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MONITORING INSTRUMENTATION FOR THE CONTINUOUS MEASUREMENT AND QUALITY ASSURANCE OF METEOROLOGICAL OBSERVATIONS

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CONTENTS

Monitoring Instrumentation For The Continuous Measurement And Quality assurance of Meterological Observations

G. A. Herbert, E. R. Green,* G. L. Koenig, and K. W. Thaut

ABSTRACT. The NOAA/GMCC program was chartered to monitor the trends in those atmospheric constituents that can cause climate change. A four-observatory network was established and a 15-year-long data base has resulted for selected variables. At the inception, a central data-recording system was established at each observatory using minicomputers to compress and record the signals from monitoring instrumentation onto a computer-compatible magnetic tape. A new, distributed recording system using microprocessors has now been developed and is reported here. The STD BUS was selected as a means of internal computer communication, thus allowing a modular design that was tailored to the specific instrumentation. The resulting Control And Monitoring System (CAMS) operates three peripherals: a microterminal, dual cartridge tape drives for data recording, and a printer. An interactive multitasking version of FORTH was adapted as the operating system software. Three separate versions of CAMS were built and programmed. They control and monitor the carbon dioxide analyzer, aerosol and solar radiation instrumentation, and meteorological signals along with surface ozone instrumentation. In a 2-yr period, the three different CAMS were programmed and tested using microprocessor development hardware. During this period, 20 (3 plus a spare for each of the four observatories and a training facility) were assembled and tested. Early results show that CAMS recovers very well from power outages, resulting in minimum data losses. By distributing the system and limiting one CAMS to meteorological sensors, it has been possible to reduce significantly electromagnetic noise pickup. Improved data quality has resulted from use of flags and the display of scaled values.

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1. INTRODUCTION

The growth in concentration of trace constituents in the atmosphere due to anthropogenic activity is well documented. The subsequent potential for them to cause climate change through redistribution of radiation is now under intense study. The Geophysical Monitoring for Climatic Change (GMCC) program, a division of the Air Resources Laboratory, Environmental Research Laboratories, NOAA, was formed in 1971 to monitor those atmospheric constituents such as CO_2, aerosols, and ozone. At that time, measurements of these and other variables were being made at the Mauna Loa Observatory (MLO) in Hawaii and at the South Pole Station (SPO), in cooperation with the National Science Foundation. Both sites are at an altitude slightly in excess of 3 km. Two sea-level stations were subsequently constructed at Barrow, Alaska (BRW), and on Tutuila Island in American Samoa (SMO). At each station there were more than 20 continuously operating sensors whose data required recording and subsequent processing for trend analysis. At this time, the instrumentation consists of condensation nucleus counters for measuring aerosol samples; nephelometers for measuring aerosol scattering; nondispersive infrared analyzers for measuring carbon dioxide concentration; Dasibi ozone meters for in-situ measuring of ozone concentration; standard meteorological instruments for measuring wind, pressure, temperature, humidity, and precipitation; pyranometers and pyrheliometers for measuring solar radiation; and atmospheric turbidity. These sensors and the resulting data are discussed in an annual series of GMCC Summary Reports. See Nickerson (1986) for the most recent status report.

In this report we describe the development and testing of an instrumentation Control And Monitoring System (CAMS) to meet the needs of the meteorological instrumentation at the GMCC observatories. By the end of 1984, each of the four observatories had three CAMS units: A CO_2 CAMS for the CO_2 system, as ASR CAMS for aerosol and solar radiation instrumentation, and a MO3 CAMS for meteorological and surface ozone instrumentation. The Aerosol-Solar Radiation CAMS is very similar in most respects to the MO3 CAMS and for that reason it will not be discussed in this report. The Carbon-Dioxide CAMS which is significently different from meterorlogy-ozone is described in a separate publication, see Herbert, et al. (1986).

2. BACKGROUND

When GMCC was organized, most of the data were recorded on strip chart recorders. Processing such data was a long, arduous task. At that time both the number of stations and the number of sensors were planned to double. To facilitate the processing and analysis of these many and varied signals, a minicomputer-controlled data acquisition system was built that would record the data on a computer-compatible magnetic tape. The system also provided control signals to operate the solenoids that switched reference gases through the infrared analyzer that monitors atmospheric CO_2, for calibration purposes (see Harris et al., 1980). This system became known as the Instrumentation Control and Data Acquisition System (ICDAS) (see Herbert et al., 1980). ICDAS consisted of a Data General Nova minicomputer with a factory-interfaced 9-track NRZI tape drive. A teleprinter was used to control the system. Customized interfaces were developed to provide analog signal acquisition and digital signal control, and to interface a battery-backed clock calendar.

ICDAS was designed with mid to late-1960 technology. For this reason, the supply of spare parts for those components using diode-transistor logic became scarce. By 1980, maintenance and repair costs were rising at an alarming rate.

The long-term monitoring of trace constituents in remote locations places a set of demands on design of instrumentation control and monitoring equipment that is different from that common to the typical laboratory environment. Reliability and ease of repair become important considerations. In the typical laboratory environment, if a problem is detected, it is often possible to call in a repair service. This is not an option at sites such as Antarctica or Samoa. The equipment must be designed such that the resident technician can make changes or repairs when necessary. A modular design is called for so that problem components can be identified. This was one of the major failings in the design of ICDAS. In terms of both hardware and software, it was a highly integrated system, and problems were therefore often difficult to isolate.

The system must also provide reasonable noise rejection and quick recovery from power outages for a continuous data stream. Most minicomputer systems, such as ICDAS, require operator intervention to recover magnetic tape operation after a power outage. For this reason, a momentary interruption in power could cause an extensive data loss if the observer was unaware of the failure.

