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October 1980

DEVELOPMENT OF A VISUAL DISPLAY AND CONTROL SYSTEM

Contract J0177020
Arthur D. Little, Inc.

BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR
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The object of this program was to extend the capabilities of visual paging systems both in size and function. The system developed uses the mine pager phone line for communication, monitoring, and remote control. A central station, using a minicomputer, transmits signals by phase inversion modulation of a 16,384 Hz carrier to as many as 999 remote units. The remote unit addressed returns an echo to indicate that it is functioning and, in the case of monitor units, to convey the monitor data. Magnetically latched display discs, which can be seen from both sides when posted, are used for visual paging. Lists of the addresses of posted pages, unanswered pages, and non-echoing units are prepared by the central station computer. The system was designed to be intrinsically safe and should operate for three months on a 12-volt lantern battery.

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FOREWORD

This report was prepared by Arthur D. Little, Inc., Cambridge, MA 02140 under USBM Contract Number J0177020. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Harry Dobroski acting as Technical Project Officer. Mr. Doyne W. Teets was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period August 1977 to October 1980. This report was submitted by the authors in October 1980.

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INTRODUCTION

The original objective of this program was to obtain a mineworthy optical/electromagnetic pager system that will alert supervisory, maintenance or other mine personnel that they are being paged on the mine pager phone system. The program goal was subsequently broadened to add monitor and control capability to the paging system, which was then renamed Visual Display and Control System (VDCS). Those objectives were achieved in a four-phase program:

Phase I -- Establish the system functional requirements
Phase II -- Design the system
Phase III -- Fabricate the system
Phase IV -- Evaluate the system performance.

The resulting Visual Display and Control System has a total capacity of 1000 addresses and is under the control of a central unit at which commands are dispatched and responses received. The VDCS as delivered has 23 addresses assigned to visual pager disks, three addresses assigned to relay control functions, and three addresses assigned to monitor functions. Since the central unit is microprocessor-controlled, the system has great flexibility and changes are easily incorporated.

PHASE I - ESTABLISH THE SYSTEM FUNCTIONAL REQUIREMENTS

The original purpose of the zone pager development program was to expand the capabilities of the visual pager developed under Contract H0252093. Early in the study it became apparent that the twisted pair pager phone line is a valuable resource, since it reaches most of the mine workings and could therefore be used for remote monitoring and control as well as paging. By adapting this broader view of the system capabilities at the beginning of the design process, it was possible to accommodate those additional functions at a later date.

The system functional requirements were arrived at through discussions with mine operators and Bureau of Mines personnel. The genesis and rationale of those requirements are discussed in detail in the Arthur D. Little Phase I report (1) and are summarized here.

System Architecture

The main guiding principle in choosing a system architecture was preservation of flexibility to modify functions or add new ones. To that end, the system components and functions were specified as follows:

1. A central control unit to be located at the pit head or mine office. This unit will transmit signals to remote units on the phone line and receive answering signals from the remote units. The central control unit will use a microprocessor and be programmed to perform the desired functions. System flexibility will be achieved through programming the central unit. The system is to contain a supervisory control loop

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(1) Arthur D. Little, Inc., Development of a Zone-Type and Single-Unit Visual Display System. Phase I report under Bureau of Mines Contract J0177020, ADL Case 80956.

whereby each remote unit, when interrogated, echoes its address and the command it received. This echo is checked against the transmitted data to detect malfunctioning remote units. The addressing system must include global addresses which permit activation of multiple display modules with a single command. Monitor unit outputs are to be logged on a hard copy device. Communications channel errors will be indicated on the console and their details will be logged on the hard copy device. The console will provide a means to display a list of all remote units which have been posted during the last five minutes, a list of all units which have been posted since system reset, and a list of all units which have had communication errors.

2. Visual pager remote units located in the mine. These will be made up from single disk display modules, each of which has a unique address. Each module contains a two-inch diameter numbered or lettered disk which can be rotated to either a horizontal or vertical position so that the disk is either invisible or visible. Multiple display units will consist of the required number of single disk modules mounted in a common housing. Each module will have a unique address so that it can be individually selected by the central controller. All communications will be initiated by the central controller. Upon receiving its address and a coded operation instruction, the visual pager unit will echo back the address and the operation code. These units will respond to three operation codes: post, which will set the display disk to post a page; clear, which will reset the display disk to clear a page; and test, which echoes the address and command but does not change the state of the display.

3. Monitor units located in the mine. These will have their own individual addresses like the visual pager units and will respond to calls initiated by the central control unit. The echo response from a monitor unit will consist of the unit address with measurement data replacing the operation code. The input voltage range for monitor units is 0 to 4.92 volts. With a six bit A/D converter, the least significant bit represents an increment of 0.078125 volts.

4. Remote control units located in the mine. These will provide for remote control of pumps, fans, regulators or other equipment in the mine. Each will have its own individual address and will echo this address and operation code when called by the central control unit. The <u>post</u> command will close a pair of relay contacts in the remote unit, the <u>clear</u> command will open the relay contacts, and the <u>test</u> command operates as in the visual pager units. The relay contacts are rated at 120 volts AC and five amperes, noninductive.

The actual system which was delivered consists of three single disk display units, two five-disk display units, one ten-disk display unit, a central control unit with hard copy device, and a monitor/control unit having three monitor and three control modules.

