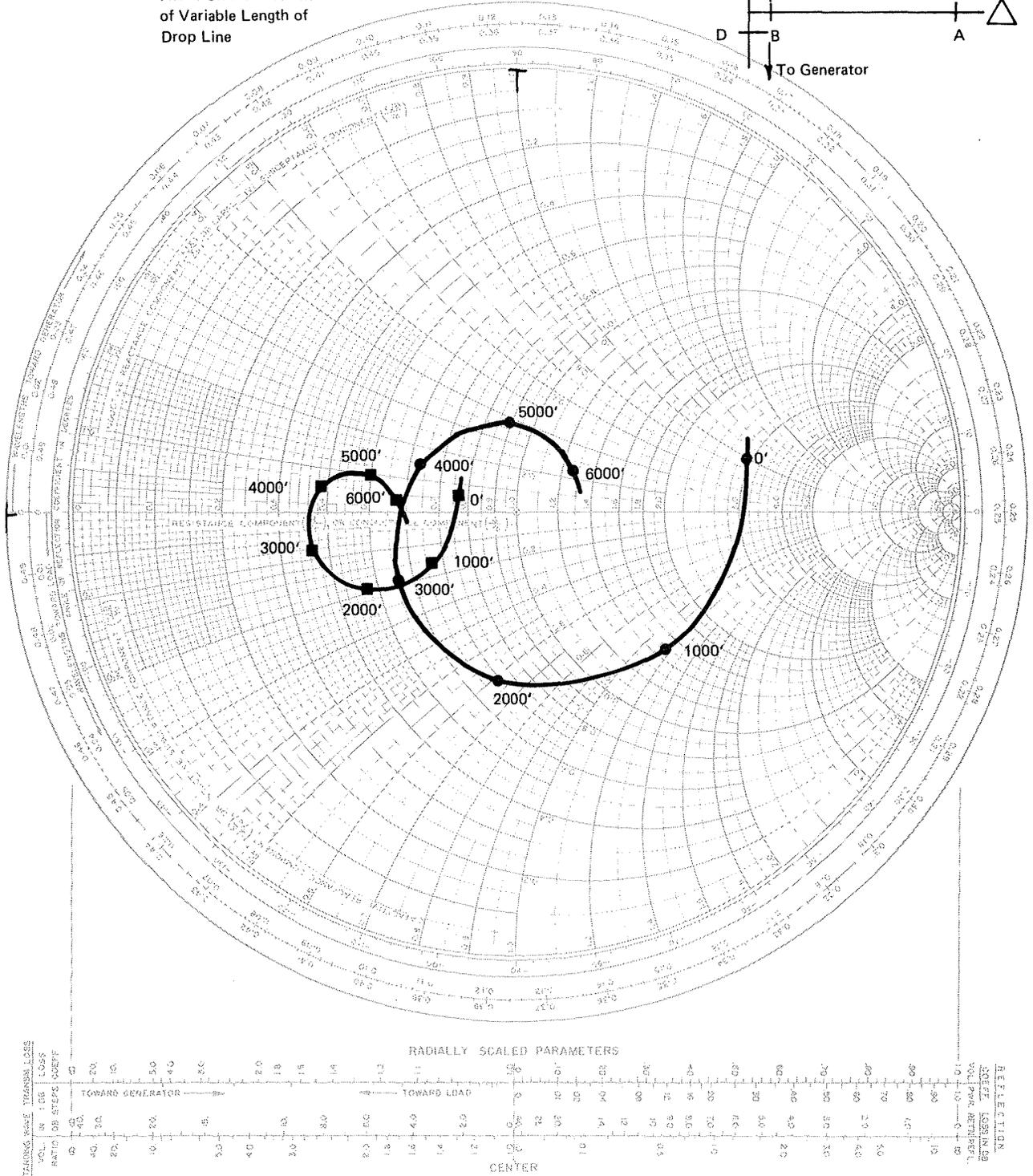
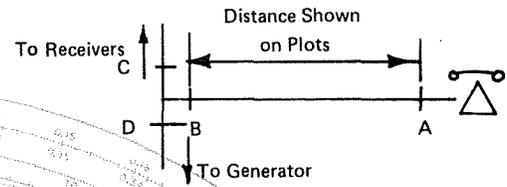
Data
 50 kHz on 19 Gauge Pair
 Phone On-Hook at End
 of Variable Length of
 Drop Line



Source: Arthur D. Little, Inc.

FIGURE 3-11 IMPEDANCE VARIATIONS CAUSED BY AN MSA PAGER II VARIABLE LENGTH BRIDGE TAP

Data
 50 kHz on 19 Gauge Pair
 Phone On-Hook at End
 of Variable Length of
 Drop Line



Source: Arthur D. Little, Inc.

FIGURE 3-12 IMPEDANCE VARIATIONS CAUSED BY AN MSA PAGER I VARIABLE LENGTH BRIDGE TAP

Figures 3-13 and 3-14 are plots showing what happens if the bridge tap is terminated in an open and a short circuit, respectively, and Figure 3-15 plots the resulting power loss.

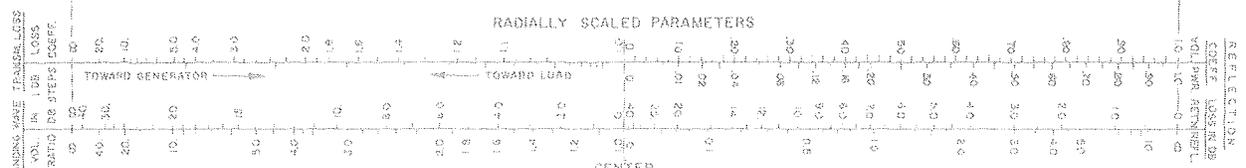
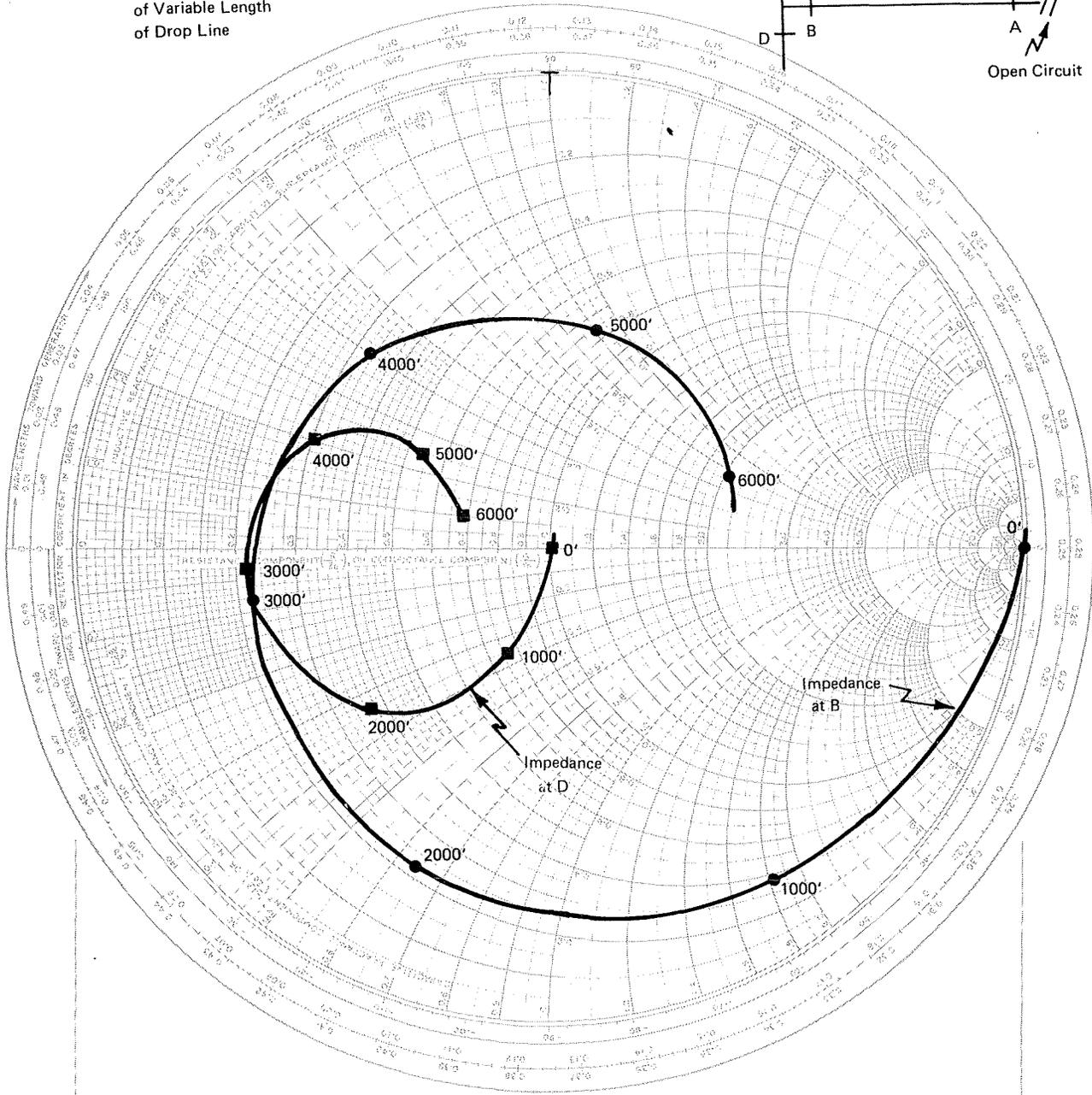
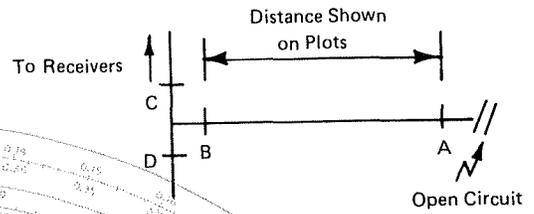
d. Estimated Power Losses

Figure 3-15 summarizes the results of analyzing the four types of bridging impedances of the last section. With the exception of the short circuit case, a 10 dB power margin will take care of any single bridge tap. In practice, a short might be inadvertently introduced into the system, but since this would affect the operation of the pager phones and other systems, it is reasonable to treat this as an academic case. This leaves the question of how small an impedance can be bridged across the line without raising the 10 dB margin. This is easy to calculate on the Smith Chart, and Figure 3-9 shows the result. The zone labeled "Forbidden Region" in the upper portion of this chart encompasses the coordinates of all bridging impedances which cause a power loss in excess of 10 dB. The impedances on the boundary of this region are very small. Typical values are (in ohms and degrees) 32 @ 0°, 30 @ 26°, 28 @ 45°, 26 @ 60°, and 25 @ 74°. None of the pager phones have an on-hook impedance this low and in our judgment, based on an examination of schematics, no pager phone has an off-hook impedance within this region. As an illustration, it would take a 0.1 μ F capacitor bridged directly across the line to have an impedance this low at 50 kHz.

