

Information Circular 9358

A Microcomputer Network for Control of a Continuous Mining Machine

By William H. Schiffbauer

**UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary**

BUREAU OF MINES

Library of Congress Cataloging in Publication Data:

Schiffbauer, William H.

A microcomputer network for control of a continuous mining machine / by William H. Schiffbauer.

p. cm. — (Information circular; 9358)

Includes bibliographical references (p. 26).

1. Mining machinery—Automatic control. 2. Microcomputers. I. Title. II. Series: Information circular (United States. Bureau of Mines); 9358.

TN295.U4 [TN345] 622 s—dc20 [622] 93-7054 CIP

CONTENTS

	<i>Page</i>
Abstract	1
Introduction	2
BITBUS defined	3
BITBUS microprocessor hardware	4
BOM/NET for the Joy 14CM	4
Nodes	4
Communications protocol for the Joy 14CM	6
Protocol command packets	6
Gateway command packet description	7
Gateway command packet general rules	7
Command packet types and definitions	7
Functional specifications defined	7
Joy 14CM Control-Status Computer—node 1	8
Description	8
Hardware	8
Software	8
Location	8
Interaction with other nodes	8
Sensor data checks	9
Offset errors	9
Over-range errors	9
Commands for node 1	10
Data commands	10
Control commands	11
System status commands	13
RS232 Gateway Node—nodes 3, 6, 7, and A	14
Description	14
Hardware	14
Software	14
Location	15
Interaction with other nodes	15
Miscellaneous	15
Remote Operator and Diagnostics Node—node 5	15
Description	15
General	15
Normal mode of operation	16
Diagnostic mode of operation	16
Hardware	17
Software	17
Location	18
Miscellaneous	18
Camera Control-Machine Status Node—node 8	18
Description	18
Hardware	18
Software	18
Location	18
Interaction with other nodes	18
Commands for node 8	18
Data commands	18
Control commands	19
System status commands	20
Remote Mining Machine and Camera Control Node—node 9	20

CONTENTS—Continued

	<i>Page</i>
Description	20
Hardware	20
Software	20
Location	21
Interaction with other nodes	21
Commands for node 9	21
Electrical Diagnostics Node—node B	21
Description	21
Hardware	21
Software	21
Location	21
Interaction with other nodes	21
Commands for node B	21
Data commands	21
Control commands	22
Master Node—node F	22
Description	22
Hardware	22
Software	22
Location	23
Interaction with other nodes	23
Operating the mining machine using BOM/NET	23
Teleoperation	23
Closed- and open-loop control	23
Normal operation	23
BOM/NET design guidelines	24
Vibration	24
Fluctuation- and transient-free power	24
Computer electrical isolation	25
Fail-safe shutdown when failures occur	25
Locating and correcting BOM/NET system failures	25
Network speed and determinism	25
Conclusions	26
References	26
Appendix.—List of suppliers	27

ILLUSTRATIONS

1. Joy 14CM computer-assisted mining machine	2
2. BITBUS hierarchy	3
3. BITBUS data link frame	3
4. BITBUS microcomputer card	5
5. BOM/NET system for the Joy 14CM	5
6. CM node data flow diagram	9
7. Gateway data flow diagram	15
8. RODNE	17
9. RODNE data flow diagram	17
10. Master node data flow diagram	22
11. Operator switch bank	24
12. Watchdog circuit	25
13. RODNE operation	25

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A•h	ampere hour	MHz	megahertz
ft	foot	ms	millisecond
kbaud	kilobaud	μs	microsecond
kbps	kilobit per second	mV	millivolt
kbyte	kilobyte	s	second
Mbps	megabit per second	V	volt

ACRONYMNS USED IN THIS REPORT

ACK	acknowledge packet	DMOO	diagnostic mode of operation
AMREDS	autonomous mining research and development system	FCS	frame check sequence
BNF	Backus-Naur Form	FS	functional specification
BOM/NET	Bureau of Mines distributed processing network	I/O	input/output
CAP	command acknowledge packet	LCD	liquid crystal display
CECP	command execution completion packet	LED	light-emitting diode
CEFP	command execution failure packet	LSB	least significant byte
CEPP	command execution preemption packet	MCT	momentary command task
CFP	command failure packet	MPHS	mechanical position and heading system
CLCT	closed-loop command task	MSB	most significant byte
CM	continuous miner	MT	master task
CMT	communications manager task	MTCT	momentary tram command task
CP	command packets	NAK	not-acknowledge packet
CPT	command processor task	NMOO	normal mode of operation
CPU	central processing unit	NNT	network node table
cr	carriage return	PROM	programmable read-only memory
CRC	cyclic redundancy check	RAC	remote access and control

ACRONYMNS USED IN THIS REPORT—Continued

RAM	random access memory	SIU	serial interface unit
RODNE	Remote Operator and Diagnostics Node	SOT	serial output task
ROM	read-only memory	UPS	uninterruptible power supply
SBT	squash button task	WTT	watchdog timer task
SDLC	Synchronous Data Link Control	XP	explosion-proof
SIT	serial input task		

A MICROCOMPUTER NETWORK FOR CONTROL OF A CONTINUOUS MINING MACHINE

By William H. Schiffbauer¹

ABSTRACT

This report details a microcomputer-based control and monitoring network that was developed in-house by the U.S. Bureau of Mines and installed on a continuous mining machine. The network consists of microcomputers that are connected together via a single twisted-pair cable. Each microcomputer was developed to provide a particular function in the control process. Machine-mounted microcomputers, in conjunction with the appropriate sensors, provide closed-loop control of the machine, navigation, and environmental monitoring. Off-the-machine microcomputers provide remote control of the machine, sensor status, and a connection to the network so that external computers can access network data and control the continuous mining machine. Because of the network's generic structure, it can be installed on most mining machines.

¹Electronics technician, U. S. Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA.

INTRODUCTION

One approach of the U.S. Bureau of Mines toward minimizing the safety hazards inherent in mining is to investigate and evaluate new technology that will remove the miners from the immediate area where dangerous tasks are performed to a safer location. This technology also has the potential to improve the production rate of existing continuous miners (CM's) by increasing their capabilities. The Bureau's research efforts toward these goals have been enhanced by the creation of a real-time control network that not only provides computer-assisted mining but also allows many diverse computer and sensor systems to interact during the mining process. Navigation, hydraulic and electrical diagnostics, and coal interface detection methods are being researched. Other pertinent Bureau reports related to this research are referenced at the end of this document.

A commercially available real-time control network by INTEL Corp., called BITBUS² (1),³ was chosen to be the

backbone for the Bureau's system. BITBUS was selected because of its low cost, reliability, simplicity of operation and maintenance, and availability from a number of vendors (see appendix). The Bureau chose specific hardware features of the BITBUS network and then created a standardized software communications method; the combination was called BOM/NET.

This report details BOM/NET (hardware and software), the network's installation for the Joy 14CM machine (fig. 1), and installation practices used by the Bureau that ensure mechanical and electrical reliability as well as fail-safe control.

²Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

³Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this report.

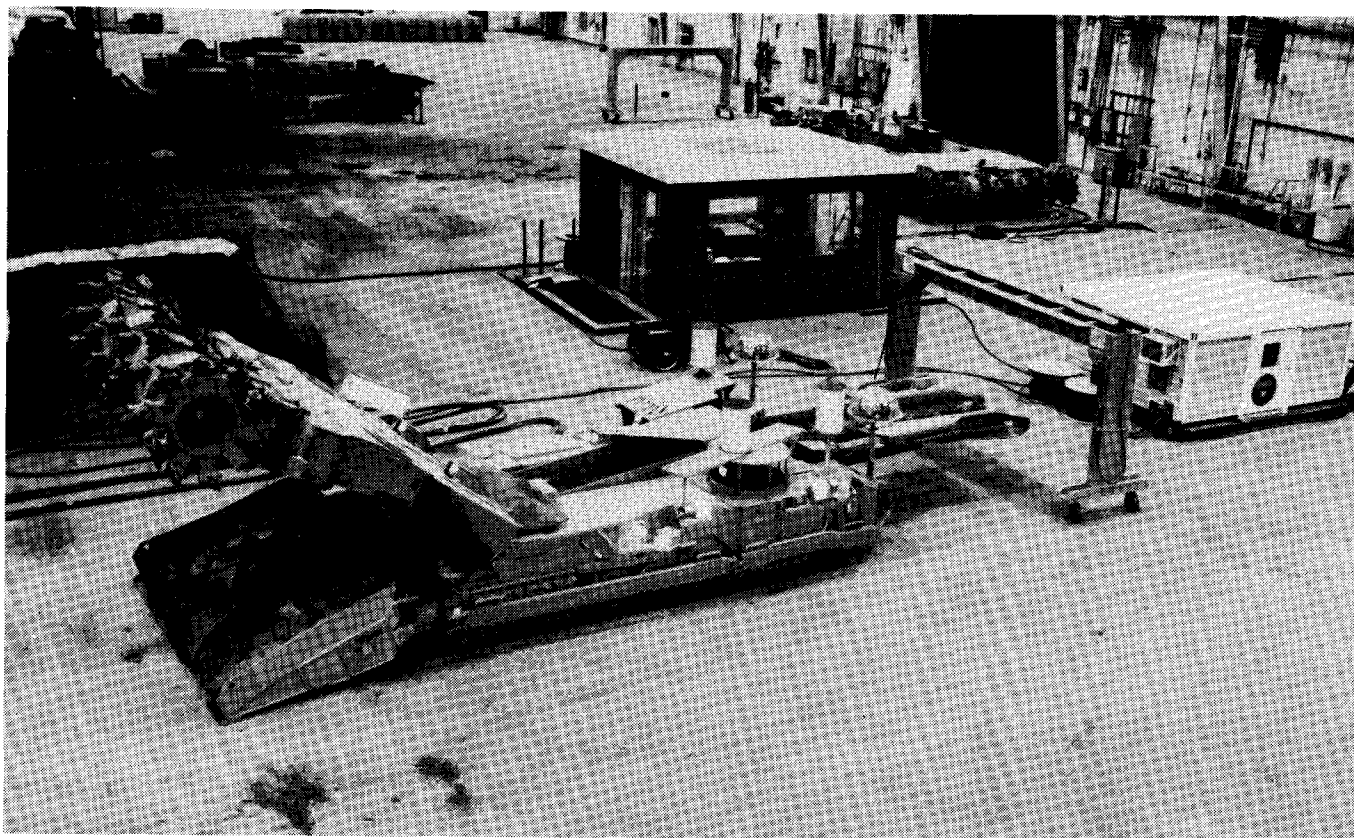


Figure 1.—Joy 14CM computer-assisted mining machine.

BITBUS DEFINED

BITBUS (2) is a serial interconnect system for distributed control applications. BITBUS is used as a field bus interface between the process and station levels of the automation hierarchy (fig. 2). The reference to "Factory" at the top of the triangle is used in the generic sense, to identify the top level of control. The BITBUS standard as detailed in this report has been given the Institute of Electrical and Electronics Engineers (IEEE) designation of IEEE P111.8.

BITBUS has four levels of definition: electrical interface, data link protocol, message protocol, and application. The electrical interface is based on Electronic Industries Association recommended standard RS-485 using twisted-pair lines with communication rates up to 2 Mbps. The twisted-pair line is differentially driven, making the line noise resistant. Noise resistance is especially important for the BOM/NET implementation of BITBUS because of the unusually harsh electrical environment in a coal mine. The electrical interface supports up to 28 nodes on a cable segment, with up to 250 nodes in a fully loaded network using repeaters between cable segments. The Bureau's implementation of BITBUS was specified for a single 1,000-ft cable segment with a maximum of 16 nodes and a communication speed of 375 kbps. The Bureau's selection of parameters was based on the general assumption that mining machines are attached to their power centers with a maximum 1,000-ft power cable, and the Bureau expects

that a computer control hut would be placed in close proximity to the power center. Since BITBUS defines 1,000-ft cable segments as having 375 kbps communication speed, this seemed to be a good choice. The maximum of 16 nodes for the network was to minimize data packet lengths while maximizing throughput.

