SYSTEM STUDY OF COAL MINE COMMUNICATIONS

Collins Radio Company

COLLINS

COLLINS RADIO COMPANY | Cedar Rapids, Iowa

USBM Contract No. S0122076

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USBM CONTRACT FINAL REPORT (CONTRACT NO. S0122076)

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Department Of The Interior

Bureau Of Mines

Washington, D. C.

Forword

This report was prepared by Collins Radio Company, Telecommunications Equipment Division, Cedar Rapids, Iowa under USBM Contract No. SO122076. 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. H. E. Parkinson acting as the technical project officer. Mr. R. Simonich 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 June, 1972 to June, 1973. This report was submitted by the authors on July 27, 1973.

This technical report has been reviewed and approved.

Disclaimer Notice

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

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LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

Collins Radio Company, through this contract with the Bureau of Mines, has conducted a System Study of Coal Mine Communications. The program was a three phase program to establish a data base, perform communication system analysis and optimization, and prepare equipment specifications to be included in this final report.

At the start of establishing a data base both a knowledge of mine communication and coal mines in general was obtained. Communication system requirements and constraints were determined along with a survey of current and potential mine communication equipment. An investigation was completed concerning theoretical LF and VLF propagation characteristics, and UHF propagation tests were conducted in a working coal mine. Different mines were contacted and on-site surveys completed with respect to coal mine communication requirements.

Various potential functional elements were combined to form coal mine communication candidate systems. These candidate systems were analyzed with respect to propagation range, mine EM noise, power output, size, weight, cost, etcetera.

A system was selected from the candidate systems and gross specifications were written and are included in this report. However, as is mentioned in section 5.0 additional Communication Research, further mine noise measurements need to be completed and utilized in the propagation predictions along with further mine on-site surveys, additional VLF communication tests, and a reevaluation of candidate systems before a final specification can be completed. These items are part of a new contract Collins has with the Bureau of Mines.

2.0 ESTABLISH DATA BASE

2.1 Gain Initial Knowledge Of Mines, Mine Communications, and Mine Communication Equipment

Information was obtained from various engineering reports, papers, Bureau of Mines personnel, Bureau of Mines contractors, mine visits, and initial conferences on coal mine communications. On site mine visits were made at different mines to determine general mine type, mine size, crew composition, mine equipment and power, current mine communications, and communication requirements independent of equipment.

All known major manufacturers of coal mine communication equipment were contacted to determine what equipment they are currently manufacturing and what was planned for future developments. Additionally, manufacturers of general type communications were investigated to determine what equipment they had and if the equipment could be used for coal mine communications. The following is a list of various manufacturers that were considered and have some potential for coal mine communication equipment:

Anaconda Telecommunications Division

Andrew Antenna

Bendix Communications Division

Collins Radio Company

Executone Communication and Sound Systems

Gai-Tronics

Mine Safety Appliances Company

Motorola Communications and Electronics, Inc.

National Mine Service Company

Plessey Communications Systems Corp.

Pye Electronics Limited

Reach Electronics

Set Com Corporation

Sonex Incorporated

Westinghouse

2.2 Determine System Requirements

An initial analysis of coal mine communication requirements was made from the knowledge obtained from various on-site mine surveys, off-site mine surveys, mine electronics equipment manufacturers, Bureau of Mines contractors, and the team of Collins' engineers.

Communication requirements on-site interviews were conducted at the following mines:

Island Creek North Branch Mine, West Virginia
Peabody River King Number 1, Illinois
Inland Steel Company, Illinois
U.S.S. Robena Number 4, Pennsylvania
Pennsylvania Power & Light Greenwich North and South Mines, Pennsylvania

Furthermore, the following mines were contacted for additional requirements information:

Pittsburgh and Midway Coal Mining Company, Missouri
Freman Coal Company, Illinois
Island Creek Coal Company, Kentucky
American Electric Power Company, Ohio

2.3 Establish VLF Theoretical Base

Various theoretical papers and Bureau of Mines investigations were analyzed with respect to VLF propagation in a coal mine environment, and it was discovered that the necessary analysis to predict system propagation range was not available. However, some of these theoretical papers were used in deriving and preparing an analysis which resulted in useable computer programs to predict system performance based on received S/N ratio.

