

AN ASSESSMENT OF LEAKY FEEDER RADIO SYSTEMS
IN UNDERGROUND MINES

James C. Cawley
U.S. Department of the Interior
Bureau of Mines
Pittsburgh Research Center
Pittsburgh, PA 15236

ABSTRACT

A summary is presented of existing leaky feeder communications systems currently in operation in North America. Background information pertaining to previous use of leaky feeder technology is discussed along with the survey methodology. A review of some pertinent facts concerning propagation in tunnels and specific reference to mine tunnel propagation is presented. A summary of the characteristics of each mine visited is presented in tabular form, and methods of procurement and maintenance are discussed. The role of user training in efficient system use is presented. Seven sites representing eight mines are included in the survey. Economic and technical topics are considered.

INTRODUCTION

Leaky feeder radio systems have become a well established technology for use in areas where normal radio propagation cannot be supported, such as railroad tunnel applications, or where a special geometry must be superimposed on the radiated signal as in Highway Advisory Radio Information systems. As a natural outgrowth of railroad and other transit applications, leaky feeder radio systems have found applications in underground mining. Extensive use has been made of leaky feeder radio systems in Great Britain where the National Coal Board (NCB) has been involved in experimentation and application of such systems for over a decade. Leaky feeder radio systems have become the backbone of British mine communications. Similar applications are also found in France, West Germany, and Belgium.

The Bureau of Mines installed a whole mine leaky feeder system in the United States at Bethlehem Steel's Grace mine in Morgantown, Pennsylvania (1)*. Technically, the system functioned as predicted, and it was anticipated that leaky feeder radio systems

* Underlined numbers in parentheses refer to list of references at the end of the paper.

would find rapid acceptance in industry. During the next few years, mines began to implement the leaky feeder concept. It seems logical, based upon the NCB and Bureau of Mines experiences with leaky feeder systems that such systems should earn a respectable share of the U.S. mine communications market, especially in light of the trend toward nontrolley haulage in newer U.S. mines. In order to assess the state of leaky feeder communications, the Bureau has sponsored a study of leaky feeder radio systems in underground mines (2).

The study uncovered an interesting array of information concerning system configuration, uses, miner acceptance, installation and maintenance costs and mine management's attitude toward the systems. The objective of the study program was to investigate as large a sample as possible of mines employing leaky feeder technology. Since no central source of information could be found, leads were obtained from radio equipment and cable manufacturers as well as those supplied by Bureau personnel. Economic as well as technical data were gathered during the survey. Where hard data were not obtainable, best estimates were attached by the survey team in order to evaluate all mines on a common basis. After all obtainable leads had been compiled, telephone contact was made with each mine to learn if leaky feeder communications were employed at the site. From this data base, it would be possible to select up to nine mines for information-gathering visits.

PROPAGATION IN TUNNELS

The use of radio in underground mines has been frustrated due to relatively poor propagation characteristics associated with mine tunnels. Researchers have modeled the underground tunnel as an imperfect waveguide whose walls partially absorb and partially reflect incident electromagnetic radiation. Propagation, therefore, is a function of both the tunnel dimensions and the surrounding material comprising the tunnel floor, ribs, and roof. Measurements of radio propagation characteristics along straight tunnels correlates to what one would expect of such a waveguide. Attenuation, expressed in db, varies linearly with distance and exhibits large losses around corners, bends, or any deviation from a straight path. Surface irregularities of the walls also contribute to path losses. Typical results of propagation losses in mine tunnels are shown in Table 1.

These measurements, made by Goddard (3), show a significant difference in communication range with antenna polarization. This fact is most noticeable in mine tunnels having one dimension significantly greater than another. Antenna polarization aligned with the longest tunnel dimension will yield the greatest communication range, a property exhibited in Table 1. The more nearly a mine tunnel approximates a square the less noticeable this polarization effect will become. The waveguide propagation mode requires tunnel dimensions greater than a wavelength of the radiated signal in order to support propagation. Range is also a weak function of both receiver sensitivity and transmitted power.

Table 1.--Propagation characteristics in a coal mine
7 ft x 14 ft tunnel cross section

Freq. (MHz)	Polarization	Coupling loss (db)	Attenuation (db/100 ft)	Bend loss (db)	Approx. range (ft) Straight line	One bend
200	Vertical	65	15	-	480	-
415	Vertical	78	6.5	35	908	369
415	Horizontal	40	5.9	35	1644	1051
1000	Vertical	65	4.3	36	1674	837
1000	Horizontal	57	2.5	38	3480	1960

The total propagation loss (between isotropic antennas) is determined from the table using the following relationship:

$$L = L_0 + A \cdot D + L_c,$$

where L = total propagation loss,

L_0 = fixed (coupling) loss,

A = attenuation/100 ft,

D = distance between transmitter and receiver (in 100 ft),

and L_c = loss associated with a 90° bend.