The data link protocol is based on the International Business Machines (IBM) Synchronous Data Link Control (SDLC) standard. SDLC is a proven reliable protocol for interconnecting a Master node to multiple slave nodes in a multidrop topology. The standard data link frame format supports node addressing, data link control functions, message transfer, and error detection. Messages are transferred in the information field (fig. 3) of the frame. The data link protocol supports message transfer with this frame format in two ways: bit error detection in the frame check sequence (FCS) field and transfer sequencing in the control field. The FCS field contains a 16-bit cyclic redundancy check (CRC) used to detect bit errors on the link. The Master node exchanges messages with a slave node using standard SDLC supervisory and information control fields. BITBUS uses information control fields to transfer messages and supervisory control fields to perform data link control functions when messages are not available. Two data link control functions are a slave node acknowledging receipt of a frame from the Master node or the Master node polling a slave node for a message. These capabilities allow messages sent to slave nodes to

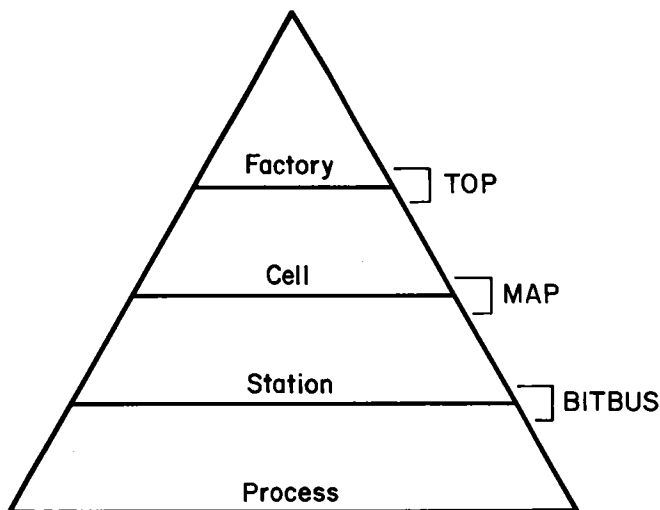


Figure 2.—BITBUS hierarchy.

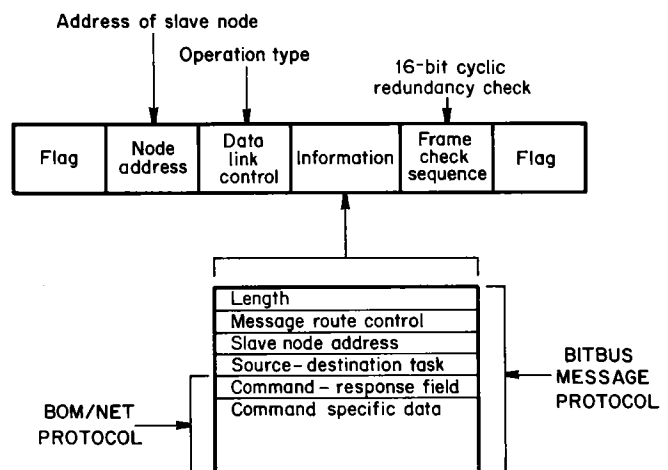


Figure 3.—BITBUS data link frame.

be immediately acknowledged by the hardware interface. Automatic acknowledgment frees up the link for the Master node to perform other operations such as sending a message or polling another slave node. Therefore, it maximizes the serial bus utilization and thus system performance.

BITBUS defines the message protocol within the data link protocol (fig. 3), and the message protocol is always 20 bytes long for BOM/NET. The message protocol defines the message structure for the information field. It also defines the order-reply mechanism for communication between tasks on the Master node and tasks on the slave nodes (a task is generally considered to be an instance of a program in execution). The message format provides an addressing mechanism to route messages to a specific task on a specific node. This protocol specifies that tasks on the Master node issue orders to tasks on the slave nodes that, in turn, respond. The data link protocol supports the

exchange by transferring the order message in an information frame. The receiving slave node immediately acknowledges the order message with an information frame if the reply from a previous order is available. The Master node then polls the slave node until it replies. This polling is performed with information frames. This algorithm minimizes unnecessary polling since a slave is polled only when one or more (maximum of seven) orders are outstanding to it.

Subsystem tasks communicate directly with the message protocol. There are at least two subsystem tasks defined in every network node. One is called the remote access and control (RAC) task, and the other is called the communications manager task (CMT). The RAC task permits network access to the input/output (I/O) in a node. The CMT includes a message protocol encoding and decoding scheme that uniquely specifies command and data packets for each node.

BITBUS MICROPROCESSOR HARDWARE

Each node in the Bureau's implementation of BITBUS (BOM/NET) consists of a microprocessor board configured to perform a system function or to work in conjunction with an attached external device to provide a system function. Each microprocessor board is based on a central processing unit (CPU) called the INTEL 8044 microcontroller. The 8044 microcontroller is a member of the INTEL 8051 microcontroller family. The 8044 microcontroller provides an 8051 CPU core and a serial interface unit (SIU). The SIU is an independent processor that provides the SDLC protocol in hardware, thus relieving the 8051 CPU core of all routine communications

overhead, allowing it to be dedicated to control functions. The two processors communicate through a time-multiplexed two-port random access memory (RAM) area. This permits both processors to run concurrently at their full speed of 12 MHz (instruction cycle is 1 μ s). The 8044 microcontroller also includes a small (2-kbyte) real-time multitasking iDCX51 operating system in read-only memory (ROM) (1). This operating system provides the BITBUS message-passing protocol, which provides multi-node message passing, and the RAC task, which was previously discussed. The iDCX51 system and the RAC task begin executing as soon as power is applied to the board.

BOM/NET FOR THE JOY 14CM

BOM/NET was built in order to tie together a variety of computer and sensor systems so that they could communicate and interact with one another promptly while controlling a CM. Each node of the network is composed of a single microcontroller card (fig. 4) dedicated to one system function, or a single microcontroller that provides a connection (or gateway)⁴ to an externally connected computer system. Additionally, each node is designed to be as intelligent and as self-sufficient as possible. This, in effect, minimizes the amount of data that passes between nodes, facilitating the highest level of real-time performance.

The network for the Bureau's Joy 14CM is shown in figure 5. The bubbles in the figure are identified as nodes

in the network, each representing one BITBUS card. The blocks in the figure represent externally connected computer systems, which are generally connected to BOM/NET through a BOM/NET gateway (the externally connected computer system takes on the node number of the gateway to which it is attached). All of the nodes in the network are connected using only a twisted-pair cable.

NODES

Node 1: CM Node—provides closed-loop control of all the Joy 14CM functions and access to all sensor-based machine data. It consists of a BITBUS card and an assortment of machine-mounted sensors and output devices.

Node 2: Gyro Node—a face navigation system (3) that provides position and heading of the Joy 14CM. It

⁴A gateway is completely described in the section "RS232 Gateway Node—nodes 3, 6, 7, and A."

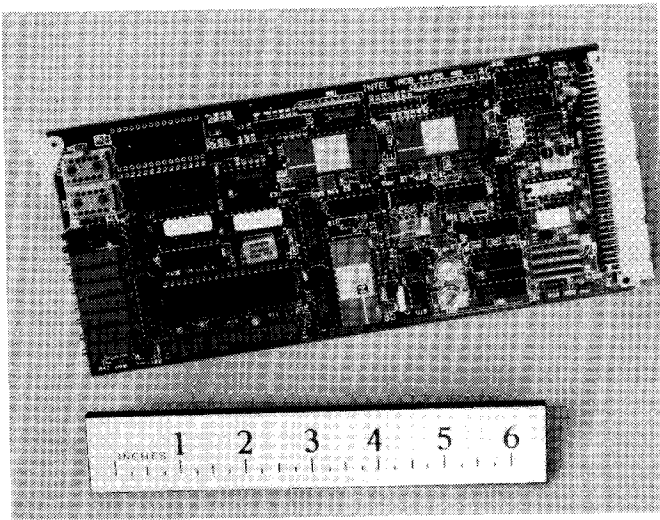


Figure 4.—BITBUS microcomputer card.

consists of a BITBUS card, a laser ring gyroscope, and clinometers.

Node 3: Laser Node—a face navigation system (4) that provides position and heading of the Joy 14CM. It consists of a BITBUS card configured as a BOM/NET gateway, an external computer system, and a cluster of lasers and machine-mounted reflectors.

Node 4: Mechanical position and heading system (MPHS) (5)—provides position and heading of the Joy 14CM. It consists of a BITBUS card and linear displacement transducers.

Node 5: Remote Operator and Diagnostics Node (RODNE)—a handheld network diagnostics tool. It consists of a BITBUS card, a keypad, and a liquid crystal display (LCD).

Node 6: BOM/NET Gateway Node—provides for future expansion of the network. It consists of a single BITBUS card.

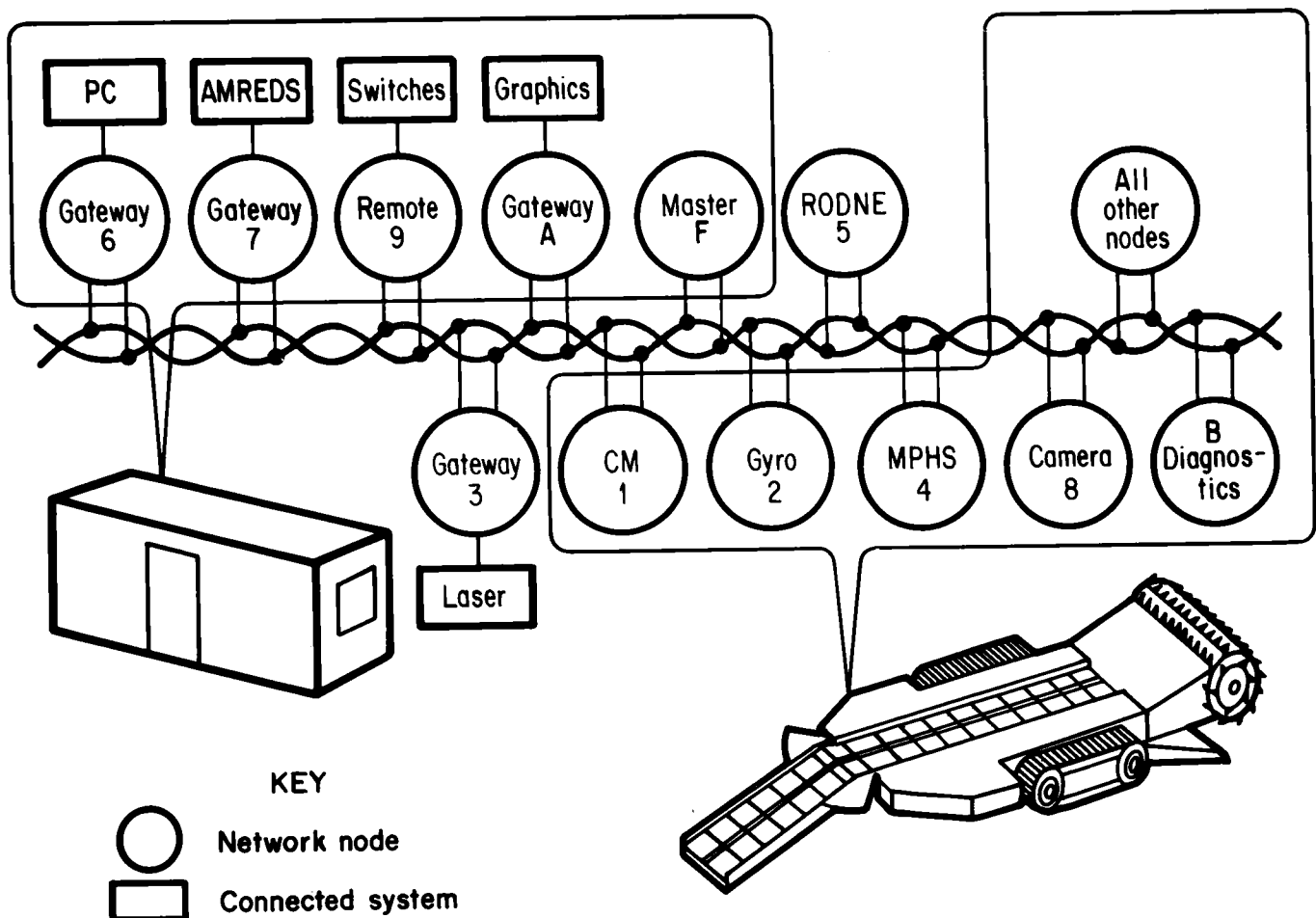


Figure 5.—BOM/NET system for the Joy 14CM.