Another factor that leads to reliable data is a systematic procedure by which the observers can evaluate data quality in real time. This requires that the instrumentation display the necessary statistics and information to facilitate such determinations. In the period of ICDAS, such determinations were usually based upon visual observation of strip chart recordings. In some cases ICDAS computed hourly average values in scientific units, but such values were only available for the previous hour because it was not possible to recover data from the magnetic tape while the system was operating. This limitation made data quality assurance a once-a-day spot check function. It was not until a listing of the tape record was returned to the station 8 to 10 weeks later that the staff could review the entire data set.

3. PURPOSE

The design goals of the new data system were two fold: to obtain more reliable hardware and software operation, and to provide access to all stored and recorded data (on a daily time scale) necessary for better quality assurance. According to Myers (1975), the key to reliability lies in modular design, which is true for hardware as well as software. Modularity is obtained when subcomponents match specific functions. Because the servo system for the tape handling function in ICDAS was complex, the tape drives used were difficult to repair and align; because ICDAS was highly integrated in design, it was often impossible to isolate a faulty component in the field. Therefore, the initial goal in the design of CAMS was for a small, reliable, relatively inexpensive, simple, and easy-to-install tape recorder. A cartridge-type tape recorder, which uses preformatted tapes, was found to meet these requirements. As with the other peripherals needed to control the operation and to print data, standard RS-232 interface protocols were considered. As a result of the decision to use a microprocessor compatible standard (STD BUS) other necessary components such as memory, clock, input output (I/O) and central processing unit (CPU) were available in modular form. Modular design allowed special functions to be met, such as switch control, special analog-to-digital converter requirements, and digital input gates, with the addition of separate modules to the system. Furthermore, as the hardware is absorbed into the operation of a particular instrument function the modules can be changed (Enke, 1982) without requiring major hardware modification. The software must change as well. In this microprocessor-controlled system the operational software is protected by placing it in eraseable programmable read-only memory (EPROMS).

The second goal, which is not completely unrelated to the first, was to build into the control and monitoring system as many data quality assurance features as possible. Signal noise rejection was accomplished by setting upper and lower limits to acceptable voltages at input and averaging the signals for as long a period as possible. The software was also written to accept calibration factors and to produce scaled values in units that are useful to the observers. In this way the observer can make quick, yet relevant, comparisons to comparable measurements from other sensor or recording devices such as chart recorders. A light-emitting-diode (LED) display as part of the CAMS, was used to show the present values being measured at 1-min intervals. Sufficient control was provided to allow the observer to monitor the signals at the input. The data are printed in averaged form (usually a 1-h average). Recovery of data recorded previously was also required for maintenance of continuity.

4. SCOPE

It was not our intent to design and build a general-purpose computer system or to adapt a personal computer to this task. Rather, a specific-purpose microprocessor-controlled system was desired. In this way individual requirements could be met by changing software. Except for unique data and control I/O requirements, common hardware was used. Special-purpose display and control devices were secured in place of the more commonly found keyboard and CRT display. It was decided that a display at some remote location would not serve the best interests of the observer while monitoring a specific sensor elsewhere. Thus, a compact-size LED display and numeric control module were selected. After testing, it was determined that the module providing both alpha and numeric input capability used keys that were too small to operate accurately if mounted vertically in a rack at eye level. Control keyboards with larger keys were available but limited the input to numeric. The plan to use a tape recorder that manages data in numbered block format much like a disk, makes possible the recall of any data on the tape at anytime. Thus, it is not necessary to do printing in real time. By incorporating this feature, it was possible to use a single printing device for a number of CAMS units. The operator controls access to the printer.

If the CAMS is to be located close to scientific instrumentation, specific size, weight, power, and cost constraints come to bear. Realistic size guidelines dictate that the CAMS be so constructed that it will mount in a standard 19-in-wide equipment rack. The size of the vertical space in the rack was determined in part by the size of the display/control module, the tape drives, and the card cage. After trying a variety of configurations, it was decided that a 7-in front panel was the minimum vertical height that allows a convenient positioning of the display/control module and tape drives.

5. HARDWARE DESCRIPTION

A CAMS consists of eight or nine different modules depending on the specific application. Of these, six modules are common to all CAMS: processing; read only memory (ROM); random access memory (RAM); serial input/output (I/O) interface; clock/calendar; and monitoring. With the exception of the monitor board which was built in house, the Mostek MD series for the Z-80 STD BUS was selected for all modules. (The STD BUS is defined in the STD Manufacturer's Group (1985) publication.)

(1.) The central processing unit (CPU) in this series is the Z-80 microprocessor. The board (MDX-CPU1) provides the counter timer circuit for the Z-80, which operates at a 2.5-MHz frequency.

(2.) The universal memory expansion board for the MD series, designated MDX-UMC, supplies eight sockets for eraceable programmable read-only memory (EPROM). Typically six 2732 EPROMs (4K bytes x 6) are needed to hold the operational software.

(3.) Battery-powered, random access memory is supplied in increments of 4K bytes per board in the MD series (MDX-BRAM). The board uses rechargeable batteries that when fully charged will power the memory for 5 days or more in the event of a power failure. In CAMS two BRAM boards are required.

(4.) The serial input/output module (MDX-SIO2) provides a multiprotocol asynchronous or synchronous I/O to the Z-80 STD BUS. The module uses a Z-80 microprocessor and provides two full-duplex RS-232 serial data channels per board. CAMS requires separate RS-232 ports for the cartridge tape unit, the microterminal, and the printer.

(5.) The clock/calendar in the MD series (MDX-BCLK) supplies data in seconds, minutes, hours, days, and months in BCD (binary-coded decimal) format. The battery backup feature retains clock/calendar operations in the absence of system power for up to 5 days on fully charged batteries. The module is specified to be accurate to 10 s per month at 25°C.