The above equation should only be used for distances of $D > 100$ ft. To appreciate the significance of the relationship between propagation losses and effective communication distances between handheld portable radios, consider the following:

The effective radiated power of a typical handheld portable is 1 W (0 dbW), and its receiver sensitivity is 1 μ V into 50 ohms (-137 dbW). Therefore, the maximum tolerable propagation loss is 137 db. Using this information, Table 1 can be used to determine the maximum communication range for this mine along a straight tunnel and around one 90° corner, assuming the same receiver sensitivity and transmitted power are used. It should be emphasized that the propagation numbers shown in Table 1 are highly variable between mines. Overburden characteristics may cause significant increases or decreases in propagation characteristics. Each mine should have measurements run to determine optimum frequencies and ranges of communications as part of any radio system procurement. Mines in our survey used 150-MHz and 450-MHz systems. The 150-MHz radios were generally used where there was no desire to communicate away from the main haulage tunnel. Line attenuation and coupling losses are minimized at 150, making it an attractive choice for large systems. The 450-MHz radio can be used for haulage communications and has significantly greater range when used in areas away from the leaky feeder cable as a point-to-point transceiver. One manufacturer now has 800-MHz equipment available which should enhance communications in tunnels of smaller cross-sectional area.

SURVEY DESCRIPTION

This project involved data collection, data evaluation, the drawing of conclusions, and recommendations concerning the usefulness and degree of implementation of leaky feeder radio systems in the underground mines of North America. Previous studies of leaky feeder cables have resulted in numerous recommendations for their use in mines, and a number of such systems have been installed and are currently in use, some for a number of years. In view of this, it was felt that there should be a body of experience available that may or may not support earlier speculation on the usefulness of leaky feeders in a mining environment.

After an exacting questionnaire was developed, a two-person survey team visited up to nine selected mines known to employ some form of leaky feeder radio system. The two team members were selected with backgrounds specifically oriented toward the needs of the study. One team member is a communications engineer with extensive experience in two-way radio systems; the second member has extensive experience in mining, mine safety, and human factors relative to mining operations. During these visits, mine personnel responsible for the maintenance and/or management of the radio system were interviewed.

A typical mine visit consisted of an in-depth interview with the individual at the mine responsible for radio system maintenance. The interview generally lasted about 2 to 3 hours and covered general mine information, technical and maintenance information, operational information, cost information, and a subjective discussion of the benefits and problems encountered in the use of leaky feeder radio. A detailed review of system configuration coupled with a performance check of system components such as repeaters, base stations, etc., was performed where permitted. Table 2 summarizes the specific characteristics found in each mine surveyed.

SYSTEM PROCUREMENT

The method of procurement was the same for nearly every system surveyed. Requests for quotation had been sent to several radio equipment manufacturers, but only one manufacturer would respond; therefore, this manufacturer installed all of the leaky feeder systems studied in the survey. As a rule, the mine operators had not prepared any detailed functional description other than expressing the desire for "good communications" in the covered areas. Systems were specified and installed, often with a performance guarantee, but the survey team could uncover no evidence that the level of performance was ever specified in writing.

A typical system in the survey consisted of about 3 miles of 1/2-inch leaky feeder cable with three repeaters. Twisted, shielded pairs interconnected the repeaters, and a voting comparator drove the

Table 2.--Communications systems summary (3)

Descriptions	Mines							Totals
	A	B	C	D	E	F	G	
Type of mine:								
Hardrock.....	X	X		X				3
Coal.....			X		X	X	X	4
Surface communications:								
Two-way radio.....	X	X	X		X	X	X	6
PBX telephone (mine owned)....	X	X	X	X				4
Underground communications:								
Pager-phone (no dial).....	X					X	X	3
Pager-phone (dial).....			X					1
Leaky feeder radio system:								
Leaky feeder cable.....	X		X	X	X	X	X	6
Twin-lead cable.....		X						1
Radio paging via leaky feeder.....				X				1
Carrier current radio system.....								0
PBX dial telephone system....		X	X					2
Characteristics of leaky feeder system:								
Multiple repeaters.....	X	X	X			X	X	5
Receiver voting scheme.....	X		X			X	X	4
Hardwire repeater interconnect	X	X	X			X	X	5
150 MHz band.....	X	X		X				3
450 MHz band.....			X		X	X	X	4
Type of radio equipment used:								
Standard radio repeater.....	X	X	X	X	X	X	X	7
Standard mobile radios.....		X			X	X	X	4
Railroad mobile radios.....	X			X				2
Repackaged mobile radios.....			X		X			2
Portable handheld radios.....	X		X	X				3
Radio pagers.....				X				1

repeaters in parallel from another audio pair carrying the voted signal. (See figure 1.) No system surveyed used the "one way" or daisy chain concept as do NCB installations. Initial purchase prices for each system ranged from a low of \$35,000 at mine E for a single repeater, five mobiles, and approximately 7,000 ft of 1/2-inch leaky feeder cable, to a high of over \$800,000 at mine A for six repeaters, 50 portables, 37 mobiles, and 15 to 18 miles of 7/8-inch leaky feeder cable. Mine E purchased six systems simultaneously. (See figures 2, 3, 4.) The typical system depicted in figure 1 would cost about \$70,000 if configured with 10 mobile radios and 10 portables.