Node 7: Autonomous mining research and development system (AMREDS) (6)—a software application that runs on a Sun workstation (see appendix). AMREDS serves as a system viewport, a platform for control program development, and a graphical display device.

Node 8: Camera Node—provides remote control of the Joy 14CM-mounted video cameras and monitors a collection of machine-mounted sensors. It consists of a BITBUS card, video cameras, and camera-control devices.

Node 9: Remote Mining Machine and Camera Control Node—provides the remote control end for the Camera Node (node 8). It consists of a BITBUS card and a collection of switches for operating the cameras.

Node A: Graphics Node (6)—a computer with monitor that provides the operator with Joy 14CM status data. It consists of a BITBUS card configured as a BOM/NET gateway and a Nippon Electric Corp. (NEC) Powermate 386/20 AT computer.

Node B: Electrical Diagnostics Node—an electrical system diagnostics device that collects data from various Joy 14CM-mounted sensors and presents its analysis on a two-digit light-emitting diode (LED) display. It consists of a BITBUS card, an LED display, and sensors.

Node F: Master Node—acts as a manager of network communications, routing the data from node to node. It consists of one BITBUS card and a 16-position switch array.

COMMUNICATIONS PROTOCOL FOR THE JOY 14CM

All communications between nodes conform to the BITBUS standard. Embedded within the BITBUS message protocol packet (fig. 3) is a unique Bureau-developed data-encoding method called BOM/NET Protocol. The protocol involves only the command, response, and data fields of a packet. The BOM/NET system is composed of a number of microcontroller boards that conform to the standards provided by INTEL Corp.'s BITBUS. Each microcontroller board is identified by a specific node number (node 1, node 2, etc.), and all references specific to that node employ the node number. Each node is connected to a common twisted-pair cable that provides the physical communication connection between nodes. The BOM/NET protocol packets and their specific implementation are described in detail in the following sections.

Protocol Command Packets

Grammar of the BOM/NET Protocol is presented formally in Backus-Naur Form (BNF) below. The BNF syntax was applied to the BOM/NET protocol to provide precise definition of it.

<BOM/NET data PACKET>

```
<header>
<terminator>
<valid character>
<letter>
<digit>
<cmd code>
<destination node address>
<target node address>
<source node address>
<data>see data field below
```

Data Field

```
<data>
<cmd type>
<parameters>
<response type>
<CAP> cmd acknowledge packet
<CFP> cmd failure packet
<CECP> cmd execution complete packet
<cmd completion data>
<CEFP> cmd execution failed
<cmd failure data>
<CEPP> cmd execution preemption
<reason code>
```

Symbols

< >

::=

|

{ }

{ }

[]

""

% %

::= <header> <destination address> <data> <terminator>

::= <header> { <valid character> } (13) <terminator>

::= "#"

::= %0DH% carriage return

::= <letter> | <digit>

::= A|B|C|D|E|F in ascii

::= 0|1|2|3|4|5|6|7|8|9 in ascii

::= <valid character> <valid character>

::= <target node address> | <source node address>

::= <valid character>

::= <valid character>

::= { <valid character> } (13)

::= <cmd> | <response>

::= <cmd code> [<parameters>]

::= { <valid characters> } (13)

::= <CAP> | <CFP> | <CECP> | <CEFP> | <CEPP>

::= "00"

::= "FF"

::= "FC" <cmd code> <cmd completion data>

::= { <valid character> } (13)

::= "FE" <cmd code> <cmd failure data>

::= { <valid character> } (13)

::= "FD" <cmd code> <reason code>

::= <valid char> <valid char>

a nonterminal or syntactical unit

"is composed of"

OR

the enclosed operator occurs zero or more times

the enclosed operator occurs up to the indicated number of times

optional element

literal string (ascii)

numeric value in the hexadecimal (H) number base

Gateway Command Packet Description

The following descriptions provide a simplified method of understanding how BOM/NET protocol packets are created for use with a Gateway node. Also, the contents of each field of the packet are described.

1. All packets start with a "#".
2. Packet information is composed of only uppercase ASCII data and only in the range of (0 to 9) and (A to F) (representing 0 to 15 in decimal).
3. Nodes are numbered from 0 to F.
4. The first data byte is the destination node for the packet.
5. The next two data bytes are command bytes (node specific).
6. Any bytes after the command are node specific.
7. Each status field byte represents four bits of information as follows: (only ASCII data are used): 1 = 0001, 2 = 0010, 4 = 0100, B = 1000. Combinations are allowed: F = 1111, A = 1010, etc. Data are represented in the following manner: 0 = off/no, 1 = on/yes.
8. All packets sent to a node shall be acknowledged by that node (to the packet source).
9. The maximum packet length is 15 bytes including the "#" and the "cr" (carriage return). Example of the maximum packet length: #123456789ABCDcr.
10. Data or status fields of any packet can be a maximum of 8 bytes long.
11. All packets end with a "cr."

Gateway Command Packet General Rules

The general rules described here provide a simple guide for creating new protocol packets that will be used with gateway nodes.

1. Any packet sent will be responded to within 1 s. Receiving nothing indicates a problem with the node that was being communicated with, or with the network itself.
2. The network can be tested by sending packet #d99cr to yourself, where "d" is your node. The "99" is just an arbitrarily picked number that is defined in each node to be a test packet. Additionally, all other nodes can be

tested by sending them packet #d99cr, where the "d" would represent the node you would like to test.

3. Gateway node 3 with an external application attached can be tested by sending an improperly formatted message through it. Example: #3234XYZcr would receive back a #3FFcr packet.

Command Packet Types and Definitions

Any protocol packet created for any node on the BOM/NET system belongs to one of six specific types. Each type identifies a specific function or operation.

Commands:

- Command packets (CP)
- Command acknowledge packet (CAP)
- Command failure packet (CFP)
- Command execution completion packet (CECP)
- Command execution failure packet (CEFP)
- Command execution preemption packet (CEPP)

Descriptions:

CP provides control functions and provides access to the status or data associated with some device.

CAP is sent in response to a CP only to acknowledge that the command is recognized as a valid command, but does not mean the command was executed successfully.

CFP is sent in response to a CP if the received packet is not a command recognized by a node or contains unknown or corrupted data.

CECP is sent after a CP has been successfully executed in compliance with the CP target parameter value or data request.

CEFP is sent if a CP was not successfully executed.

CEPP is sent when a previously activated process has been interrupted and a new process is begun, based on data contained in the new packet.

CAP, CECP, and CEPP can generally be referred to as "acknowledge" (ACK) packets. CFP and CEFP can generally be referred to as "not-acknowledge" (NAK) packets.

FUNCTIONAL SPECIFICATIONS DEFINED

A functional specification (FS) has been created for each of the nodes of the BOM/NET system. A FS is a Bureau standardized method of fully documenting the hardware, the software, and the operational characteristics of each node. This method includes the definition of the BOM/NET communications protocol packets defined in the previous section of this report. The FS for each node is in the form of a template, where each cell of the

template is filled in with the appropriate data. Where requested data for a specific node are not relative, the cell is marked "not applicable" or "none." The FS's for BOM/NET follow in numerical order (node 1, node 2, etc.). Duplicating some portions of FS's is intentional so that all of the characteristics of each node in the network may be identified as separate entities. The cells with no data are not listed in this report.

JOY 14CM CONTROL-STATUS COMPUTER—NODE 1

Description

Node 1 provides primary control of the Joy 14CM and also provides the status and output data of CM-mounted sensors. The node consists of one BITBUS microcontroller board with additional peripheral hardware. The algorithms that define node operation are contained in an onboard programmable read-only memory (PROM) chip. The node provides various modes of operation. They include Momentary Primitives, Momentary Tramming Primitives, Closed-Loop Control, Latching Primitives, and analog and digital input requests. On powerup the microcomputer ensures that all digital I/O ports are latched to the "open" or "off" state (with exception of the built-in watchdog timer). Analog and digital data can be accessed at that time using the protocol packets.

Hardware

Node 1 consists of one INTEL Corp. iRCB44/20a BITBUS microcontroller board, with one Computer Dynamics CDX48 parallel expansion board attached to the iRCB44/20a SBX port. An SBX port is an industry standard hardware method of enhancing a microcontroller's capabilities. Sixteen analog inputs are interfaced to the iRCB44/20a board through a 3b series analog I/O rack from Analog Devices. Forty-eight digital I/O points are interfaced to the CDX48 board from two separate PB24Q backplanes from OPTO 22 Corp. Power for the hardware is supplied from an uninterruptible power supply (UPS), 110 V ac input with six different dc output voltages: +5 V, +12 V, -12 V, +15 V, -15 V, and +24 V outputs.

Software

Application software is written in ASM 51 and PL/M 51 programming languages and an iDCX51 operating system is used to provide multitasking abilities as well as network operation (ASM 51, PL/M 51, and iDCX51 are INTEL Corp. products that are designed for use with BITBUS).

On powerup, a software application called the RAC task (fig. 6) is made active. It runs under the control of the iDCX51 operating system. Both the RAC task and iDCX51 system are resident in the ROM portion of the 8044 CPU chip onboard the iRCB44/20a card. The RAC task provides control and communications link with the Master node. A few other tasks, which are software applications specific to this node, are also made active on power. These tasks are resident in the onboard PROM chip, and they also run under the control of the iDCX51

operating system. The first of these tasks is called the communications manager task (CMT). All data packets coming from the Master are routed through the RAC task, and then to the CMT. The CMT can do one of three things: remove data from a full packet, insert data into an empty packet, or echo the packet. In all cases the packet is returned to the Master. A key element of the CMT is its use of the command-response field of incoming packets as a "packet function field." Any commands or data delivered to this node are processed and in some cases are transferred to another task on this node called the command processor task (CPT). The CPT has the function of intercepting all packets received from the network. The CPT extracts the command from the packet and executes it or causes the activation of another task such as the momentary command task (MCT), momentary tram command task (MTCT), or the closed-loop command task (CLCT). Additionally, the CPT has the responsibility of providing an acknowledgment to the commanding node. The MCT provides open-loop control of selected devices of the CM. Each controllable CM part has a unique identification command code (BOM/NET communications protocol command) that is defined for the CM. The MTCT provides open-loop control of the right and left track of the CM. The CLCT provides for the automated movement of selected CM appendages to positions relative to the CM frame and verified by position sensor feedback. The final task of the CM node is the watchdog timer task (WTT). This task is simply a timer task that toggles an externally connected system status device. If the network locks up or fails for any reason, the externally connected hardware lifts the power to the CM and it stops in its present position. The WTT is used as a fail-safe device that keeps the CM from operating in an uncontrolled manner.

Location

Node 1 is located onboard the Joy 14CM mining machine in the computer explosion-proof (XP) box.

Interaction With Other Nodes

The powering up of the CM also causes node 1 to be powered up. The microcomputer is initialized as well as the appropriate I/O devices (watchdog timer, CM latches). Node 1 is now ready to accept BOM/NET communication protocol packets from other nodes connected to BOM/NET. The first packet sent to node 1 after powerup should be the "pump on" packet. Then a complete diagnosis of the CM and its sensors should be performed to ensure proper operation. Upon successful completion of the powerup and CM diagnostics, any built-in function can be performed.