It is reasonable, therefore, to assume that a single bridge tap will cause a power fade of no more than 10 dB. In order to avoid repeatedly engineering special situations, though, conservative practice dictates that any single bridge tap will produce a 10 dB fade – i.e., a carrier system must be engineered to contend with a loss of this magnitude. The two ways in which it can do this are:

- (a) Use brute force to overwhelm the fade. Typical carrier systems put something like +5 dBm (five dB above a milliwatt) of carrier power on the line. Boosting the output to 1 watt would give an additional margin of 25 dB to cope with fades. On a simplistic basis, if 6 dB is allowed for each additional mismatch beyond the first, this 25 dB margin would cope with some three bridge taps across the carrier line. Boosting the power output, however, is not a simple matter. Power increases lead to problems of cross-talk and singing point margins which can be expensive to solve.
- (b) Use specially designed adapters to interface the carrier line to pager phones. In addition to eliminating the power fade problem, these adapters could solve another problem. Many carrier systems (in particular, the Anaconda system examined in Section E below) use the physical pair to trickle charge batteries at the remote

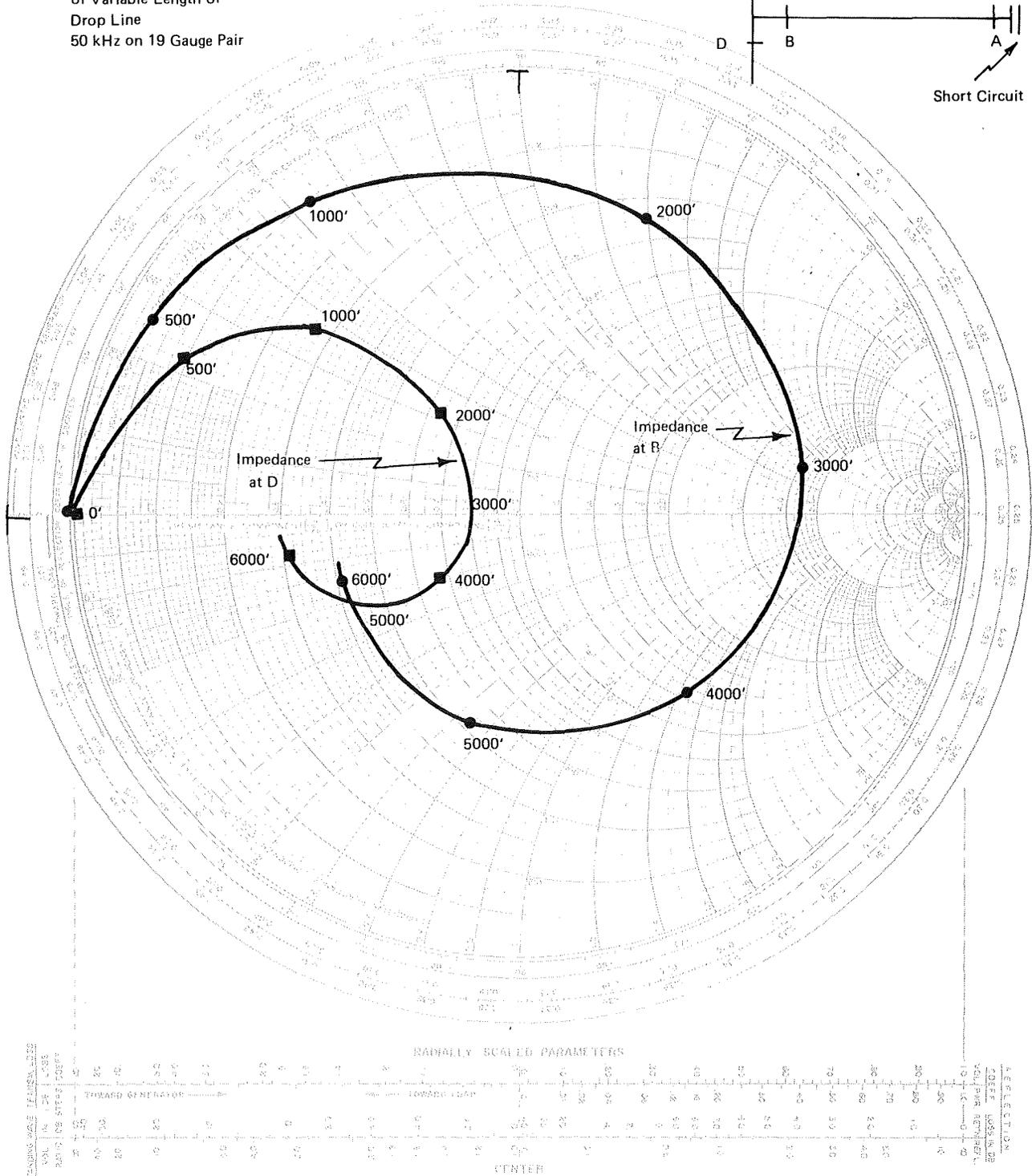
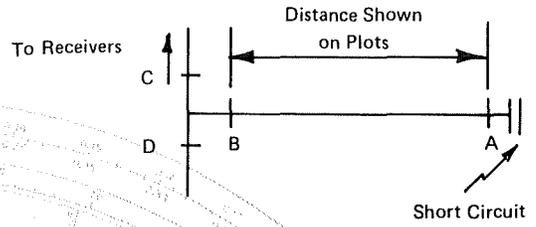
Data
 50 kHz on 19 Gauge Pair
 Open Circuit at End
 of Variable Length
 of Drop Line



Source: Arthur D. Little, Inc.

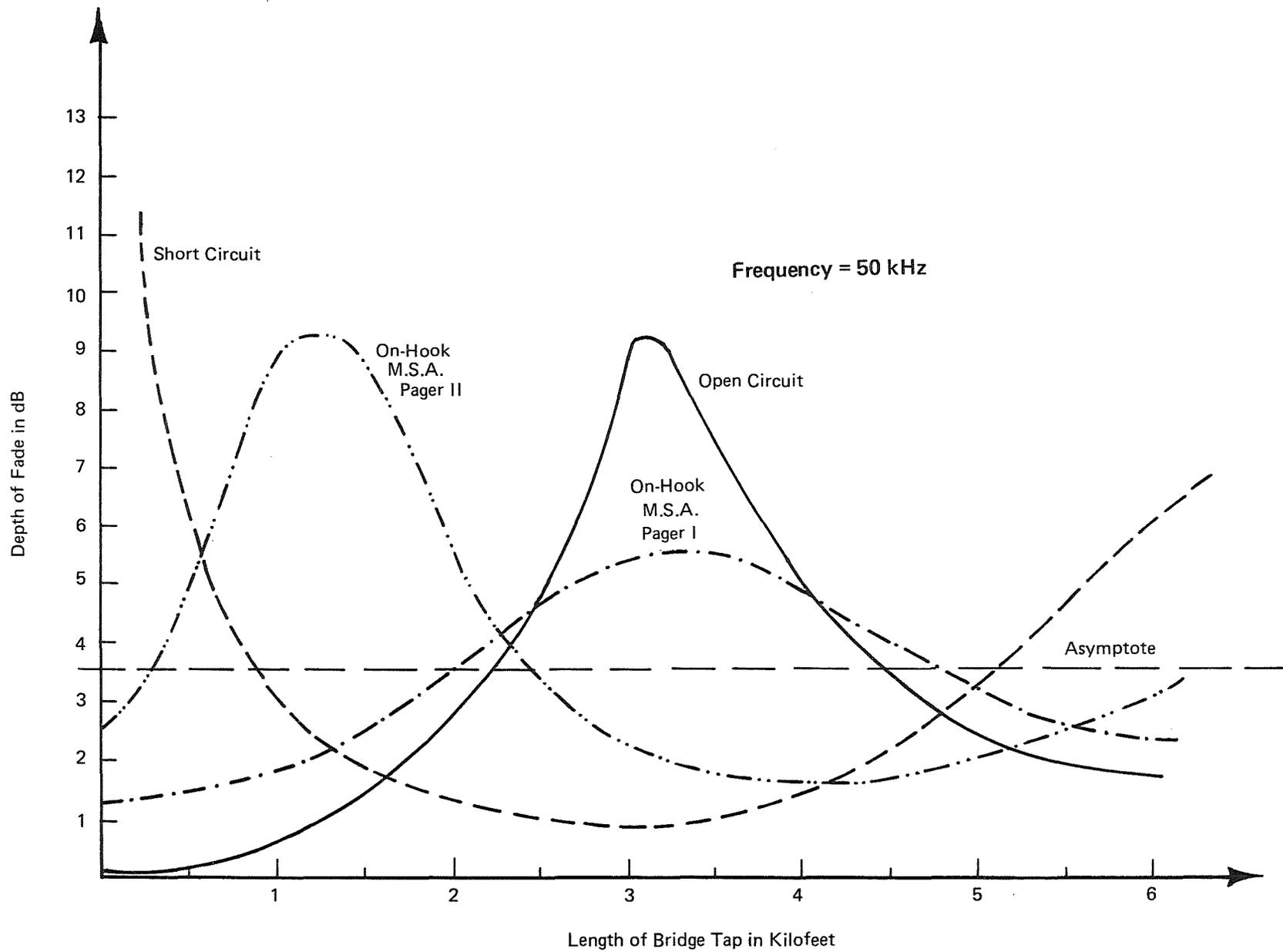
FIGURE 3-13 IMPEDANCE VARIATIONS CAUSED BY AN OPEN CIRCUIT VARIABLE LENGTH BRIDGE TAP

Data
 Short Circuit at End
 of Variable Length of
 Drop Line
 50 kHz on 19 Gauge Pair



Source: Arthur D. Little, Inc.

FIGURE 3-14 IMPEDANCE VARIATIONS CAUSED BY A SHORT CIRCUIT VARIABLE LENGTH BRIDGE TAP



Source: Arthur D. Little, Inc.

FIGURE 3-15 DEPTH OF FADE AS A FUNCTION OF LENGTH OF DROP LINE

telephone drops. The dc signaling systems used by pager phones would interfere with this function, and the adapter could also be designed to solve this problem. However, such an adapter would not be inexpensive. We estimate that it would have a factory cost in the neighborhood of \$150, and thus a selling price of at least \$300.

2. Noise Environment

Unfortunately, there are few data available to assess the noise environment that carrier systems would encounter on mine telephone lines.* The only noise relevant to the carrier operation is the induced, unbalanced voltage or current in the twisted pair. Common mode or longitudinal voltages do not affect operation because systems are carefully balanced to eliminate their effects.

The only relevant noise data available are the spectra shown in Figures 3-16 and 3-17, which is the current in one wire of the pair. Unfortunately, these data were taken at 11:42 a.m., and there is reason to believe that this was lunch time and the mine was inactive. The low band spectrum of Figure 3-17 fails to show the 60-cycle harmonics present in most of the data of NBS Technical Note 654. Figures 3-18 and 3-19, for example, show the voltage on one wire with respect to the rail, and it can be seen that at 4:30 p.m., power harmonics litter the spectrum. For the broad band case, Figure 3-18, harmonics protrude some 10 dB above the base level.

To translate the noise spectra of Figures 3-16 through 3-19 into power, one needs to know, or to estimate, the impedances on which they were applied. The voltage spectra of Figures 3-18 and 3-19 are undoubtedly longitudinal noise working into a high impedance. If an impedance on the order of 100,000 ohms is assumed, 50 can be added to the scale of dB and it can then be labeled dBm (dB relative to one milliwatt of power), as shown in Figure 3-18. This implies that in the neighborhood of 50 kHz, the longitudinal noise power was in the range of -70 dBm. Figure 3-16, on the other hand, represents the unbalanced noise – i.e., the differential mode noise of interest to carrier systems. For properly terminated (or long) 19 gauge twisted pair, the impedance is 135 ohms, which gives a conversion factor of 21 to add to the dB scale to convert it into dBm, as shown in Figure 3-16. Noise around 50 kHz has a power reading of some -95 dBm then, and this fits with the -70 dBm figure for longitudinal. It implies an equivalent 25 dB imbalance to ground, which is a reasonable value.

Assuming these conversion factors are correct leaves two questions concerning the differential noise of Figure 3-16. The first is how high would the

*All Data used here are from NBS Technical Note 654, Electromagnetic Noise in Robena No. 4 Coal Mine, April 1974.