In general, unless there is some overriding maintenance consideration, it is always cheaper to configure a leaky feeder system with 1/2-inch cable instead of 7/8-inch cable. Figure 5 illustrates a hypothetical 4-mile leaky feeder system using 1/2-inch cable, requiring a repeater in every 5,000-ft section and a 7/8-inch cable requiring a repeater in every 10,000-ft section. Obviously, if 7/8-inch cable is used in a mine system other considerations, such as repeater reliability, downtime, or difficulty in repeater maintenance must be considered of sufficient importance to offset the sizable cost difference shown in figure 5.

System specifications during the procurement phase was an area universally neglected by mine operators. Consulting firms with expertise in leaky feeder applications are available, and mine operators would be wise to have a system acceptance specification as well as a system operational specification prepared as part of a bid package. The cost of such planning would be cheap insurance to those contemplating a sizable leaky feeder installation.

SYSTEM MAINTENANCE

System size, as mentioned in the previous section, varies considerably. Obviously, this has a direct influence on the budget required for system maintenance. The quality of maintenance was another factor that varied a great deal. The in-house maintenance program at mine A proved to be the highest quality maintenance found during the study but it also proved to be the most expensive at \$28,000 annually. Mines B, C, and D had contracted maintenance to an outside firm but did routine equipment cleaning and cable repairs on an in-house basis. Maintenance expenditures at these mines averaged approximately \$7,200 annually. Mines F and G utilized only contract maintenance. Portable equipment was removed by mine personnel and serviced in the contractor's repair shop. Repeaters were repaired on site only as necessary. This arrangement cost each mine approximately \$5,000 annually.

The systems operated by mine A and mine E present an interesting contrast and vividly illustrate the importance of quality maintenance to the success of a leaky feeder radio system. Each system is discussed in more detail in the following paragraphs. The ore haulage

system at mine A consisted of one inbound track and one outbound track each approximately 10 miles long. Both tracks occupied the same tunnel. The leaky feeder system provided reliable communications along the haulage tunnel and ore loading areas. The mine is relatively new, and the leaky feeder system was installed as the original communication system. Due to the continuous communication provided by the leaky feeder system, five inbound and five outbound trains may use the haulage-way simultaneously. Mine management stated that the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, has approved a 10-train haulage system only because of the reliable, continuous communication provided by the leaky feeder radio system.

During the first year, mine A contracted all maintenance to an outside organization. This arrangement proved unsatisfactory because downtime was excessive. Due to the remote location of mine A, outside service personnel might not respond to a call for 4 to 8 hours. In the event of a communications failure, ore haulage was limited to one inbound and one out-bound train, reducing mine output by 80 percent for the duration of the failure. Obviously, this situation could not be tolerated.

Today, mine A has an in-house staff of one supervisor and six FCC-licensed technicians who maintain the leaky feeder system along with the mine telephone system, pager-phone system, and a surface radio system. It was observed during the site visit that the quality and professionalism of the electronic maintenance staff was outstanding. A regular schedule of preventative maintenance and performance testing is performed every 6 months or as part of normal servicing. This system was installed simultaneously with the opening of the mine. No former basis of comparison exists for economic consideration; however, management states that production would be limited to one-fifth of its present level because of a two-train operating limit. Mine management fully supports the leaky feeder system and is convinced that the \$800,000 procurement can be soundly justified.

A totally different experience occurred at mine E. Six single repeater systems were purchased for installation in six small, short-life coal mines. A typical system is shown in figure 4. Of the six systems originally installed, only two remain. Several of the mines have been depleted, and one has converted to the use of carrier phones. Neither of the two remaining systems is operationally up to standards. The survey team checked the repeater transmitter (normally rated 70 W) in one mine and found the output to be only one-half W. The leaky feeder cable itself was in poor repair owing to poor splicing techniques and the method in which the cable was handled by maintenance crews. When moving sections of cable, the crews would cut it down and use a utility jeep to drag the cable to its new destination. As a result, much of the re-used cable was stretched and had severely abraded

jacketing, allowing moisture to seep in, damaging the conductors. A lack of proper maintenance instruction was also evident in the splicing techniques used. The mine maintenance personnel would strip the cable to be spliced, twist the center conductors together, and permit the outer conductor to remain open. Not only did this cause line impedance problems but it also provided a place for moisture to enter the cable.

