AN INMARSAT-C GOES, AND EIA485 HYBRID COMMUNICATION SYSTEM FOR GLOBAL EXPERIMENT CONTROL¹

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Abstract - The Atmospheric Radiation Measurement (ARM) program is constructing cloud and radiation monitoring instrumentation that will be deployed at several island sites in the Tropical Western Pacific Ocean. The atmospheric radiation and cloud systems (ARCS) must operate with minimal maintenance for decades, producing and storing many megabytes of data per day. A reliable global communication system is an essential element of the ARCS design. It must provide immediate direct access to the equipment. High availability and reasonably low cost are essential for this very long-term deployment. Providing executive management and control, the communication system incorporates several special technologies to meet its requirements: (a) INMARSAT-C provides a simple two-way messaging capability (b) Built-in GPS in the INMARSAT-C radio provides an accurate time standard. (c) The NOAA GOES satellite provides a one-way link for hourly health and basic measurement data. (d) An EIA485 local area network provides a digital link throughout the installation. (e) Node units located conveniently throughout the ARCS and linked by the EIA485 network allow an almost un-

limited flexibility and expandability. (f) A robust packet protocol ensures message security and accuracy. The complete communication, control, and data acquisition system is described in detail. The ability of the system to adapt to other physical configurations (telephone, UHF, telnet) is discussed.

INTRODUCTION

The Atmospheric Radiation Measurement (ARM) Program, supported by the U.S. Department of Energy, is a major program in atmospheric measurement and modeling [Stokes & Schwartz, 1994]. The program is intended to improve the understanding of processes that affect atmospheric radiation and the description of these processes in climate models. The ARM program will build and deploy highly instrumented measurement sites for up to ten years at land and ocean locations (Figure 1). Each site will be comprised of customized sea-container laboratories which have been fitted with instrumentation, computers, and communication hardware. The first *Atmospheric Radiation Cloud Station*

Figure 1. Map of the GOES and INMARSAT satellite footprints. An ARCS sites will be installed on Manus Island in early 1996. Nauru Island is a possible next site. Future installations are planned for the North Slope of Alaska (NSA). The communication base station is located on Long Island, NY.

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Figure 2. An ARM-ARCS site is a cluster of sophisticated instrumentation integrated into a single data management system. The ARCS is comprised of four seacontainers which have been converted to laboratories and utility vans. Data from the Radio Acoustic sounder System (RASS), an existing sensor operated by NOAA, is collected by the ARCS. Data loggers at each instrument cluster digitize low-level analog signals and transmit data via EIA422 connections.

(ARCS) will be deployed on Manus Island, Papua New Guinea in early 1996. Additional ARCS are planned for other sites in the tropical Pacific Ocean and on the north slope of Alaska.

The ARCS goal is extremely ambitious: *to operate a collection of state-of-the-art atmospheric instrumentation in a remote setting with minimal attendance for more than a decade.*

The Manus site (Figure 2) will study the atmosphere with remote sensing instruments—a micro-pulse lidar (MPL), millimeter-wave (35 GHz) radar (MMWR), whole-sky imager (WSI), microwave radiometer (MWR), and a radio-acoustic sounding system (RASS)—and conventional meteorological instrumentation measuring meteorological conditions (MET), local upward radiation fluxes (GND), and downward, i.e. sky, radiation fluxes by a variety of techniques and wavelengths (SKY). More than 20M bytes of data will be collected daily and stored on mass storage media for post-processing in the United States. The communication system provides an immediate means of monitoring the performance of the complex assemblage of computers (> 16) and instrumentation (> 30 surface measurements and 8 vertical profiles).

This paper describes the unique communication, control, and data acquisition system that will provide the ability to remotely control and monitor instrumentation from/to anywhere on the Earth, be-

tween $\pm 70^\circ$ latitude. Cost, flexibility, portability, reliability, and data through-put were considerations in the design. The resulting instrumentation is a unique synthesis of several new and different technologies.

Design Goals. The communication system has the following general design features.