<u>System Size</u>

The system is to have the capability of addressing 1000 remote units, including global addresses.

Special Requirements for Remote Units

The remote units of all types located underground must be designed to meet some rather restrictive requirements. In addition to the rugged construction needed to survive in a mine environment, these include:

- Underground units must be intrinsically safe. Therefore, these units must use battery power and draw very little current in the standby state (that is, when not responding to signals from the central control unit). Typical twelve-volt batteries have about ten ampere-hour capacity and will give three months' service at a two milliampere rate. This problem was solved in the previous visual pager by using a dc "wake-up" signal on the phone line to turn on the receiver power. A similar technique will be used in this application, except a carrier frequency tone burst will be used as the "wake-up" signal.

- The underground units must be connected to the phone line all the time and therefore must not load the line. The characteristic impedance of a pager phone line is about 135 ohms. The VDCS units must have an input impedance much higher than this. The visual pager receiver had a 40 kilohm impedance. The VDCS receiver impedance will be about as high.

- VDCS receivers both above and below ground must accept signals over a wide range of power. The attenuation of the phone line can be as high as 3 dB per mile and, in addition, there are losses because of impedance mismatch (low impedance pager phones; in particular, the MSA pager I and II phones, and branches or taps on the line). These reflective losses could total 20 dB. Since noise on the phone line is expected to be about 35 millivolts in a 500 Hz bandwidth (2), the receivers

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(2) N.B.S. Technical Note 654, Electromagnetic Noise in Robena No. 4 Coal Mine. April 1974.

should be designed to detect signals as small as about 100 millivolts. Maximum transmitter power will be about 1 watt or about 10 volts rms on a 135-ohm impedance line. Therefore, the receivers must work well over at least a 40 dB range and be protected against transients.

Signal Transmission

The signals for the zone pager are transmitted by phase inversion modulation of a carrier frequency. This method of modulation has the advantages that it is easy to modulate and demodulate the signal and that it is highly efficient. Most of the transmitted power is contained in the sidebands which convey the information. Only a small amount of power remains at the carrier frequency.

The carrier frequency was chosen in the range of 10 to 20 kilohertz. The spectral density of noise on the pager phone line has a broad minimum at about 16 kilohertz (2). Noise increases significantly below this frequency. Attenuation increases with frequency by about 0.25 dB/mile in this octave. The exact frequency does not seem to be a critical parameter, and the selection of this frequency was made during the detailed design phase, based on the availability of suitable oscillator crystals. The standard electronic watch crystal (32,768 Hz) is used to produce a 16,384-Hz carrier frequency and a 128 bit per second data rate. The signal format is shown in Figure 1. An initial tone burst is used to "wake up" the remote units. This is followed by two bytes, each containing a start bit, eight data bits, a parity bit, and two stop bits. The remote unit echoes back two bytes. Display units and control units echo the address and command code for verification of the communication path. Monitor units echo the address and the six bits of measured data.