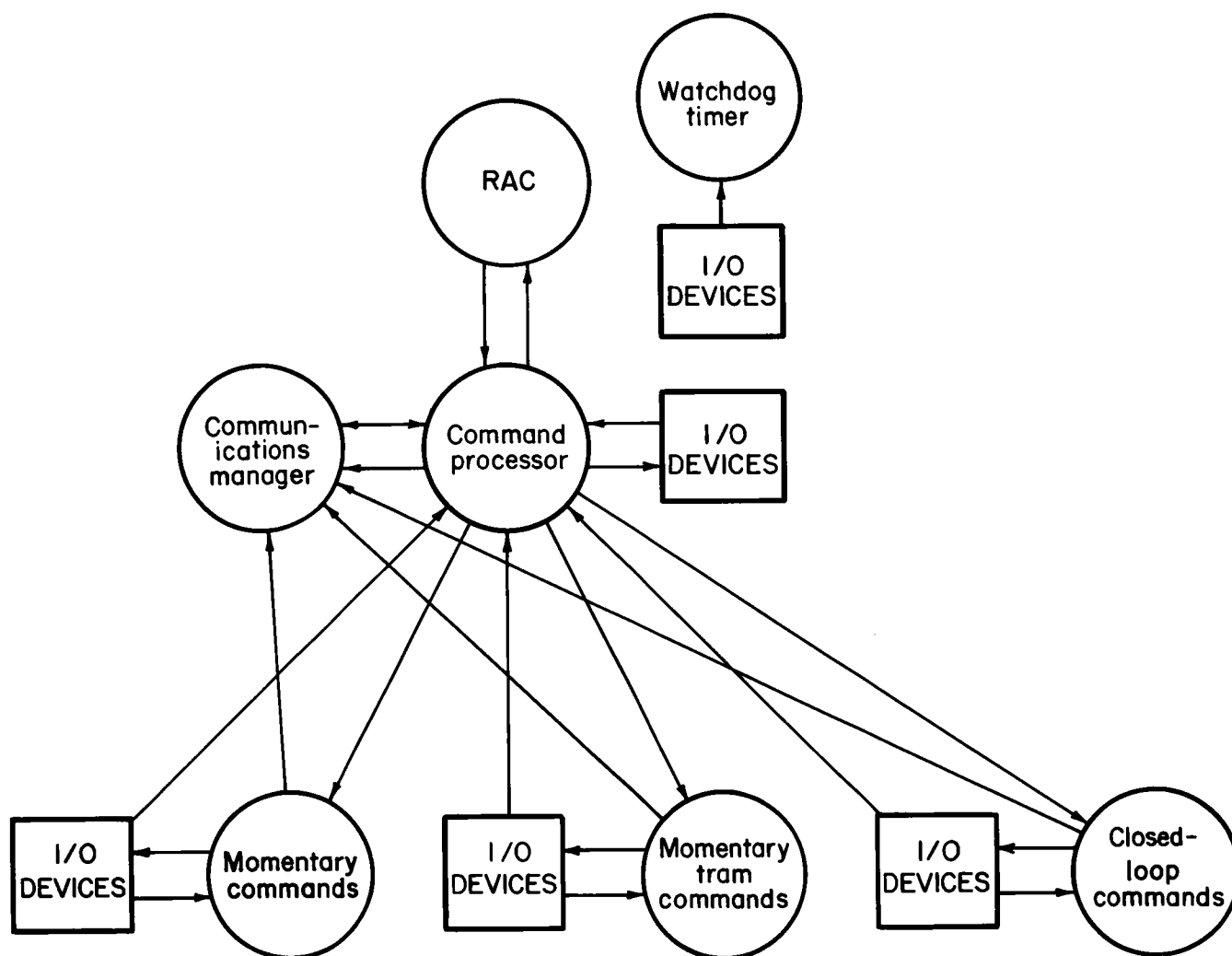


Figure 6.—CM node data flow diagram.

Sensor Data Checks

Node 1 supplies verification of data provided by sensors that include offset, over range, and sensor failure detection. Each sensor associated with this node is attached through an analog conditioning module that can provide a 0 to 10 V dc output. In the case of the sensors associated with the closed-loop functions, this would be relative to the minimum to maximum movement of the appendage to which it is attached. Employing the full range of the voltage output of the conditioning module, however, will limit the hardware's ability to detect sensor failure or sensor calibration problems. By employing an offset and a range technique, one can detect both sensor failure and sensor calibration problems; therefore, these techniques are employed. As a standard, 0.5 V dc was selected to be the minimum output and 9.5 V dc was selected to be the maximum output of all the analog channels.

Offset Errors

Offset errors are indicated when the voltage input is less than 0.5 V dc. Packets received when sensor errors exist are returned to the sender as a CFP. The sensor problems can be identified by sending a node status packet.

Over-Range Errors

Over-range errors are indicated when the voltage input is greater than 9.5 V dc. Packets received when sensor errors exist are returned to the sender as a CFP. The sensor problems can be identified by sending a node status packet.

Commands for Node 1

Node 1 CP's provide control of the CM and also provide access to the output data and the integrity of CM-mounted sensors. The CP's are grouped into three areas: sensor output data, sensor integrity data, and CM control commands.

The responses to CP's generated by node 1 are grouped into five areas: CAP, CFP, CECF, CEFP, and CEPP.

The definition of each of these response packets is given in the "Command Packet Types and Definitions" section of this document.

Data Commands

Data commands return to the requestor, sensor data output in the format described in the following section "Responses to Data Commands." Upon reception of a data CP, node 1 responds by sending a packet back to the source node. There are three possible response packets: CECF, CEFP, and CFP. The CAP's are not used for responses to CP's (for data commands) in an effort to minimize the amount of traffic on the network. Responses to all data commands are expected to be almost instantaneous, but can never be more than 1 s. If the response is later than 1 s or if there is no response, there is most likely a failure.

Data commands:

<u>CP</u>	<u>Definition</u>
#180cr	Request analog channels 0 and 1
#181cr	Request analog channels 2 and 3
#182cr	Request analog channels 4 and 5
#183cr	Request analog channels 6 and 7
#184cr	Request analog channels 8 and 9
#185cr	Request analog channels 10 and 11
#186cr	Request analog channels 12 and 13
#187cr	Request analog channels 14 and 15

Analog channel assignments:

- 0 conveyor swing
- 1 not assigned
- 2 gathering head position
- 3 not assigned
- 4 shear elevation
- 5 not assigned
- 6 conveyor elevation
- 7 thermocouple
- 8 stabilizer jack elevation
- 9 gathering head and conveyor motor current

- 10 left cutter motor current
- 11 right cutter motor current
- 12 pump motor current
- 13 ventilation motor current
- 14 left tram motor current
- 15 right tram motor current

Responses to data commands

CECF

<u>CECF</u>	<u>Definition</u>
#1FC80yyyzzzcr	Analog channels 0 and 1

The first digit indicates the packet came from node 1. The "FC" identifies the packet as a CECF type. The CECF's show a "yyy" and "zzz" field. These represent 12-bit binary data provided in ASCII format (range 000 to FFF (0-4095), representing 0 to 10 V dc, or 2.44 mV per bit). The "yyy" is the first channel requested; "zzz" is the second channel requested. The data there are represented as follows:

1st channel
 y y y
 MSB LSB

2d channel
 z z z
 MSB LSB

where MSB = most significant byte

LSB = least significant byte

CEFP

The CEFP is sent if a CP has been recognized as a valid command but for some reason the data could not be obtained or the sensor failed.

<u>CEFP</u>	<u>Definition</u>
#1FE80xxxcr	Analog channels 0 and 1

The first digit indicates the packet came from node 1. The "FE" identifies the packet as a CEFP type. The data field "xxx" contains a reason why the packet failed.⁵

⁵Details of the format of the "xxx" field can be obtained from William H. Schiffbauer, U.S. Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA 15236.

CFP

The CFP is sent if the command is not recognized as a valid command or data contained in the packet do not conform to the format of packets provided by node 1.

<u>CFP</u>	<u>Definition</u>
#1FFcr	Packet not formatted properly

Control Commands

Control commands permit the operator to command all appendages and control devices on the CM. The commands are grouped into four areas: Momentary Primitives, Momentary Trammig Primitives, Closed-Loop Primitives, and Latching Primitives. Upon receiving a control CP, node 1 will respond by sending a packet back to the source node. There are five possible response packets: CAP, CECF, CEPP, CEF, and CFP. The CAP's are not used for responses to CP's for the Latching Primitives. A CEF indicates a failure.

Momentary Primitives:

<u>CP</u>	<u>Definition</u>
#101xxxcr	Conveyor elevation up
#102xxxcr	Conveyor elevation down
#103xxxcr	Conveyor swing right
#104xxxcr	Conveyor swing left
#105xxxcr	Gathering head down
#106xxxcr	Gathering head up
#107xxxcr	Stab jack up
#108xxxcr	Stab jack down
#109xxxcr	Shear up
#10Axxxcr	Shear down
#10Bxxxcr	Conveyor reverse
...	
#10Fxxxcr	Turn off all Momentary's.

The Momentary CP's to node 1 packets show data bytes as "xxx." These represent tenths of a second in the range of (000H to 12CH) (same as 0.0 to 30.0 s) (001 = 0.1 s, 00A = 1.0 s, 00F = 1.5 s).

Momentary Trammig Primitives:

<u>CP</u>	<u>Definition</u>
#120xxxcr	Tram low speed forward
#121xxxcr	Tram high speed forward
#122xxxcr	Tram low speed reverse
#123xxxcr	Tram high speed reverse
#124xxxcr	Tram forward turn right

#125xxxcr	Tram forward turn left
#126xxxcr	Tram reverse turn right
#127xxxcr	Tram reverse turn left
#128xxxcr	Pivot right
#129xxxcr	Pivot left
#12Axxxcr	Pivot right high speed
#12Bxxxcr	Pivot left high speed
#12Cxxxcr	Tram high speed forward turn right
#12Dxxxcr	Tram high speed forward turn left
#12Exxxcr	Tram high speed reverse turn right
#12Fxxxcr	Tram high speed reverse turn left
...	
#13Fxxxcr	All stop.

The Momentary Trammig CP's to node 1 packets show data bytes as "xxx." These represent tenths of a second in the range of (000H to 12CH) (same as 0.0 to 30.0 s) (001 = 0.1 s, 00A = 1.0 s, 00F = 1.5 s).

Closed-Loop Primitives:

<u>CP</u>	<u>Definition</u>	<u>Range of "xxx" in degrees</u>
#140xxxcr	Conveyor elevation	0 to 6.1 (03DH)
#141xxxcr	Conveyor swing	0 to 86 (35CH)
#142xxxcr	Shear	0 to 44 (1B8H)
#143xxxcr	Gathering head	0 to 10 (96H)
...		
#14Fxxxcr	Turn off Closed-Loop Primitives.	

The CP's to node 1 packets show data bytes as "xxx." These represent tenths of a degree in the range of (000H to 12CH) (same as 0.0° to 30.0°) (001 = 0.1°, 00A = 1.0°, 00F = 1.5°).

Latching Primitives:

<u>CP</u>	<u>Definition</u>
#160cr	Conveyor forward on
#161cr	Conveyor forward off
#162cr	...
#163cr	...
#164cr	Pump on
#165cr	Pump off
#166cr	Cutting motor on
#167cr	Cutting motor off
#168cr	Water spray on
#169cr	Water spray off
#16Acr	Fire control on
#16Bcr	Fire control off
#16Ccr	Circuit breaker trip
...	
#16Fcr	Turn off all Latching Primitives.

Responses to Control Commands

CAP's

CAP's are sent in response to a CP only to acknowledge that the command was recognized as a valid command; they do not mean the command was executed successfully. The first digit indicates the packet came from node 1. The next two digits, "00," identify the packet as a CAP. The final two digits are just an echo of the actual command received at node 1. Note that the Latching Primitives have no CAP's.

Momentary Tramming Primitives

<u>CAP</u>	<u>Definition</u>
#10020cr	Tram low speed forward

Latching Primitives

CAP

None

CECP's

CECP's are sent after a CP has been successfully executed in compliance with the CP target parameter or data request. The CECP's for all of node 1's control commands (Momentary, Momentary Tramming, Closed-Loop, and Latching Primitives) have the same structure as shown below.

CECP
#1FC22xxxxcr

The first digit indicates the packet came from node 1. The "FC" that follows is a code that identifies the data as valid. The next two digits are just an echo of the initiated command. In this case it was a "right tram forward" command. Other commands would replace the "22" with their own unique command code. The "xxx" identifies a parameter ID specific to the particular command and falls in the range of 000 to FFF in the hexadecimal numbering system.

The Closed-Loop Primitive commands generate one CECP response the first time the particular appendage reaches its target window.

CEPP's

These CEPP packets are sent when a previously activated process has been interrupted and a new process is begun, based on data contained in the new packet. The

CEPP's for most of node 1's control commands (Momentary, Momentary Tramming, and Closed Loop Primitives) have the same structure as shown below. Note, however, that the Latching Primitives have no CEPP's.