- Independent operation. It is self-powered and independent from the rest of the system.
- Continuous unattended operation. It is powered by three independent power sources: mains, solar batteries, and an internal DC uninterruptable power supply. The combination of these provides immunity to long or short term power interruptions.
- Global access. It is accessible to scientists, technicians or maintenance persons from any location on the Earth.
- Security. Accessibility to vital elements of the system is restricted to designated users.
- System status and control. A direct and reliable means for providing essential system information and for performing crucial control functions is crucial. The communication system is a direct link from users to the system.
- Reliability. A mean time between failure (MTBF) of five years (the same specification is applied to

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Figure 3. The global communication system uses two different satellite networks: GOES for data recovery and INMARSAT-C for system control. The EIA485 network links the Node Data Units (NDU), the Data Management System (DMS), the Monitor and Control System (MACS), and the Communication System (COMS). The communication base station allows operator control and automatically recovers data messages from either the INMARSAT or the GOES links.

the payloads on the National Data Buoy network) and a lifetime of ten years based on mean time between maintenance (MTBM) of six months.

COMMUNICATION SYSTEM OVERVIEW

The overall system design (Figure 3) meets the goals just listed. Elements of this overall description will be described in detail in later sections of this paper.

- **COMS.** At the remote site, COMS is a low-power DC computer, INMARSAT-C radio, and independent power system in a single package. A message can be sent via INMARSAT-C to or from any device on the local-area network (below). COMS simply acts as a filter, rejecting any packets that are not correct. GPS time messages are available from the INMARSAT-C radio, and COMS broadcasts regular time packets onto the local-area network.
- **Local Area Network.** An EIA485 local area network provides a simple digital communication link to elements of the ARCS. The LAN is reliable, low power, and noise immune.
- **MACS.** The monitor and control system is a low-power DC computer, GOES data collection platform, and independent power system in a single package. MACS collects hourly averaged scientific data from the DMS and utility data from the node data units, then sends out the coded GOES data message. MACS can also send the same diagnostic data via INMARSAT if GOES is unavailable. It monitors van status and generates alarm messages. MACS has the ability to collect data sets from some instruments in the event the DMS is not operating.
- **DMS.** The data management system is the data collection workhorse for ARCS. It is a highly reliable implementation of a Sun workstation with copious tape recording capability. All elements of the DMS are redundant, including the processors.
- **NDU.** The node data units are small micro-power data collection devices that are placed in the network as required throughout the ARCS system. They perform monitor and control tasks on command and initiate certain alarm messages. One NDU is located in each seacontainer.
- **COMSAT.** COMSAT is a U.S. service provider for the INMARSAT satellite system. Messages can be transmitted to the ARCS in several different ways: (a) direct transmission from an INMARSAT-C radio; (b) dial-up service to COMSAT; (c) Internet email service provided by COMSAT. *Note, at this time the Internet connection is rudimentary.* In all cases, the system is a "store-and-forward" design whereby messages are processed by the INMARSAT system and appear at the other end a few minutes later.
- **NOAA, NESDIS.** The GOES satellite data service

is operated by the National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite and Information Dissemination Service (NESDIS). Transmissions are available by dial-up service.

- **ARCS Base Station.** The ARCS communication base station is a multi-tasking computer that performs several tasks: (a) Monitor INMARSAT message traffic. (b) Provide an operator interface for sending control commands to the remote sites. (c) Routinely dial up and collect GOES data and forward them on to analysis sites. (d) Send alarm announcements when emergency messages are received.

THE EIA485 MAIN NETWORK

The EIA485 network links ARCS modules with a simple twisted-pair cable through which "packets" are traded. The EIA485 standard has been gaining

considerable popularity over the past ten years or so and is now a standard means for linking intelligent equipment in industrial applications. As a result of this popularity more and more instruments and sensors are designed with EIA485 capability.

Several EIA485 networks are used in ARCS. The ARCS network links COMS, MACS, and all node devices on the site and is shown in Figure 3. In addition, each node data unit uses a *local network* (Figure 6) for data

collection and control functions within the same van. EIA485 operates at high baud rates on a multi-drop network with receive and transmit lines on the same twisted pair. Balanced drivers and receivers help eliminate line noise and allow transmissions over large distances. Up to 32 different devices spread over hundreds of meters can be daisy-chained together on a single cable. All devices on the network have individual addresses and only respond to messages with their own address attached.