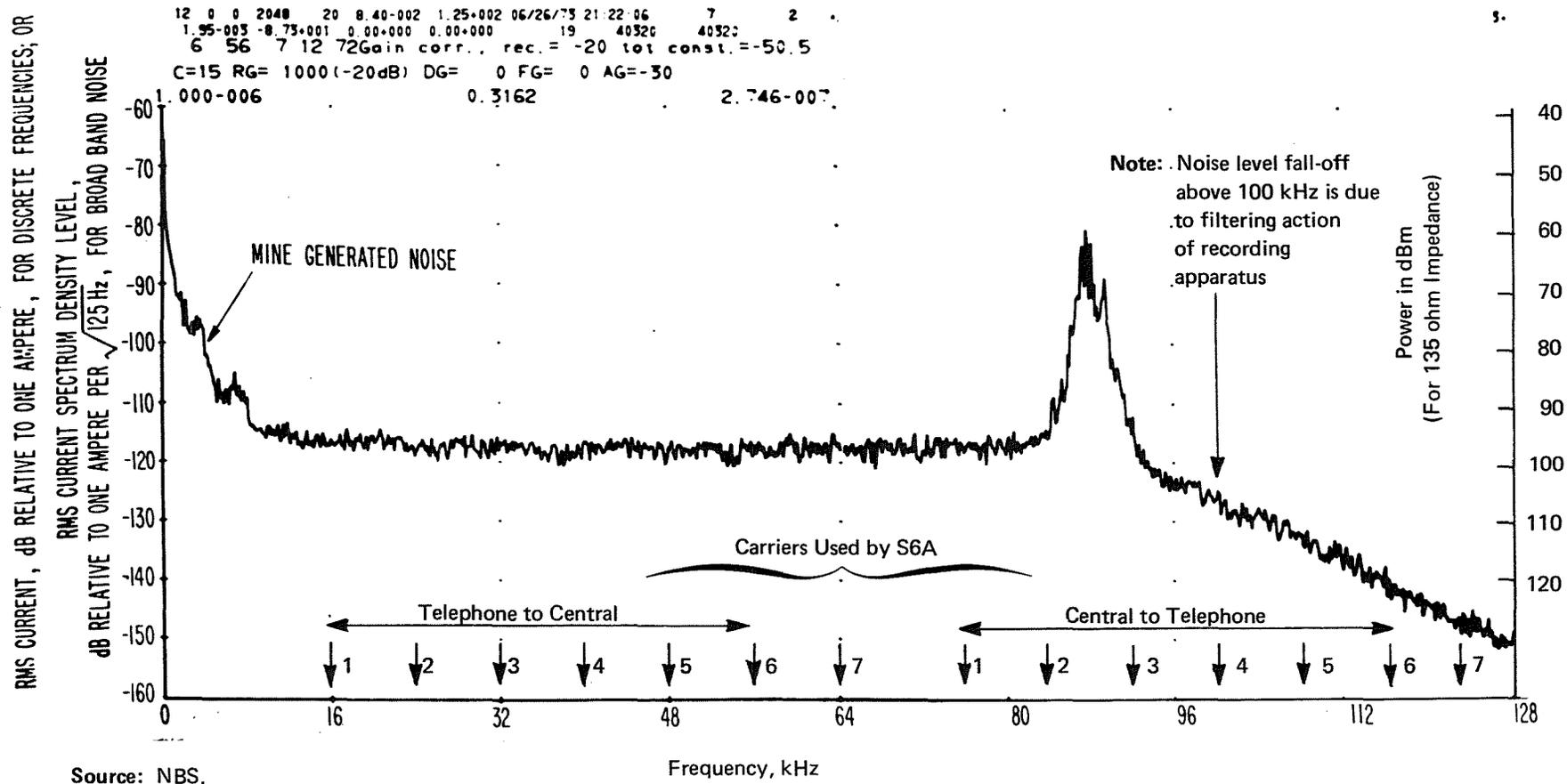
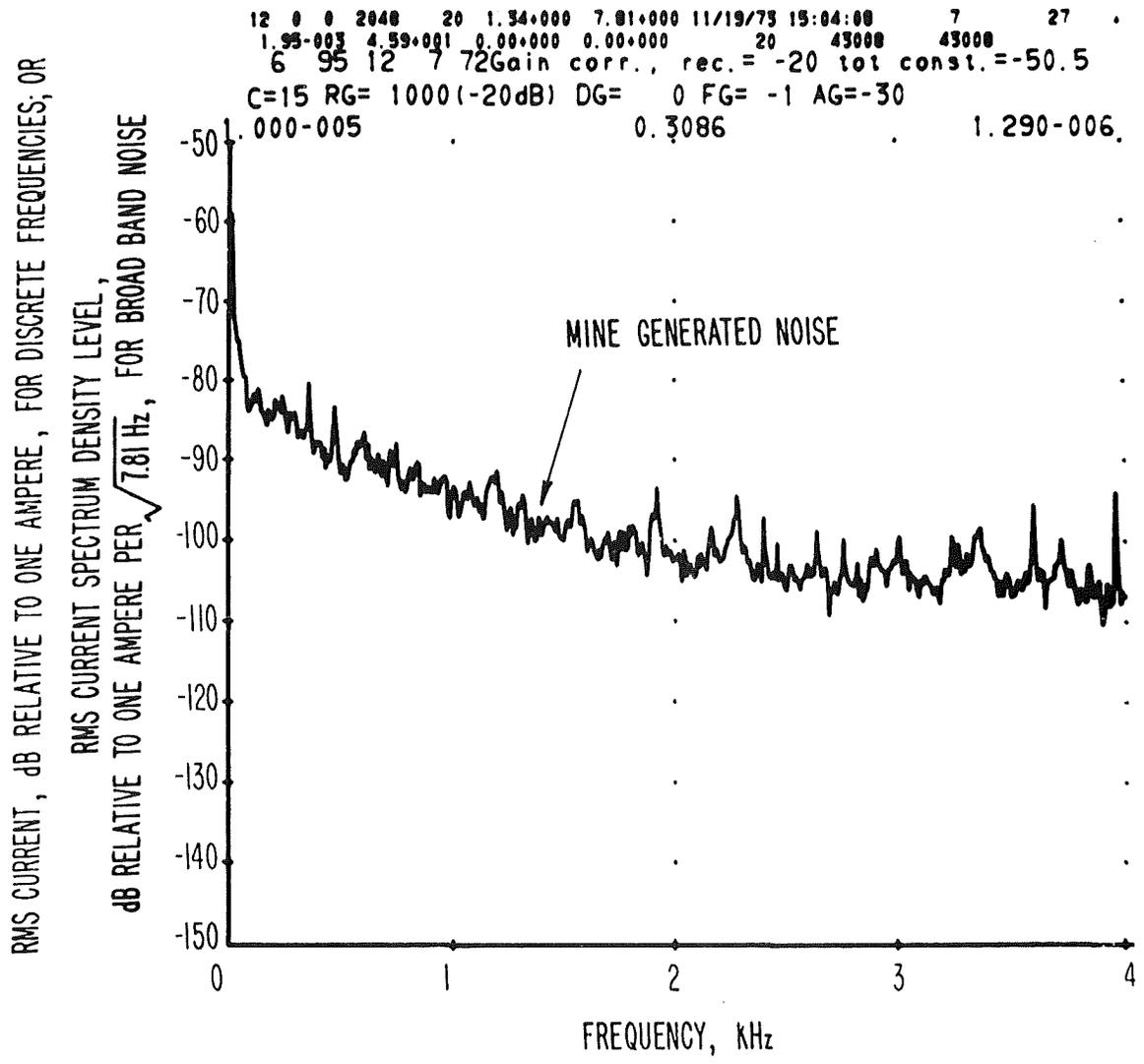
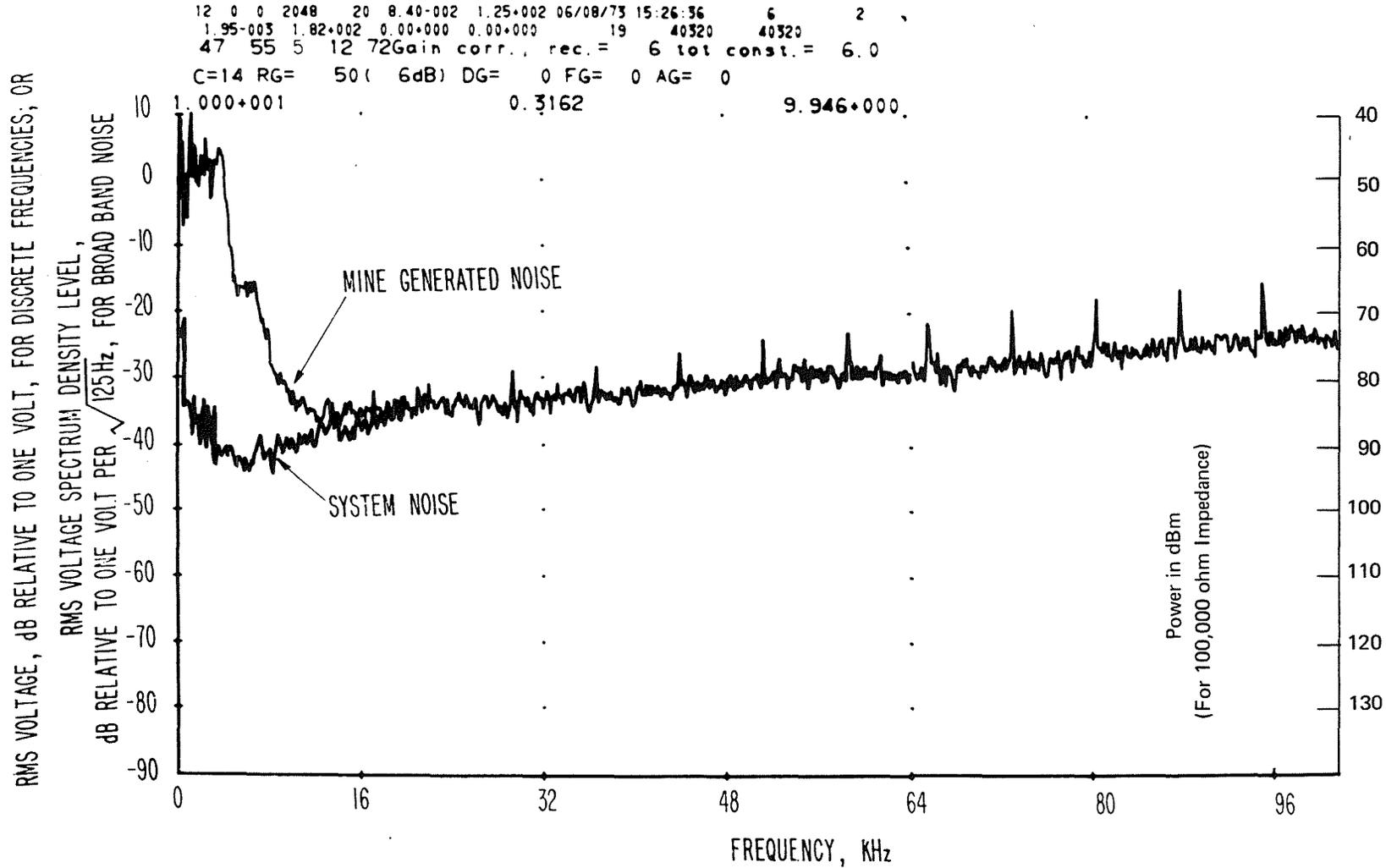


FIGURE 3-16 SPECTRUM OF CURRENT IN ONE PHONE WIRE, OBTAINED WITH A CURRENT PROBE 1 kHz TO 100 kHz, ROBENA NO. 4 MINE, UNDERGROUND, 1 TO 100 kHz, 11:42 A.M., DECEMBER 7, 1972. SPECTRAL RESOLUTION IS 125 Hz.



