A MULTIPLEXED PHONE SYSTEM FOR SMALL MINES

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ABSTRACT

A new phone system was developed that provides eight full duplex communications channels over a single twisted shielded phone line, with no central switching station or line amplifiers. This system greatly simplifies installation and maintenance over that required with conventional switching systems.

The system is based on microprocessor technology and digital frequency synthesis. Frequency division multiplexing is used over a bandwidth of approximately 300 kHz, and a baseband voice channel (compatible with conventional pager phones) is provided as a backup to assure communication if the multiplex features fail. Multiplex operations are controlled over a 30-kHz digital channel. The system is designed to operate with up to 16 km (10 miles) of cable plant and a maximum phone separation of 8 km (5 miles).

The digital techniques permit a limited amount of monitoring and control capability to each phone. This consists of two pair of contact inputs or outputs, to be used as desired. These "flags" may be read or controlled by a dispatcher's phone.

INTRODUCTION

Good communication is necessary for effective mine management, without which a lack of coordination in the movement of personnel, ore, and supplies will inevitably result in periodic bottlenecks that cause lost production time. Additionally, valuable time may be lost in obtaining help for an injured miner or in correcting an unsafe mine condition if a good communications system is not present.

Unfortunately, this has not always been an easy task. The mine environment can be extremely harsh on electronic equipment. Environmental stress causes corrosion and physical abuse can cause catastrophic equipment failure. Consequently, many mines have found that any system more complicated than a simple pager phone is unsuitable.

Recent advances in technology are removing these environmental restraints. Large-scale integrated circuits are now replacing racks of discrete circuitry, and they are inherently cheaper and more reliable. Consequently, it is now possible to introduce more sophisticated technology into mines while improving reliability.

This technology has begun to find application in mine telephones and several multichannel phone systems have been developed. These systems include both multiwire and multiplex transmission schemes. Both types have performed well and met some communications needs of mines. However, there are some drawbacks to previously developed equipment.

Multiwire phone systems by nature require at least one wire pair per communication channel. This presents no particular technical difficulties, but often mines balk at installing any system requiring a wiring practice unfamiliar to mine personnel. Consequently, multiwire systems have not yet found widespread application in the mining industry.

Multiplex systems have eliminated most of these cable problems, but at the cost of added equipment complexity. To date, there is no commercially produced multiplex system for use in mines that can function over a single wire pair on a mine-wide basis without in-line repeaters or central control. This extra equipment causes reduced reliability, and failure of an in-line repeater can destroy the integrity of the entire communication system.

To overcome these problems, the Bureau of Mines has entered into a joint venture with Catalyst Research Corp.[1] to develop an eight-channel multiplex phone system capable of communicating over a minimum distance of 5 miles (8 km) with no in-line repeaters or central control. In addition to multiplex features, each phone contains a resident pager phone to provide all-page capability and act as a emergency backup.

MULTIPLEX SCHEMES

The first major decision in designing the multiplex phone system was in deciding whether to use time division multiplexing (TDM) or frequency division multiplexing (FDM). Such factors as cost, system reliability, and technical constraints were considered. When all factors were weighed, FDM was chosen. A brief discussion of the factors pertinent to this decision follows.

TDM communication channels must be sampled at a minimum rate of two times the bandwidth of the channel.[2] This information is then digitized and combined with samples from all the other channels and transmitted to a receiver where it is decoded and reassembled into analog form. This method can utilize digital circuitry and is thus able to efficiently exploit recent

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[1]Bureau of Mines Contract H0395000, Multiplexed Telephone System for Small Mines, Catalyst Research Corp. Available for consultation at Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

[2]Mischa, Schwartz. Information Transmission, Modulation, and Noise. McGraw-Hill Book Co., New York, Second Edition, 1970, p. 119.

advances in digital technology. However, TDM does present difficulties in data transmission if distances exceed 1.6 km (1 mile) or so.