Figure 4. The packet is composed of an attention character, header, message, checksum, and end character.

Packet collisions are possible and must be minimized. The ARCS network operates at 19200 bits/sec and the maximum allowable message size is 1024 characters. All Node Units are silent unless commanded to reply (speak only if spoken to) or if an alarm state is detected. The network should be active only a small fraction, approximately 2%, of the time. The normally-passive Node Units will initiate alarm messages in certain events: if the smoke alarm switch is closed and if the temperature exceeds a set amount. Alarm actions are described later.

All communication on the network must follow a prescribed packet protocol (Figure 4). A packet is composed of an attention character (#), a forty-character ASCII header, the message, a three-character checksum, and an end-of-transmission character, <eot> (ASCII value = 4).

The to-address directs the packet to a particular device on the ARCS network. Device addresses follow a specific pattern.

ARCS PACKET ADDRESSES

0000-0099	Land base stations sites. #0000-communication base station.
0100-0199	ARCS#1 addresses. Address 0199 is the local global address. See Figure 3.
0200-0299	ARCS#2 addresses. Address 0299 is the local global address.
nn00-nn99	Same as above for ARCS#nn.

The numbers 0199, 0299, ... are reserved as "global" address. All devices on the network should accept global messages. Devices do not reply to a global message. A main use of the global message is time synchronization. The INMARSAT-C radio also receives GPS position and time. Routinely the COMS computer transmits a global time command and all devices synchronize their internal clocks.

The packet checksum is derived in the following way. Each character in the header and message string are added in a sixteen-bit register which is left-bit shifted after each binary addition. The resulting binary number is encoded into three pseudo-ASCII characters (described later).

#01990000,950423,081023,0003,0,12,01/01,0UTCcbHc

Figure 5. Example of a global time packet. The to-address 0199 and the message "UTC" designate a global time address. Checksum characters are "cbH."

NODE DATA UNITS

A Node Data Unit (NDU) is an intelligent device on the EIA485 network that performs a given set of tasks and responds to queries and commands from other network devices. One NDU in each sea-container performs the following functions (Figure 6)

- Interior temperature and RH: Measure the temperature and relative humidity in the container. Send an alarm packet if the temperature exceeds set limits. Shut down the container if the temperature exceeds a critical limit.
- Monitor the smoke alarm. Send an alarm packet if the smoke alarm is active.
- Door status. Monitor whether the door is open or closed.
- Power control: The NDU controls a set of 120 VAC receptacles via the Intelligent Power Controller (IPC). The IPC communicates with an EIA232 serial link to the node unit. AC power from the scientific main supply is controlled by the IPC.

Figure 6. Functional block diagram of a Node Data Unit showing the analog input, serial ports, switched power lines, and local network.

On command, the NDU can turn off power to any selected port, it can re-establish power to a port, or it can cycle power off then back on after a delay. This latter function allows a reboot of computers or instruments that might have suffered software lockup.

- **Local EIA485 network:** The NDU provides considerable expansion capability by incorporation of a local EIA485 network. The NDU switches from the main network to the local one in order to collect data. We have selected a set of 485-compatible data modules sold by Soltec, Inc. Called the "Adam Series," the modules are simple addressable devices for data collection. Different modules are available for digital input or output, analog-to-digital conversion, or relay closures. The NDU uses a pass-through protocol where messages it receives over the main network are passed directly to the local network and the reply returned to the original sender. By selecting the proper module, the NDU can monitor and control many elements in the ARCS vans with no additional software. The electrical, air conditioning, and UPS systems in each van are controlled and monitored by sets of the Adam modules.
- **Electrical mains power control:** In each van, an Adam module monitors the three voltages and three currents of the three-phase electrical power coming into each container. On command, the incoming mains power contactor can be turned on or off. A feedback voltage confirms contactor operation.
- **Air conditioner monitor and control:** Air control in the tropical environment is crucial. Two large air conditioners and heating coils (to help control humidity) are controlled by a master heating, ventilation, and air conditioning (HVAC) control unit and thermostat. The control unit alternates between each air conditioner on a daily cycle. If the temperature exceeds a set amount, both air conditioners are activated. Two Adam units monitor the master control and report which air conditioners are operating and also certain alarm states. If necessary, the master control can be disabled. A latching relay circuit provides control of each element of the HVAC system (AC1 on/off/normal, HTR1 off/normal, ...).
- **Uninterruptable Power Supply (UPS) control.** A Clary UPS in each van provides scientific power at 120 VAC and 60 Hz. The UPS is capable of operating equipment for three hours in the event of a mains failure. In this time a backup generator should commence operation. An Adam unit monitors and controls the local UPS. Alarm states (e.g. low battery, power loss, etc.) and battery