(6.) The monitor board was designed and built by NOAA staff to generate a reset pulse after a power failure. Circuitry is also provided to generate an error message if the temperature is above or below safe operating limits.

In addition to the basic functions required in all applications, there are special input and output requirements that are met by special boards. These include the acquisition of voltages in analog form; signal acquisition in digital form; the acquisition of serially transmitted signals over longer distances using RS-422 protocol; and for the measurement of CO_2, digital control of calibration functions.

(7.) The signals from most of the sensors are a fluctuating DC voltage that typically range between 0 V and 10 V. An STD BUS compatible analog-to-digital converter compatible with the STD BUS was selected and provided single-ended or differential input, gain control from software to a maximum gain of 8, and the option of adding more channels than the 16 provided in the single-ended configuration. The converter is a Data Translation DT2742 with an accompanying ±15 V power supply (DT2715). It provides 12-bit resolution, 8 channels in differential input mode, and 16 channels in single-ended input mode. Linearity is specified to be ±1/2 Least Significant Bit (LSB) and the accuracy is ±0.03% FSR, Full Scale Range.

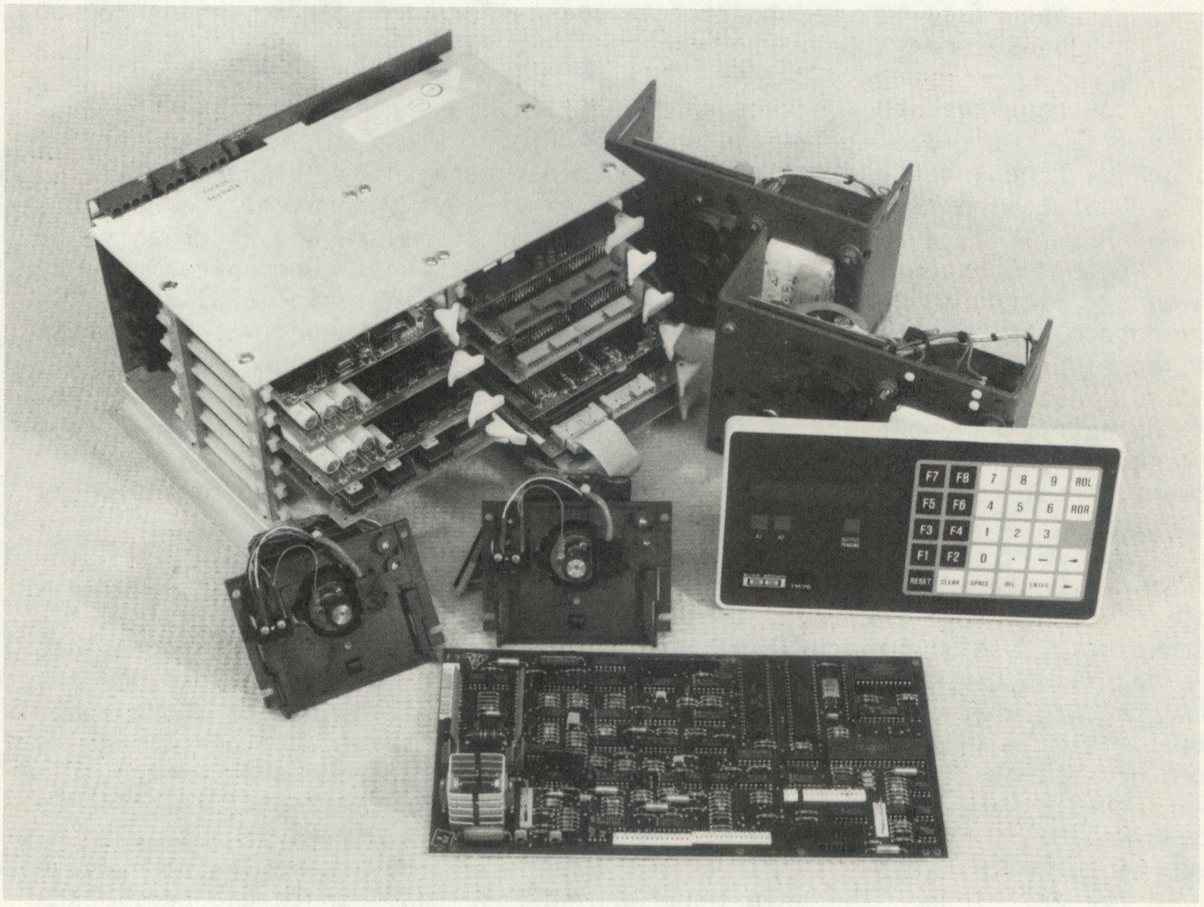

Figure 1.-- The major components of CAMS. The board in the foreground contains the electronics to control the tape drives. The microterminal control panel is shown on the right-hand side. The remainder of the electronics are on the boards positioned in the card cage.

(8.) Signals that are in digital form are acquired using a transistor-transistorlogic (TTL) input port card (Pro-Log, 7603). The card provides eight, 8-bit gated input ports. The input port lines are attached to 16-pin dual in-line package (DIP) sockets on the card. The input lines are TTL compatible with an input rating of 4 low-power Schottky TTL loads.

(9.) Serial data transmission over long lines, up to 1.2 km, is obtained using an RS-422 protocol. The board that provides two independent RS-422 channels is a Mostek MDX-422. The module can be operated in asynchronous or synchronous mode.

(10.) Digital control is made possible with a digital I/O bus interface module (MDX-DIOB1), which interconnects the STD BUS and Mostek's digital I/O bus. It provides parallel, memory-mapped I/O to a maximum of 64 8-bit ports. As many as 256 relay modules on 16 DIOB's can be serviced by this module. The digital I/O bus interface is used to operate the calibration gas solenoids for CO_2 measurements.