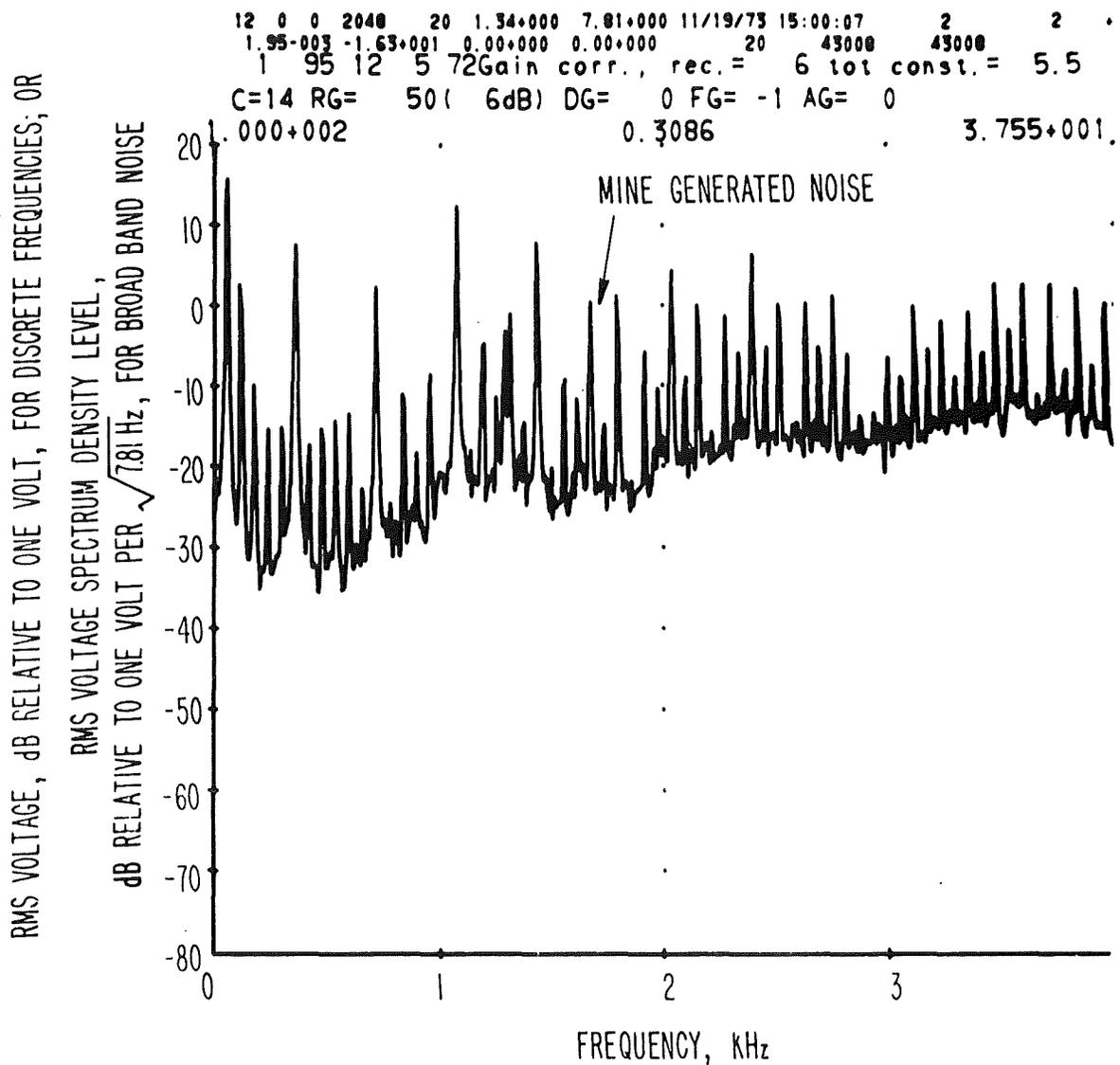
Source: NBS.

FIGURE 3-17 SPECTRUM OF THE CURRENT ON ONE PHONE WIRE OBTAINED WITH A CURRENT PROBE, ROBENA NO. 4 MINE, UNDERGROUND, 100 Hz TO 3 kHz, 11:42 A.M., DECEMBER 7, 1972. SPECTRAL RESOLUTION IS 7.81 Hz.



Source: NBS.

FIGURE 3-18 VOLTAGE SPECTRUM MEASURED BETWEEN ONE PHONE WIRE (Of Two) RELATIVE TO A RAIL, 1 kHz TO 100 kHz, ROBENA NO. 4 MINE, UNDERGROUND, 4:30 P.M., DECEMBER 5, 1972. SPECTRAL RESOLUTION IS 125 Hz.



Source: NBS.

FIGURE 3-19 SPECTRUM OF THE VOLTAGE MEASURED ON THE MINE PHONE WIRE RELATIVE TO THE RAIL, ROBENA NO. 4 MINE, UNDERGROUND, 100 Hz to 3 kHz, 4:30 P.M., DECEMBER 5, 1972. SPECTRAL RESOLUTION IS 7.81 Hz.

harmonic lines be if the mine had been active? It can be inferred from Figure 3-18 that 10 dB is the answer to that question. The second question is more difficult. Would the base line of Figure 3-16 move up if the mine were active? An answer can be inferred by reviewing other data taken during active and inactive periods. Mr. W. Bensema of NBS was kind enough to review his logs and supply the information shown in Figures 3-20, 3-21, and 3-22. These show abstracts of the APD data and the arrows indicate the data taken during inactive periods. Looking at the trend of Figure 3-20 shows that, if anything, noise during inactive periods is higher than during active periods. Figure 3-21 confirms this impression, and Figure 3-22 appears to indicate a stand-off. A margin of 6 dB would give some reassurance, so it will be assumed that during an active period the base line of Figure 3-16 would move up 6 dB.

The last matter which must be factored into any noise budget is the bandwidth of the carrier channel. Most, if not all, of the carrier systems of interest use a bandwidth of some 6500 Hz at the carrier frequency. Since the processing used for Figure 3-16 employed a bandwidth of 125 Hz:

$$10 \log \frac{6500}{125} = 17 \text{ dB}$$

must be added to the numbers cited. Thus, for:

(A) Carrier channels in the range 15 to 80 kHz and beyond 92 kHz, the noise budget is:

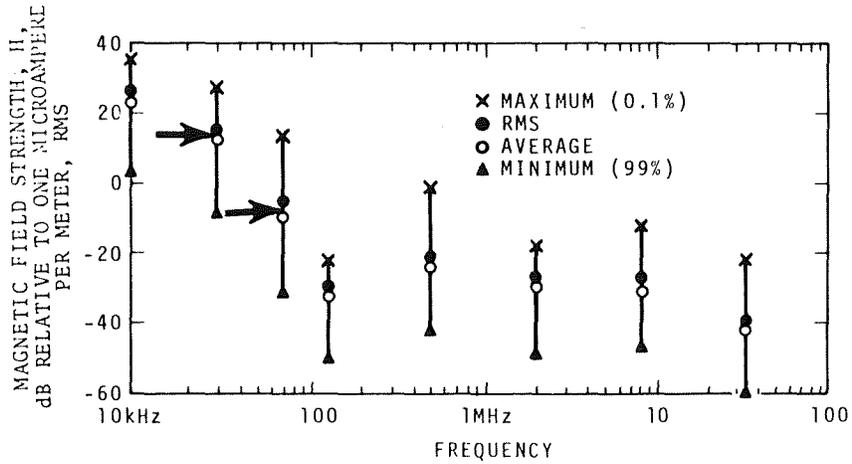
(a) Factors to be added:

Increase in base line	6 dB
Harmonic lines	10 dB
Bandwidth	<u>17 dB</u>
Total	33 dB

(b) Readings:

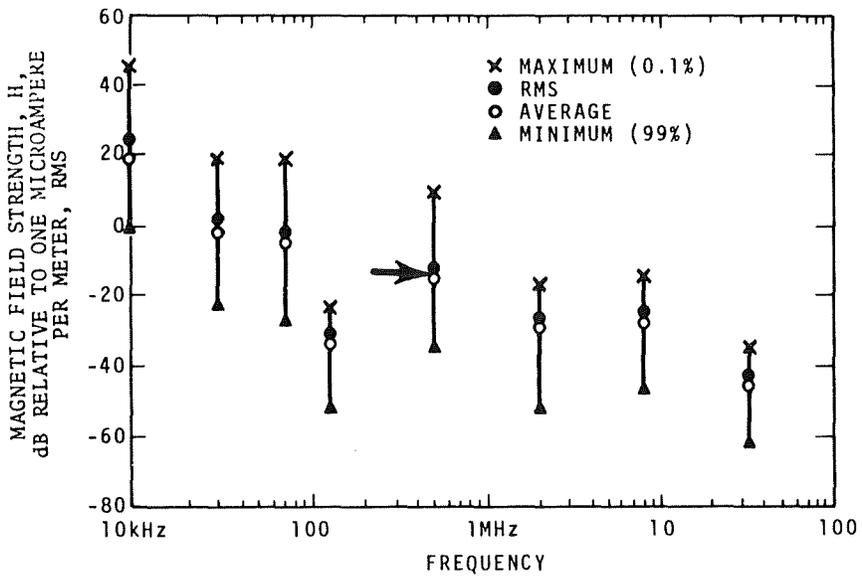
Noise from Figure 3-16	- 95 dBm
Factors from (a) above	<u>33 dB</u>
Result	- 62 dBm

To obtain a signal-to-noise ratio (S/N) of 30 dB, which is reasonable but not outstanding telephone quality, a minimum received carrier power of -32 dBm is needed.



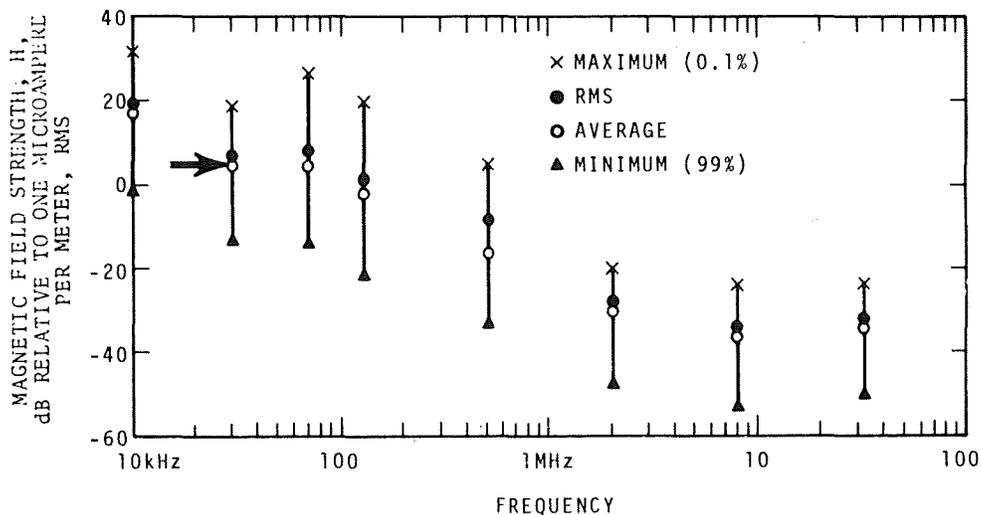
Source: NBS.

FIGURE 3-20 FIELD STRENGTH EXCURSIONS BETWEEN 0.1% AND 99% OF THE TIME AS A FUNCTION OF FREQUENCY, VERTICAL COMPONENT, DECEMBER 5, 1973.