An eight-channel full duplex system requires approximately 50 kHz bandwidth. In a TDM system this means a minimum sampling rate of 100K samples per second. If samples are digitized to an accuracy of 6.25%, a minimum of four bits are needed per sample. This results in a baud rate of 400 kHz and the addition of a guard band[3] between bits raises this rate to 800 kHz. To transmit an 800-kHz digital signal would require a cable with a capacity in excess of 2 MHz. The addition of start bits, stop bits, address, etc., would increase this requirement even further. It is almost impossible to attain this type of transmission capacity at a distance of 5 miles (8 km) without the aid of repeaters. Consequently the TDM option was eliminated as a viable choice.

The second multiplexing scheme is FDM. In this scheme each communication channel is translated to a separate portion of the spectrum. Information in these channels may be either FM or AM modulated, and bandwidth of about 10 kHz can easily accommodate a voice grade channel. Eight full duplex channels would require a bandwidth as small as 160 kHz.

FDM is relatively straightforward and is frequently used in radio communcation. Troubleshooting is slightly easier than with a TDM system, but FDM equipment does require the use of a number of analog circuits. However, the complexity of this circuitry may be reduced by proper channel selection at the cost of some increase in bandwidth. Thus, FDM was chosen for the multiplexed phone system.

Much of the complexity in FDM systems results from the need to filter out signals and noise at frequencies outside the receive bandwidth. Therefore, a scheme was developed to reduce filter requirements for the multiplexed phone system. This consisted of separating channels by 20 kHz instead of 10 kHz and in raising the channel frequencies to a point where the entire eight full duplex channels would be contained in a single octave. In this manner, harmonics from any transmitter would fall into a frequency range above the highest channel. This meant placing the communications channels from 340 kHz to 640 kHz. At these frequencies a 8-km (5-mile) range is practical without repeaters by utilizing a high quality twisted shielded pair (TSP) cable. This required a dynamic range of approximately 60 db, which was achieved.

CONTROL

The multiplexed phone system is functionally similar to the commercial phone system; this means control of the system is automatic. Control is accomplished by a network of microprocessors (one in each phone), which share system decisionmaking via a digital communications channel centered at 30 kHz. This protocol minimizes the possibility of a single phone failing in a manner that would disrupt the entire multiplex system.

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[3]Ibid. p. 172.

The microprocessor circuitry controls the generation of all audio cues (busy signal, dial tone, etc.). This is to provide the user with commercial phone system-type feedback signals that are readily recognizable. The ringing signal is generated at the called phone and sent back to the caller via the audio channel. This also informs the user that the line between the two phones is good. The use of these signals combines to give a good overall indication of the system's status.

RESIDENT PAGER PHONE

In order to retain all-page capability, each Multiplex Phone[4] has within it a resident pager phone that functions independently of the phone's microprocessor. This sytem utilizes baseband communications and dc signaling like a standard pager phone. In fact, the multiplexed phone system can be interfaced to an existing pager phones with the addition of a decoupling circuit to prevent the pager phones from loading down the higher frequency channels of the multiplexed phone system. If the all-page function is used when private conversations are in progress, the page broadcast is superimposed upon the existing private message. Thus the listener can respond to whichever message is most important. It was felt that the ability to page all phones within the system (even those already involved in a conversation) was essential in the event of an emergency. It should be noted that the page system can act as a backup if the multiplex features fail. A complete spectrum of the multiplex system is shown in figure 1.

SYSTEM POWER

The multiplexed phone system was designed to meet the Mine Safety and Health Administration's (MSHA) certification requirements for use in gassy mines. This limited powering alternatives, and battery power was ultimately selected.

To minimize the power drain of the Multiplex Phone, a two-level power-up sequence was installed. Each phone contains a low-power 30-kHz detector, which is continually active. If 30 kHz is noted, a phased locked loop demodulator and digital address decoder are activated. This device then scans for its address and proceeds to power up the microprocessor only if it is being called. In this manner projected battery life has been extended to 4 months (depending on use).