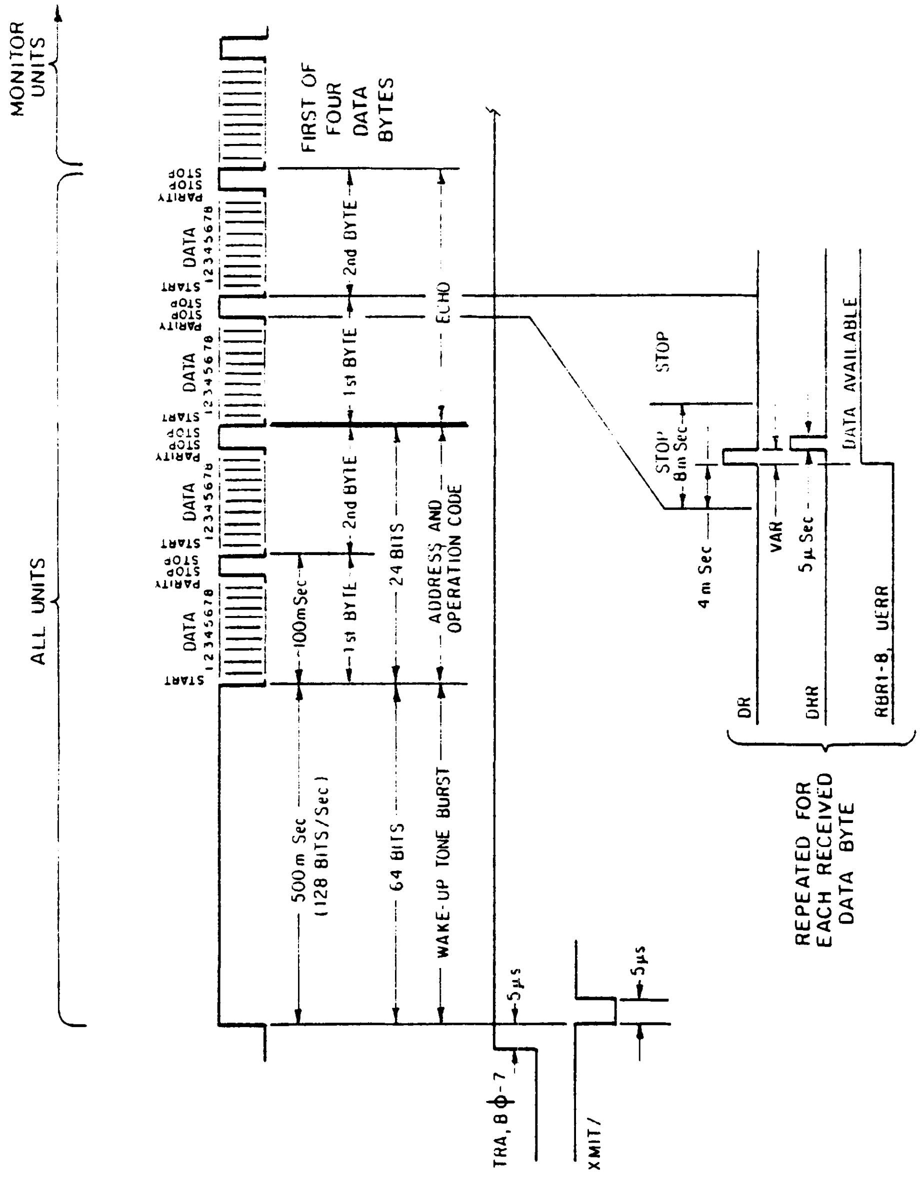


Figure 1

Wireline Transceiver Timing

PHASE II - DESIGN THE SYSTEM

Figure 2 shows a block diagram of the VDCS designed in response to the functional specifications from Phase I. The control console is shown in Figure 3. Figure 4 shows the control console and two of the six remote units, the monitor and control unit and the ten-disk visual display unit. Figures 5 and 6 show the display unit disks, one set of five disks attached directly to the display unit and the other set of five connected to the unit by cable.

Table 1 shows the addresses currently assigned to the various remote units. To post, clear, or test a unit, one enters first the three digits of its address (e.g., 016), then the desired command. As each address digit is entered, it appears in the CURRENT display. When the command digit is entered, it appears briefly in the CURRENT display, which then blanks while the command is being executed. The command execution sequence is shown in Figure 1. If the address and command code in the echo match those transmitted, the system assumes that the remote unit has executed the command properly. The address and command will appear in the STATUS display and the NORMAL light will light. If there is a disagreement in either address or command, or an incomplete echo, or if there is no echo at all, the STATUS display will show the status of the remote unit prior to the command and the ERROR light will light. In addition, a detailed description of the error is logged on the printer. (See the TECHNICAL MANUAL for details.) In both cases, the contents of the CURRENT display are transferred to the PREVIOUS display.

When one of the monitor units is posted, the six bit reading is stored in the controller memory and can be observed by entering the monitor unit address, followed by a DISPLAY command. The data value is typed on the printer in units of 7.8125 volts (e.g., 4.92 volts is printed as 00.63). For convenience in repeatedly addressing the same unit, the RE-ENTER button can be used to transfer the address shown in the