CEPP
#1FD01cr

The first digit indicates the packet came from node 1. The "FD" that follows is the code that identifies this packet as a CEPP. The next two digits are just an echo of the initiated command, in this case a "conveyor up" command. Other commands replace the "01" with their own unique command code.

CEFP's

CEFP packets are responses sent to identify problems in attempting to complete a command directive. The CEFP's for all of node 1's control commands (Momentary, Momentary Tramming, Closed Loop, and Latching Primitives) have the same structure as shown below.

CEFP
#1FE41xxxxcr

The first digit indicates the packet came from node 1. The "FE" that follows is a "failure" code that indicates that the identified command failed to complete its intended directive. The next two digits are just an echo of the initiated command. In this case it was a closed-loop "conveyor swing" command. Other commands would replace the "41" with their own unique command code. The "xxx" identifies a parameter ID specific to the particular command. This will be in the range of "000" to "FFF" in the hexadecimal numbering system.

CFP's

CFP's are sent in response to a CP if the received packet did not contain a command recognized by a node or contains unknown or corrupted data. The CFP's for all of node 1's control commands (Momentary, Momentary Tramming, Closed-Loop, and Latching Primitives) have the same structure as shown below.

CFP
#1FFcr

The first digit indicates the packet came from node 1. The "FF" that follows is a code that identifies this packet as a CFP, indicating that the identified command failed to complete its intended directive.

System Status Commands

System status commands return sensor output data. Upon reception of a CP, node 1 responds by sending a packet back to the source node. There are three possible response packets: CECF, CEFP, and CFP. The CAP's are not used for responses to System Status Commands. Responses to all System Status Commands are almost instantaneous, but can never be more than 1 s. A failure is suspected if the latter is the case.

Status Commands:

<u>CP</u>	<u>Definition</u>
#170cr	Status of lower 12 bits of port j0
#171cr	Status of upper 12 bits of port j0
#172cr	Status of lower 12 bits of port j1
#173cr	Status of upper 12 bits of port j1
#174cr	Status of analog channels 0 to 7
#175cr	Status of analog channels 8 to 15
#176cr	Status of a select combination of data
...	
#190CR	All stop
#199cr	Communications verification packet.

The system status CP's to node 1 all begin with the number "1." The two digits that follow identify the specific commands to be selected.

Responses to System Status Commands

CECP's

CECP's are sent after a CP has been successfully executed. The structure is shown below.

CECP
#1FC70xxxxcr

The first digit indicates the packet came from node 1. The "FC" that follows is CECF code that identifies the data as valid. The "70" indicates that this packet is a response to "#170cr" command. Other commands (#171cr, #172cr, etc.) cause their own unique code to be echoed (#1FC71xxxxcr, etc.). The "xxx" in the response packets is interpreted as follows: each "x" will be in the range of "0" to "F," which is the hexadecimal representation in ASCII of 4 bits of binary data (i.e., 0001 = 1, 0010 = 2, 0100 = 4, 1000 = 8, 1010 = A). The following shows what each bit represents for each status packet.

#1FC70xxxxcr

xxx = 100 conveyor elevation up
xxx = 200 conveyor elevation down

xxx = 400 conveyor swing left
xxx = 800 conveyor swing right
xxx = 010 shear up
xxx = 020 shear down
xxx = 040 stab jack up
xxx = 080 stab jack down
xxx = 001 gathering head up
xxx = 002 gathering head down
xxx = 004 pump on
xxx = 008 pump run

#1FC71xxxxcr

xxx = 100 conveyor forward on
xxx = 200 conveyor forward run
xxx = 400 conveyor reverse on
xxx = 800 cutter on
xxx = 010 cutter run
xxx = 020 right tram forward
xxx = 040 right tram reverse
xxx = 080 left tram forward
xxx = 001 left tram reverse
xxx = 002 tram fast
xxx = 004 water spray
xxx = 008 fire suppression

#1FC72xxxxcr

xxx = 100 circuit breaker trip
xxx = 200 watch dog toggle
xxx = 400 safety switch

Response packets #1FC74xxxxcr and #1FC75xxxxcr provide a quick status of all 16 channels of analog input data. Again, each "x" will be in the range of "0" to "F," which is the hexadecimal representation in ASCII of 4 bits of binary data (i.e., 0001 = 1, 0010 = 2, 0100 = 4, 1000 = 8, 1010 = A). For response packet #174xxxxcr, the data are as follows. A channel number is identified only when the analog input voltage exceeds 1/3 full scale.

xxx = 001 analog channel 0
xxx = 002 analog channel 1
xxx = 004 analog channel 2
xxx = 008 analog channel 3
xxx = 010 analog channel 4
xxx = 020 analog channel 5
xxx = 040 analog channel 6
xxx = 080 analog channel 7

For response packet #1FC75xxxxcr, the data are as follows:

xxx = 001 analog channel 8
xxx = 002 analog channel 9
xxx = 004 analog channel 10

xxx = 008 analog channel 11
 xxx = 010 analog channel 12
 xxx = 020 analog channel 13
 xxx = 040 analog channel 14
 xxx = 080 analog channel 15

For response packet #1FC76xxxxr, the data portion of the packet is in binary format and should not be passed through a normal gateway node because it could cause unpredictable results in some computers. Node A has been specially constructed to interpret the binary data, change them into ASCII format, and then output them to a RS232 device. The binary data are 7 bytes long and are formatted as follows:

byte 1 = the most significant 8 bits of analog channel 0
 byte 2 = the most significant 8 bits of analog channel 2
 byte 3 = the most significant 8 bits of analog channel 4
 byte 4 = the most significant 8 bits of analog channel 6
 byte 5 = the most significant 8 bits of analog channel 8
 byte 6 = the most significant 8 bits of analog channel 10
 byte 7 is divided into bits as represented by the following:

bit 0 = conveyor status
 bit 1 = pump status
 bit 2 = water spray status
 bit 3 = fire suppression status
 bit 4 = oil level status
 bits 5 to 7 are not assigned.

CEFP

The CFP is sent if a CP has been recognized as a valid command but for some reason the data could not be obtained.

CEFP
 #1FE70xxxxr

The first digit indicates the packet came from node 1. The "FE" that follows is a CFP code that indicates node 1 was unable to provide the data requested. The "70" indicates that this packet is a response to a request for System Status. The data field "xxx" will contain a reason why the packet failed.

CFP

The CFP's are sent in response to a CP if the received packet does not contain a command recognized by a node or contains unknown or corrupted data.

CFP
 #1FFCr

The first digit indicates the packet came from node 1. The "FF" is a CFP code that indicates the command failed to complete its intended function.

RS232 GATEWAY NODE—NODES 3, 6, 7 AND A

Description

Gateway nodes are designed only to provide a 9,600-baud RS232 port connection to BOM/NET. When a dumb terminal or external computer is attached to the RS232 port, it can interact with any node connected to BOM/NET, provided that the BOM/NET protocol structure is honored. Additionally, when the RS232-connected device communicates with a particular node of the network, then the command set specified for that particular node must also be honored. When a Gateway node receives the final byte from the RS232-connected device, the packet is checked for BOM/NET protocol structure compliance. If the packet is correct, it is delivered to the network. If the packet is incorrect, an error packet is delivered to the network, #7FFCr, which is directed to echo it back to node 7, which then ships it out the RS232 port to the externally connected device.

Hardware

Gateway nodes are built from an INTEL iRCB44/10a BITBUS microcontroller board, with one INTEL iSBX351 serial communications module attached to an iRCB44/10a SBX port. Power for this node is supplied from a UPS, 110 V ac input with +5, +12, and -12 V dc outputs. Communications with all other nodes are dictated by conformance to the BOM/NET communications protocol defined in the "Communications Protocol for the Joy 14CM" section of this report. The hardware connection between all nodes in BOM/NET is a twisted-pair cable. The hardware connection to the iSBX351 board is a standard RS232 port connection, and the iSBX351 board is configured to operate at 9,600 baud, with one stop bit and no parity. The RS232 connection can be attached to a properly configured dumb terminal or external computer system. The BITBUS board operates at a speed of 375 kbaud.

Software

Application software is written in ASM 51 and PL/M 51 programming languages. An iDCX51 operating system provides multitasking abilities as well as network operation.

Powerup activates a software application called the RAC task (fig. 7). The RAC task runs under the control of the iDCX51 operating system. Both the RAC task and iDCX51 system are resident in the 8044 CPU chip on-board the iRCB44/20a card. The RAC task provides control and acts as a communications link with the Master node. A few other tasks, which are software applications resident on this node, are also made active on powerup. These tasks are resident in the onboard PROM chip, and they also run under the control of the iDCX51 operating system. The first of these tasks is called the CMT. All data packets coming from the Master are routed through the RAC task, and then to the CMT. The CMT is extremely compact to provide the best possible real-time performance. The CMT can do one of three things: remove data from a full packet, insert data into an empty packet, or just echo the packet. In all cases the packet is returned to the Master. A key element of the CMT is its use of the command-response field of incoming packets as a "packet function field." Any commands or data delivered to a Gateway are processed and in some cases are transferred to another task. The "serial input task" (SIT) accepts data from its RS232 serial input port at 9,600 baud. The SIT tests the data to ensure they do not exceed the maximum packet size. Also, SIT tests each

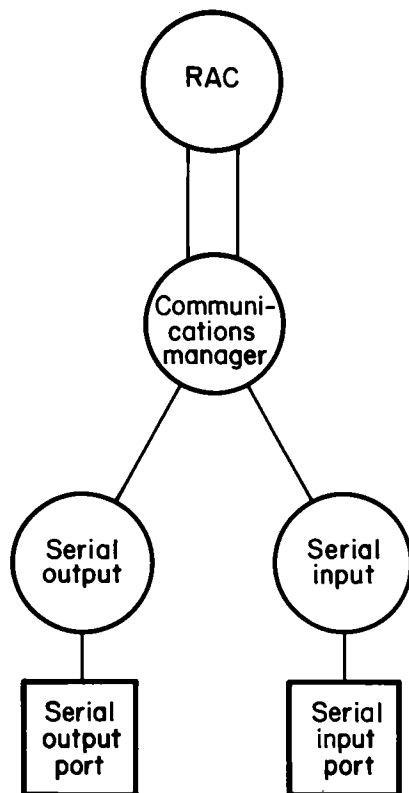


Figure 7.—Gateway data flow diagram.

byte to make sure that they are all valid. If both conditions are true, then SIT informs CMT that this node has data to transfer to another node, and when CMT is ready, it does so. If the serial input port packet is the wrong length or if the data are invalid, SIT causes a NAK to be sent out to the "serial output task" (SOT). The SOT simply takes any command or data directed to the node from the network, and ships it out the RS232 port at 9,600 baud. It is important to note that all system acknowledgments and command processing become the responsibility of the computer system connected to the BOM/NET Gateway.

Location

Nodes 3, 6, 7, and A are located in the computer chassis in the control hut.

Interaction With Other Nodes

Packets delivered to the RS232 port are tested for compliance with the BOM/NET protocol structure and when correct are sent to the intended target node. Packets received via BOM/NET are delivered to the RS232 port. It is the responsibility of the external device to respond as required. The device connected to the RS232 port has its own defined command set, which must conform to the BOM/NET protocol structure.

Miscellaneous

Gateway node A has been specially modified to handle binary data instead of the normal ASCII data.

REMOTE OPERATOR AND DIAGNOSTICS NODE—NODE 5

Description

General

The Remote Operator and Diagnostics Node (RODNE) is multifunctional. It can provide for CM powerup and initialization, sensor verification, network communication verification, system diagnostics, and remote control. Operation is totally menu driven, requiring minimum human input for any selected function. Upon powerup, complete self-verification of all hardware and software is performed. Powerup also brings up a menu that enables the operator to make RODNE a master node or a slave node. RODNE will remain as selected for the remainder of this powerup sequence. During CM operation,

the operator always has the ability to totally power down all commandable CM functions by pressing the all-stop squash button.

Normal Mode of Operation

The normal mode of operation (NMOO) is available only when RODNE is a slave node. There are two types of operations in the NMOO—Joy 14CM initialization and Joy 14CM operation. The Joy 14CM initialization mode allows the operator to follow a preplanned script to fully test the CM. The Joy 14CM operation mode lets the operator test individual machine functions specific to the Joy 14CM.