SPECIAL FUNCTIONS

Additional capacity is available with the addition of two optional pieces of equipment, a conference call unit and a dispatcher's phone. These units add much flexibility to the system.

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[4]Trademark of Catalyst Research Corp., Baltimore, MD; Use of company or trade names is for identification purposes only and does not imply endorsement by the Bureau of Mines.

The conference call unit will enable a three-way private conversation. This unit is expected to be useful in much the same manner as the conference call capability of an aboveground phone system. It complements the basic phone system but is not required. The dispatcher's phone provides a variety of functions. It is a Multiplex Phone with some additional programming capacity, and it can be useful in monitoring the system. It displays which channels are active and can, upon command, check the battery status of each Multiplex Phone. It can also preempt a conversation in progress so that a party involved in a private conversation may be reached without the use of an all-page call.

The microprocessor used in each Multiplex Phone has flags which can be either read or set. Two of these flags are not used and remain available for use as contact-type inputs or outputs. The dispatcher's phone can read and/or set flags to monitor and/or control parameters in the mine. One example would be the monitoring of a float switch. Application of this system is flexible and depends on mine requirements.

SYSTEM STATUS

In December 1981, an in-mine test was initiated to evaluate a system of 17 phones. This included approximately 4.5 km (2.8 miles) of cable with another 4.5 km (2.8 miles) of loss artificially simulated.

The cable used for this test is a 124-ohm low-loss TSP with #16 AWG solid conductors. All taps and splices were made with conventional splicing techniques and enclosed in plastic junction boxes. Resistive power dividers were used for all taps over 50 m (150 ft) in length, and all cable runs over 50 m (150 ft) were terminated resistively.

To date, the system has performed well with only one failure attributable to the phones. This was a failure of a microprocessor board. The only other failures have been breakage of conductors in the TSP. Battery life has been as long as 4 months depending upon phone usage. The Multiplex Phone is shown in figure 2 and its specifications are contained in the appendix.

FUTURE DEVELOPMENT

Plans exist to extend the capability of the multiplexed phone system in the future. These plans currently call for the development of a data interface that will enable Bell 103-type equipment to function over the system, the development of a unit to interface with the commercial phone system, and the development of a small phone branch exchange (PBX) which will provide a subscriber service drop to a system of up to eight phones. Work in these areas has been completed through breadboards.

CONCLUSION

The Bureau of Mines, in conjunction with Catalyst Research Corp., has developed a cost effective multiplexed phone system that provides eight full duplex voice grade channels at a distance of up to 8 km (5 miles), which is controlled by a distributed microprocessor system. This distribution enhances system reliability. Each phone also contains a resident pager phonem for all page and emergency calls.

Special features are available by the addition of specialized pieces of equipment. A dispatcher's phone has been developed and a conference call unit is currently under development. A small PBX and a commercial phone system interface are planned in the future.

APPENDIX

Multiplex Phone™ Specifications

Channels:	1 all-page/emergency baseband 1 30-kHz FSK digital control 8 FM full duplex voice grade
Range:	8 km (5 miles) minimum with 16-km (10-mile) cable plant
Power:	12 Vdc battery (NEDA 926)
Dimensions:	12 in x 10-1/2 in x 5 in
Transmit Power:	All-page: 10 V p-p Digital: 2.5 V p-p Voice: .1 V rms
Receive Sensitivity:	All page: .25 V rms Digital: 10 mV Voice: 100 µV
Receive Selectivity:	Digital: ± 9 kHz, -40 db Voice: ± 15 kHz, -70 db
Adjacent Channel Rejection:	80 db
Cable:	124 ohms low loss TSP #16 AWG conductors (Belden 9860 or equivalent)