Source: NBS.

FIGURE 3-21 FIELD STRENGTH EXCURSIONS BETWEEN 0.1% AND 99% OF THE TIME AS A FUNCTION OF FREQUENCY, HORIZONTAL COMPONENT E-W, DECEMBER 5, 1973.



Source: NBS.

FIGURE 3-22 FIELD STRENGTH EXCURSIONS BETWEEN 0.1% AND 99% OF THE TIME AS A FUNCTION OF FREQUENCY, VERTICAL COMPONENT, DECEMBER 7, 1973.

(B) Carrier channels near the peak trolley phone interference frequency:*

(a) Factors to be added	33 dB as before
(b) Reading from Figure 3-16	- 60 dBm
Result	- 27 dBm

For a S/N ratio of 30 dB, the minimum received carrier strength needed is +3 dBm.

E. APPLICATION OF THE ANACONDA S6A SYSTEM

The summary of available carrier systems (Section IIIA2) concluded that the Anaconda S6A was one of the few systems deserving serious consideration. To bring noise budgets and cost considerations into focus, this section will examine the performance of the S6A in the mine environment.

*Note the trolley phone was active in Figure 3-16, but not in Figure 3-17; about the only good break in the data.

1. Electromagnetic Considerations

The Anaconda S6A is a seven-channel system and Figure 3-23 shows the general specifications of the system. The following items are worth noting in regard to its suitability for mine applications:

- The system provides a suitable number of channels (seven) and uses a single pair.
- The specifications headed “Environment” and “Mechanical Specifications” make the system look more practical for mines than most multiplex equipment.
- The system allows branches to individual conventional dial telephones.
- Remote units at the telephones have batteries which are trickle charged over the pair. Although this feature necessitates an expensive adapter for each existing pager phone (see Section IIID1d above), it enables the system to be freestanding and not connected to 110-volt power below ground.

It is worth repeating here that, in common with all available subscriber carrier equipment, the Anaconda system is designed to interface a central office at one end and conventional telephones and *only* conventional telephones at the other. It was designed as a transparent substitute for copper pairs connecting the telephone office to subscriber telephones. To perform its signaling and supervision functions, it expects to receive central office signals at one end (such as the ringing voltage generated by the office to ring the telephone) and reproduce them at the other (it remotely generates ringing voltages to ring the bells as needed). Conversely, it expects to 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 – i.e., one cannot tell from the outside whether the system or copper pairs are being used.

In mine applications, the C.O. unit would interface equipment at the dispatcher’s location or mine communication center, and the remote units would interface telephones underground. The carriers used by the S6A are shown in Figure 3-16. It can be seen that the trolley phone affects transmission from the central unit. In this particular instance, channels 2 and 3 are affected but, in general, since trolley carriers can operate anywhere from 60 to 120 kHz, any pair of these central-to-telephone channels are vulnerable. Assuming that these noisy channels are not going to be discarded, they must contend with a noise level of -27 dBm, from (B) of Section IIID2 above. The S6A can insert its carriers at a

GENERAL

Number of Channels: Up to seven on one pair.

Facilities: Single or mixed gauge exchange cable. Plastic or paper insulated 26, 24, 22 and 19 gauge. Also open wire.

Protection: Built-in gas tubes and zener diodes for cable applications. Additional buffer protection recommended for open wire.

Compatibility: S6A is fully compatible with the S6 Station Carrier system and with the ES-1 Electronic Switching system.

DERIVED CHANNELS

Bandwidth: Each channel 300 Hz to 3000 Hz with 4 dB total deviation.

Ringing Options and Subscriber Loop Resistance:

Ringing Option	Type of Service	Subscriber Loop*
SPS	Bridged Single Party	200Ω-800Ω
BFR	Bridged 1 to 5 Party Harmonic, Decimonic, Synchronomic (15-70 Hz)	200Ω
SPR	Superimposed Selective: 1 to 4 Party Semiselective: Up to 8 Party	200Ω-800Ω
DCR/DFR	Frequency Selective: and/or Coded	200Ω-800Ω
GND ST	Ground Start	200Ω-800Ω

*Maximum DC loop resistance beyond the Subscriber Terminal is dependent upon the carrier voltage level at the

Subscriber Terminal ($\pm 130V$ minus previous voltage losses).

Terminal Impedance: The minimum echo return loss and singing point are 18 dB and 15 dB, respectively, when compared with an impedance of 900 ohms in series with 2.16 μf .

Compandors: Built-in 30 dB advantage (25 dB subjective), 60 dB dynamic range.

Terminal-to-Terminal Net Loss: 4 dB ± 2 dB at 1 kHz.

Idle Channel Noise: 20 dB rnc maximum (with entire system active).

CARRIER FREQUENCY

Type of Modulation: Amplitude (AM) double sideband, transmitted carrier.

Frequency Allocation: Carriers spaced at 8 kHz as follows. Subscriber-to-CO 8 to 56 kHz, CO-to-Subscriber 76 to 124 kHz.

Nominal Carrier Line Length: 140 dB at 112 kHz with three repeaters and with all seven subscribers at the far end of the system.

Repeater Spacing: Nominal 35 dB (28 dB to 42 dB).

Subscriber Terminal Location: Anywhere within 0 to 40 dB of the CO Terminal or 0 to 35 dB of a Repeater.

POWER

Power Requirements: The entire system is powered from the CO Terminal. The Subscriber Terminal batteries are constantly trickle charged via $\pm 135V$ applied to the carrier pair at the CO Terminal.

Power Supply/Carrier Loop Resistance: With DC/DC Converter, 2200Ω. With Current Limiter, 1900Ω. These line resistances may be increased by insertion of remote power.

Central Office Current Requirements: With $-48V$ only, 1 to 1.2 amps. With $-48V$ and $\pm 130V$, $-48V$ drain is 0.5 to 0.8 amps and $\pm 130V$ drain is 0.1 to 0.12 amps.

ENVIRONMENT

Ambient Conditions: The system is designed to work in the following:

Relative Humidity: 95%

Central Office Temperature: $+30^{\circ}$ to $+140^{\circ}F$ (-1.1° to $+60^{\circ}C$)

Remote Equipment Temperature: -40° to $+140^{\circ}F$ (-40° to $+60^{\circ}C$)

MECHANICAL SPECIFICATIONS

Central Office: One 7 inch (17.8cm) vertical shelf (4 rack-mounting spaces) in a 19 inch or 23 inch (48.3 or 58.4cm) rack will house 7 channel-ends (one S6A CO Terminal).

Repeaters: Repeater housings are die cast aluminum. The single housing, capable of amplifying one complete system in both directions, measures 14.8" x 5.5" x 4.8" (37.6 x 14 x 12.2cm). The dual weatherproof housing, for two complete systems, measures 18" x 6" x 6" (45.7 x 15.2 x 15.2cm). The multiple shelf, for up to six complete systems, mounts in a 23" (58.4cm) rack and measures 23" x 12" x 6" (58.4 x 30.5 x 15.2cm).

Subscriber Terminals: Subscriber housings are weatherproof die cast aluminum. The single housing, for one subscriber, measures 14.8" x 5.5" x 4.8" (37.6 x 14 x 12.2cm). The dual housing, for two subscribers, measures 18" x 6" x 6" (45.7 x 15.2 x 15.2cm). The multiple subscriber shelf, for up to seven subscribers, mounts in a 23" (58.4cm) rack and measures 23" x 12" x 6" (58.4 x 30.5 x 15.2cm). All product specifications are subject to change without notice.



Source: Anaconda Telecommunications, 305 N. Muller, Anaheim, California 92801 (714) 635-0150

FIGURE 3-23 S6A SYSTEM SPECIFICATIONS

power level of +5 dBm and is designed to have up to three repeaters in the line to overcome attenuation. In the present case, the noise margin at the transmitter is $5 + 27 = 32$ dB on the channels affected by trolley carriers. If the noise margin demanded at the telephone is 30 dB, repeaters must be placed at $32 - 30 = 2$ dB intervals along the line. For 19 gauge cable, this implies a repeater spacing of only 1700 feet and a total system length of only 1.2 miles. Other S/N margins give the following numbers:

<u>S/N</u> <u>(dB)</u>	<u>Repeater Spacing</u> <u>(Kilofeet)</u>	<u>Total System Length</u> <u>(Miles)</u>
25	6,000	4.4
20	10,000	7.6
15	14,000	10.8
10	19,000	14.4

These are not very attractive figures, so suppose the noisy channels, channels 2 and 3 of Figure 3-16, are abandoned or reserved for noncritical purposes. The system now has five working channels which contend with a noise level of -62 dBm, from (A) of Section IIID2 above. This allows a comfortable S/N margin of 35 dB to be adopted at the telephone. Repeater spacing becomes:

$$(+5 +62) - 35 = 32 \text{ dB.}$$

On 19 gauge cable, this is about 5 miles and allows a total system length of 20 miles.

The nature of the adapter of Section IIID1d, needed to interface existing pager phones with the twisted pair, is worth a brief discussion. Although the adapter removes power fades, its principal purpose is to remove the dc signaling of the pager phones from the line. The S6A puts minimum dc voltages of +70 and -70 volts* on the line to provide current to the telephone in the off-hook condition and battery charging when on-hook (the batteries are used for ringing the telephone). These voltages are incompatible with those used by pager phones, and hence it is necessary to remove one of the two from the physical pair. Removing the pager phones dc necessitates providing an in-band or tone signaling system, in the adapter, to substitute for the dc signaling. The battery of the pager phone would power the adapter. Although this is complicated, it's simple compared to the problems encountered in attempting to remove the carrier system dc. To power the system from batteries or local 110-volt power involves installing 110-volt batteries or redesigning the power supply, or both. Another consideration in the decision to place the adapters on the pager phones is the nature of the

*The maximum voltages are +135 and -135 volts, for a total of 270 volts across the pair.

base band (0 to 3 kHz) left by the carrier system. The pager phones need this spectrum for voice; and although the carrier system "doesn't use it," there are no specifications on the hash the S6A, or any other carrier system, throws into this band. For the S6A, there is in the telephone units a dc-to-dc converter operating at 4 kHz; hence, some filtering will be needed to roll this off. It appears easier to do this in an adapter attached to the pager phone than one attached to the carrier system.

2. System Costs

In order to obtain an estimate of the problems involved in using the Anaconda S6A, the system will be applied to the "Typical Mine" of Section II. In Figure 2-3 a single pair runs throughout the mine and pager phones on the pair serve six working sections, the inactive mined panels and the haulageways. To use the carrier system, the pager phones must be removed from the pair and then reconnected to it via an adapter. Once this has been done we are in principal at liberty to install carrier phones anywhere on the pair. We estimate the factory cost of an adapter to be about \$150 and hence its selling price would be at least \$300.