voltage are monitored using the local EIA485 network. The UPS can be shut down and a feedback relay confirms the control state.

The NDU (Figure 6) is a small watertight box containing a microprocessor and interface circuit board. The microprocessor is the Tattletale Model TT5F-512 manufactured by Onset Computers Inc. The eight-channel, twelve-bit, analog-to-digital converter can be connected to measure sensors as needed. By addition of a resistor, 4-20 mA analog signals can be measured. The TT5F has 13 digital input/output lines under software control that are used on the interface circuit for a variety of purposes. Two serial ports, COM1 and COM2, are available. COM1 is a 19200-baud port with hardware buffering of in and out strings. It is used for network communication. COM2 is a software serial port with programmable baud rates and is used for communication to external instruments with serial interfaces. A four-way multiplex circuit allows COM2 to operate any of four software-selectable ports. The COM2 port supports two serial lines (TD, RD) and two control lines (CTS and RTS). All the COM2 lines are software selectable as inputs or outputs and can be used in a variety of ways. In the ARCS configuration we use COM2 lines to monitor the smoke alarm and the intrusion switch.

The Tattletale was programmed in a compiled form of BASIC called TXBASIC which is supplied by Onset. TXBASIC handles floating-point numbers, named sub-routines, 32-character variable names, arrays, time keeping, and clock delays. As a tokenized compiled language, it is quite fast, yet is easy to program and change. The 128-byte EEPROM on the TT5F provides adequate space for calibration constants, setup parameters, and other variables that must be preserved during power off. The flash EPROM on the TT5F makes re-programming the NDU a simple matter of downloading a hex file. The unit can be re-programmed in about three minutes without opening the box.

The UPS is powered from two different sources; the main EIA485 network cable carries a second wire pair with +12 VDC and an DC uninterruptable power supply is used for added reliability. The UPS for the NDU is a Synergetics Model 3489A DC supply. The UPS provides continuous power to the node making it independent of the ARCS mains power system. A fourteen-hour, sealed, lead-acid battery, which can be combined in parallel to an external set of batteries, is maintained at full charge by a unique temperature-compensating circuit. The UPS accepts AC, solar, or wind power sources for its charging circuit, but only AC is used in this application.

The intelligent power controller (IPC) is the Model 3200 by Pulizzi Inc. The IPC communicates at 2400 baud via a three-wire (RD, TD, GD) serial port. The transmit line on each IPC is controlled by a relay and each IPC has a unique address. Thus several IPCs with different addresses can be connected together with their receive, transmit, and ground lines in parallel. When an IPC is addressed, it closes its transmit relay and communication with a host device is established. ARCS uses only one IPC at each node at this time, but additional units can be added as required.

MONITOR AND CONTROL SYSTEM (MACS)

The MACS is the primary executive to the communication system. It monitors all node units, executes commands issued from the experiment center, and provides a user interface for local control of ARCS. Extreme high reliability is essential for MACS's key role. A special computer was designed and built for both MACS and COMS.

The resulting MACS package (Figure 7) is a 400 mm high (9, 1.75 in. rack units) by 483 mm (standard rack) assembly mounted in a rugged shipping box made especially for rack equipment. The four sub-modules: the Serial Switch, the PC104 computer, the MACS box, and the keyboard are described below.