System requirements for data entry, display, and control are met by a microterminal (Burr-Brown, TM-76), shown in Fig. 1 along with the other major components. The microterminal provides numeric data entry, alpha-numeric display that can be scrolled, and a set of eight keys to control the operation of the CAMS. It is a small (216 mm by 114 mm by 15 mm) rugged alternative to more fragile and expensive CRT and keyboard combinations. Communication between the microcomputers and the microterminals is in serial ASCII with RS-232C protocol at baud rates of 300 bytes per second. A tough, water-resistant front panel protects the LED displays, indicators, and full numeric keyboard. Tactile feedback, display blinking, and character display confirm operator entry, and, because of its design simplicity, the microterminal does not require special operator training. The functions are predefined in software, thus, depressing a function key initiates a preprogrammed action by the CPU.

As can be seen in Fig. 2, the Digital TU-58 is a compact and mechanically simple cartridge tape recorder. The recorder is a random-access, fixed-length-block, mass storage device. It uses preformatted tape cartridges that store 262 kilobytes of data in 512-byte blocks. There are 256 blocks on each of two tracks, which may be accessed in a fashion similar to data stored on disks. A simple file-oriented structure was implemented in the operating system by setting aside the first block on the tape to store a directory. The tape cartridges are miniature reel-to-reel packages containing 42.7 m (140 ft) of 3.81-mm (0.150 in) wide tape (Fig. 3). The tape is driven at a single drive point, which engages a roller, which, in turn, moves an elastomer drive belt in the cartridge. The belt loops around both tape spools and provides uniform tension and spill-free winding without mechanical linkage, allowing high reliability for the entire system.

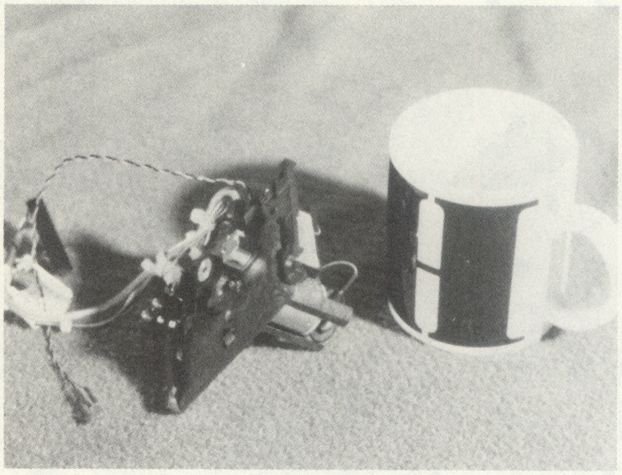

Figure 2.-- The magnetic tape drives used in CAMS. Note the relatively compact construction.

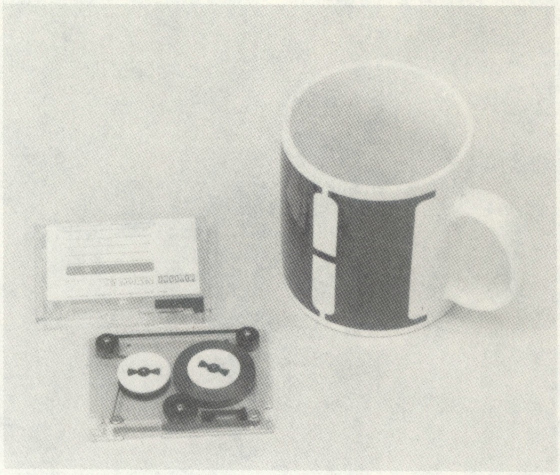

Figure 3.-- An exposed view of the cartridge tape.

The control and drive circuitry of the TU-58 is located on a single circuit board (pictured in the foreground of Fig. 1). Although the controller supports one or two drives, only one drive can operate at a time. A microprocessor controls all the activities of the TU-58 including the mechanical actions of the drives themselves. Head and motor selection, speed and direction changes, etc., are managed by output from I/O ports on a peripheral IC's. The TU58 communicates with the host computer in full-duplex, asynchronous, RS-232 protocol at 4800 baud.

The modules are housed in an aluminum enclosure measuring 48.3 cm by 17.8 cm by 55.9 cm (19 in x 7 in x 22 in), which fits in a standard equipment rack. The enclosure is shown in various stages of assembly to illustrate its modular nature (Fig. 4). The STD BUS requires +5 V and ±12 V DC which is supplied by two separate supplies as shown (Lambda models LNS-X-5-OV and LND-X-152). The card cage (Mostek, MD-CC6) is positioned adjacent to the power supplies. A fan and filter are mounted on the right side to cool the printed circuit boards and power supplies. Power is supplied through the back cover of the enclosure. An RF filter is part of the AC socket (Corcom 3EFI), and the line is fused. A complete list of the components and manufacturers is included in Appendix A. The front panel is a modular unit in itself, containing the display/control module, the tape drives and tape controller. All contacts between the Serial input/output (SIO) modules and the front panel are by connector disconnect. The wiring necessary to interconnect the major components is specified, and illustrated in Appendix B. The monitor board is described in appendix C.