The analysis and resulting papers that were written are listed in the following:

(1) Signal To Noise Analysis For Loop-To-Loop Mine Communications - I

(2) Signal To Noise Analysis For Loop-To-Loop Mine Communications - II

(3) Signal To Noise Analysis For Downlink Line Source Mine Communications

(4) The Field Equations For A Submerged Horizontal Electric Dipole - I

(5) The Submerged HED and VMD - II

(6) The Field Components Of A Submerged Infinite Line Source

(7) On Intra-Mine Wireless LF Communications

(8) Results Of The Submerged Infinite Line Source Analysis

(9) Users Guide For Mine Communication's Propagation Programs

In the course of the analytical work which was accomplished, several basic computer programs were written and are summarized in the paper entitled, "Users Guide For Mine Communication's Propagation Programs." These programs use propagation range calculations with external noise data to perform the following specific tasks:

(1) Communications between a vertical magnetic dipole (VMD) on the surface and submerged VMD.

(2) Communications between an infinite line source on the surface and submerged line source or VMD.

(3) Intra mine communications between submerged horizontal electric dipoles (HED), between HED and VMD, or VMD to VMD.

(4) Intra mine communications from a submerged infinite line source.

2.4 Establish UHF Experimental Propagation Base

Since Collins could not find useable theoretical information or experimental data on UHF propagation in coal mine tunnels, an experimental measurement program was devised to obtain this data in a working mine. Radio propagation measurements were conducted in a coal mine at UHF (200 to 1000 MHZ) and VLF (1 to 50 KHZ) to characterize the transmission loss of intra-mine paths. Field testing was conducted during the last week of November, 1972, at a coal mine operated by Inland Steel Company, near Sesser, Illinois.

Measurements included the effects of frequency, polarization, antenna type, and distance. UHF tests included propagation along straight tunnels and around corners and a comparison of results using passive reflectors at tunnel corners. VLF tests evaluated the performance of roof bolt and loop antennas. The results of this portion of the program are in a report entitled, "Coal Mine Communications Field Report", and the following paragraphs briefly summarize the results.

At UHF a strong dependence of signal attenuation on frequency and polarization was noted. Along a straight tunnel, attenuation rates varied from 15-25 dB/100' at 200 MHz to 2.5-4 dB/100' at 1 GHz. Horizontal polarization was found to yield significantly improved results compared to vertical or cross polarization. The attenuation of horizontally polarized signals averaged 40 dB less than vertically polarized signals at 415 MHz and 30 dB less at 1 GHz. Considerable attenuation was observed in radio signals propagated around tunnel corners. Signal attenuation was approximately 45 dB at a point 20 feet past the corner at 415 to 1000 MHz. The rate of attenuation past 20 feet averaged 30 dB/100' as opposed to the 3-6 dB/100' rate observed in the main tunnel at 415 and 1000 MHz. Complete signal depolarization was noted along the cross tunnel as opposed to the strong horizontal polarization observed in the main tunnel. The use of a corner reflector raised the signal level from 20-30 dB at a point 65 feet past the corner. At 1 GHz, the reflector appeared to lower the attenuation rate along the cross tunnel, resulting in even greater effective gains further away from the corner. Using the experimental results, a 415 MHz system with 146 dB of range could communicate 1800 feet in a straight tunnel and an identical 1 GHZ system could communicate 3200 feet in the same tunnel. Furthermore, predictions have been made for typical coal mine UHF communication coverage.

At VLF, minimum attenuation between two roof bolt antenna occurred in the end-to-end configuration, but other combinations yielded only 10-15 dB more attenuation. Attenuation was relatively flat over the frequency range 1 to 50 KHz and exhibited an attenuation rate of approximately 5 dB/100' for all frequencies and orientations. Maximum attenuation for a roof bolt to loop antenna system occurred along the axis oriented vertically. The field strength produced by the roof bolt antenna was relatively independent of frequency over the range 1-50 KHz. The attenuation rate averaged 4 dB/100' over all frequencies and orientations with individual measurements deviating only slightly from the average.

3.0 COMMUNICATION SYSTEM ANALYSIS AND OPTIMIZATION

Various potential functional elements or separate communication links have been defined. Some of the VLF and LF functional elements include various configurations of loop-to-loop intra-mine, loop-to-loop uplink and downlink, loop-to-line source intra-mine, line source-to-loop intra-mine, line source-to-line source intra-mine, and line source-to-line source uplink and downlink. Other functional elements include various combinations of dial telephones, pagers, carrier phones, wired multiple channel transceivers, UHF radio, UHF radio using relays, and UHF radio using reflectors or multiple antennas.

Selections of different potential functional elements were combined to form candidate systems that satisfy the current coal mine communications requirements. The candidate systems were then analyzed using the data base propagation information. Mine noise data, available at the time, was used to make propagation predictions with the various parameters being antenna type, antenna size, antenna weight, transmitter power, frequency, overburden depth, and ground conductivity.