Serial Switch

The Serial Switch module provides a back-up capability for collecting data in the event the DMS fails. Several instruments are located in open spaces well away from the vans. These instruments communicate via an EIA422 serial line which uses two balanced signals carried on separate shielded twisted wire pairs. With EIA422 signals can be transmitted over great distances with minimal noise or attenuation problems. The Serial Switch accepts up to eight EIA422 cables and converts them to EIA232 serial which can then be routed to the DMS. This is the default condition. However, under MACS control, all the lines can be routed at once to a multiplex input to MACS where the data can be accessed and a reduced data set transmitted via satellite.

PC104 Computer

The MACS and COMS computers were designed to meet the following severe set of design goals:

- Continuous operation.
- Low power DC battery operation.
- Watchdog timer resets any system crashes.

- Modular and expandable.
- No moving parts—use PCMCIA.
- Operate -40°C to +50°C and 100%RH.
- Portable with rugged packaging.
- Power monitor and control functions.
- EIA485 and two or more serial ports.

Convert EIA422 from data loggers to EIA232.

Figure 7. The Monitor and Control System (MACS) provides executive control of the ARCS system. In addition, it collects hourly data sets, compacts them into a pseudo-ASCII format and sends them via the GOES or INMARSAT satellites.

A standard IBM-style personal computer could be programmed to perform the MACS tasks, however, no off-the-shelf, personal computer met all reliability and system requirements. In particular, the memory-resident power control software used by battery-powered laptops subverts any remote reboot capability. It was decided that we could only meet the requirements of an , environmentally hardened low-power, watchdog-timer-controlled, robust system by building one. A design based on the PC104 computer modules was developed (Figure 7).

The PC104 standard allows many different manufacturers to produce standard components for a modular computer system. The specifications for the modules generally include low power and wide temperature ranges in keeping with the intended industrial applications. The particular design in

cludes the following features:

- **386 processor:** The 386 processor was selected because it had 16-bit address lines but was relatively low power. Our applications did not require high speed or addressing capability, but battery power was crucial.
- **PCMCIA capability:** There is no hard drive on this computer (although one can be added easily). We elected to use a solid-state PCMCIA technology which has no moving parts. A 20 megabyte flash card contains the complete software development system. New software is easily installed by simply plugging in a new PCMCIA card.
- **Analog-to-digital converter and power management:** An eight-channel analog-to-digital converter is adapted to measure supply voltages and charging rates. Extra channels are available for special uses. If battery voltage to the computer decreases below a set limit, it can go into power conserving states by turning off power channels to the radio.
- **Watchdog timer:** An independent hardware watchdog timer circuit is integral to the system. The computer must toggle a reset line to the timer on a regular basis. If the reset is not set within the timeout period, the watchdog timer forces a hard reset of the computer.
- **Low power operation:** The PC104 computer current drain is 200 mA with the LCD monochrome display turned off and approximately 1 A with the display on. Under normal, unmanned, conditions the display is off.

MACS Module

The MACS box combines several of the MACS components. The display is a high intensity monochrome LCD flat display. It was selected because of its relatively low power, because it can be switched off easily, and because it operates over a wide temperature range.

The GOES data collection platform (DCP) and 12 Watt transmitter, manufactured by Vitel Inc., are packaged in the MACS box. It is essential that the DCP maintain completely uninterrupted power so its internal clock will not drift. A DC UPS with sealed battery maintains the DCP operation during any power outages. GOES transmissions are 30 sec long each hour and the rest of the time the DCP and transmitter draw only a few milliamps. Thus the UPS with a 14 A-hr battery will provide backup for several days.

GOES DATA TELEMETRY

An important element of the communication sys-

tem is the transfer of a subset of the data to the experiment center. Daily examinations of the data allow remote assessment of system quality.

The INMARSAT-C telemetry link provides an excellent two-way, command and query operation. Using the double-hop method with a radio at the remote site and at the base station eliminates delays and confusion using dial-up or other mail-type services. However, today's prices are high (2¢ per character) for any volume of data transfer.