Diagnostic Mode of Operation

The diagnostic mode of operation (DMOO) is available whether RODNE is a master or a slave node. As a master, the DMOO lets the operator attach to a single node (from nodes 1 to F) to perform a complete analysis using the lowest level of communication (BOM/NET communication protocol packets) in dumb terminal fashion. As a slave, RODNE interacts with a BOM/NET Master and other slave nodes, again in dumb terminal fashion.

Joy 14CM Initialization

To provide safe operation, the checks below need to be performed every time the CM is powered. It is the responsibility of this node to generate commands that exercise the CM (node 1) and then present the human operator node 1 responses (via the LCD device). Additionally, the human operator must visually verify that the generated commands perform the correct function on the mining machine. The Joy 14CM initialization tests are analogous to preflight checks for aircraft. The ordering of commands in the following initialization script provides a complete integrity analysis of the CM. Failure of the CM to meet a minimum performance level for any of the generated commands requires a recalibration and/or repair of some CM device. After making RODNE a slave node, the operator begins the Joy 14CM initialization mode by selecting that option from the NMOO menu. The operator is prompted step by step and must respond to each prompt. This interaction continues until completion of the initialization script, or until the operator halts the process.

Initialization script:

1. turn pump on
hydraulic pump flow - *
hydraulic pilot pressure - *
line voltage - *
2. stab jack down (1 s)

3. stab jack up (1 s)
4. shear up (30°) - @
5. water spray on (2 s) - *
6. water spray off - *
7. conveyor forward on (2 s)
8. conveyor forward off
9. gathering head down - (5°)
10. gathering head up - (10°)@
11. cutting motor on (2 s)
12. cutting motor off
13. tram lo speed forward (2 s)
14. tram hi speed forward (2 s)
15. tram lo speed reverse (2 s)
16. tram hi speed reverse (2 s)
17. tram forward turn right (2 s)
18. tram forward turn left (2 s)
19. tram reverse turn right (2 s)
20. tram reverse turn left (2 s)
21. pivot right (2 s)
22. pivot left (2 s)
23. shear down - (15°) - @
24. conveyor swing left (20°) - @
25. conveyor swing right (70°) - @
26. conveyor swing (44°) - @
27. conveyor elevation down (1.6°) - @
28. conveyor elevation up (4.8°) - @

* This item does not yet exist, but may be used at some time in the future.

@ These machine functions are executed in the closed-loop mode and must operate at a minimum rate of 30%. Each machine function has an inherent travel distance and rate of movement. Based on these parameters, and allowing for a minimum movement rate of 30%, a time to completion for each function has been defined. If a function does not perform at that rate, a failure message appears on the LCD display.

Joy 14CM Operation

The Joy 14CM operation mode is selected from the NMOO menu. This mode allows the operator to build a BOM/NET communications protocol command to be sent to node 1. These commands include Momentary, Momentary Tram, Closed-Loop, Latching Primitives, Status, and Analog Status. After each command is delivered to node 1, RODNE waits for an expected response (or responses) from node 1, including CAP's and CECF's. A verified successful completion of a command by node 1 is acknowledged on RODNE's LCD screen. Failure to acquire the expected node 1 responses causes an error message to be displayed on RODNE's LCD screen.

Diagnostics

The DMOO is not limited to use on the Joy 14CM machine. Any node on the network can be evaluated and tested. Normally, these tests are run with a complete group of network nodes, including the Master. Optionally, the operator can make this node act as Master (only on powerup) so that individual nodes can be tested by RODNE without requiring the presence of any other network node.

Hardware

The hardware consists of one INTEL Corp. iRCB44/10a BITBUS microcontroller board, with attached CDX48a digital I/O card, one LCD (4- by 20-character) display (Industrial Electronic Engineers, Inc.), one 4 by 4 (16 keys) keypad, two small (key-type) status LCD displays, one on-off switch, and a large red (all-stop) squash button. The hardware is mounted in a plastic box (fig. 8). A detachable 7.2-V 8-A·h nickel-cadmium battery pack supplies power to the board. The BITBUS board operates at a speed of 375 kbaud.

Software

Application software is written in ASM 51 and PL/M 51 programming languages. An iDCX51 operating system is used to provide multitasking abilities as well as network operation.

Powerup activates a software application known as the RAC task (fig. 9). It runs under the control of the iDCX51 operating system. Both the RAC task and iDCX51 system are resident in the 8044 CPU chip on the iRCB44/10a card. The RAC task provides control and

communications with the Master node. Other tasks, which provide local control, are also made active on powerup. These tasks are resident in the onboard PROM chip, and they also run under the control of the iDCX51 operating system. The first of these tasks is the CMT. The CMT first causes a prompt message to be sent to the LCD screen. This message prompts the operator to select Master or slave operation. If the slave operation is selected, all data packets coming from the Master are routed through the RAC task, then to the CMT. The CMT is extremely compact to provide the best possible real-time performance. The CMT can do one of three things: remove data from a full packet, insert data into an empty packet, or echo the packet. In all cases, the packet is returned to the Master. A key element of the CMT is its use of the command-response field of incoming packets as a "packet function field." If the operator, on powerup, selected the master mode of operation, then the CMT task operates quite differently. With RODNE as Master, the CMT creates the one-system packet. All interchanges over BOM/NET are then handled by the CMT. Data are collected from the operator and inserted into the packet, then shipped to the operator-selected node. When the packet returns, the appropriate data are presented to the operator. In both the master and slave modes of operation, all commands or data delivered to this node are processed by another node resident task, the CPT, whose function is to intercept all packets received from the network. The CPT extracts the command from the packet and processes it. One other task resides in this node, the squash button task (SBT). It has the sole purpose of waiting for the squash button to be pressed by the operator. When the button is pressed, the SBT sends an all-stop packet to the CM.

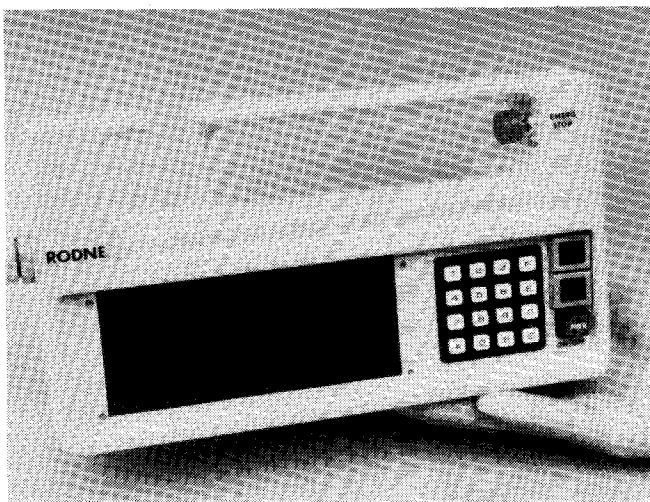


Figure 8.—Remote Operator and Diagnostics Node (RODNE).

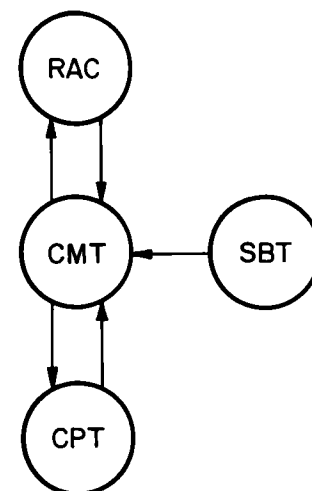


Figure 9.—RODNE data flow diagram (CMT = communications manager task; SBT = squash button task; CPT = command processor task).

Location

RODNE is portable and connects to the system with a twisted pair cable.

Miscellaneous

The large red all-stop squash button causes all commandable CM actions to halt.

CAMERA CONTROL-MACHINE STATUS NODE—NODE 8

Description

Node 8 controls two CM-mounted cameras and also supplies the status and output data of CM-mounted sensors. The node consists of one BITBUS microcontroller board with an assortment of peripheral hardware. The algorithms that define node operation are contained in an onboard PROM chip. The analog- and digital-input-request functions provide the analog-input value of selected analog-input sensors, and the status of selected input switches. The node conforms strictly to the BOM/NET Communications Protocol section of this document. On powerup, the microcomputer ensures that all digital I/O ports are latched to the "open" or "off" state. Analog and digital data can be accessed at that time using BOM/NET protocol packets.

Hardware

Node 8 consists of one INTEL Corp. iRCB44/20a BITBUS microcontroller board, with one Computer Dynamics CDX48 parallel expansion board attached to the iRCB44/20a SBX port. Eight analog inputs are interfaced to the iRCB44/20a board through a 3b series analog I/O rack from Analog Devices. Twenty-four digital I/O points are interfaced to the CDX48 board from one PB24Q backplane from OPTO 22 Corp. Power for the hardware is supplied from a UPS with dc outputs. Communications with node 8 are provided by BOM/NET as defined in the "Command Packet Types and Definitions" section of this document. The hardware connection between all nodes in BOM/NET is a twisted-pair cable. All nodes in the network operate at 375 kbaud.

Software

Application software is written in ASM 51 and PL/M 51 programming languages. An iDCX51 operating system provides multitasking abilities as well as network operation.

On powerup, a software application called the RAC task is made active. It runs under the control of the iDCX51 operating system. Both the RAC task and iDCX51 system are resident in the 8044 CPU chip onboard the iRCB44/20a card. The RAC task provides control and communications link with the Master node. A few other tasks, which are software applications specific to this node, are also made active on powerup. These tasks are resident in the onboard PROM chip, and they also run under the control of iDCX51 operating system. The first of these tasks is the CMT. All data packets coming from the Master are routed through the RAC task, and then to the CMT. The CMT is extremely compact, which provides the best possible real-time performance. The CMT can do one of three things: remove data from a full packet, insert data into an empty packet, or echo the packet. In all cases the packet is returned to the Master. A key element of the CMT is its use of the command-response field of incoming packets as a "packet function field." Any commands or data delivered to this node are processed and in some cases are transferred to another task on this node called the CPT. The CPT has the function of intercepting all packets received from the network. The CPT extracts the command from the packet and executes it, or causes the collection of analog input data.

Location

Node 8 is onboard the Joy 14CM mining machine in the interface XP box.

Interaction With Other Nodes

Powering up the CM also powers up node 8, which initializes the microcomputer as well as the appropriate I/O devices. Node 8 is then ready to accept BOM/NET packets from other nodes connected to BOM/NET.

Commands for Node 8

Node 8 CP's provide control of two CM-mounted cameras and access to the output of selected sensor data.

The responses to CP's generated by node 8 are grouped into five areas: CAP, CFP, CECF, CEFP, and CEPP.

The definition of each of these response packets can be found in the "Command Packet Types and Definitions" section of this document.

Data Commands

Data commands provide the output of selected sensors. Upon receiving a data CP, node 8 responds by sending a packet back to the source node. There are three possible

response packets. They are the CECF, CEFP, and CFP. In an effort to minimize the amount of traffic on the network, CAP's are used for responses to CP's for data commands. Responses to all data commands are expected to be almost instantaneous, but never can be more than 1 s. A failure is suspected if the response is more than 1 s.

<u>CP</u>	<u>Definition</u>
#820cr	Request analog channels 0 and 1
#821cr	Request analog channels 2 and 3
#822cr	Request analog channels 4 and 5
#823cr	Request analog channels 6 and 7

Responses to Data Commands

CECP

<u>CECP</u>	<u>Definition</u>
#8FC20yyyzzzcr	Analog channels 0 and 1

The packet's first digit indicates it came from node 8. The "FC" identifies the packet as a CECF type. The CECF's show a "yyy" and "zzz" field. These represent 12-bit binary data provided in ASCII format (range 000 to FFF, representing 0 to 10 V dc, or 2.44 mV per digit). The "yyy" is the first channel requested, "zzz" is the second channel requested. The data are represented as follows:

1st channel
 y y y
 MSB LSB

2nd channel
 z z z
 MSB LSB

where MSB = most significant byte

LSB = least significant byte

CEFP

The CEFP is sent if a CP has been recognized as a valid command but for some reason the data could not be obtained or the sensor had a failure.

<u>CEFP</u>	<u>Definition</u>
#8FE20xxxcr	Not defined

The packet's first digit indicates it came from node 8. The "FE" identifies the packet as a CEFP type. The data field "xxx" contains a reason why the packet failed.