The Central Office Terminal of the S6A would be installed on the pair at the dispatcher's location. This is a rack-mounted unit measuring 7 x 19 x 12 inches and was shown in Figure 3-7a. This unit is normally powered off the -48 volt batteries at a central office and hence, in the mine application, a power supply must be added. To allow for outages of 110-volt ac power, the supply should incorporate standby batteries. Several commercial power supplies of this type are available. The other equipment needed for the S6A terminal is the switch board or PABX to provide a central office type interface. Since this equipment is needed for any conventional multichannel system, and since its size, cost and nature can vary considerably depending on taste, it will not be factored into the cost comparisons made in this report. Exclusive of this, the equipment cost at the dispatcher location is:

S6A Terminal	\$1147
Power Supply	340
Batteries (Rechargeable Gel Cells)	160
Rack and Misc.	<u>153</u>
Total	\$1800

At every point within the mine where a carrier phone is needed, the subscriber terminal shown in Figure 3-7c must be bridged onto the pair. This housing can be plugged with P.C. cards to serve one or two telephones. For complete flexibility the system will be equipped with seven of these terminals,

each plugged to serve one telephone. In addition to the connections the terminal makes to the twisted pair to access the carrier, a pair of wires runs from the terminal for telephone connections. Up to five telephones may be connected to this pair, but all of them would be extension telephones on the same channel. For ruggedness these telephones would be wall mounted in a housing. A suitable type would be the Model GB5955 made by Allen Tel Products. The cost of a subscriber drop equipped with one telephone on the end of 2000 feet of drop wire is:

Housing	\$154
Electronics	235
Drop Wire	133
Splice Block	10
Telephone	<u>98</u>
Total	\$630

The size of the mine wire instrumenting is such that the system needs no repeaters on the twisted pair. In larger mines the repeater shown in Figure 3-7b may have to be inserted in the twisted pair to overcome its attenuation. The cost of the repeater, \$230, is not a significant item.

In theory, a system consisting of one central terminal and seven subscriber telephones allows complete flexibility. Anywhere in the mine a carrier phone is needed, either to relieve traffic or to allow privacy, a subscriber terminal can be bridged across the pair. The system provides seven channels running from the dispatcher's office to these individual locations. Each location can talk directly to the dispatcher and/or via the dispatcher's switchboard to another location. The telephone at each location accesses one and only one channel.

The equipment cost of the system can be broken down as follows:

Pager Phone Adapters (17 x \$300)	\$ 5,100
Central Office Unit from above	1,800
Telephone Terminals (7 x \$630)	<u>4,410</u>
Total	\$11,310

These costs do not include the cost of the presently installed twisted pair. Section II discusses that wire cost.

3. Alternative Configuration

The system of the previous section has several severe practical limitations, which bear repeating:

- The pager phone twisted pair can have 270 volts on it. This is a severe maintenance hazard.
- The S6A does not specify what hash it creates in the base band 0-3300 Hz, nor have the Anaconda engineers measured it. The pager phones use this band and it would be unfortunate if it turned out to be noisy.
- The analysis of Section IIID showed that the noise would make two or more channels of the carrier system very noisy.
- The conventional dial telephones it provides are not permissible and hence cannot be too near the working face. In addition, in the event of an interruption in the air flow, the system has to be shut down shortly thereafter.
- The system is designed to interface conventional telephones and cannot provide channels for pager or other non-conventional telephones.
- Although we have made a design sketch of the adapter needed for a Gaitronics Pager Phone to estimate feasibility and cost, we are not certain of these matters. Furthermore, it is very likely that each make of pager phone would require a different adapter.

Some of these drawbacks can be overcome by considering a different system configuration. We could leave the present twisted pair system in place in its entirety and run additional wire into the mine for the exclusive use of the carrier system. This violates one of the ground rules adopted at the beginning of this study; viz., we would study how to increase the utility of the existing twisted pair. From a practical and economic viewpoint, it is worth considering dedicating a separate pair of wires to the multiplex equipment.

The conventional way of using the S6A is to make the carrier transmission pair a continuous run, with no branch points, from the central office terminal out to the farthest subscriber terminal. As and when channels need to be dropped, subscriber terminals are inserted in the carrier pair and the telephone pair from the terminal run to the telephone location. A suitable cable to use in mines is a figure-eight 19 gauge single pair cable with a 0.019 inch steel messenger. As of August 1974, this cable cost \$350 per mile, and we will use it for both the carrier pair and the telephone loop.

The central office terminal with its power supply is located at the dispatcher's office as before. The carrier pair then runs the full length of the main haulageway. Subscriber terminals are located in the main haulageway, where they are easy to service, and are left in place as long as possible. As and when phones need to be moved, the telephone loop rather than the terminal is moved. This arrangement gives the system a close resemblance to how it is used above ground. The limit of the length of the telephone pair for the Anaconda S6A is 200 ohms and thus for 19 gauge cable implies that the distance of the telephone from its associated subscriber terminal must be no more than 2.4 miles. This gives the telephone considerable mobility. One suitable arrangement for our typical mine is to locate three dual and one single subscriber terminals along the length of the transmission pair on the main haulageway. Allowing each telephone to have a one-and-a-half mile loop, the cost of the wire which must be installed is:

Main Haulageway	3.5 miles x \$350	=	\$2225
Telephone Loops	7 x 1.5 x \$350	=	<u>3675</u>
Total			\$5900

This figure is close to the cost of the pager phone adapters used in the system of the previous section, and these items are not needed for this system. Equipment costs for the system can be broken down as follows:

Wire	\$ 5,900
Central Office Unit	1,800
Telephone Terminals	<u>4,410</u>
Total	\$12,110

In addition to this equipment cost, there will be the labor cost for installation. This is higher than for the system of the previous section, but it is doubtful if the difference would be more than \$1000 or so.

The outstanding advantage of this configuration is that, from a technical standpoint, one can be confident that it will work. It does not have to postulate adapters or gamble on baseband noise. The configuration is the same as that which works in conventional telephones in thousands of installations.

F. EXPERIMENTAL SYSTEMS

It would be inadvisable to close this section without mentioning a system with which John Burr of Lee Engineering is planning to experiment. The systems engineering of the idea is not complete, and the system is "available" only in the sense that its components are either shelf items or can be quickly designed and breadboarded. This lack of availability clearly removes it from the scope of this

study, but from a technical standpoint, the system is a logical extension of the pager phone concept and it deserves attention.

It can be argued that only a fraction of the telephones in a mine need a multichannel capability. Each working section and a few other key points need one multichannel telephone apiece. The remaining telephones, say 50% of the total, can be pager phones. A limited and spotty demand of this type could indicate the need for a decentralized system in which system functions are incorporated in every multichannel telephone. This would make the multichannel telephone very expensive (\$2000 to \$3000, at a guess), but would provide a very flexible system.

As an illustration, consider a multichannel telephone with the following operating characteristics:*

- *Transmission.* Each telephone can access and operate over four trolley-phone channels on the twisted pair. To overcome power fades, carrier is transmitted at a level of a few watts. Lamps on the telephone indicate the busy/idle status of the channels.
- *Power.* The phone is dc decoupled from the twisted pair, and it is powered with 110 volts ac (a limitation) and standby batteries.
- *Signaling.* All signaling is done by means of inband tones, and every phone continuously monitors all four channels.
- *Paging.* Each phone has ten buttons which enable it to page any one of nine zones, or, on the tenth button, all nine zones. When the phone comes off-hook, it seizes an idle channel by putting carrier on it and indicates with a lamp which channel it has seized. Depressing a zone button puts an inband tone on the carrier which alerts the phones of that zone to actuate their paging circuits and to stand by for an incoming call. Paging then takes place.
- *Talking.* When any telephone of the paged zone comes off-hook, it automatically puts the voice signal on the channel over which it was paged. It also injects an out-of-band tone (less than 300 Hz, for example) to indicate to all other phones that the channel is excluded — i.e., the channel is private and must not be accessed. This privacy can be removed by the called party by momentarily depressing a “conference” button.

*It should be emphasized that very little thought has been devoted to the systems aspects of this example. The purpose is to illustrate a concept.

- *Controlled Access.* A phone can be manually instructed to seize a particular channel, and it will do so provided the exclusion tone is not present.

It can be appreciated from this brief description how complicated a multi-channel telephone of this type would be. The advantage of the system is that phones can be added as needed with the same incremental cost. It is not necessary to first purchase the overhead of a controller. An important disadvantage of this fully automatic system described is that if one telephone becomes defective, it could have a failure mode which fouls up all or part of the entire system. Systems which required more manual control, and hence were less vulnerable in this way, could be designed.

IV. MULTIPAIR WIRED SYSTEMS

In the telephone industry, operating companies regard multiplex systems as substitutes for copper pairs and require them to prove in as cost competitive with multipair cable systems. The cost trade-off analysis must take into account such factors as the skill required to install, alter, and maintain a system in addition to the initial equipment costs. For mine applications, multiplex systems still need to be compared with copper pairs, with the addition that the mine environment in which the system is installed and operated must be taken into consideration.

In this section we will examine the effectiveness of using a multipair cable in mines and develop costs for multipair systems. 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 during the life of the mine and specifying the proper multipair distribution system.

A. DESCRIPTION OF MULTIPAIR SYSTEM HARDWARE

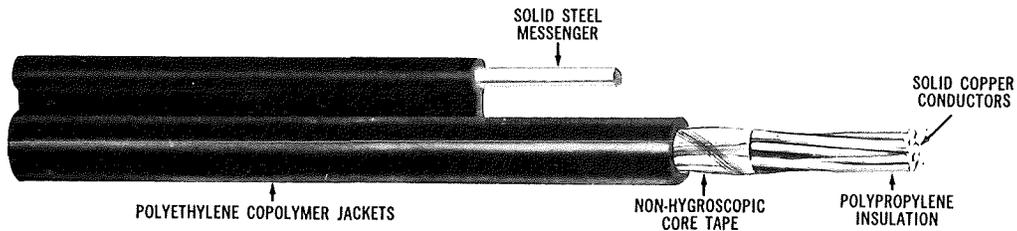
The hardware for a multipair system is of proven reliability and has stood the test of time. All of these materials have been used for aerial distribution systems in the telecommunications industry, and were refined over the years to survive in any part of the world with a minimum of preventive maintenance. They were designed to be installed by linemen working in all kinds of weather while standing on ladders or aerial platforms. In our judgment, multipair equipment can be handled by electricians in the underground environment of the coal mine. The only new skill that mine personnel will have to learn is the splicing of small diameter wires. Crimp type splice connectors such as "Scotchloks"* are available to simplify the splicing of multipair cables. Insulation stripping is not required when using this type splice.

1. Figure-Eight Multipair Cable

The main element in this type of system is the cable, called figure-eight aerial distribution wire (see Figure 4-1). In cross section, the wire looks like a figure-8 with a solid steel support wire, called the messenger, in the top half and a core of twisted pairs in the lower half. The lower core is protected by a non-hygroscopic tape for mechanical protection, and if shielding is required, an 0.008 inch thick corrugated aluminum tape is applied over the core tape. The outer jacket, covering and connecting the support wire and core, is black virgin, high molecular weight, polyethylene copolymer and is highly resistant to abrasion, moisture permeation, and environmental stress cracking. The pair wire is solid, commercially pure, annealed copper with polypropylene copolymer insulation for high

*Product of 3M Co.

tensile strength, and improved resistance to abrasion, impacts, and crushing. Each pair is twisted to a lay length different than any other pair in the core to minimize crosstalk. One conductor of a pair is color coded by a solid body color with a contrasting spiraling color strip. The other conductor has the complementary color combination. There are 25 standard color combinations in use as shown in Table 4-1. The first pair is always the blue/white combination. Cables containing more than 25 pairs are formed into pair units, and the units are bound with color coded string or tape for unit identification. Table 4-2 shows the range of major characteristics of multipair cable, which are available from telecommunications cable manufacturers. Table 4-3 shows the cost of cables that are most applicable to our application. Figure-eight 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.



Source: Anaconda Wire and Cable Co.

FIGURE 4-1 MULTIPAIR FIGURE-8 CABLE

TABLE 4-1

STANDARD COLOR CODING FOR MULTIPAIR DISTRIBUTION CABLES

Pair Number	Color		Pair Number	Color		Pair Number	Color	
1	Blue	White	9	Brown	Red	17	Orange	Yellow
2	Orange	White	10	Slate	Red	18	Green	Yellow
3	Green	White	11	Blue	Black	19	Brown	Yellow
4	Brown	White	12	Orange	Black	20	Slate	Yellow
5	Slate	White	13	Green	Black	21	Blue	Violet
6	Blue	Red	14	Brown	Black	22	Orange	Violet
7	Orange	Red	15	Slate	Black	23	Green	Violet
8	Green	Red	16	Blue	Yellow	24	Brown	Violet
						25	Slate	Violet

Source: Telephone Industry Standard.