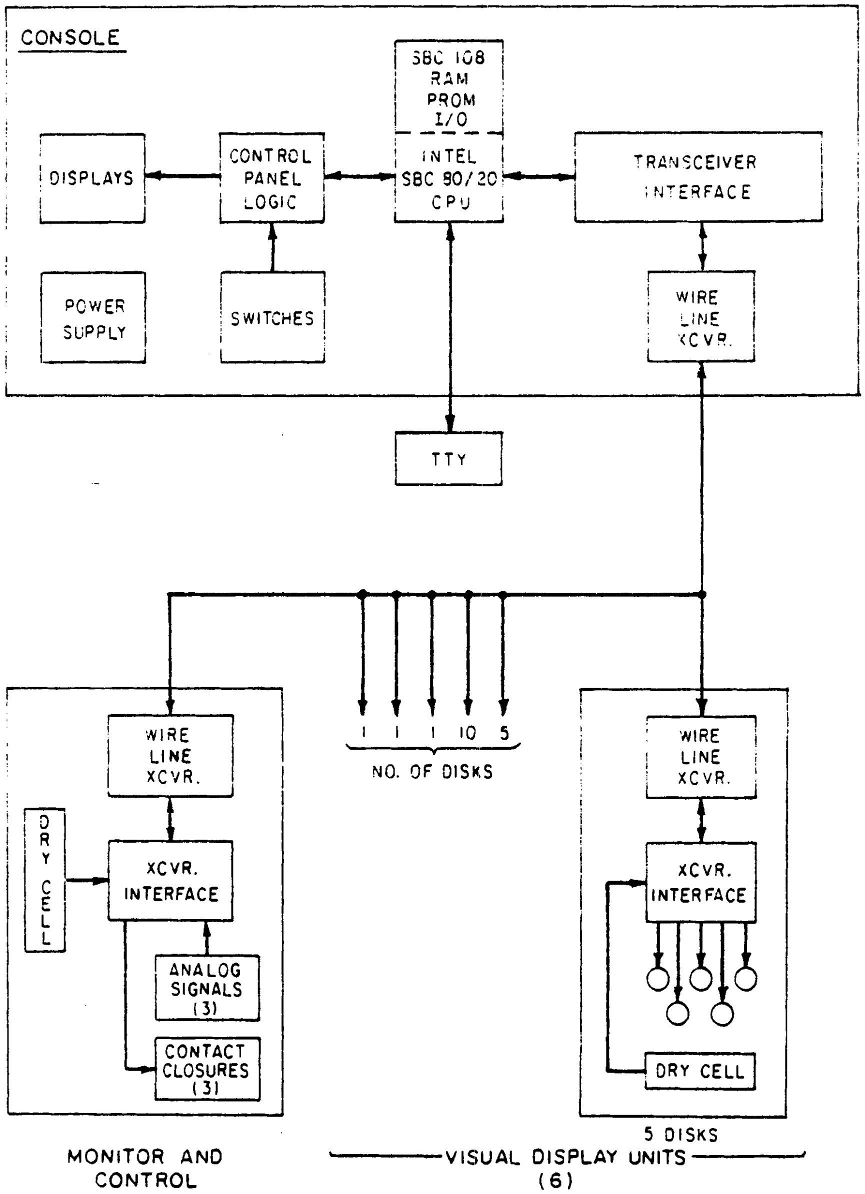


Figure 2

Visual Display and Control System Block Diagram