Special emphasis was placed on the improvement of production that results from improved mine communication with the communication system designed such that it will be operational during a disaster or emergency. Channels were also made available for underground monitor sensors of environment parameters. Trade-off criteria was established for comparison purposes and a candidate system was selected that had a good probability of satisfying the user requirements. Although a detailed cost analysis will be made in the future, preliminary system costs were considered in system selection. Specifications for such a system are included in the following sections.

4.0 COMMUNICATION SYSTEM SPECIFICATIONS

Preliminary gross equipment specifications for a coal mine communication system are presented in the following sections. These specifications were selected from various potential functional elements that could be used for mine communications. They are based on currently available noise data and communication requirements.

The coal mine communication system was broken down into independent communication networks that will be tied into a mine communication center. These networks are the fixed station mine communications together with a wireless extension of the fixed station, haulage communication, and hoist communication. All communication networks will at least have the capability to be monitored at the mine communication center and some may be tied together at this center. Monitor or sensor information will be sent over communication channels to be received at the communication center.

4.1 Communications Center

From the current requirements, it is apparent that the larger mines, over 500, 000 tons per year, need some type of communication center. For example, one mine that was interviewed last summer has since then placed personnel underground with the sole duty to monitor the paging phone and act as a communication center.

The communication center will integrate the various communication networks and environmental sensor networks positioned underground and above ground. This communication center meets its goal of integrating the different complex networks by providing the following:

(1) Providing a center where communications for all networks can be located at one position where an operator can use and monitor the available equipments.

(2) Providing a center where alternate communication paths can be connected, utilized, and monitored for emergency or disaster conditions.

(3) Providing a center for monitoring and processing the data from the networks of safety sensors.

(4) Providing a center for the dispatcher for those mines that require vehicle operator control.

(5) Providing a message handling service for the communications system.

(6) Providing a center for at least one outside telephone station.

4.2 Fixed Station Communication Unit

Two types of fixed station communication units are needed for coal mine communications. The first type of unit will be a master unit used in the communication center and the second unit will be used throughout the mine similar to the current mine pager phone. Each unit shall be tied in parallel and communicate over coax or a single twisted pair of mine phone wire. A redundant path back to the communication center will be provided for emergency situations.

The fixed station working communication unit shall be capable of providing voice communications between working sections, maintenance shops, critical belt locations, supply shops, supervisors office, the communication center, and any other underground and above ground locations selected by personnel of the individual mine. This unit shall also receive paging messages from the communication center and transfer mine sensor information back to the communication center.

The master fixed station communication unit will provide voice communication, paging messages, and collection and displaying of mine sensor information from each working unit.

4.2.1 Fixed Station Communication (Working Unit)

The unit will be capable of multiple channel two-way simplex voice operation with loudspeaking pager, data transfer, and emergency signaling capability. A redundant path back to the communication center shall be provided. For example, the phone wire could be run through a bore hole and then overland to the communication center. Various wireless extensions into the working section are available and can be selected depending upon economics and the desired grade of service required by the individual mine. These options together with the gross specifications for this working unit are as follows:

(1) Push to page loudspeaker page capability using the 300-3300 HZ baseband. This provides the all call feature needed and since the baseband is used, should be the most reliable portion of the system. Only the loudspeaker will respond to the page when called and not the handset.

(2) Eight 6 KHZ narrowband FM frequency division multiplex (FDM) communication channels using the frequency range of 5 to 100 KHZ selecting bands that do not interfer with normal trolley phone communications.

(3) Each station shall have a frequency assigned that can be used for an emergency uplink signal. The signal will be a low duty cycle pulsed carrier and is radiated by driving a loop of wire wrapped around a coal piller. Since selected miners may carry portable emergency transmitters with frequencies of 1000 HZ to 3030 HZ and optimum frequencies for uplink propagation appears to be from 1000 to 6000 HZ, the frequency of each station shall be selected from the 3500 HZ to 5000 HZ range with individual frequencies falling between the 60 HZ harmonics. Coded emergency messages can be utilized.

(4) Six of the eight channels will be used for simplex voice communication. Each channel will be scanned and a light indication will be given to indicate channel usage (light on for channel in use). Two channels will be such that when communication is established, the channel will be secure. The remaining four channels will be the party line type with the transmitter activated by the push-to-talk button on the

handset. There shall be the capability to expand to more channels should a future need arise. Initial contact shall be through the baseband page where an individual is contacted and told what channel to use for the communication. Then the called party can switch to the appropriate channel and the conversation can be completed.