TABLE 4-2

RANGE OF MULTIPAIR CABLES COMMERCIALY AVAILABLE

	<u>Range</u>	<u>Units</u>
Number of Pairs	1-400	Pairs
Messenger Size	0.109-0.250	Inches, diameter
Conductor Size	26-19	AWG, American Wire Gauge
Conductor dc Resistance	43-220	ohms/mile @68°F

Source: Arthur D. Little, Inc.

TABLE 4-3

MULTIPAIR CABLE COSTS

<u>Description</u>	<u>Number of Pairs</u>	<u>Cost/Mile*</u>
19 gauge figure-8 cable w/0.109 dia. messenger, and unshielded polyethylene jacket	2	\$ 600
	3	\$ 690
	6	\$1100
	12	\$1820
22 gauge figure-8 cable w/0.109 dia. messenger, and unshielded polyethylene jacket	2	\$ 460
	3	\$ 520
	6	\$ 730
	12	\$1170

*Average price September 1974.

Source: Arthur D. Little, Inc.

2. "J" Hook Supports

The hardware available to mount this type of cable is called a "J" hook tangent support and is a multi-source item (see Figure 4-2). It consists of a "J" hook that holds the cable during positioning and tensioning, and two clamping plates that tighten onto the messenger wire for permanent support. The clamping plates are designed to grab the messenger without biting through the jacket or webbing. This allows the clamp to be relocated or the cable to be reused. These clamps can be fastened with roof bolts to the overburden, or directly to supporting timbers along the walls. The distance between clamps depends on the amount of sag allowable and the tensile strength of the messenger wire.

3. Splice Cases

Another important piece of hardware needed for a multipair system is the splice case, also called cable closure (see Figure 4-3). These are available from several manufacturers in a number of sizes, depending on pair count. The case is mounted to and supported by the messenger and does not have to be mounted to the wall of a tunnel. The “U” shaped cover is easily removed for unobstructed access to the splice area. To expose the individual color coded pairs, the outer jacket is removed only from the cable core. These cases are used for both straight through and branch splicing. The splice case protects the exposed pairs from the surrounding environment and allows easy re-entry for maintenance and modification. For branching applications, terminal blocks are installed inside the case as shown in Figure 4-4. This provides silicon bronze binding posts as taps for the individual pairs. From these posts a single pair cable can be run out through the bottom of the case to individual telephones or a smaller multipair cable can be run for distribution to submains. For straight through splicing only a crimp connector is required.

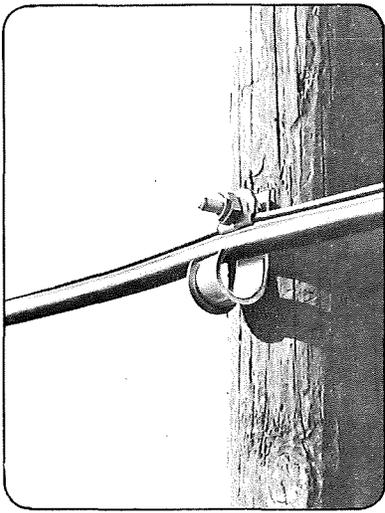
4. Crimp Type Splice Connectors

The most reliable method of making the actual splice is to use a crimp type splice connector as shown in Figure 4-5. Millions of these connectors are used each year in the telecommunication industry. These connectors are designed to splice together any two solid copper plastic insulated wires in the 19-26 AWG range without first having to strip off the insulation. The two wires are inserted into the connector port and then the connector is squeezed together with a pair of parallel, flat jaw pliers to complete the electrical connection. Special tools are available from some manufacturers that automatically feed the connector from a cartridge and crimp it, such as the “Scotchlok” tool shown in Figure 4-6. The connector is also available with a grease sealant inside it to give complete moisture protection for the copper wires.

Although the installation of splice cases and crimp connectors will require some new training of mine electrical and/or maintenance personnel, the elimination of wire stripping from the splicing operations greatly reduces this problem.

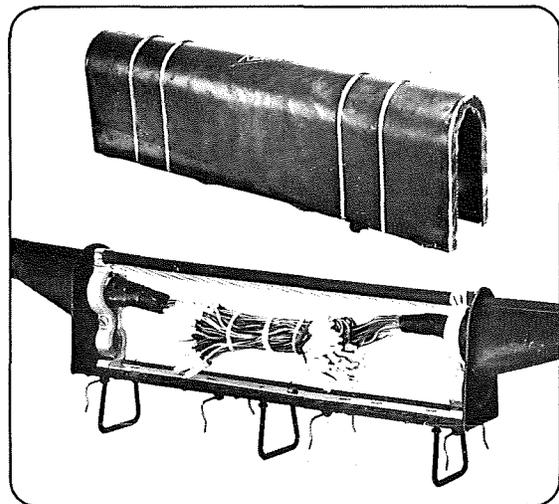
B. MULTIPAIR CABLE COSTS FOR A TYPICAL MINE

In Section IID we developed costs for a single pair cable system using a representative moderate-sized fictitious mine. A description of our typical mine is contained in Section IID1. The same mine will be used to produce cost information concerning a multipair cable system (see Figure 4-7).



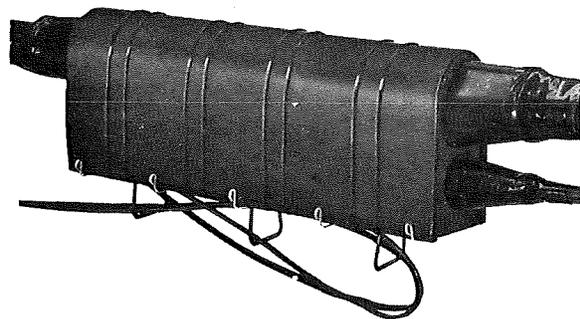
Source: Reliable Electric Co.

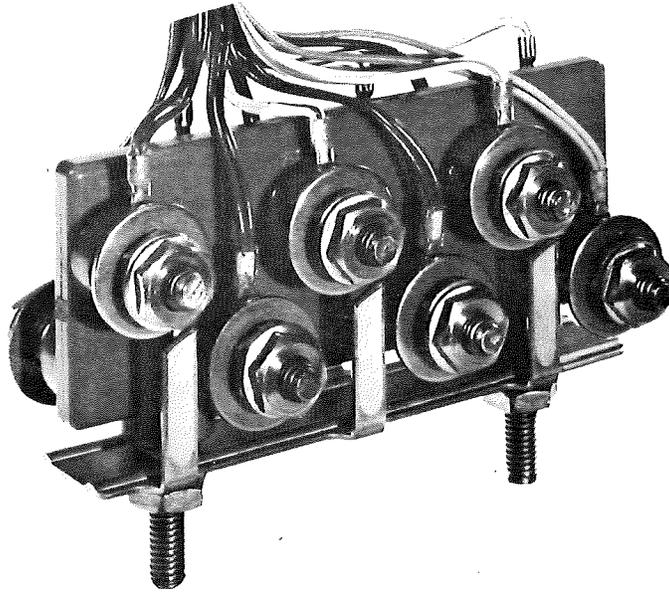
FIGURE 4-2 "J" HOOK TANGENT SUPPORT



Source: Reliable Electric Co.

FIGURE 4-3 FIGURE-EIGHT TYPE SPLICE CASE



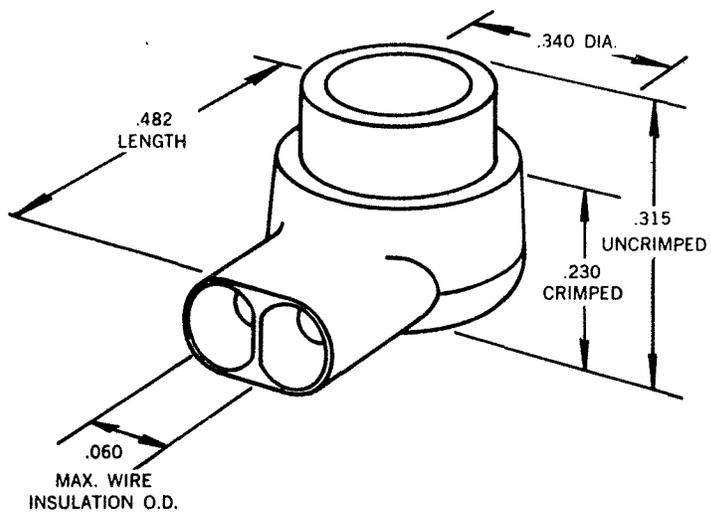


Source: Reliable Electric Co.

FIGURE 4-4 SPLICE CASE TERMINAL BLOCK

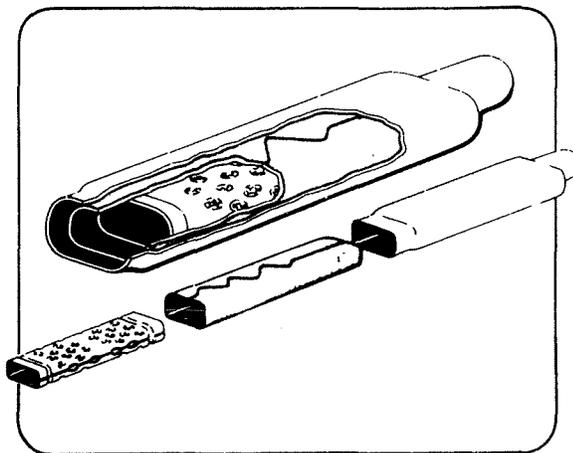
A single pair cable system using pager telephones restricts the mine communication system to a single channel multi-party configuration. Introducing multi-pair cable into the mine communication system allows one to expand the number of channels to whatever is necessary for efficient voice traffic.

By choosing 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 are 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 6-pair cable placed in the main haulageway will accommodate the above required pairs while leaving an extra two pairs for environmental and equipment monitoring, or as spares for future expansion. Three-pair cable is appropriate for the submains because no more than four sections will be in use 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, so that it remains within 500 feet of the working face.



Source: 3M Co.

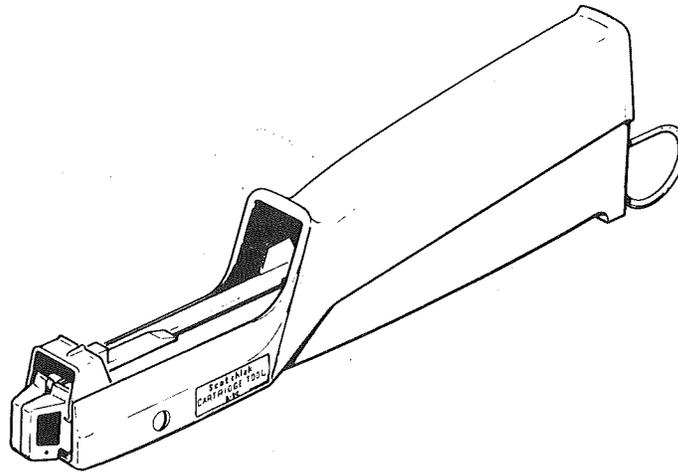
"SCOTCHLOK"



Source: Reliable Electric Co.

B-WIRE CONNECTOR

FIGURE 4-5 TWO EXAMPLES OF CRIMP TYPE SPLICE CONNECTORS



Source: 3M Co.