CFP

The CFP is sent if the command is not recognized as a valid command or data contained in the packet do not conform to the format of packets provided by node 8.

<u>CFP</u>	<u>Definition</u>
#8FFcr	Packet not formatted properly

Control Commands

Control commands permit the operator to perform selected functions on selected cameras for 0.4 s, at which time the selected function will turn off.

Camera 1:

<u>CP</u>	<u>Description</u>
#801000008cr	Zoom out
#801000002cr	Zoom in
#801001000cr	Focus out
#801004000cr	Focus in
#801002000cr	Iris closed
#801008000cr	Iris open

Camera 2:

<u>CP</u>	<u>Description</u>
#801040000cr	Zoom out
#801010000cr	Zoom in
#801080000cr	Focus out
#801020000cr	Focus in
#801000001cr	Iris closed
#801000004cr	Iris open
#801000010cr	Tilt down
#801000020cr	Tilt up
#801000040cr	Pan right
#801000080cr	Pan left

Both cameras:

<u>CP</u>	<u>Description</u>
#890cr	All stop

The first digit indicates it came from node 8. The two digits that follow identify the specific command. The all-stop function for both cameras is "90" followed by the "cr." The only other control command, "01", provides control of both cameras in one packet. Multiple commands can be performed in one packet by adding up the characters in hexadecimal (i.e., #801000020cr + #801008000cr etc.).

The 0.4 s of execution shown in the description was an arbitrarily selected value based on system dynamics.

Responses to Control Commands

At the present time control commands provide just two responses, CAP's and CFP's.

CAP's

CAP's are sent in response to a CP only to acknowledge that the command was recognized as a valid command but not that the command was executed successfully.

<u>CAP</u>	<u>Definition</u>
#80001cr	ACK

The first digit indicates the packet came from node 8. The next two digits, "00", identify the packet as a simple acknowledge. The final two digits are just an echo of the actual command received at node 8.

CFP's

CFP's are sent in response to a CP if the command is not recognized as a valid command or data contained in the packet do not conform to the format of packets provided by node 8.

<u>CFP</u>	<u>Definition</u>
#8FFcr	NAK

System Status Commands

Only one system status command is presently provided for node 8: the communications verification command.

<u>CP</u>	<u>Definition</u>
#899cr	Communications verification

Responses to System Status Commands

<u>CAP</u>	<u>Definition</u>
#80099cr	ACK

The first digit indicates the packet came from node 8. The "00" is an ACK identifying valid data. The "99" is an echo of the initiated command.

REMOTE MINING MACHINE AND CAMERA CONTROL NODE—NODE 9

Description

Node 9 interfaces to a camera and remote-control console that reside in the remote operator's control hut.

Hardware

Node 9 is built from an INTEL iRCB44/10a BITBUS microcontroller board, with one CDX48a module attached to the iRCB44/10a SBX port. A UPS with 110 V ac input and multiple dc outputs supplies computer power. Communication with all other nodes is dictated by conformance to the BOM/NET Communications Protocol section of this document. The hardware connection between all nodes in BOM/NET is a twisted-pair cable. The BITBUS board is configured to operate at a speed of 375 kbaud.

Software

Application software is written in ASM 51 and PL/M 51 programming languages. An iDCX51 operating system is used to provide multitasking abilities as well as network operation.

On powerup, a software application known as the RAC task is made active. It runs under the control of the iDCX51 operating system. Both the RAC task and iDCX51 system are resident in the 8044 CPU chip on-board the iRCB44/10a card. The RAC task provides a control and communications link with the Master node. A few other tasks, which are software applications specific to this node, are also made active on powerup. These tasks are resident in the onboard PROM chip, and they also run under the control of iDCX51 operating system. The first of these tasks is the CMT. All data packets coming from the Master are routed through the RAC task, and then to the CMT. The CMT is extremely compact, which provides the best possible real-time performance. The CMT can do one of three things: remove data from a full packet, insert data into an empty packet, or echo the packet. In all cases the packet is returned to the Master. A key element of the CMT is its use of the command-response field of incoming packets as a "packet function field." Any commands or data delivered to this node are processed and in some cases are transferred to another task on this node, the CPT. The CPT has the function of intercepting all packets received from the network. The CPT extracts the command from the packet and executes it or causes the collection of status data from a remote-control switch panel.

Location

Node 9 is located in the computer chassis in the control hut.

Interaction With Other Nodes

Switch positions from a camera and mining machine control panels are echoed on both the CM and the Camera Control node.

Commands for Node 9

Node 9 CP's provide control of selected machine-mounted devices and access to the output of selected sensor data.

The responses to CP's generated by node 9 are grouped into five areas: CAP, CFP, CECF, CEFP, and CEPP.

The definition of each of these response packets can be found in the "Command Packet Types and Definitions" section of this document.

ELECTRICAL DIAGNOSTICS NODE—NODE B

Description

Node B provides the status of a collection of electrical diagnostic (on-off type) sensors. The algorithms that define node operation are contained in an onboard PROM chip. The algorithm looks at a matrix of status points on the CM electrical system and then deduces failures. Any one failure is latched on the LED device, and a status packet can be sent to identify the failure. The status of any sensor can be obtained over BOM/NET by using the defined protocol packets. The node conforms strictly to the BOM/NET protocol specification. On powerup, the microcomputer ensures that all digital I/O ports are latched to the "open" or "off" state.

Hardware

Node B is built from an INTEL iRCB44/10a BITBUS microcontroller board, with one CDX48a module attached to the iRCB44/10a SBX port. Power for this node is supplied from a 110 V ac input linear power supply with dc outputs. Communication with all other nodes is dictated by conformance to the BOM/NET Communications Protocol section of this document. The hardware connection between all nodes in BOM/NET is a twisted-pair cable. The BITBUS board is configured to operate at a speed of 375 kbaud.

Software

Application software is written in ASM 51 and PL/M 51 programming languages. An iDCX51 operating system is used to provide multitasking abilities as well as network operation.

On powerup, a software application called the RAC task is made active. It runs under the control of the iDCX51 operating system. Both the RAC task and iDCX51 system are resident in the 8044 CPU chip onboard the iRCB44/10a card. The RAC task provides control and communications link with the Master node. A few other tasks, which are software applications specific to this node, are also made active on powerup. These tasks are resident in the onboard PROM chip, and they also run under the control of the iDCX51 operating system. The first of these tasks is the CMT. All data packets coming from the Master are routed through the RAC task, and then to the CMT. The CMT is extremely compact to provide the best possible real-time performance. The CMT can do one of three things: remove data from a full packet, insert data into an empty packet, or echo the packet. In all cases the packet is returned to the Master. A key element of the CMT is its use of the command-response field of incoming packets as a "packet function field." Any commands or data delivered to this node are processed and in some cases are transferred to another task on this node, the CPT. The CPT intercepts all packets received from the network. The CPT extracts the command from the packet and executes it or causes the collection of status data from a control switch panel.

Location

The node is located onboard the Joy 14CM machine in an XP box.

Interaction With Other Nodes

Powering up the CM also causes node B to be powered up. Node B is then ready to accept BOM/NET packets from other nodes connected to BOM/NET.

Commands for Node B

Node B command packets provide control and monitoring of the node B data.

Data Commands

Data commands tell the requestor the status (on or off) of specific input ports that relate to specific sensor points in the mining machine's electrical system.

<u>CP</u>	<u>Description</u>
#B01cr	Port J0 and port A bit status
#B02cr	Port J1 and port B bit status
#B03cr	Failure mode status

Responses to Data Commands

```
#BFC0100000000cr
#BFC0200000000cr
#BFC0300cr
```

The first letter in the response packet indicates it came from node B. The "FC" identifies the packet as a CECF type. The "01" to "03" that follow are just an echo of the original command. All data that follow represent the particular port's status, where "1" represents an "on" state, and "0" represents an "off."

Control Commands

The control commands permit the commander to reset any failure code locked in the LED display by replacing the code with "00" or "no failure."

Responses to Control Commands

```
#B0099cr
```

The response packet #B0099cr is the only acknowledge packet for control commands.

MASTER NODE—NODE F

Description

The function of node F is to provide for complete BOM/NET node-to-node communication and interaction. The speed of the network communications is configured for 375-kbaud operation. The software of node F is structured such that the maximum possible speed is provided for passing the one and only network packet between active nodes in the network. On powerup, node F compares its built-in table of active nodes in the network to its active node switch panel, then sends a poll packet to the first active node. If node 1 is the first active node, and it is turned on and working correctly, a response from node 1 is sent to the Master. The response from node 1 can be one of three types: an acknowledge packet, a communication failure packet, or a command response packet. If the packet was an acknowledge or failure packet, then the Master again looks at its active node table and active node switch panel to see which node should be communicated with next. If the packet was a command-response type, the packet is forwarded by node F to another node.

Upon successful completion of the transfer, the Master then communicates to the next active node. The actions described above are the only functions of the Master node as it is presently configured. In order for the network to operate at its absolute maximum speed, it is the responsibility of each node being communicated with by the Master to process the network packet as fast as possible. It is recommended that each slave node in the network dedicate one task to communication handling of the network packet. This task should receive the packet, test for packet type, extract data as required, respond as required, and ship the packet back to the Master. This task should be as short as possible in order to maintain network performance. It is also very important to note that if a packet received at node x contains data (indicated by a packet length greater than 7) to be transferred to this node, then you must not put data into this packet. The correct procedure is to extract the data, ship the data to another task, and then ship an empty packet back to the Master. Data from node x can only be inserted into an empty packet received from the Master.

Hardware

The Master node is built from an iRCB44/10a BITBUS microcontroller board. Power for this node is supplied from a UPS, 110 V ac input with +5, +12, and -12 V dc outputs. Communication with all other nodes is dictated by conformance to the BOM/NET protocol, which is defined elsewhere in this document. The hardware connection between all nodes in BOM/NET is a twisted-pair cable.

Software

All application software is written in ASM 51 and PL/M 51 programming languages. An iDCX51 operating system provides for network operation and multitasking.

On powerup, a software application known as the RAC task (fig. 10) is made active, then a task called the master

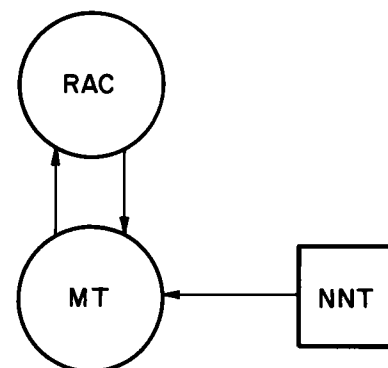


Figure 10.—Master node data flow diagram (MT = master task; NNT = network node table).

task (MT) creates the one and only packet for the network. The MT first looks at the status of its active node switch panel, then compares it to the active network node table (NNT). The MT then sends the packet to poll the first node. If the node is active in the network, it processes the incoming packet and ships it back to the Master (the SDLC protocol provides for failures). The Master receives the return packet and looks at the command-response field to see what response was provided. The response could be one of three types: an acknowledge, a communication failure, or a communication directive to a specific node. If the packet was an acknowledge or a communication-failure type, the Master simply polls the next active node. If the packet was a communication-directive type, then the Master sends the packet to the node defined in the packet, and waits for its return. The

Master then polls the next active node. This polling sequence continues until the last active node is processed, and then the first active node is polled and so on. The described sequence continues until poweroff.

Location

Node F is located in the control hut.

Interaction With Other Nodes

On powerup, this node polls the first node in its active node table and compares it to its active nodes' switch panel; it then polls the first active node and provides responses as required. This sequence repeats until poweroff.

OPERATING THE MINING MACHINE USING BOM/NET

TELEOPERATION

Nodes 1, 8, 9, and A provide teleoperation of the Joy 14CM. Teleoperation depends heavily on the human operator's eyes and intuition. The operator manipulates a bank of switches that are attached to node 9 (fig. 11) that correspond to control functions for the Joy 14CM machine. The actions are echoed at the Joy 14CM. The operator verifies the results by watching the output of two machine-mounted cameras on two TV monitors housed in the control hut. The operator also can watch graphical displays of critical Joy 14CM parameters.