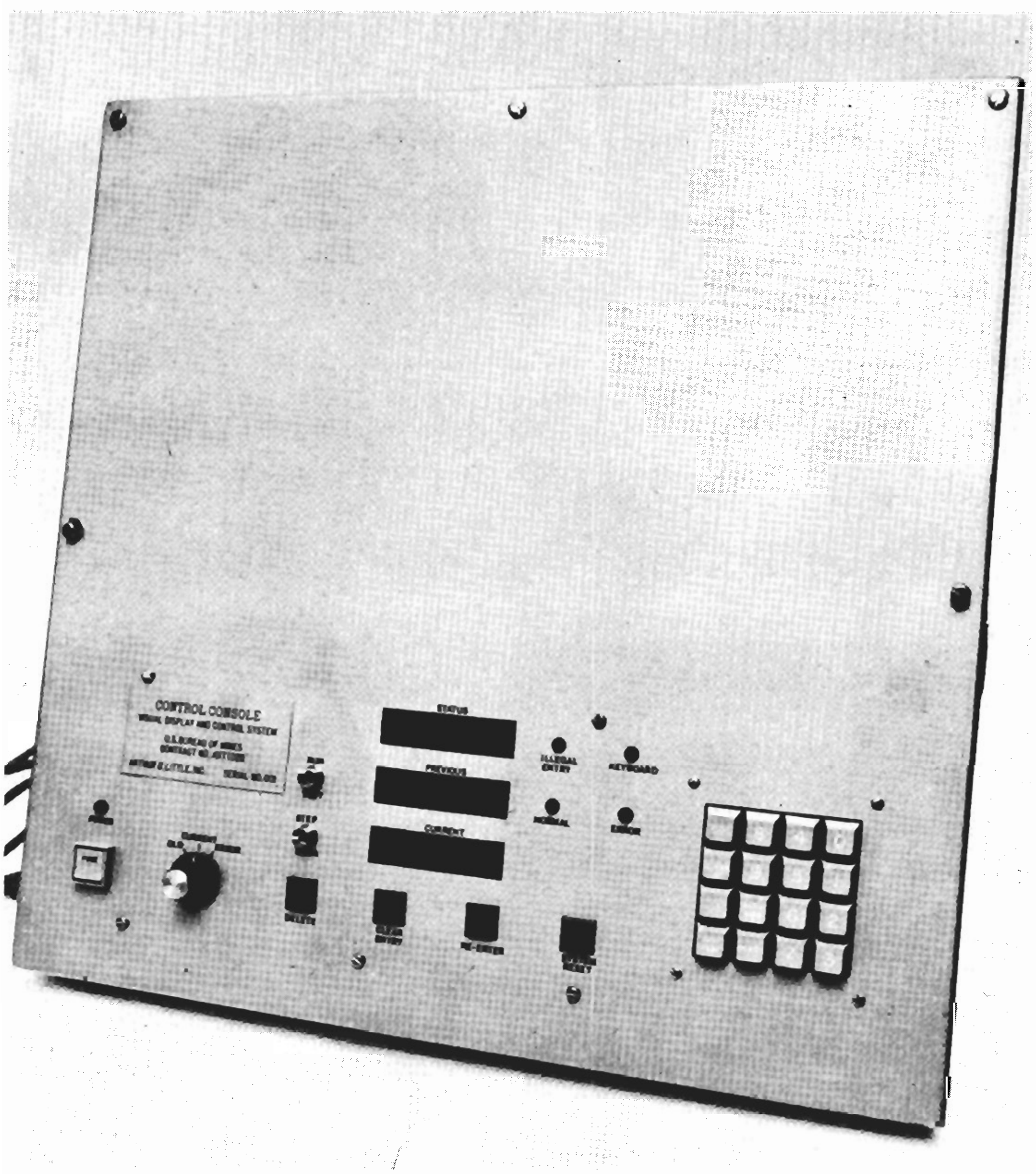
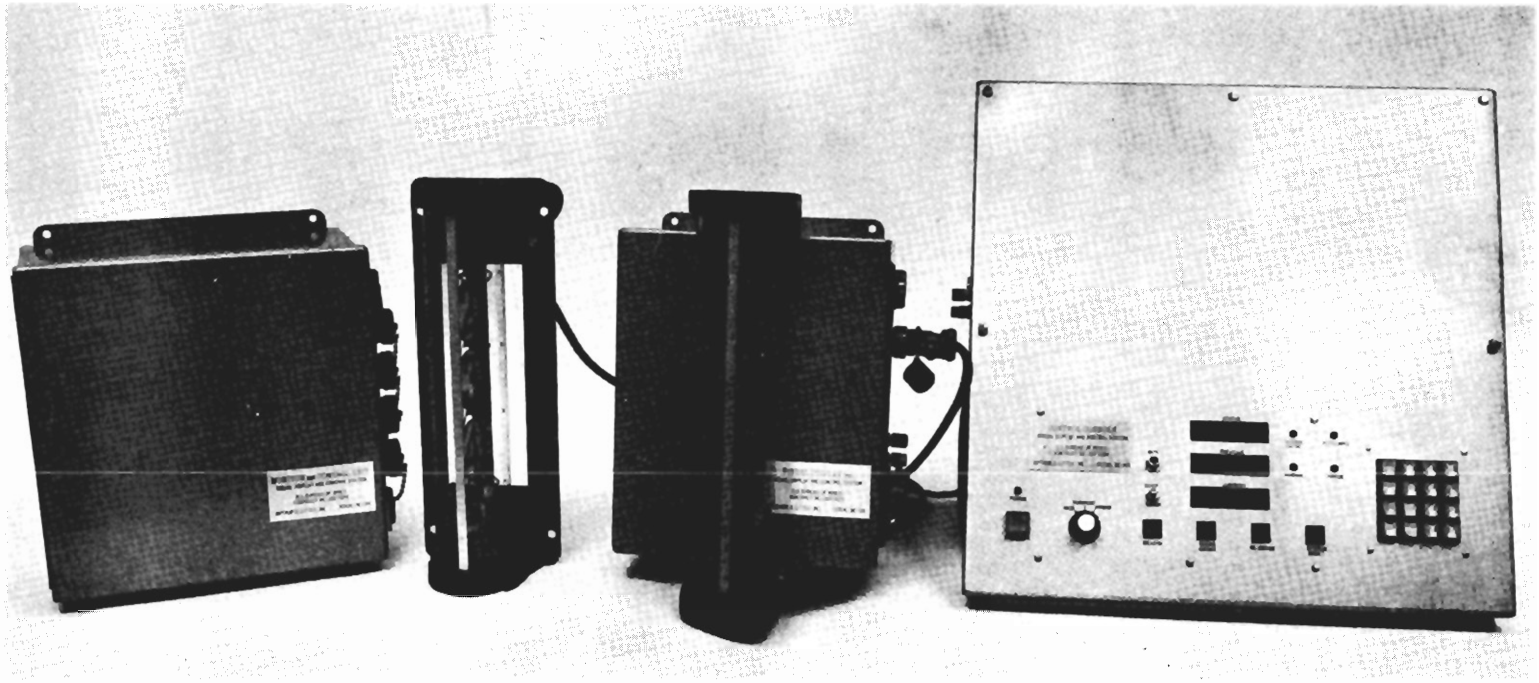