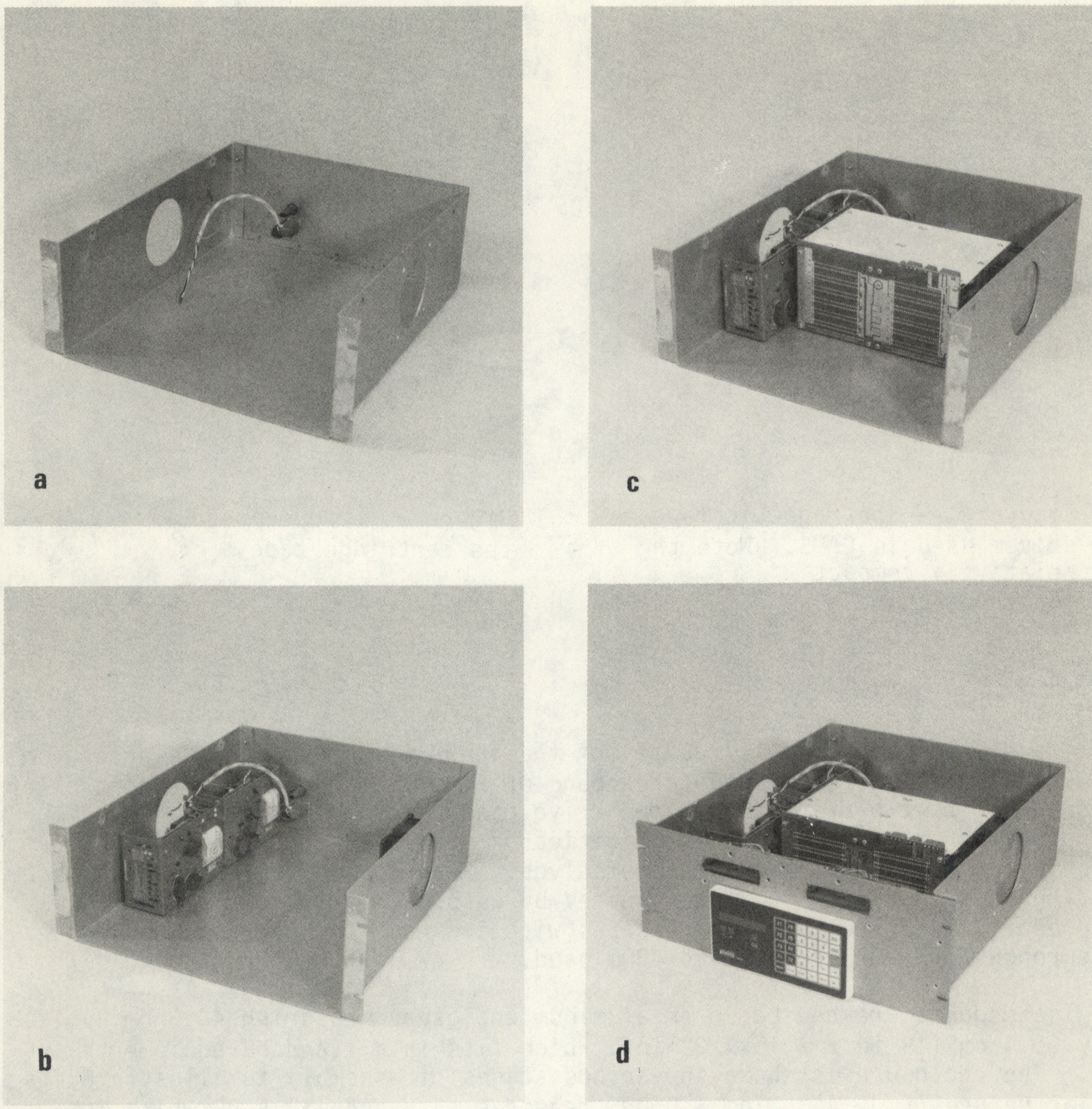

Figure 4.-- The assembly of the CAMS. In (a) only the power wire is shown. In (b) the two power supplies have been installed. In (c) the card cage has been added. And in (d) the front panel, with the microterminal, tape drives, and controller, has been attached.

The electronic-component, printed circuit boards have temperature specification of from 0°C to 60°C, although the battery performance begins to deteriorate at temperatures of 40°C. The most critical operating temperature specifications are those for the magnetic tape recorders, for which the upper limiting temperature is 32°C. The drives are located ahead of most of the heat-producing electronics in the cooling stream. Tests have indicated that the temperature in the vicinity of the drives is only 6°C to 8°C above ambient. The power supplies also lose capacity with increasing temperature, but the output is maintained within ±5% limits at 40°C. A 10°C increase in temperature causes an 11% decrease in power capacity. By blocking the airfeed to the enclosure, it was possible to obtain outlet temperatures between 45°C and 50°C. These conditions were maintained for several hours without experiencing a failure. The power supply voltages were within specification and the clock maintained accurate time. Heat is also dissipated from the power supplies directly to the enclosure by conduction. During one extreme test when temperatures of 62°C were obtained, the clock lost 7 seconds in a 2-day period. With normal circulation at room temperatures of 27°C, the outlet air temperature averages about 38°C at 1.6 km altitude. For the most part, the components are operating at less than 60% of specified maximum temperature.

The only component of CAMS that is located outside the enclosure is the printer. By means of an RS-232 switch, a single printer is shared by the three CAMS. The Epson MX-80 dot-matrix printer featuring 80-CPS bi-directional printing was chosen for this task (Fig. 5). The MX-80's were purchased with intelligent serial interfaces, for serial data communication from CAMS. With this interface asynchronous serial data transmission at 2400 baud (RS-232C) is accomplished at 1-page increments. A 2K buffer memory on the communication board makes possible the transfer of a page at a time.

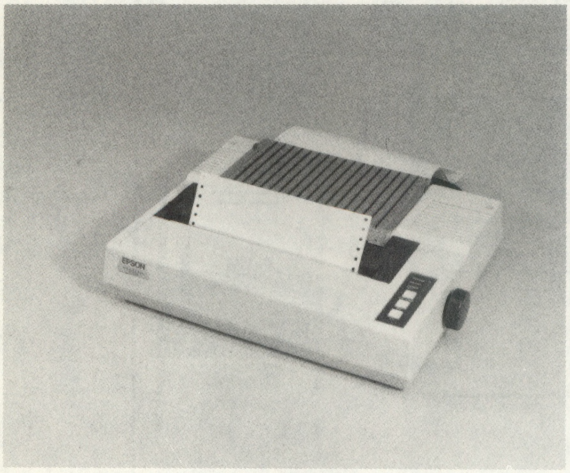

Figure 5.-- The Epson MX-80 printer used to print tabular results from each of the three CAMS installed at each observatory.