(5) One of the FDM channels will be used to send data to the base station concerning various mine sensors. Each communication unit shall have the capability to transmit data from six separate sensors. The input voltage to the unit from the sensor shall be from 0 to 5 VDC. Typical of the parameters monitored are air velocity, methane, and carbon monoxide with samples taken in both intake and return air. Since this unit can and will be used in locations where there is no need to collect and transfer data, this channel shall be of modular construction and need not be used when not required reducing the equipment cost correspondingly.

Data will be collected from each station every minute. The equipment design can be such that as the master unit sends out a start pulse and its associated clock pulses, individual stations will wait their turn and when their turn comes, they will transmit the data back to the master station for display or processing. An alternate could be the master station addressing each station with a control word which requests data from the individual station. Using this method, control information could also be sent to the station controlling some function in the area.

(6) The last of the eight FDM channels will be used to provide wireless communication which will extend communication beyond the location of the fixed station communication working unit. The communication unit can be of modular construction such that, depending on the mine requirements and economics, either two-way voice using UHF radio, LF voice paging, or VLF call alert can be provided by adding the appropriate module to the unit.

Two-way section communication can be best accomplished using portable radio similar to Motorola's HT220 series. Because the 1000 MHZ short range initial attenuation is slightly higher than the attenuation at 415 MHZ, the 415 MHZ appears to be the better frequency for short range around coal piller type of communication. The radios will be interfaced to the FDM channel which will be used only for this type of wireless communication. A two frequency radio relay station will be positioned in the center of the working location and interfacing wiring will be run back to the communication unit. Portable units, given to select miners, will have two channels. Channel one will transmit on f_2 and receive on f_1 with the radio relay receiving on f_2 and retransmitting on f_1 to any other portable unit. This will provide two-way communication between portables with twice the total coverage as portable to portable. Channel two will provide two-way communication between portables and the master communication unit located at the communication center and will transmit and receive both on f_1. Figure 4.2.1-1 shows the operation of the system using the radio relay on channel 1 or local portable-to-portable communication. Portable to master station communication is shown in Figure 4.2.1-2 where the signal is placed on the phone wire using the FDM channel intended for wireless communication.

Because of the possiblility of missing communication on one channel of a two channel system, both channels need to operate with identical receive frequencies. Furthermore, a selective tone controlled squelch needs to be incorporated in the relay station when transmitting from the master station to a specific working section if more than one working section is equipped with this type of UHF radio.

One-way wireless voice paging can be best accomplished in the frequency range of 70 to 100 KHZ with either a large loop or roof bolts for transmitting antenna. Therefore, the FDM channel frequency shall be selected from the frequency range of 70 to 100 KHZ since this would eliminate any frequency