FIGURE 4-6 "SCOTCHLOK" CARTRIDGE TOOL

1. Main Haulageway Cable and Hardware Cost

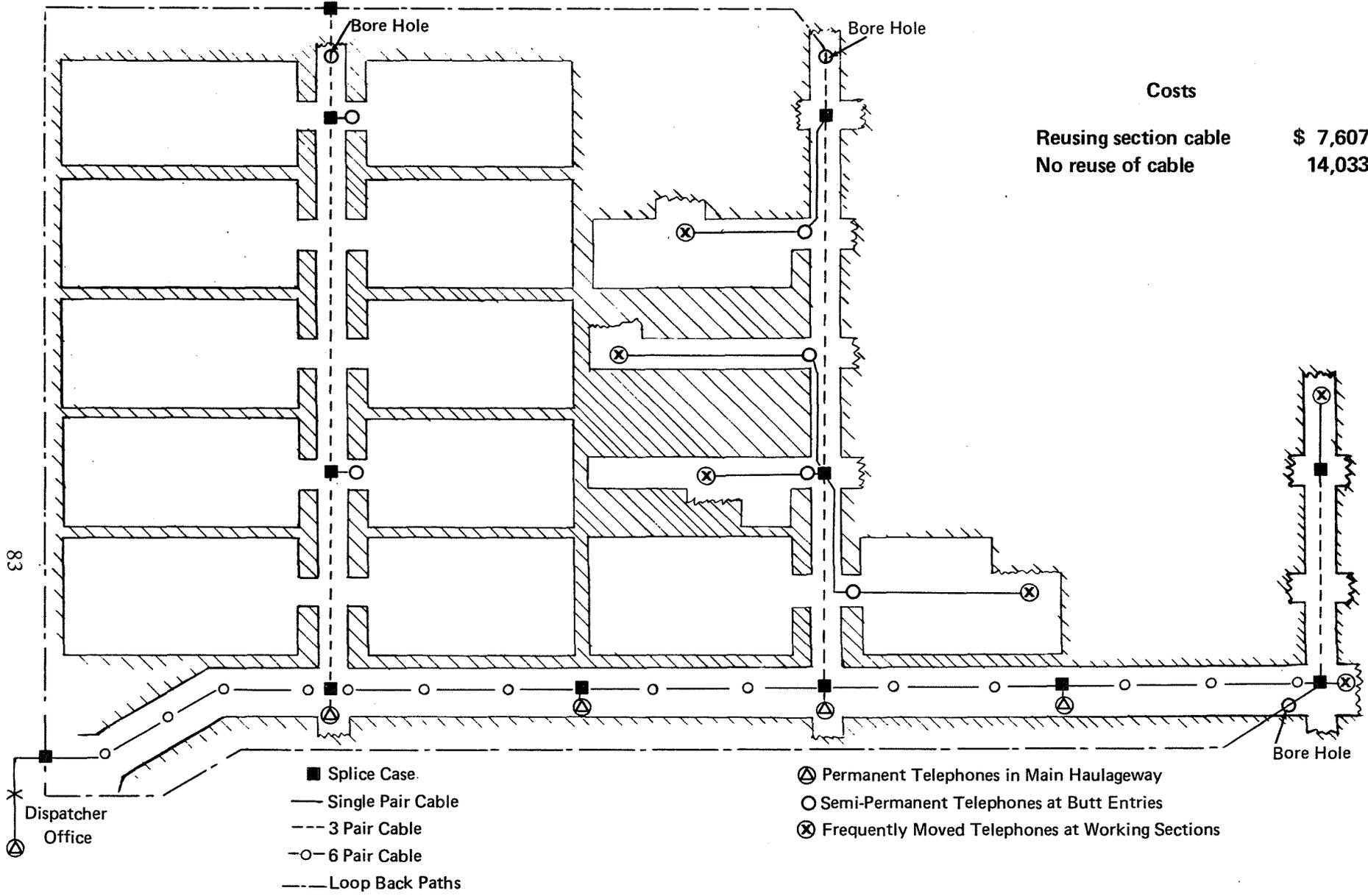
Due to the 3.5 mile length of the main haulageway and its seven phones in parallel across one pair, a 19 gauge 6-pair cable has been selected for the haulageway. The following materials are required for the main haulageway cabling system.

● 3.5 miles of 19 gauge 6-pair cable (see Table 4-3) @ \$1100/mile	\$3850.00
● 7 splice cases with 6-pair unprotected terminal blocks @ \$9.00 ea.	63.00
● 200 "J" Hooks @ \$0.80 ea. (approximately one every 100 feet)	<u>160.00</u>
Main Haulageway Cost	\$4073.00

2. Submain Cable and Hardware Cost

The submains with only two phones per pair, and run lengths of less than one mile, can use 22 gauge wire. A splice case at every third section entry should be sufficient in this application and will reduce labor costs. The following materials are required for an average submain cabling system.

● 0.8 mile of 22 gauge 3-pair cable @ \$520/mile	\$416.00
---	----------



Costs

Reusing section cable	\$ 7,607
No reuse of cable	14,033

- Splice Case.
- Single Pair Cable
- - - 3 Pair Cable
- 6 Pair Cable
- - - Loop Back Paths
- △ Permanent Telephones in Main Haulageway
- Semi-Permanent Telephones at Butt Entries
- ⊗ Frequently Moved Telephones at Working Sections

Source: Arthur D. Little, Inc.

FIGURE 4-7 MULTIPAIR INSTALLATION IN TYPICAL MINE

● 2 splice cases with 6-pair unprotected terminal block @ \$9.00 ea.	18.00
● 45 "J" Hooks @ \$0.80 ea.	<u>36.00</u>
Average Submain Cost	\$470.00

3. Section Cable and Hardware Cost

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 3000 foot reel of wire that travels with the section phone would reach any location in an 800 x 2100 foot panel. Plastic drop wire has been chosen for the section cable. This 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. The stainless steel drop wire clamp used with this cable can be hooked to roof bolts or nailed to support timbers. The following materials are required for an average section cable installation.

● 0.5 mile of 18 AWG plastic drop wire @ \$225/mile	\$113.00
● 30 drop wire clamps @ \$0.20 ea.	<u>6.00</u>
Average Section Cost	\$119.00

4. Total Cable and Hardware Cost

The total cost of the multipair wire hardware for the representative fictitious mine of Figure 4-7 at the 3-submain stage of development is:

● 1 main haulageway	\$4073.00
● 3 submains @ \$470 ea.	1410.00
● 6 sections @ \$119 ea.	<u>714.00</u>
Total Cost	\$6197.00

If we assume that the section wiring will be reused as the mine expands, then the cost of three more submains must be added to the above to obtain the total cost to reach the 6-submain stage of mine development.

● Total cost, with reuse of section wiring	\$6197.00
● 3 submains @ \$470 ea.	<u>1410.00</u>
Total (with reuse of section wiring)	\$7607.00

The above costs represent the total capital investment in communication wiring up to the 6-submain stage of mine development treated in Section II. If we leave all section wire in place, then we must add the cost of 54 more section cables to establish a cost for the case with *no* reused wire.

● Total cost of 6-submain stage with reused section wire	\$ 7,607.00
● 54 sections @ \$119 ea.	<u>6,426.00</u>
Total (with no reused wire)	\$14,033.00

5. Cost Comparison Between Single and Multipair Cable Installations

Before comparing material costs, the differences between labor costs should be examined. Since the stringing costs should be the same for both single and multipair installations, any differences in labor costs will be caused by the additional splicing required for the multipair cable. If we assume that tapping the single pair cable to make a branch circuit takes the same time as making a single splice for the multipair cable, then the labor involved for the additional multipair splicing operations required can be calculated. For the single pair layout, the number of branch circuit taps required for the 6-submain mine development stage of Figure 2-3, is equal to the number of splice taps (6) required in the main haulageway plus the number of panels per submain (10), times the number of submains (6) for a total of 66 tap pairs. The total number of taps is therefore 132 for the single pair system.

The number of splices for the multipair system is the number of splice cases (6) in the main haulageway times (6) pairs/case, plus the total number of submain splice cases (12) times (3) pairs/case for a total of 72 splices. These are really splice pairs, and since 2 splices are required per wire when using terminal blocks, the above-mentioned 72 splices must be multiplied by 4 to get a total of 288 splices for the mine of Figure 4-7. Using crimp type splice connectors and applying them at the conservative rate of 30 per hour, 7.5 hours will be needed to make the 220 additional splices in the multipair system. This additional labor cost is negligible compared to the material costs.

Now we can compare material costs between a single pair cable plan and a multipair cable plan at the 6-submain stage of development. Both plans were designed for the same mine; therefore, this is a fair comparison. First, let us compare systems in which the *section cable is reused*.

● 14 AWG neoprene single pair cable (see Section IID3, Plan A)	
Total Cable Cost	\$17,200.00

- Multipair cable plan
(see Section IVB4)

Total Cable Cost	<u>\$ 7,607.00</u>
Difference	\$ 9,593.00

The second comparison will be between the same two plans only this time with *no reuse of section cables*.

- 14 AWG neoprene and 18 AWG building wire single pair cable (see Section IID3, Plan C)

Total Cable Cost	\$25,100.00
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- Multipair cable plan (see Section IVB4)

Total Cable Cost	<u>\$14,033.00</u>
Difference	\$11,067.00

In both comparisons the multipair cable plan was approximately \$10,000 less expensive. This occurs because the smaller gauge wire allowed in the multipair cable, due to fewer phones placed in parallel per pair, keeps the per mile cost of multipair cable competitive with the larger gauge single pair cable.

C. ADVANTAGES AND DISADVANTAGES OF MULTIPAIR SYSTEMS

Two questions worthy of consideration at this point are: How well does a multipair communication system meet the needs of the coal mine end user?; and What improvements can be incorporated into a multipair system that are not possible with the present day single pair mine telephone system?

1. Advantages

- *More Channels.* Using multipair cable, a system can be designed with as 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 situations 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. 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. In the mine example of Figure 4-7, the main haulageway cable could be increased from 6 to 12 pairs for an additional cost of \$720 per mile or \$2520 for the 3.5 miles shown.

2. Disadvantages

- *Increased Operating Costs.* Any multipair system incorporating all of the above advantages will cost more than a single pair system, even though the multipair cable costs less than the single pair cable. 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 trouble-shoot this somewhat more complex system. This training is a one-time cost.

In conclusion, a disadvantage of all wired systems is the problem of a severed cable caused by a roof fall, explosion, or fire. The added strength of the messenger wire in figure-8 cable provides protection from minor falls parting the cable. The broken cable problem can be further minimized by the use of loop back techniques. Surface loop back is possible by renting pairs from the local telephone company. Underground loop back can be designed into the mine telephone system by looping together the ends of the submain cables and bringing these back via a different underground route to the mine communications center. In both of the above loop back cases, two paths will be provided for every pair in the system.

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16. Abstracts Available analog and digital telephone multiplexing equipment is investigated for its potential to upgrade the traffic handling capacity of present mine phone systems and provide for selective calling. The assessment includes the impact on and constraints imposed by overall mine communications, safety regulations, present mine pager phones and phone line networks, potential interference from trolley wire communications, pager phone interfacing and line conditioning requirements, and cost. A "representative mine" in a communications sense is formulated to serve as a common basis for system and cost comparisons. The investigation reveals that only two or three frequency multiplexed subscriber carrier systems can be considered as serious candidates. However, a more detailed assessment of their practicality for a hypothetical mine installation indicates that even these candidates are largely unsuitable for most underground coal mines, thus requiring the development of special multiplex systems or the use of multipair cable to obtain more channels. The practicality and cost of installing multipair cable in underground mines is also assessed.			14.	
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