With the exception of the RS-422 interface (MDX-422) all the major components of M03 CAMS are illustrated in Fig. 6 showing their relationship to the STD BUS. Consistent with the STD BUS concept, Fig. 6 is the "wiring diagram" for the M03 CAMS.

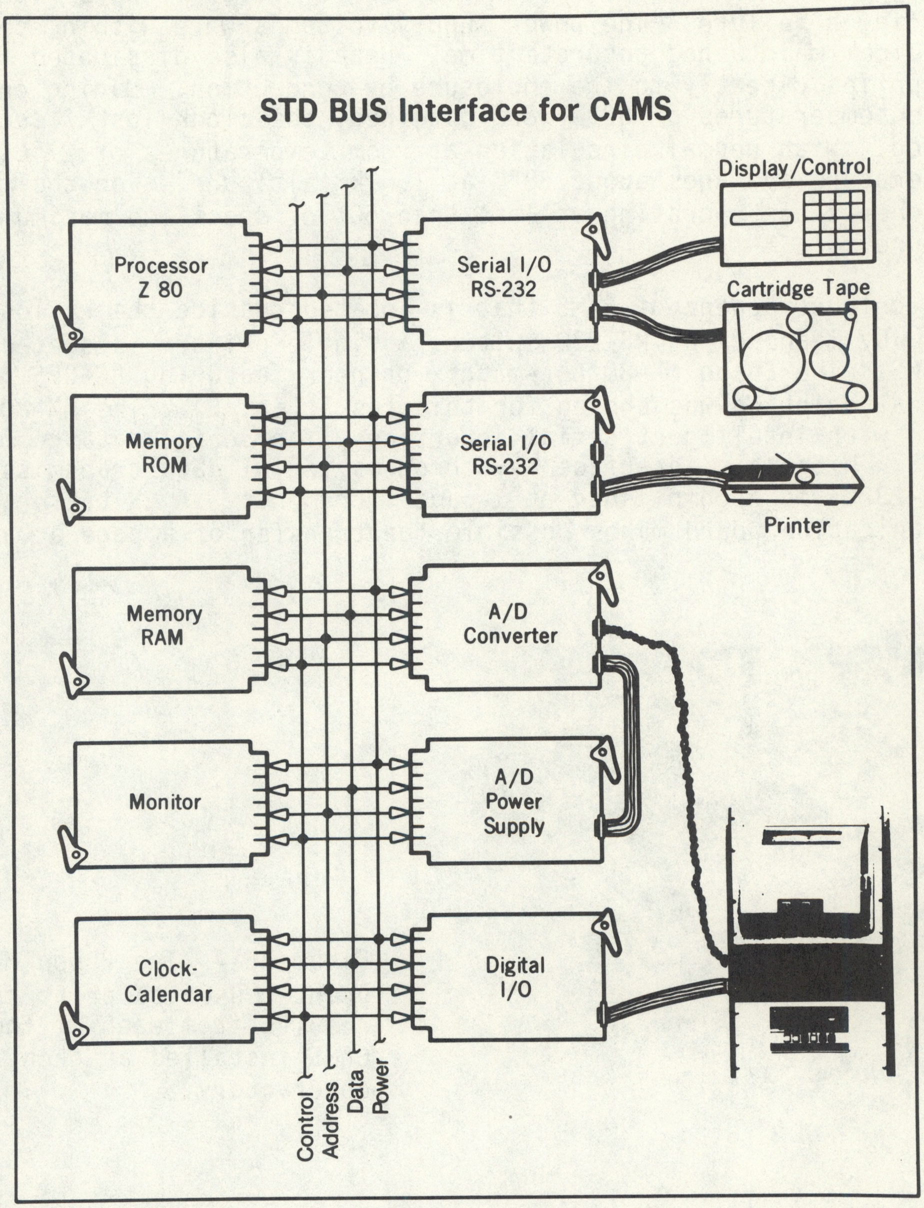

Figure 6.-- A block diagram showing the interconnection and BUS affiliation of the major components of the M03 CAMS.

6. SOFTWARE DESCRIPTION

Reliable computer-aided instrumentation that is designed for continuous operation is ensured through the use of carefully designed and thoroughly tested software. Because of its basic structure, which consists of a collection of functional modules represented by words, the language FORTH was chosen as the operating system for CAMS. By its very nature it supports modular design, which in the long term greatly facilitates testing (Brodie, 1981). FORTH is the unusual, high-level language developed by Charles Moore for instrumentation control applications. Its suitability for microprocessor applications rests primarily with its minimal overhead, which yields extremely compact code that compiles into space roughly equivalent to that required by assembly language programs, and which runs at roughly the same rate. Speed is of utmost importance in continuously operating multitasking systems, such as CAMS. The use of FORTH also facilitates extensibility by providing a minimum set of constructs that can be used to build any new construct such as a data structure (Harris, 1980). This aspect of FORTH's structure is consistent with the requirements for transformation suggested by Enke (1982). The version of FORTH used in CAMS was purchased from Microsystems, Inc., of Pasadena, CA. Software was developed on a Tektronix 8002A microprocessor development system.