Figure 3.

Control Console



CONSOLE, TEN DISK DISPLAY UNIT, MONITOR AND CONTROL UNIT

Figure 4

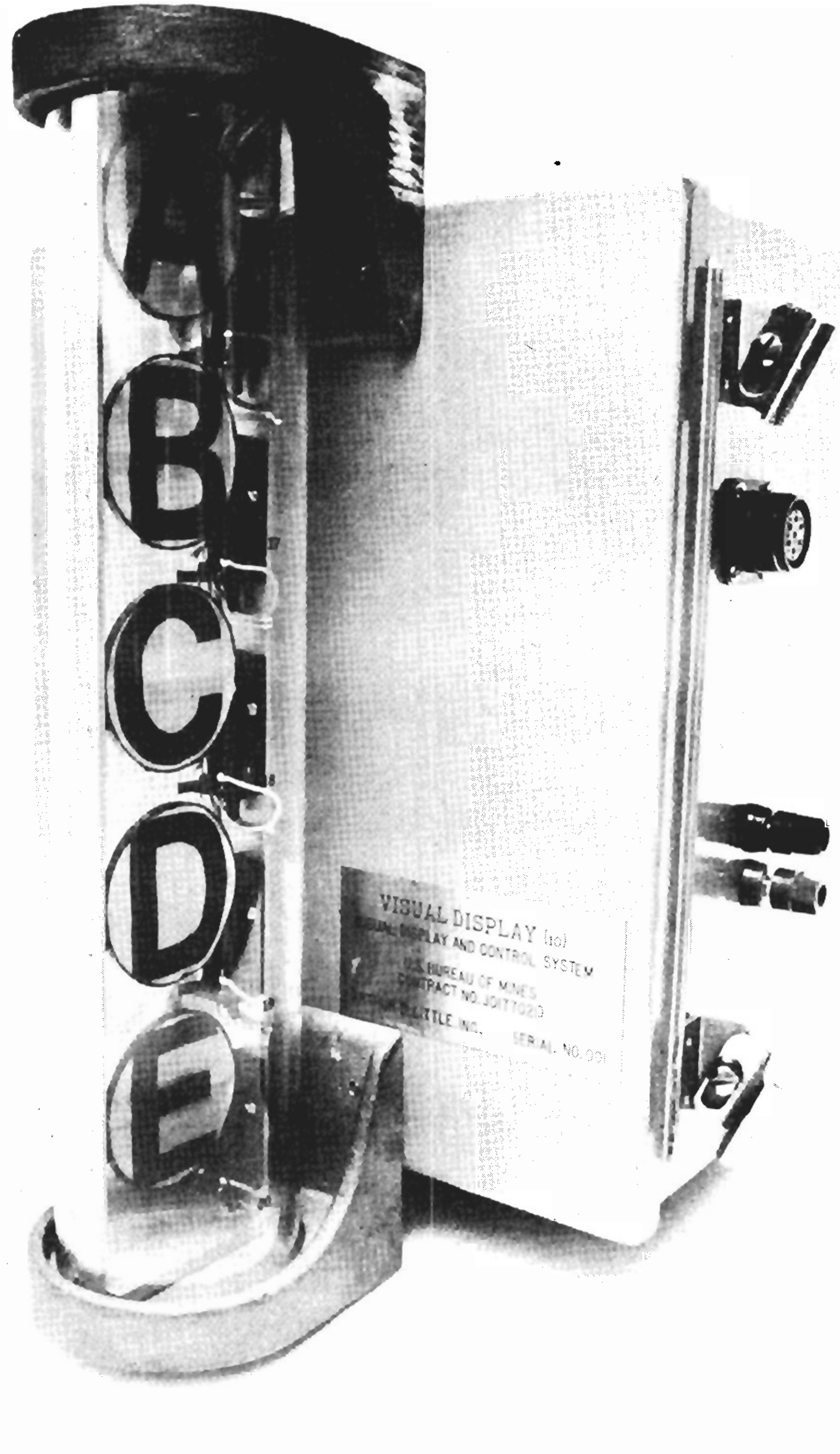


Figure 5.
Display Unit

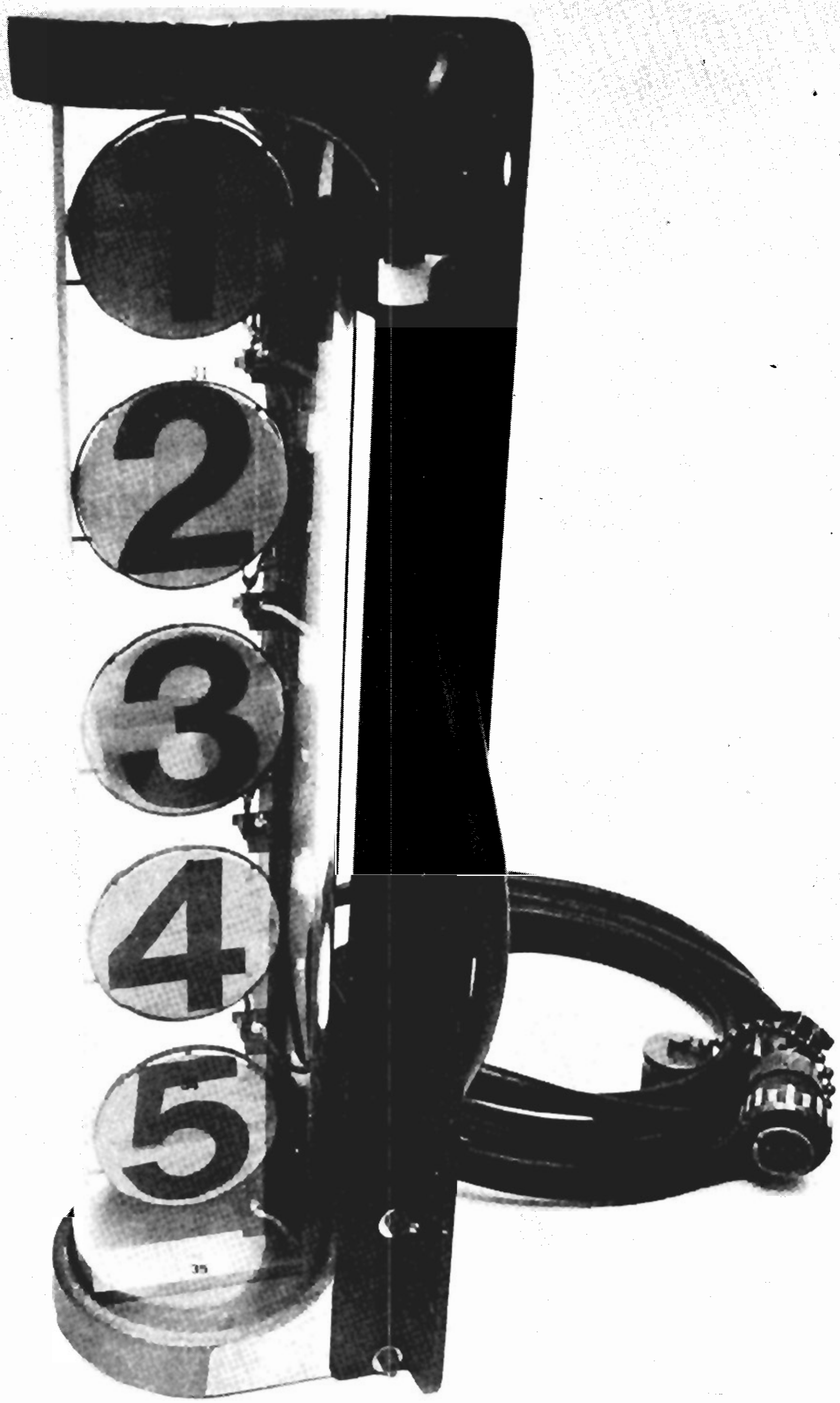


Figure 6.