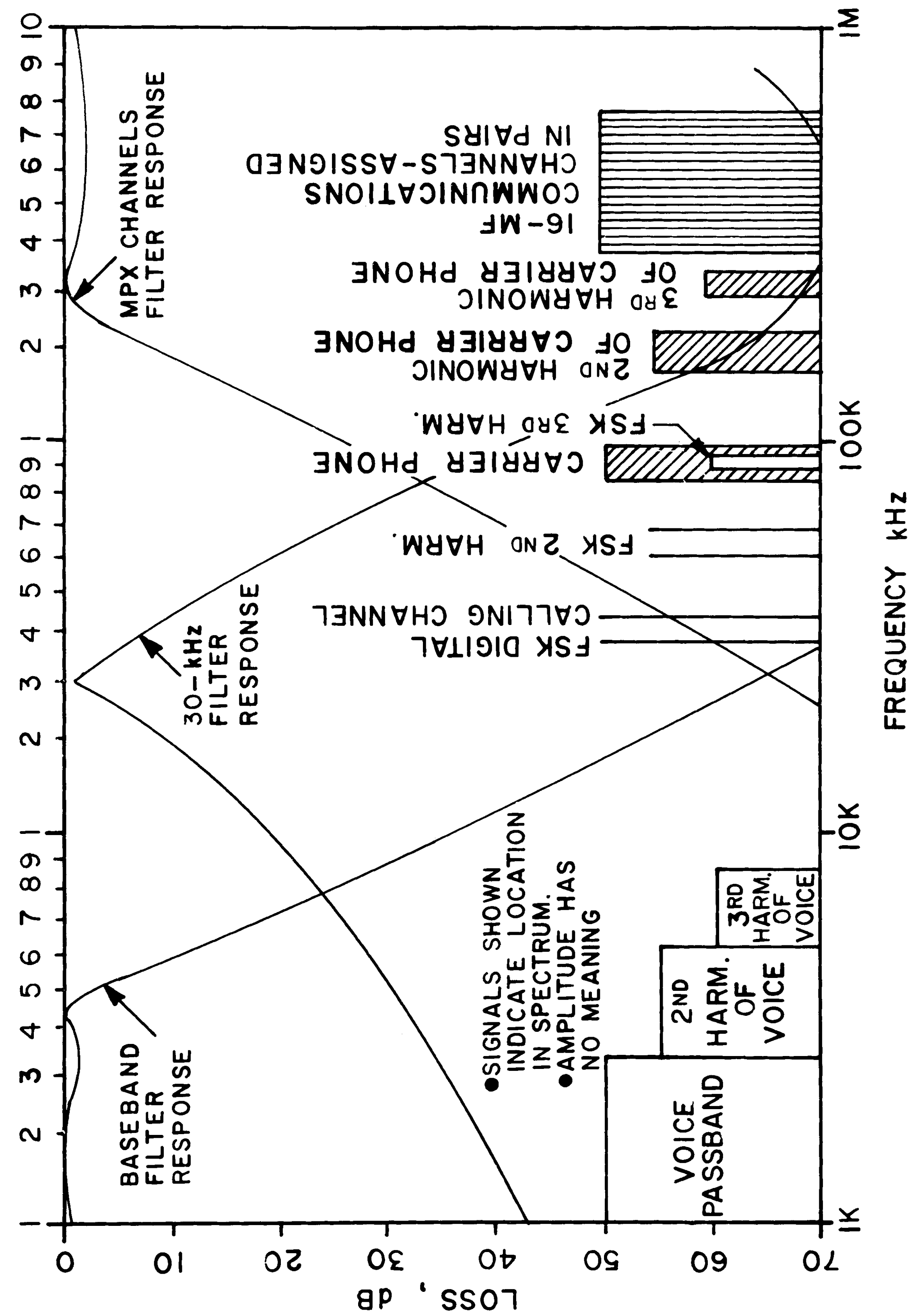

FIGURE 1. - Multiplex system spectrum