Dedicated real-time applications add a new dimension to microprocessor systems such as CAMS. There is a need to support concurrent operations, usually involving data input and output processes that need to be handled in a rapidly interleaved, time-shared manner. In CAMS such needs arise when signal acquisition and digital conversion must occur independently and asynchronously and when data output to the tape unit or printer must occur simultaneously. This situation is frequently handled by use of a combination of interrupt-driven processes in the foreground while slower operations are relegated to the background. This method fails when lengthy processes in the foreground block interrupts from lower priority tasks for too long. The background program often takes the form of a loop that performs each function assigned to it in order. As the loop becomes too big, it is often necessary to subdivide these functions into smaller routines and to interleave their execution, to share the processor between them, and to obtain a reasonable appearance of a time-shared operation. The multitasking system used on the CAMS, RTOS-80Z (Microsystems, Inc., Pasadena, CA), provides an organization to background program management. RTOS-80Z is compatible with the FORTH compiler.

The multitasking control system (MTCS) handles CAMS operations as a number of tasks with a priority assigned to each task. Although tasks are generally separate program entities that are intended to execute independently, they can share common resources such as peripherals and data structures and can communicate with one another. The MTCS scheduler is activated by an interrupt from the CAMS hardware at 10 ms intervals, at which time it examines the priority of the task currently running to verify that a higher priority task is not ready and waiting. From the running state, a task can exit to a suspended state where conditions for rescheduling to a ready state are assigned, or the task can exit to a dormant state where it will stay until a start command is issued by the background program to move the task to a state of ready. When the time-slice interrupts the MTCS scheduler, it stops the running task, places it in the ready queue, and examines the queue for the highest priority task. That task becomes the running task for the next interval. The MTCS supplies a number of commands and service calls for starting, stopping, and resuming task execution. Communication between the tasks can be carried out using event flags and semaphores. When two or more tasks need to share a common resource, in this case a peripheral device such as the tape recorder, display, or printer, a semaphore is used to control access. The semaphore limits access to selected devices in a "first-come first-served" order. The MTCS is designed to be as transparent to interrupts as possible. A Z-80 microprocessor system such as CAMS, operating at 2.5 MHz, adds less than 160 µs to the execution time of the interrupt routines.

CAMS software is operated through a set of function keys on the microterminal. The function keys are in two rows in the center of the display/control module, labeled F1 through F8 (see Fig. D1). The keys are assigned as follows: F1 is assigned to the calendar/clock, providing a reset function. F2 displays the readings of the analog-to-digital converter. Voltages can be displayed in terms of bits or their millivolt values. F3 controls the operation of the magnetic tape recorders. The function includes operations to check the performance of a tape cartridge before recording and/or the orderly changing of tapes. F4 is used to send data to the printer. F5 is a system function that allows the operator to investigate the cause of an "auto restart." This message appears on the display after every restart. F5 is also used to clear the message from the display. The next two functions, F6 and F7, are used to control the processing of data. The first allows the insertion of calibration and related factors into the CAMS; the second provides for the activation of calibration functions. F8 provides a directed start/restart sequence for those situations when battery-backed RAM fails. A more complete explanation of the function key assignment of the MO3 CAMS can be found in Appendix D.

7. CAMS DEVELOPMENT AND DEPLOYMENT

On the basis of a very preliminary set of requirements that was established from experience with ICDAS as a starting point, a basic set of module requirements was formulated. Using a microprocessor development laboratory and the associated emulator package, we tested and evaluated selected STD BUS compatible boards. These included battery-backed RAM and clocks, digital I/O, and RS-232 modules from different vendors. By April 1982 a very preliminary prototype unit was assembled and operational. By September of that same year two additional prototype units were operational. Later in the year one was sent to MLO to serve as a data acquisition system for a set of research instrumentation that measured solar irradiance. This system contained all the I/O functions planned for CAMS except printout, and used an interrupt-driven version of FORTRAN as a compiler. Through experience with this unit, it was determined that FORTRAN was too slow to operate interactively for GMCC applications. The FORTH compiler for the development laboratory was acquired in December 1982, and the multitasking software was acquired in June 1983. Because of the success of the MLO solar radiation instrument, it was decided to conduct an evaluation of the analog-to-digital converter. Using FORTH, a second instrument was programmed to record voltage levels and compute first-and second-order statistics. This project was initiated at MLO in July 1983 and ran with minimum difficulty until the power was interrupted by a lava flow in April 1984. By October 1983 the multitasking routine was successfully integrated with the FORTH programs and machine language device drivers. By the end of the year, 16 of the required

20 CAMS had been constructed. A floating-point software package was procured to facilitate the computation of second-order fits required by the CO_2 analysis. In March 1984 it was determined that to obtain a reliable restart

Figure 7.-- The completed installation of the MO3 and ASR CAMS in Barrow. The MO3 CAMS is in the left-hand rack above the wind recorder and dew point hygrometer.

after a power outage, an internal restart had to be issued after the power stabilized. The detection of stable power and the issuance of the interrupt signal was designed onto a separate board known as a "monitor board." A complete description of this module can be found in Appendix C. It was designed in house, and 20 were assembled by June 1984. Software testing for all three units was completed in May 1984. In addition to the meteorology-ozone CAMS, individual units were constructed to record aerosol and solar radiation signals as well as the CO_2 measurements. See Herbert et al. (1986) for details on the CO_2 CAMS. A sequence was begun whereby the three specific units for each station were tested for a 6-week period before shipping. Once shipped, the next set of three was put in the test sequence. The BRW CAMS units were installed in August 1984 (Fig. 7), SMO in October 1984, and SPO and MLO in November 1984. Because of shipping requirements, the SPO CAMS units were tested earlier in the year.