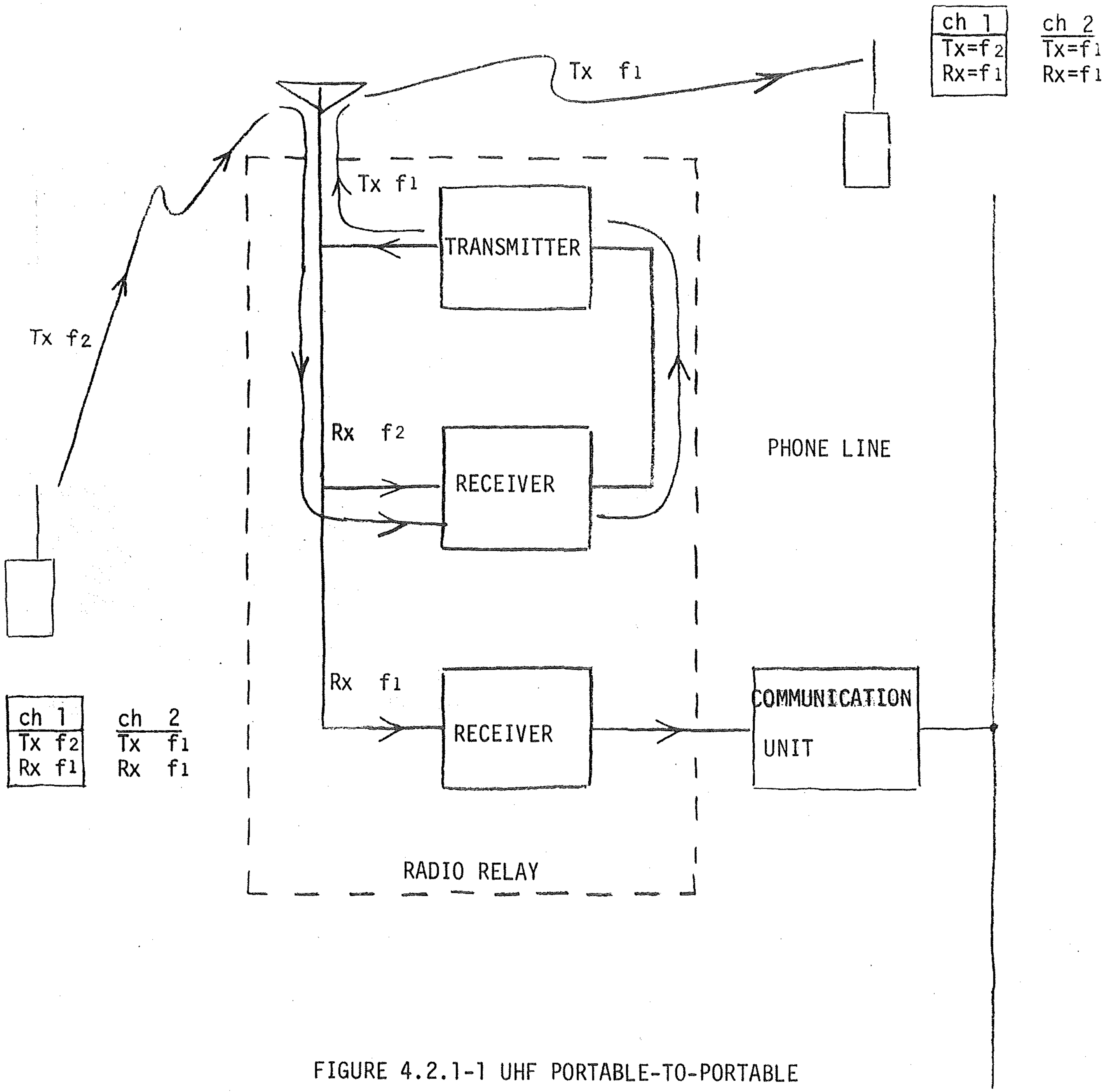

FIGURE 4.2.1-1 UHF PORTABLE-TO-PORTABLE

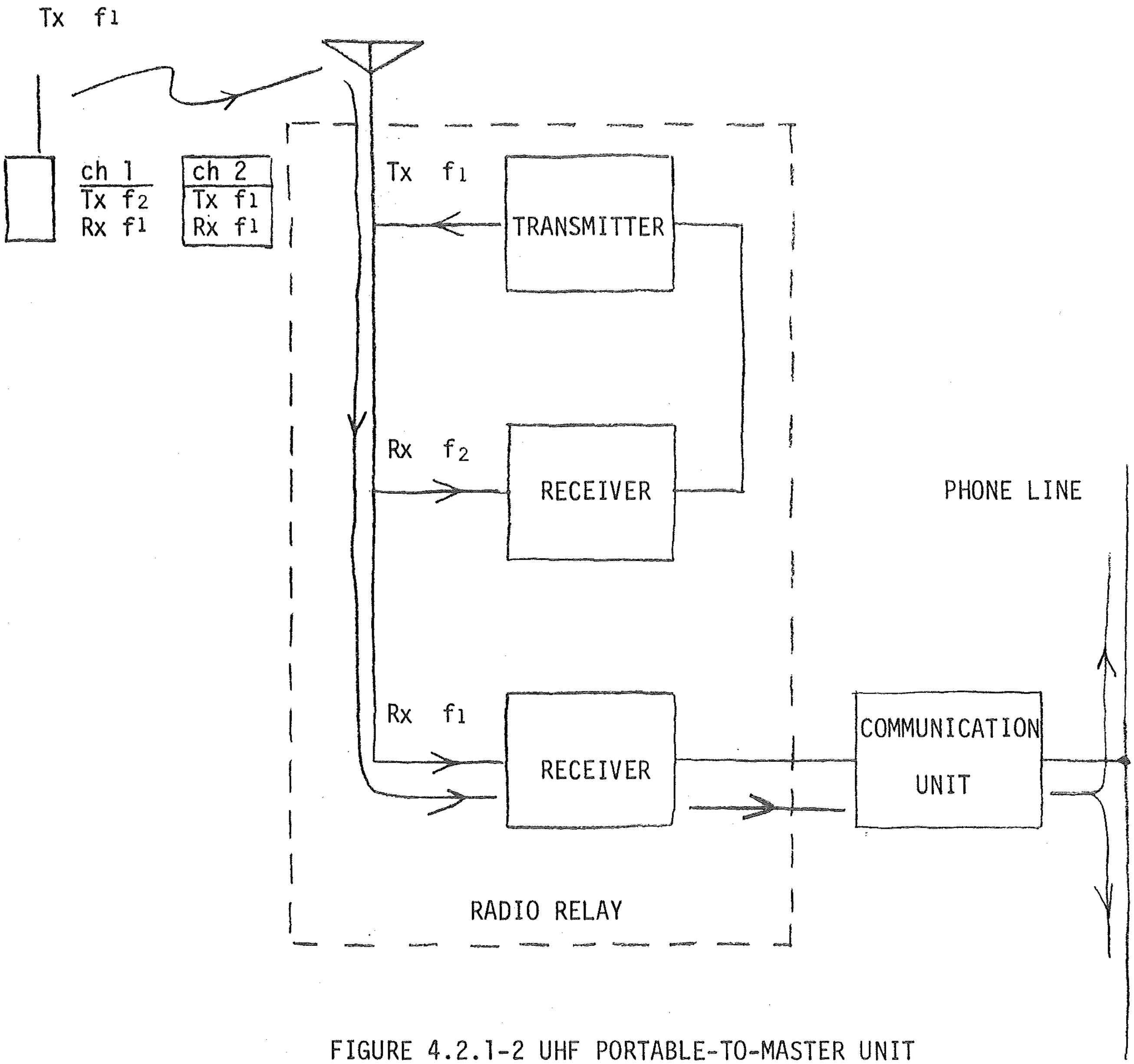

FIGURE 4.2.1-2 UHF PORTABLE-TO-MASTER UNIT

conversion at the communication unit. Pocket pagers with selective and all call features similar to the Reach VIP can be used for portable units supplied to select mine personnel. This concept can also be applied to mines with trolley communication by selecting the pager frequency such that interference does not occur with normal trolley communication.

One-way LF call alert paging can best be accomplished in the 70 KHZ to 100 KHZ frequency range since from all indications, this frequency range is where the S/N is largest. However, with the use of narrowband receivers and the emergency signal capability designed into the communication unit, theVLF frequency used from 3500 HZ to 5000 HZ can be used to send a call alert to a portable receiver. One duty cycle can be used for a selective call and a different duty cycle can be used for an all call. Information from the master unit or communication center sent to activate these units selectivity will come over the FDM channel assigned to wireless communication.

4.2.2 Fixed Station Communication (Master Unit)

This master unit will be located in the communication center and will be capable of communicating with and collecting data from all working units positioned underground and above ground and shall have the following features:

(1) Loudspeaking page capability identical to the working unit.

(2) Six FDM channels identical to the working unit.

(3) Continuous monitoring of the loop back signal and control of the communication path selected should an emergency occur and the phone wire breaks.

(4) Continuous collection and clocking of all data received from working units equipped with the data module and appropriate sensors. Display and or transfer of this data to appropriate processing computers or centers. Control of select underground function if the requirement exists.

(5) Selective communication to and from the working units utilizing the wireless mode selected. This will use either two-way radio, LF voice one-way paging, or VLF call alert.

4.3 Haulage Communications