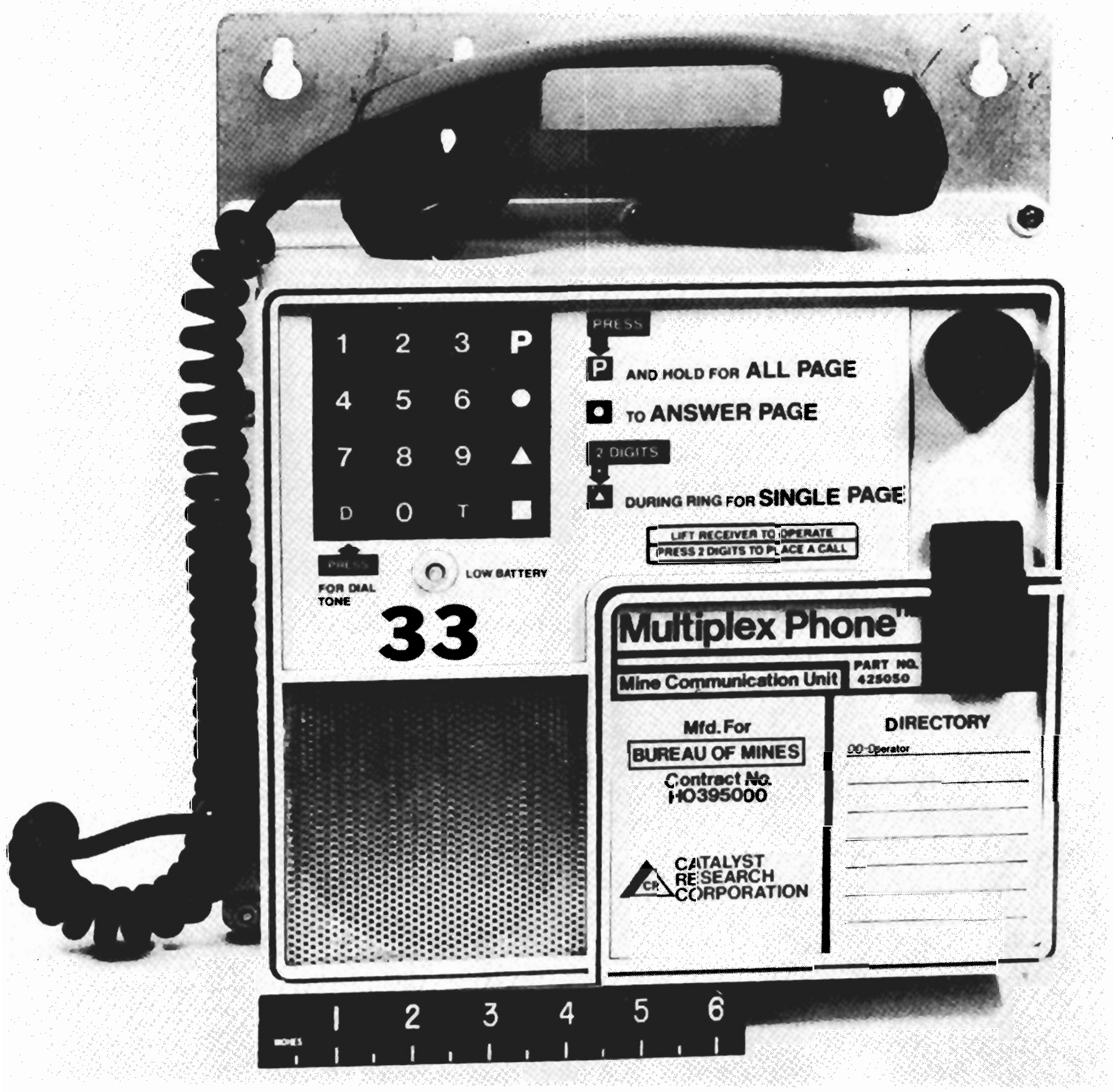

FIGURE 2. - Multiplex Phone