A time and material maintenance contract had been in effect with a local repair organization. The local repair organization had convinced the mine personnel that only FCC-licensed technicians could perform routine tasks such as changing microphones. An additional problem occurred when personnel changes in the maintenance department left no one to supervise radio system maintenance. The outside maintenance organization was allowed to be summoned by virtually anyone and with no subsequent verification that the calls had been made or that service had been adequately performed. Mine management terminated maintenance on the system as repair costs surpassed \$15,000 monthly. A new supervisor has been appointed to oversee the system, but management has decided to abandon all leaky feeder systems.

The difference between mine A and mine E seems to be one of the commitment made by mine management to maintain the system. With the exception of mine E, maintenance costs of the systems studied were not excessive. The system at mine E performed satisfactorily until it was allowed to degrade. Comments such as "dislike" and "distrust" are heard from the miners, as well as other expletives. Mine A management considers the system to be "uneconomical" and "totally unsatisfactory."

USER TRAINING

There was no organized training of mine personnel in the use of portable or mobile equipment, and several problems were recognized as a result. Primarily, when miners did not understand the purpose of the system, they tended to speculate that mine operators only wanted to "spy" on them. Reacting to a perceived threat to independence, a miner in this situation will tend to abuse equipment more than one who has a clear understanding that the system will be of personal benefit by increasing information flow during emergency situations as well as save time during major equipment outtages. Routine location of key personnel underground was one of the main uses of the studied systems.

Sufficient recognition must be given to the miner's and, to a lesser extent, the first line supervisor's resistance to change. This resistance can be lessened by a short training class explaining the use of the system and how the equipment can be operated efficiently. Emphasis should be placed on the fact that the radio system will save needless traveling within the mine and that its purpose is not surveillance of individual personnel.

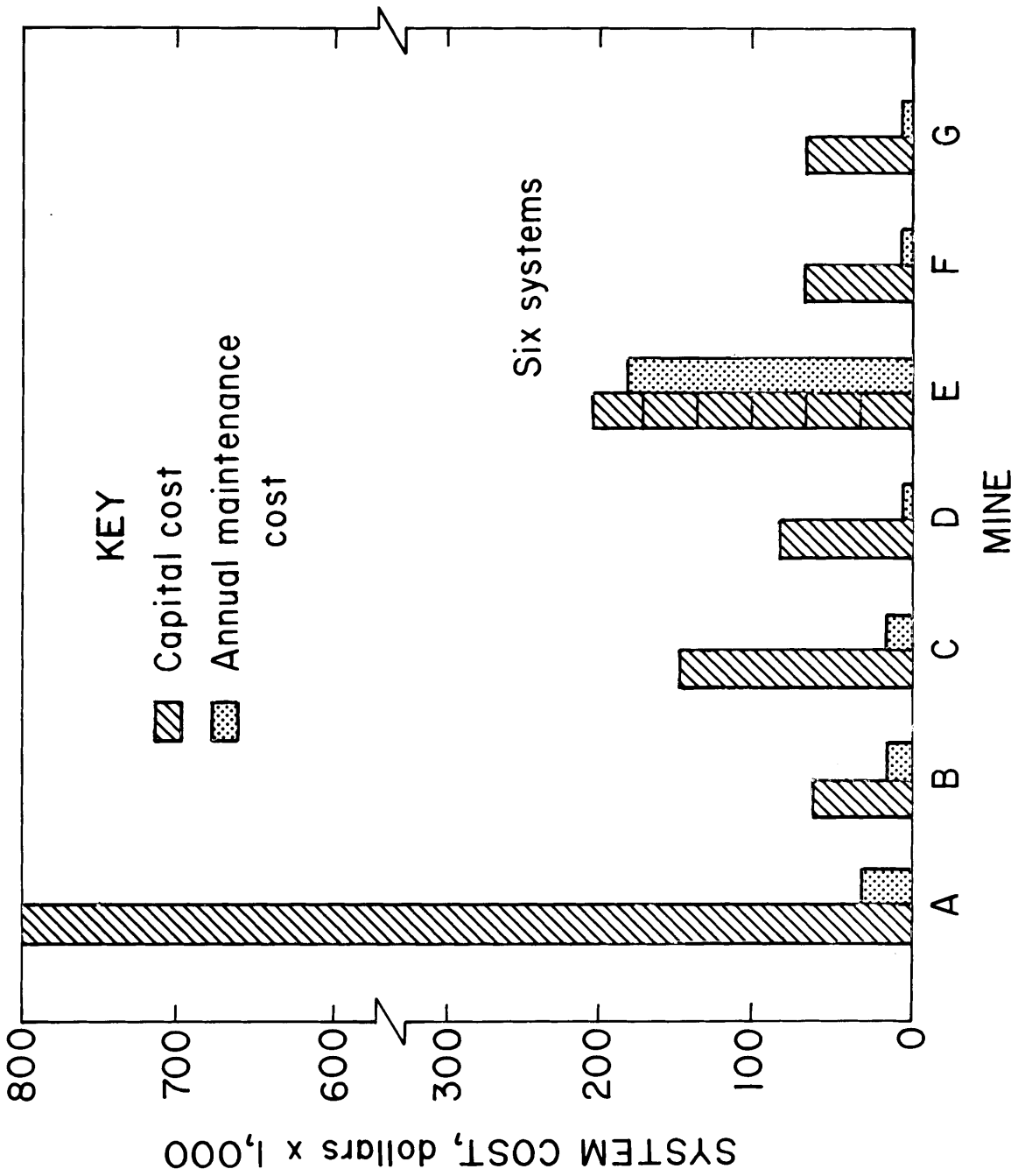
Several mines reported that after an initial period of adjustment miners who carried portable radios regarded them as a status symbol, designating them as VIP's in the mine operating structure. In these situations, there was significantly less abuse of radio equipment.