CLOSED- AND OPEN-LOOP CONTROL

Closed-loop control of the Joy 14CM requires less network overhead than open-loop control. A closed-loop command, such as "move the conveyor to 5°," sent from node 6 to node 1, executes entirely on node 1, and requires the transmission of only one command packet over the network. By contrast, an open-loop command, such as "move the conveyor up" (sent from node 6 to node 1), requires node 6 to poll node 1 repeatedly until the "conveyor up" sensor indicates that the conveyor is at 5°.

NORMAL OPERATION

Many CM control scenarios can be contrived using BOM/NET. Generally, the autonomous mining research and development system (AMREDS) controls the whole

mining process. AMREDS provides many modes of operation including joystick, simulation, and scripting. The joystick mode allows the operator to control individual parts of the CM in a mode very similar to that of the human operator. This mode is generally used for demonstration and diagnostics of the system. The simulation mode allows the operator to construct long scripts of CM functions performed sequentially by a wire-frame model of the CM on the operator's local monitor. None of the commands in the simulation mode ever go to the CM. The primary mode used to operate the CM is the scripting mode provided by the AMREDS package. The scripting mode allows the operator to select from any number of previously created scripts. Scripts can contain complete powerup and coal production cycles as well as CM shutdown. The scripts can even access navigation data and ensure that the CM is kept on its preplanned path. The script can be made to be dynamically altered if conditions during the mining process change. The operator of the system can watch the outputs of all the environmental systems of the CM, as provided on the AMREDS monitor, to ensure all systems are functioning properly. The operator can stop any active process by hitting any key on the AMREDS node keyboard. Present plans call for archiving long scripts of field data of CM-human operator interactions while actually producing coal. The CM will then be run at the Bureau's mining equipment surface test facility using scripts created from the field data. This type of analysis will help to fine-tune software algorithms to closely mimic real production operations.



Figure 11.—Operator switch bank.

BOM/NET DESIGN GUIDELINES

Continuous miners present many problems to unprotected computer hardware. The vibrations on these machines are tremendous. The electrical power provided to CM's is characteristically poor, and brownouts and blackouts occur often. Also, the computers can have simple component failure and may contain software bugs that could cause the machine to perform incorrectly. Details of the Bureau's design that addresses each of these problem areas follow. List of suppliers of specific components can be found in the appendix.

VIBRATION

Continuous miners are not good bases for mounting computer hardware. Extreme vibrations generated by the CM could destroy even ruggedized systems. The Bureau addressed the vibration problem in a number of ways. First, hardware was selected that was built for vibration-prone environments including computer boards, computer chassis, power supplies, sensor-conditioning modules, and optical relays. All the components were mounted on a

uniform sized plate that was 1/4 inch thick and that bent minimally when stressed. All bolts, nuts, and screws used employed either locknutting or captive and bonding techniques to prevent movement when exposed to vibration. Additionally, special vibration mounts were used to attach the computer mounting plates in XP boxes.

FLUCTUATION- AND TRANSIENT-FREE POWER

Mine electrical power systems are characteristically bad for operating computer hardware, especially when the CM is operating in a production situation. Yet, that is when the computer should work flawlessly. The 110 V ac on CM's have been observed to fluctuate as much as $\pm 25\%$. Added to that are transients caused by lighting and inductive load switching that can be as high as 2,000 V and can last up to 500 μs . "Brownouts" (line voltage drops below an acceptable level) and "blackouts" (total power outage) also occur in mine power systems. The Bureau's approach to the mine power problem was to choose a heavy-duty, industrial-grade, transient-arresting device and

a UPS that includes battery backup. The combination of these two devices provides fluctuation- and transient-free power during the poorest mine power conditions.

COMPUTER ELECTRICAL ISOLATION

Mine power systems can not only affect the power supplied to the computer, but can also induce problems into the control, monitoring, and communication lines that are attached. In addressing the control-line problem, the Bureau used optically isolated electronic relays that provide complete electrical isolation of the computer from the CM control devices. In addressing the monitoring problem, the Bureau used transformer-isolated sensor-conditioning modules that provide complete electrical isolation of the sensors from the computer chassis. The communication lines (twisted-pair line) that connect between the various BOM/NET computers employ a special transient-arresting, optically coupled device that functions well in the worst electrically noisy environment.

FAIL-SAFE SHUTDOWN WHEN FAILURES OCCUR

In a mine production environment, it is inevitable that equipment failures will occur, and those failures could well include the computer system. This possibility must be especially taken into account since the computer has complete control of the mining machine. Not only can the computer hardware fail, but the software can also fail. The Bureau's system addresses the problem using a special "watchdog timer" circuit (fig. 12) that watches the computer's power signal and software signal. If either signal is not present, the watchdog timer removes the power from the CM control devices, stopping the CM in its present position.

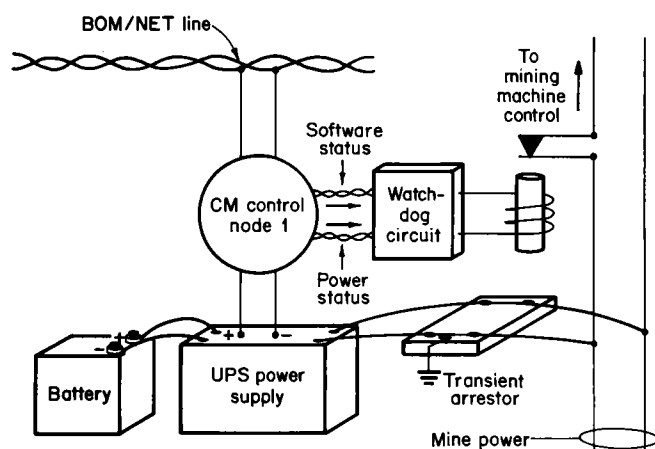


Figure 12.—Watchdog circuit.

LOCATING AND CORRECTING BOM/NET SYSTEM FAILURES

BOM/NET has proven to be very reliable on the systems on which it has been installed, but there have been failures. In general, the failures were caused by simple problems such as broken wires and loose components. However, there were a few failures that were very hard to troubleshoot because of the inability to isolate the point in the network where the failure occurred. The characteristic of this network is that as many as 28 computers can be attached to a 1,000-ft cable. In order to isolate a problem, individual computers must be isolated to determine if each is working correctly, then the whole network tested with all the computers interacting. When the network was designed, there was no device available that could isolate network problems. The Bureau developed the Remote Operator and Diagnostics Node (RODNE), that provided the capabilities required (fig. 13). RODNE can be plugged into a node in the network, and with a typed command, it can be determined if the node is performing correctly based on the responses shown on RODNE's display screen. RODNE can also be plugged into the network to interact with the whole network to determine the network's integrity.

NETWORK SPEED AND DETERMINISM

Each node active in the network adds a 2- to 3-ms delay to the network throughput, giving the network a predictable determinism mainly because of the round-robin scheduling algorithm the Master employs. If all 16 nodes are active, the delay would be 32 to 48 ms. The Master, however, has a bank of switches that permits the human operator to select only the nodes that are needed at the time. If the operator needs only nodes 1 and 6 for an

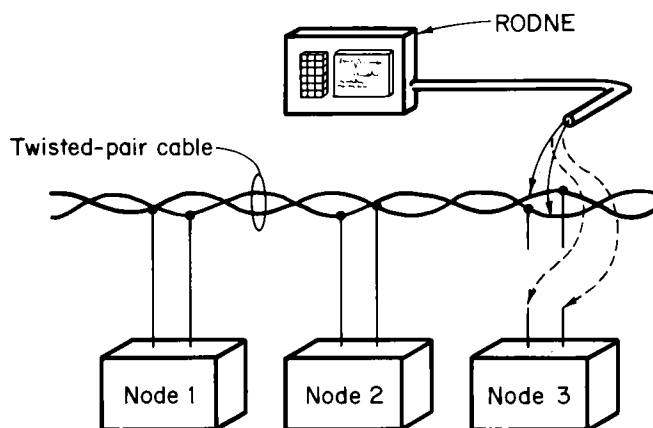


Figure 13.—RODNE operation.

application, the network throughput delay can be reduced to 4 to 6 ms, giving the best possible network performance. This kind of network customization is most useful for

applications like teleoperation and data collection, which require a high throughput.

CONCLUSIONS

The U.S. Bureau of Mines has integrated a distributed processing network called BOM/NET and has installed it on a Joy 14CM. The network functions as a communications and control system that permits computers and intelligent sensor systems to interact with the machine while

the machine produces coal. The installation of the network has accelerated the collection of data and the generation of intelligent navigation and control algorithms. The functionality of the system lends itself to potential use on most mining machines.

REFERENCES

1. INTEL Corp. (Portland, OR). Distributed Control Modules Databook 230973-004, 1988, 153 pp.; iDCX51 Distributed Control Executive Guide 460367-001, 1987, 546 pp.; INTEL BITBUS Microcontroller Interconnect AR-351, 1987, 32 pp.; OEM System Handbook, 1986, 22 pp.
2. Rupp, J. BITBUS: A Good Choice for the Factory Floor. *Instrum. & Control Syst.*, v. 6, June 1991, pp. 73-75.
3. Sammarco, J. J. Mining Machine Orientation Control Based on Inertial, Magnetic, and Gravitational Sensors. BuMines IC 9326, 1990, 23 pp.
4. Anderson, D. L. Position and Heading Determination of a Continuous Mining Machine Using an Angular Position-Sensing System. BuMines IC 9222, 1989, 8 pp.
5. Jobes, C. C. Mechanical Sensor Guidance of a Mining Machine. Paper in Proceedings of The Tenth WVU International Mining Electrotechnology Conference, Morgantown, WV, July 24-27, 1990. WV Univ., Morgantown, WV, 1990, pp. 89-93.
6. Ausefski, D. L. Researcher's Interface Software for Computer-Based Mining System Development and Testing. Paper in the Proceedings of The Tenth WVU International Mining Electrotechnology Conference, Morgantown, WV, July 24-27, 1990. WV Univ., Morgantown, WV, 1990, pp. 130-133.

APPENDIX.—LIST OF SUPPLIERS

The following is a list of vendors who can supply parts for the microcomputer control network described:

BITBUS is available from, but not limited to, the following vendors:

- Cincinnati Electronic Systems, 420 Wards Corner Road, Loveland, OH 45140;
- Computer Dynamics, 107 S. Main Street, Greer, SC 29651;
- Datel, 11 Cabot Road, Mansfield, MA 02048;
- Datem Ltd., 148 Colonnade Road, Nepean, Ontario, CANADA K2E 7R4;
- Encoder Products Co., 1601B Dover Rd. HWY-2, P.O. Box 1548, Sandpoint, ID 83864-0868;
- Gespac, 50 West Hover Ave., Mesa, AZ 85210;
- Hauni Richmond, 2800 Charles City Rd., Richmond, VA 23231;
- Kepco Inc., 131-138 Sanfor Ave., Flushing, NY 11352;
- Micronetics, P.O. Box 347, Greendale, WI 53124;
- MicroSwitch, 11 W. Spring St., Freeport, IL 61032;
- Phoenix Contact, P.O. Box 4100, Harrisburg, PA 17111;
- Wizdom Systems Inc., 1260 Iroquois Ave., Naperville, IL 60563.

Sun Workstation 3/160:

Sun Microsystems, Mountain View, CA 94042.

Vibration mounts to attach the computer mounting plates in XP boxes:

Stock Drive Products, New Hyde Park, NY 11040.

Transient-arresting device:

General Semiconductor Industries, Tempe, AZ 85282, AC Line Protector Model 587B051.

Uninterruptible power supply (UPS):

TII Electronics Inc., Copaigue, NY 11726, Switching Power Supply With Battery Backup EHVO-170.

Optically isolated electronic relays:

Opto 22 Corp., Huntington Beach, CA 92647, Optically Isolated I/O Relays.

Sensor conditioning modules:

Analog Devices Corp., Norwood, MA 02062, Model 3B Series Analog Conditioning Modules.

Transient-arresting optical-coupled device for communication lines:

INTEL Corp., Hillsboro, OR 97123, RCX 900 Isolation and Transient Protection Module.

Watchdog timer:

Brentek Intl., Reading, PA 19603, Brentek Watchdog Timer Module.

LCD display:

Industrial Electronic Engineers Inc., 7740 Lemona, Van Nuys, CA 91405.