The Geosynchronous Orbiting Environmental Satellite (GOES) provides an excellent alternative for data telemetry. In early 1995, after the successful launch of GOES-8, the GOES-7 was moved to a permanent position at 135°W, over the Pacific Ocean. The tropical western Pacific Ocean came into the GOES-7 footprint and thus gave the opportunity for telemetering data via the GOES data channel.

Currently, GOES data rates are only 100 characters per second. Plans are to increase to 1200 baud in 1996. With a typical time window assignment of one minute only about 500 characters may be transmitted. The ARCS program has been granted four-minute transmission windows which, at 100 baud, allows a maximum message size of approximately 2200 characters.

Figure 8. A block diagram of the Monitor and Control System (MACS).

Only ASCII characters are allowed over the GOES transmission link and the most compact data format is a "pseudo-ASCII" (binhex) transmission format. The two most significant bits in each eight-bit character in the pseudo-ASCII format are set to '01' and the remaining six bits are part of a binary number. The resulting 64 characters are in the range [64, 65, ..., 127], which corresponds to the IBM ASCII character set [0, A, D, ..., _,]. Thus if a variable is assigned a single pseudo-ASCII character it can be resolved into 1 part in 64. If it is assigned two characters it can be resolved into 1 part in 4096, and so forth. The resulting string is 50% greater than a binary string but less than half the size of the corresponding ASCII string. As a final adjustment, the character is replaced by a '9' which is printable. The is replaced during the decoding process.

Two minutes before the assigned GOES transmission time, the MACS queries the data management system and all node data units and creates a pseudo-ASCII message with over 400 different variables. All variables are scaled to integers according to a special GOES conversion table which is maintained in a computer spreadsheet. All transmitted variables are listed in the table in the order of transmission. Along with each variable are minimum and maximum expected values and the desired resolution expressed as a number of desired pseudo-ASCII characters. The spreadsheet allows flexibility to change resolutions, add/delete variables or alter minimum and maximum values.

Variables are scaled into an integer value according to the specified resolution range as defined by the table. A scale value of zero is reserved for missing or bad data. The computed scale integer is

$$I = \text{rnd} \left[(2^{6n} - 2) \left(\frac{x - x_0}{x_1 - x_0} \right) \right] + 1$$

where n is the number of characters desired, x is the floating-point variable, and x_0, x_1 are the minimum and maximum scaling parameters.

As an example, suppose a radiation flux variable is specified to have a minimum-maximum range of 0 to 1500 W m^{-2} and will require 2 ASCII characters. The transmitted resolution (1:4094) will be 0.37 W m^{-2} . A measurement of 985 W m^{-2} will scale to an integer value of 2689 which converts to the pseudo-ASCII characters "Qf". Finally, the data message is wrapped into a standard packet as described above. In this way, with the checksum attached, error-free transmissions are assured.

One minute before transmission time, the DCP sends a prompt to the MACS and requests data. MACS expects to see this prompt and once it is received, the

data packet is sent to the DCP buffer. The DCP will transmit any received ASCII characters. If the MACS does not send a string, the DCP will affirm it is alive by transmitting a "No Data" message.

If the DCP prompt is not received, the data will be sent to COMS. The hourly data packet may also be sent to COMS for INMARSAT transmission as an alternate telemetry path. The MACS can be commanded via INMARSAT to send all hourly data both to COMS and to GOES.

COMS INMARSAT INTERFACE

The Communication System (COMS) provides a transparent interface to the INMARSAT-C satellite network (Figure 9). Any packets received from INMARSAT are put onto the EIA485 network directly. Any packets addressed to the addresses #0000 to #0005 will be transmitted immediately out from the remote site to the Inmarsat address corresponding to the packet to-address. Currently packets can be sent to two different remote radios, to the COMSAT Internet service, and to the COMSAT dial-up service called 'Clink'.

The Trimble Galaxy radio maintains contact with the INMARSAT system. The radio is manufactured to exacting reliability standards and is made for continuous use on ships and trucks. The PC104 computer uses an OEM software shell provided by Trimble. The shell provides for user customization yet maintains complete control of the radio. Cus-

Figure 9. A block diagram of the Communication system (COMS). The INMARSAT-C radio provides two-way digital communication. It includes a GPS receiver and provides location and UTC standard time. Redundant power sources ensure continuous operation.

tomized software monitors the network and incoming messages and provides packet recognition and acknowledgement. Packets addressed to 'local' addresses are ignored, but any packets addressed to external locations are transmitted immediately. COMS maintains a table of INMARSAT addresses and will forward packets to the correct address.