CONCLUSIONS

- (1) All of the systems studied were supplied by a single radio manufacturer. Little variation was evident in the systems and they tended to be routine adaptations of surface radio technology.
- (2) Five systems used 1/2-inch leaky feeder cable. Mine A used 7/8-inch leaky feeder cable, and mine B used RG-86U, an obsolete 200-ohm twin-lead.
- (3) It is less expensive to configure a system with 1/2-inch than 7/8-inch leaky feeder cable.
- (4) In-house technical expertise was generally nonexistent, and consulting expertise was not solicited during the planning phase of the procurement. Such expertise would benefit the mine in the purchasing phase.
- (5) In all cases but one, the systems were purchased without generating operating or acceptance specifications.
- (6) The mines did not sufficiently investigate the suppliers of available equipment.
- (7) In all cases studied, the miners were not properly trained in the use of the radio equipment. This gave rise to the following problem areas:
 - a. The systems were not used to their full potential.
 - b. Miners were unaware of the cost of a portable radio and abused the equipment. This tended to increase maintenance costs.
 - c. The miner's natural resistance to change caused rejection or excessive criticism of the system.
- (8) Miners frequently viewed the radio as a means for management to tighten its control over them.

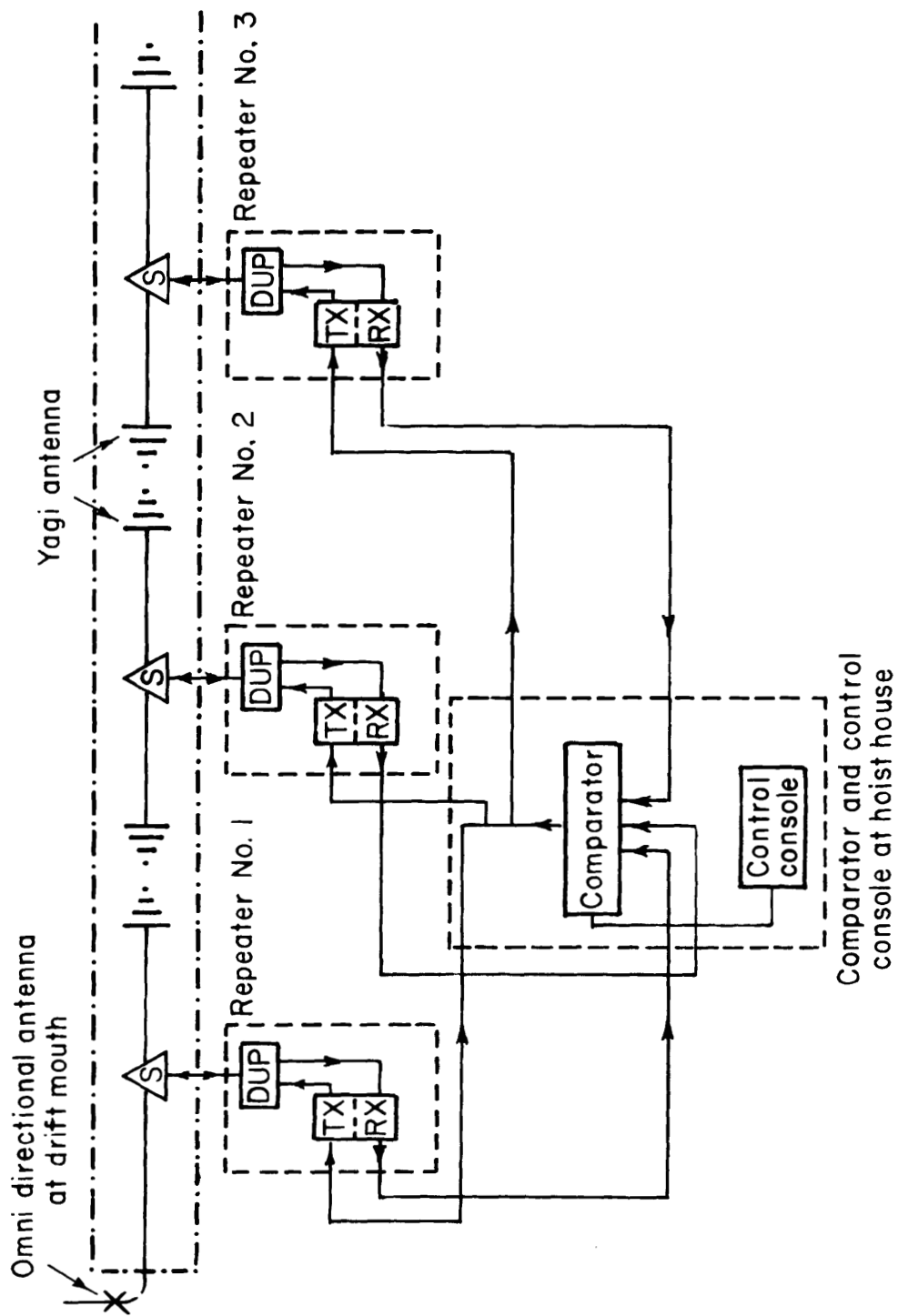
BIBLIOGRAPHY

1. Chufo, Robert L. and Paul D. Vancura, "The Installation, Operation and Maintenance of an Underground Minewide Radio System," Proc. of 1976 IAS Annual Meeting, pp 1196-1202.
2. Goddard, A. E., Radio Prop., "Measurements in Coal Mine at UHF and VLF," In Proc. Thru-the-Earth Electromagnetics Workshop, August 15-17, 1973, ed. by R. G. Geyer, Colorado School of Mines, Golden, Colo., December 1973, pp 54-61.
3. Updyke, Dana, Howard C. Turnage, and Wayne Muhler, PhD, "Evaluation of Leaky Feeder Communication Systems in Underground Mines," Draft report, contract J0199048, Atlantic Research Corporation. June 1980. (Contact author of this paper concerning further information of availability of this information.)