At present there appears to be two types of haulage communication systems that can be used for mines with vehicles that draw power from overhead trolley wires or mines with vehicles that draw power from self contained sources. A reliable LF carrier phone that multiplexes the carrier on the trolley wire will satisfy the first mine, and a UHF radio system with appropriate repeaters will satisfy the communication requirements of the mine with vehicles that have self contained power sources. The following two sections will give preliminary gross specifications for these two systems.

4.3.1 Carrier Phone Haulage Communications

Current interviews and on-site inspections of mines that have carrier phone vehicle haulage has shown that if the problems associated with null or dead areas could be solved, the vehicle mounted carrier phone meets most haulage requirements at a reasonable cost. Since the problem appears to be line impedance change as a function of vehicle number and location and the resulting standing wave, a dual frequency diversity radio has a high probability of success.

The vehicle mounted transceivers shall employ frequency modulated dual frequency transmitters at 36 KHZ and 52 KHZ with a dual frequency receiver designed to select the strongest signal. One common voice message shall be sent and received such that all vehicles can receive the same set of messages.

Each unit will have a self contained emergency operation battery that is trickle charged from the trolley line. During normal operation, power will come from the trolley line and not the battery. The unit shall be capable of being removed from the vehicle in case of power failure and operate normally once it is connected to the trolley wire remote from the vehicle. This will allow personnel to have some type of communication should they be forced to leave their vehicles during am emergency or power failure.

4.3.2 UHF Radio Haulage Communications

Consideration has been given to various wireless communication systems for haulage communication. These investigations include guided radio, leaky coax, leaky twin lead, antennas positioned in coax, various combinations of radio relays, and one frequency repeater systems. Although detailed system cost will be investigated in the new study contract, an initial cost and performance estimate appears to favor the three frequency radio relay wireless communication system.