Separate Disk Module

Table 1

Address Assignments for TEMS and VDCS

Address	Function	
000	Unused	
001	Global, Addresses 16 - 46	
002	Global, Addresses 16, 21, 26 (All A disks)	
003	Global, Addresses 17, 22, 27 (All B disks)	
004	Global, Addresses 18, 23, 28 (All C disks)	
005	Global, Addresses 19, 24, 29 (All D disks)	
006	Global, Addresses 20, 25, 30 (All E disks)	
007	Global, Addresses 16, 17, 18, 19, 20	
008	Global, Addresses 21, 22, 23, 24, 25	
009	Global, Addresses 26, 27, 28, 29, 30	
010	Global, Addresses 31, 32, 33, 34, 35, 36, 37, 38 (disks 1 to 8)	
011	Global, Addresses 39, 40, 41	
012	Global, Addresses 42, 43, 44	
013	Global, Addresses 16 - 25	
014 - 015	Global, Unused	
016 - 038	Display Unit Disks	
039 - 041	Monitor and Control Unit Relays	(VDCS
042 - 043	Unused	only)
044 - 046	Monitor and Control Unit Analog Voltages	
047	Unused	
048	Monitor Unit (TEMS only)	
049	Unused	

PREVIOUS display to the CURRENT display. CLEAR ENTRY clears the CURRENT display to permit correction of an error in entry. The ILLEGAL ENTRY light comes on if a command digit is entered in the address field or vice versa.

The system controller maintains three lists on which it keeps track of the status of the remote units. The CURRENT list is a record of all units which have been successfully posted in the last five minutes, and the OLD list is a record of all units posted since the most recent system reset, except for those on the CURRENT list. Units are automatically moved from the CURRENT to OLD list after five minutes have elapsed since posting. The ERROR list is a record of all units which have experienced communication errors. These lists can be displayed by momentarily placing the STEP/SCAN switch in the SCAN position. The KEYBOARD light will go out, indicating that the system is now in the automatic list display mode. The contents of the list selected by the LIST SELECT switch will then be displayed in the STATUS display, showing the address of each unit on the list for two seconds and repeating indefinitely. Alternatively, the list can be stepped through manually by repetitively placing the STEP/SCAN switch in the STEP position. At any time that an address is in the STATUS display, either in the STEP or SCAN mode, it can be removed from the list by pressing the DELETE button. Addresses will automatically be removed from the CURRENT and OLD lists by a clear command to that unit. Addresses will automatically be removed from the ERROR list by a successful communication sequence to that unit.

The system will automatically return to the keyboard mode, ready to accept commands, when any of the sixteen keypad keys is operated. The SYSTEM RESET button does just that and is used only to recover from a system hang-up state where the normal keyboard functions are not operational.

Recognizing the experimental nature of the VDCS, it was designed with built-in capability to modify its software for test purposes. This facility is accessed via the RUN/TEST switch and is described in the TECHNICAL MANUAL (3), which also contains complete schematics and descriptions of all system components. The OPERATOR'S MANUAL (4) gives complete operating instructions.

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(3) Arthur D. Little, Inc., Technical Manual for the Through-the-Earth Monitor System and the Visual Display and the Control System. USBM Contract No. J0177020. October 1980.

(4) Arthur D. Little, Inc., Operator's Manual for the Visual Display and Control System. USBM Contract No. J0177020. October 1980.

PHASE III - FABRICATE THE SYSTEM

During this phase, the following units were fabricated:

- 1 ea. Control Console serial number 001
- 1 ea. Zone Visual Display (10) serial number 001
- 2 ea. Zone Visual Display (5) serial numbers 002, 003
- 3 ea. Unit Visual Display (1) serial numbers 004, 005, 006
- 1 ea. Monitor and Control serial number 001
- 1 ea. Printer NCR260 serial number 02 (purchased)

The down-mine units are enclosed in gasketed housings. Most of the circuits in the remote units are CMOS to maximize battery life. Current drain of remote units in their quiescent state is two milliamps or less, except for the Monitor and Control Unit, whose current drain is 4.6 milliamps. The useful battery life will be greater than three months for the display units and greater than 2.3 months for the Monitor and Control Unit.

The control console is also housed in a gasketed steel box. The microprocessor components are mounted in a standard Intel card cage along with the transceiver circuits. Keyboard and display circuits are mounted directly on the front panel. The printer is a standard 30 character per second commercial unit.

PHASE IV - EVALUATE THE SYSTEM PERFORMANCE

Following fabrication, each of the units was tested for transmitter output, sensitivity to received signal level and, in the case of remote units, for sensitivity to battery voltage. The signal was attenuated by a 135 ohm T pad unit until the unit's receiver just failed to work properly, and this value of minimum input signal was recorded. White noise, band-limited to 20 kHz, was also injected onto the line and the value recorded at which it began to cause errors in data reception. These values, normalized to the 3 kHz receiver bandwidth, vary between 12 and 34 millivolts. Since the noise level in a 3 kHz band is expected to be as high as 86 millivolts in the noisiest mine, the units will have to be operated at reduced gain in such an environment, so the operating range will be somewhat shorter in such a mine. Table 2 lists these results for all unit tests, together with transmitter output voltage and function tests for each disk. Battery current drain in the quiescent state was measured for each remote unit, as were the battery voltages required for a normal echo return and for proper disk operation.