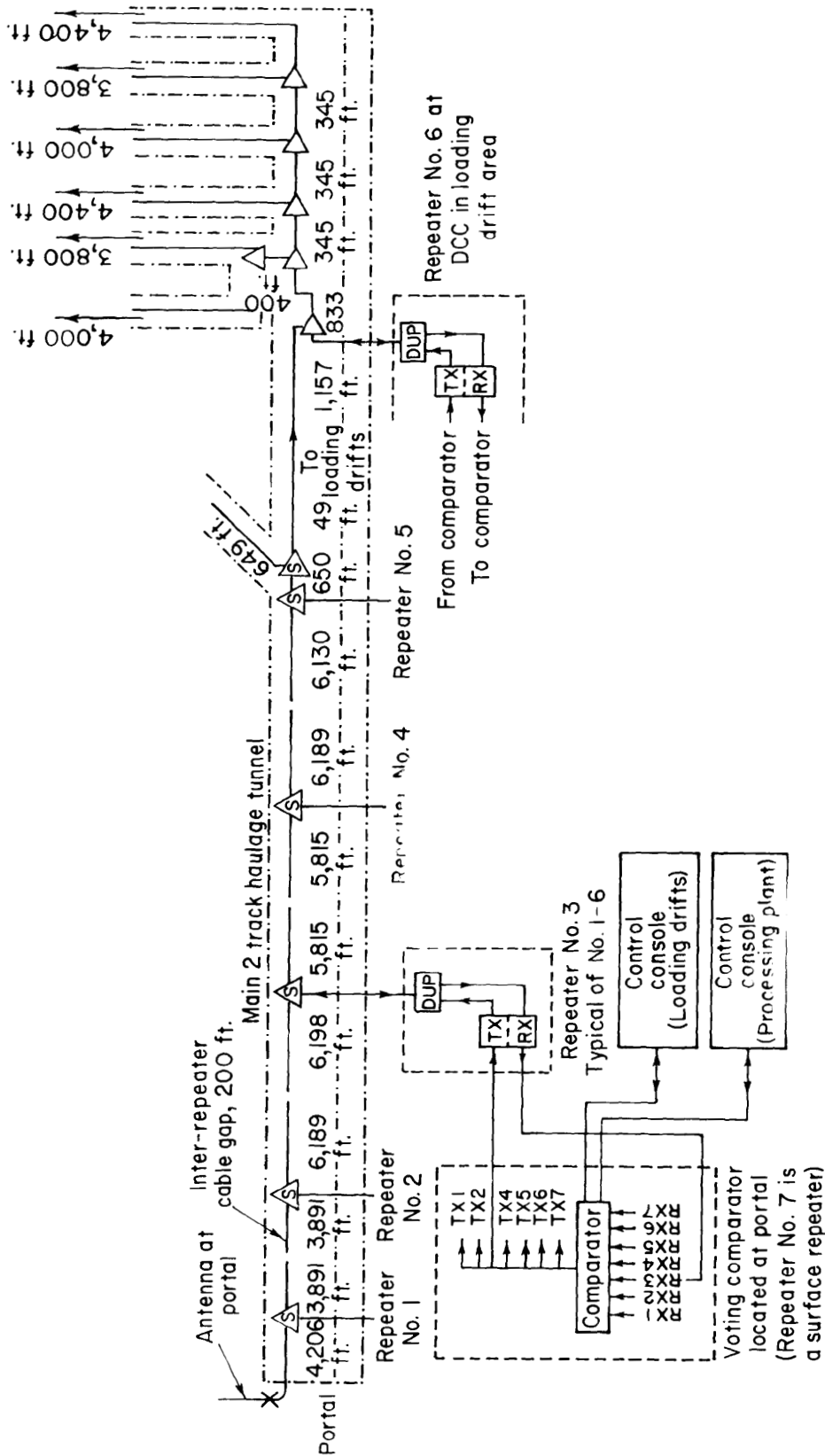
PGH-80
408

2. Procurement and maintenance costs of seven mines in the study.



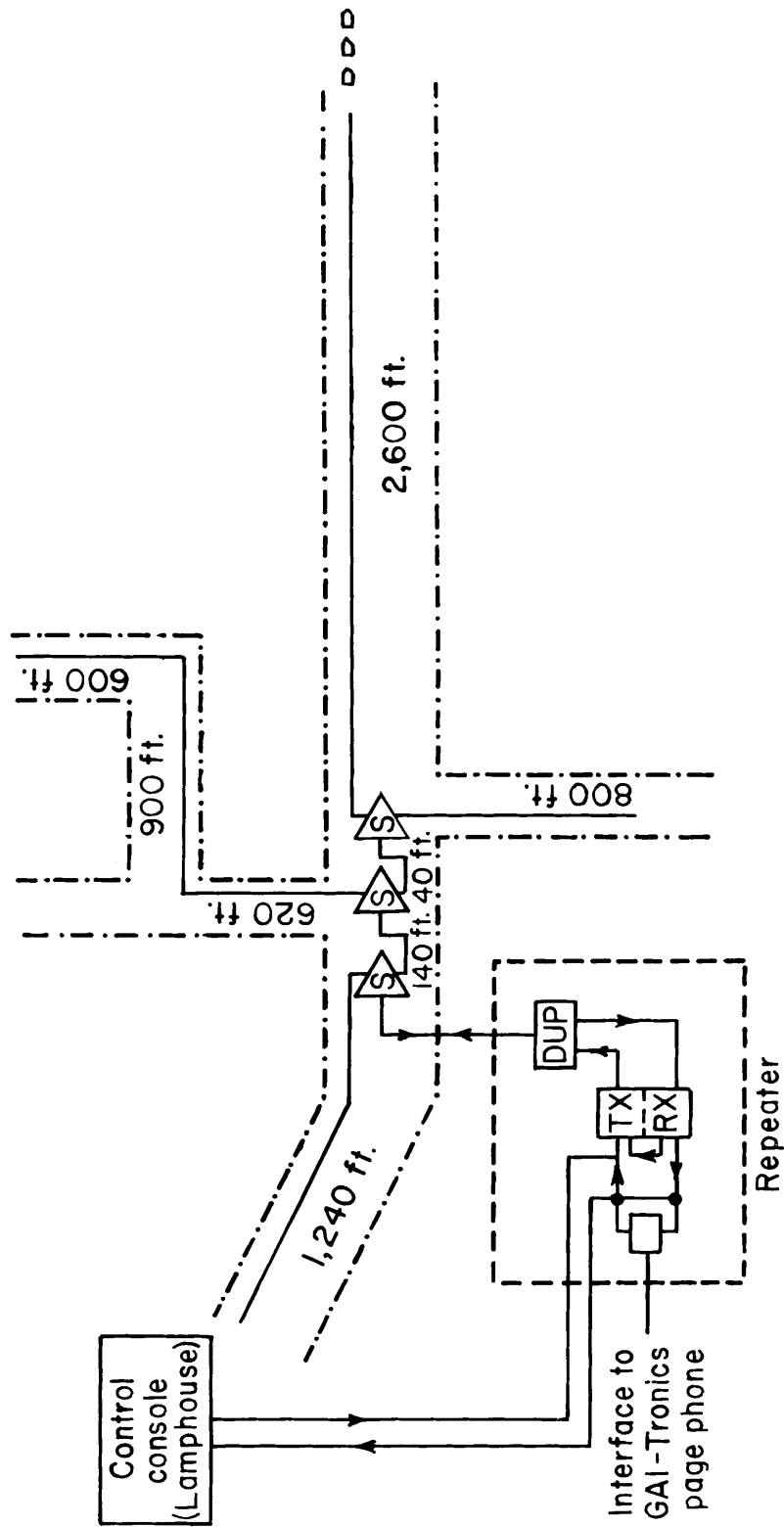