Studies to date have shown the best UHF frequencies for coal mine radio communications are around 1000 MHZ. Measurements in a coal mine tunnel have led to the conclusion that at these frequencies a reasonable coal mine tunnel range for one watt units is 3200 feet. So in a mine, with miles of haulageways, some form of relaying must be used and this is a three frequency radio relay. The fixed relay stations are party-line connected through a single lower frequency transmission line. Thus going along the haulageway, the relay stations need not be in radio range of each other. But it is necessary that some relay station be within 3200 feet of any portable station in the haulageway; thus fixed stations can be positioned every 6400 feet along the main haulageway. So, for example, for a five mile haulageway only five relay stations are needed instead of the ten needed if radio relaying were used.

Because line loss would be intolerable at 1000 MHZ, the radio frequency must be shifted down to some lower loss carrier frequency or if available baseband audio. The portable unit transmit frequency (relay station receive frequency) is slightly different from its receive frequency (relay station transmit frequency). This is done so that relay station incoming and outgoing radio frequency signals, differing by perhaps 100 dB, can be kept from the transmitter and receiver respectively in each relay station.

Figure 4.3.2-1 is a block diagram showing three portable and two of the five relay stations. Not obvious from the diagram but important to the argument, is that portable stations A and B are not within range of each other but are both within range of the same relay station. For instance, A and B could be 2000 feet on opposite sides of the same relay station. In the figure A is the station transmitting and B and C receiving.

Each relay station to-line amplifier shall have on their output a line detector to test for party-line faults in either direction. Should an indication of fault be given, the line in that direction will automatically be disconnected and communications will be via the redundant emergency loop back path.