The Monitor and Control Unit analog data channel was tested at several voltages, with the results shown in Tables 2 and 3. Table 3 shows that the A/D converter linearity is preserved within its 6-bit resolution.

Table 2.

VDCS Test Results

10 Display Unit Serial Number 001

Disc	Address	Post	Clear	Test
A	016	x	x	x
B	017	x	x	x
C	018	x	x	x
D	019	x	x	x
E	020	x	x	x
1	031	x	x	x
2	032	x	x	x
3	033	x	x	x
4	034	x	x	x
5	035	x	x	x

Transmitter output into 135 ohms:	9.2 volts
Minimum input signal:	68 mV
Minimum input to saturate amplifier:	195 mV
Maximum noise (3 kHz band):	28 mV
Battery current, quiescent:	1.83 mA
Minimum battery voltage for disk operation:	10.56 V
Minimum battery voltage for Echo normal:	9.11 V

5 Display Unit Serial Number 002

Disc	Address	Post	Clear	Test
A	021	x	x	x
B	022	x	x	x
C	023	x	x	x
D	024	x	x	x
E	025	x	x	x

Transmitter output into 135 ohms:	8.5 V
Minimum input signal:	86 mV
Minimum input to saturate amplifier:	250 mV
Maximum noise (3 kHz band):	34 mV
Battery current, quiescent:	1.98 mA
Minimum battery voltage for disk operation:	10.80 V
Minimum battery voltage for Echo normal:	7.35 V

Table 2 (continued)

VDCS Test Results

5 Display Unit Serial Number 003

Disc	Address	Post	Clear	Test
A	026	x	x	x
B	027	x	x	x
C	028	x	x	x
D	029	x	x	x
E	030	x	x	x

Transmitter output into 135 ohms:	8.8 V
Minimum input signal:	73 mV
Minimum input to saturate amplifier:	230 mV
Maximum noise (3 kHz band):	29 mV
Battery current quiescent:	1.73 mA
Minimum battery voltage for disk operation:	10.40 V
Minimum battery voltage for Echo normal:	6.50 V

Single Display Unit Serial Number 004

Disc	Address	Post	Clear	Test
6	036	x	x	x

Transmitter output into 135 ohms:	8.8 V
Minimum input signal:	80 mV
Minimum input to saturate amplifier:	210 mV
Maximum noise (3 kHz band):	32 mV
Battery current, quiescent:	1.82 mA
Minimum battery voltage for disc operation:	9.60 V
Minimum battery voltage for Echo normal:	5.08 V

Single Display Unit Serial Number 005

Disc	Address	Post	Clear	Test
7	037	x	x	x

Transmitter output into 135 ohms:	8.7 V
Minimum input signal:	74 mV
Minimum input to saturate amplifier:	190 mV
Maximum noise (3 kHz band):	33 mV
Battery current, quiescent:	2.00 mA
Minimum battery voltage for disk operation:	10.10 V
Minimum battery voltage for Echo normal:	9.25 V

Table 2 (continued)

VDCS Test Results

Single Display Unit Serial Number 006

Disc	Address	Post	Clear	Test
8	038	x	x	x

Transmitter output into 135 ohms:	8.6 V
Minimum input signal:	74 mV
Minimum input to saturate amplifier:	200 mV
Maximum noise (3 kHz band):	29 mV
Battery current, quiescent:	1.88 mA
Minimum battery voltage for disk operation:	9.40 V
Minimum battery voltage for Echo normal:	7.50 V

Monitor and Control Unit Serial Number 001

Relay	Address	Post	Clear	Test
1	41	x	x	x
2	42	x	x	x
3	43	x	x	x

Transmitter output into 135 ohms:	8.7 V
Minimum input signal:	84 mV
Minimum input to saturate amplifier:	200 mV
Maximum noise (3 kHz band):	33 mV
Battery current, quiescent:	4.63 mA
Minimum battery voltage for relay operation:	7.60 V
Minimum battery voltage for Echo normal:	6.71 V

Control Console Serial Number 001

Transmitter output into 135 ohms:	9.8 V
Minimum input signal:	24 mV
Minimum input to saturate amplifier:	50 mV
Maximum noise (3 kHz band):	12.4 mV

Table 3.

Monitor and Control Unit

A/D Converter Test (Address 045)

Input		Readout
Volts	Volts/0.078125	
0	0	00.00
1	12.8	00.12
2	25.6	00.25
3	38.4	00.38
4	51.2	00.51
4.92	63.0	00.63

CONCLUSIONS

The Visual Display and Control System achieves the objective of a mineworthy paging, monitor, and control system. Two aspects of system performance should receive further attention: The noise immunity of the receivers should be improved in order to permit operation to maximum ranges in the noisiest mines, and the threshold battery voltage for disk operation should be reduced so that the echo function fails first. Both improvements are achievable by a modest amount of redesign.

INVENTIONS

There were no inventions made in conjunction with this contract.