PGH-80
404

1. Block diagram of a typical leaky feeder communication system.



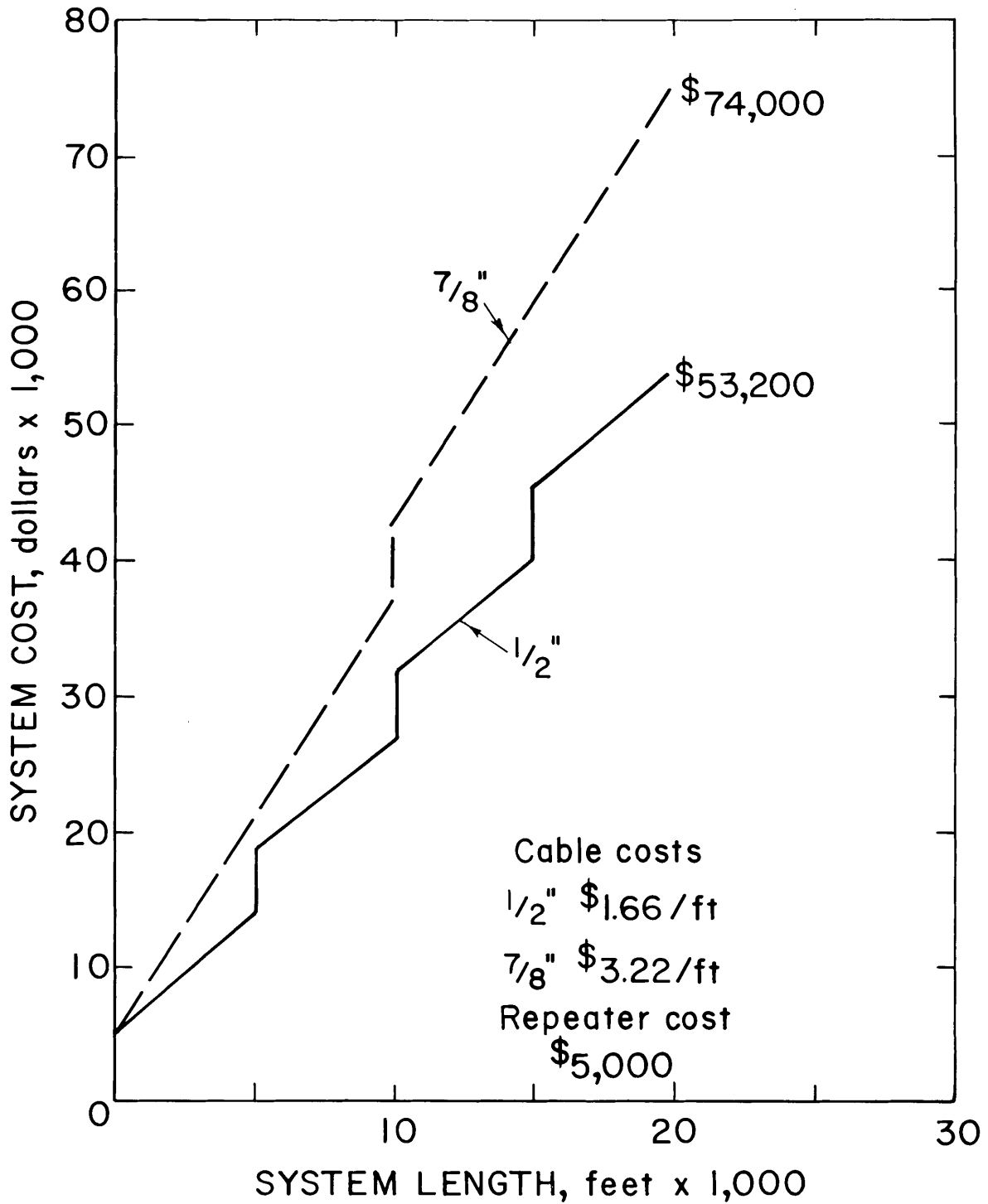
PLH-80
403

3. System configuration of mine A.



PGH-80
405

4. System configuration of mine E.



5. System procurement costs vs system size for 1/2- and 7/8-inch leaky feeder cable.

PGH-80
407