The transceiver also operates as a GPS receiver and thus provides location and a precise UTC time. On a regular interval, the COMS computer polls the time and resets its internal clock. The COMS time is transmitted regularly on the EIA485 network as a global packet (Figure 5.). Time synchronization to better than ± 0.2 sec is thus provided.

Redundant power sources.

Three different DC power sources are combined for maximum reliability. The AC scientific power supply, derived from the UPS is the primary power source. The grid power from the island utility is backed up by a 50 KW diesel generator with automatic switching. A 50 W photovoltaic (PV) array acts as a secondary power source. The PV has the capacity to operate the system continuously in the event of permanent power outage. A third power source, from the small DC UPS supply in the COMS box, provides enough power to operate the system a few hours if all power is disconnected during installation, maintenance, or for demonstration purposes.

COMMUNICATION BASE STATION

The communication base station (see Figure 3) provides a direct satellite to ground receiver station for the INMARSAT-C telemetry. An operator uses the ground station to exchange commands and data with the remote site. Information can be exchanged by other routes. The other routes are identified by different addresses and the COMS keeps a cross-reference of these addresses with the appropriate Inmarsat addresses: (a) COMSAT maintains a dial-up message center called SkyLink. (b) An Internet email service is being developed. This method holds promise for the long term although today it has proven to be slow and unreliable. (c) Optional base stations will be maintained at different sites although only one site, with address 0000, is considered the "experiment center" to which all alarms are addressed.

The tasks of the base station computer are easily handled by a standard PC computer, type 486 or higher. The base station operates three different applications:

- "Galaxy" user software is a standard Trimble product. This software allows the user to send and receive packets to any of the several sites.
- GOES dial-up software. Routinely calls the DCS, downloads the available data, formats it into an ASCII flat file, then places the data file in an Internet FTP site where it can be collected by scientists for analysis.
- Alarm response software looks for the particular alarm messages that might be sent from any site. Alarm packets are described below.

GOES data collection.

The GOES data are available from the NOAA National Environmental Satellite Information Service (NESDIS) by a dial-up procedure. The base station computer is programmed to call NESDIS daily or on manual command and download all packets. The downloaded packets are decoded and formatted into plain text flat files. These files are then placed on an Internet FTP site where they are available for scientists.

The GOES data provide an immediate snapshot of the data and the condition of the equipment at the remote site.

Alarm Packets

Alarm packets are generated when conditions at the remote site exceed set limits. Examples are high temperatures, power loss, or failed instruments. The system must accommodate alarm messages that arrive at unusual times. Humans must be notified in the event of an alarm. An automated method of doing this is presently being implemented. We intend using a dialup capability offered by the Skypage nationwide pager service. Key persons in the ARM project carry pagers which operate nationwide and have text capability. When an arriving packet is recognized as an alarm, the software will automatically place a telephone call to the Skypage computer and send the alarm message to several designated persons. Each emergency has its own response scenario.

Corrective Actions

If problems are detected, a plan for corrective action is used. Experts are called or paged for a conference call, and the best action is determined. An example of such a corrective action might be a cold reboot one of the instruments by cycling its AC power. The command for the reboot will be initiated from the base station. The complete cycle of command and acknowledgement usually takes

about 3 minutes.

FUTURE DEVELOPMENT

The ArmCom design allows a variety of communication links in and out of the remote network. The INMARSAT-C radio link can be replaced easily by a telephone-modem link, including a cellular receiver. UHF radio, either standard narrow-band FM or spread spectrum are good candidates for alternate telemetry links. The COMS computer can be re-programmed to accept any of these communication devices and handle packets into or out of the network. The rest of the system including MACS, data management computer, and node data units operate unaware of the changes.

In support of planned deployments in the Arctic and on the Alaskan north slope, we are developing a UHF radio link.

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