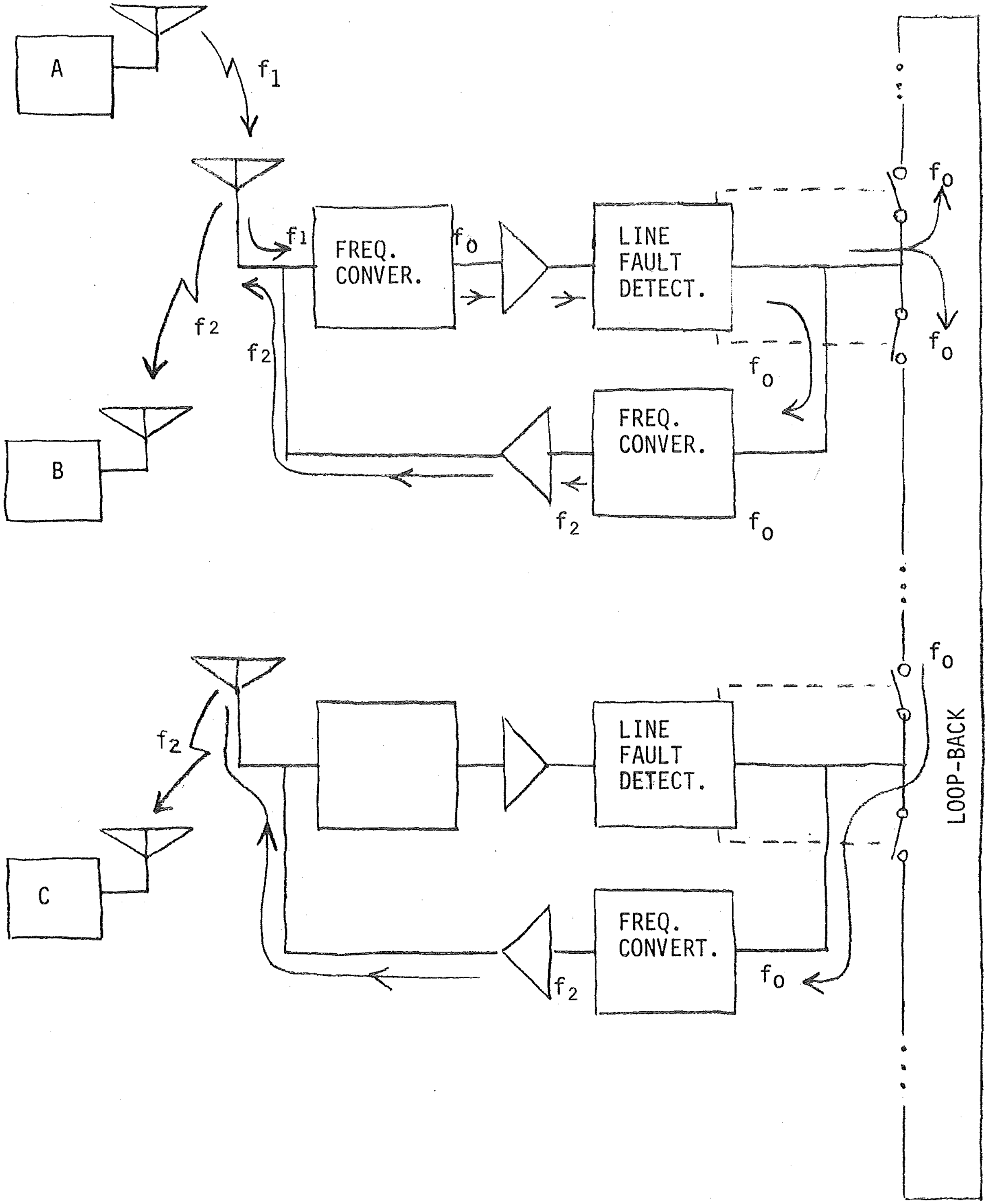

FIGURE 4.3.2-1

TRI-FREQUENCY HAULAGE COMMUNICATION

4.4 Hoist Communication

For coal mines with overburdens under 1200 feet, the present wired communication system looks satisfactory with party-line phones at the top of the shaft, the bottom, in the cage, hoist room, and in the communication center. These phones can be continuously in contact with each other whether or not the cage is moving, and independent of its position.

For those mining operations where a more extensive communications system is desired, both production and maintenance communications can be added to the coal hoist, emergency hoists, and one or more remote located fixed station.

For the typical mine, communications at hoist room, top and bottom, cage, and communications center is considered currently adequate.

5.0 ADDITIONAL COMMUNICATIONS RESEARCH

The current work will be extended, through a new research contract, to include additional requirement analysis along with reevaluation of various systems as new complete mine noise data is made available. Also, the systems need to be reevaluated as new equipments, coupling techniques, and requirements are generated. Additional communication testing will be completed to validate some of the LF theory. Moreover, a final, rather than gross, equipment specification will be developed for new mine communication equipment.

The new work will include a set of detailed mine requirements, reevaluating systems with new NBS noise data, additional LF communication tests, reevaluating candidate systems, and writing a final specification for the new equipment. The final specifications are anticipated two months after completion of contract. The contract completion date is February 21, 1974.

6.0 OTHER RELATED ACTIVITIES

During the course of the program additional activities and design efforts were required.

One of the major activities included participation in the Bureau of Mines Technology Transfer Seminar on Mine Communications. A paper was written and presented March 21 and 22, 1973 at the seminar entitled, "Interconnecting New Communications to Existing Systems."

Another activity was the design, testing, and assembly of four UHF-to-carrier Phone Interface units. These interface units coupled a Motorola HT220 UHF transceiver to a Mine Safety Appliance 1601P carrier phone for radio-to-carrier simplex relay operation. The four units were delivered to the Bureau of Mines; two in December, 1972 and two in February, 1973.

Appendix A. List Of Papers and Reports

The following is a list of the Major papers, reports, and memos written for the various phases of the program and submitted to the Bureau of Mines:

LF and VLF Propagation

(1) Signal To Noise Analysis For Loop-To-Loop Mine Communications - I

(2) Signal To Noise Analysis For Loop-To-Loop Mine Communications - II

(3) Signal To Noise Analysis For Downlink Source Mine Communications

(4) The Field Equations For A Submerged Horizontal Electric Dipole - I

(5) The Submerged HED and VMD - II

(6) The Field Components Of A Submerged Infinite Line Source

(7) On Intra-Mine Wireless LF Communications

(8) Results Of The Submerged Infinite Line Source Analysis

(9) Users Guide For Mine Communication's Propagation Programs

UHF Propagation

(1) Coal Mine Communications Field Test Report

System Requirements

(1) Communication System Requirements For Coal Mines; Dated January 8, 1973

(2) Communication System Requirements For Coal Mines; Dated February 19, 1973

(3) Robena Number 4 Mine Communications Survey Report

(4) Greenwich Mine Communications Survey Report

Appendix A. (Cont'd)

Communication System Analysis And Optimization

(1) Independent Communication Networks Or Potential Functional Elements; Dated February 19, 1973

Conference Papers

(1) Interconnecting New Communications To Existing Systems

(2) Radio Propagation Measurements In Coal Mines At UHF and VLF

Miscellaneous

(1) UHF-To-Carrier Phone Interface Unit; Dated December 21, 1972