8. THE METEOROLOGY-OZONE CAMS

8.1 Sampling and Averaging Considerations

For the past 10 years (longer at MLO) the GMCC staff have operated the minimum number of weather instruments to provide a continuous local observation of wind, pressure, temperature, and humidity. Standard meteorological instruments have been used for this purpose. Where appropriate, they have been installed in accordance with standards established by the World Meteorological Organization. Specificially, temperature and humidity measurements have been made at a height of 2 m, wind above 10 m. At all stations aerovanes are used to measure winds. They produce a voltage (0.2 V per m s^{-1}) and a digital, binary count to represent wind direction from a synchro (1 bit per 1.4° deg.). Because of the remote nature of all the observatories and the extreme Arctic condition of two, the aerovanes were chosen as the most rugged anemometer available and in common use. A pressure transducer is used as a barometer to measure station pressure. Linearized thermistors are used to measure air temperature at all stations except at the South Pole where platinum resistance elements are employed. Dew point hygrometers are used to measure humidity. A complete description of the response characteristics of these sensors along with changes in their deployment can be found in the GMCC Summary Reports (i.e. Harris and Nickerson, 1984). The ozone sensor, which is also recorded by the MO3 CAMS, is a Dasibi-type sensor that produces an updated binary coded decimal output every 10 s (see Oltmans, 1985, for details).

Because of the nature of the sensors and atmospheric variability, the spectrum of variations in the signal to be recorded decreases rapidly at frequencies of 0.1 Hz or greater. With increasing frequencies the next major noise source is at 60-Hz. To limit the influence of 60-Hz noise, a five-point digital filter was built into the subroutine that operates the analog-to-digital (A/D) converter. This was accomplished by averaging five readings of the A/D converter spaced approximately 33 ms apart, such that the average includes five different portions of the 60-Hz sine wave. Using this technique of noise rejection it was not possible to sample the incoming voltages at rates in excess of 1 per second. The digital signals are not filtered in this way. All incoming signals are tested against predetermined limits to exclude transients.

8.2 Processing of Signals

Signal processing is carried forward in three steps. First, the incoming signals in analog voltage form are digitized and tested against limits stored in the identification file, IDF (Fig. 8). The limits are expressed in bits (0 to 4095) and stored in the columns labeled MAX and MIN, in the IDF. If the voltages fall outside the specified limits the valve is ignored. Digital signals from the wind direction translator, the surface ozone sensor, the rain gauge and the calibration and fault indicators for the dew point hygrometer and thermometer aspirators are not subjected to limits. In the airflow of each aspirated solar shield there is a flow-sensing switch that opens when the

ID FILE

STA : 199
DATE: 86029
TIME: 2210

CH	ID	HT	SN	MAX	MIN	OFFSET	SCALE	MISC	MISC	DATE
1	RF	0	0	2100	2000	0	0	5000	79	9/84
2	PP	900	2366	3500	2200	23641	2163	0	0	7/85
3	TR	0	0	1200	900	0	0	2496	79	9/84
4	TA	251	2	4000	2100	10605	-4000	167	-273	8/84
5	TB	1527	4	4000	2100	10600	-4000	166	-273	8/84
6	TC	0	3	4000	1600	10620	-4000	0	0	10/85
7	DP	246	7162	3300	100	2458	1000	3001	79	9/85
12	WS	1671	576	1000	-1000	3	251	1055	238	8/84
13	WS	0	0	1000	-1000	17	213	367	202	0/00
14	WS	0	0	0	0	0	0	0	0	0/00
15	WS	0	0	0	0	0	0	0	0	0/00
16	WD	0	0	0	0	0	0	0	0	0/00
17	WD	0	0	0	0	0	0	0	0	0/00
18	OZ	0	1321	10000	0	116	0	0	0	0/00

BOX ID 231

PRECIP SCALE: 10

Figure 8.-- A typical printout of an identification file.

flow is interrupted. In this way the acquisition of temperatures data is interrupted when the aspirator fails. Window limits are specified for the reference voltage (RF) station pressure (PP), temperature circuit reference voltage (TR), the air temperature at 2 m height (TA), the tower top temperature (TB), the space thermometer (TC), and the dewpoint temperature (DP) (see Fig. 8). The wind is treated in a different way. The wind speed (WS) and direction (WD) are scaled, and orthogonal components are computed before the limits are applied. Thus the limits that are listed in the MAX and MIN columns in the IDF are integers representing the maximums north-south speeds (Channel 12) and east-west speeds (Channel 13) for each maximum in miles per hour x 10. For the most part the limits are the maximum and minimum values determined from 7-year-long climatologies for the individual stations with an additional 10% to allow for new record valves.

Second the values used to scale the signals are stored in the identification file under the headings of OFFSET and SCALE (see Fig. 8). For the most part all the signals are linear:

Dispalyed value = "OFFSET" + (Measured voltage * "SCALE").

In the case of the wind, a two-part linear approximation to the calibration is made. All values, whether displayed, or the 10-min or 1-h recorded or printed, use the same calibration factors. When changes are introduced, the effect is immediate. Not all variables require calibration factors, specifically the scale and offset for the bus voltage, reference voltage, temperature reference voltage, and the wind direction are set in software. For surface ozone, only the scale is set in software. The remainder are determined by the calibration procedures outlined below. The MO3 CAMS does not perform floating point arithmetic; thus it is necessary to scale all calibration parameters to a sufficient size in order to obtain the required resolution.

8.2.1 Temperature

In the case of temperature, a linearized thermistor sensor is wired into a modified bridge circuit that is represented by the following equation:

$$E_{OUT} = -0.00559149\ E_{IN}\ T + 0.593\ E_{IN}.$$

E_{IN} is a bridge voltage, 2.5 V DC, that is supplied by a precision voltage source. But E_{IN} drifts to a significant degree that it must be measured along with E_{OUT}. In application the above equation takes the form,

$$T = 106.05 - 178.84\ \frac{E_{OUT}}{E_{IN}}.$$

CAMS treats the calibration in the following way,

$$T = (\text{"OFFSET"} + \text{"SCALE"}\ \frac{V_{TA}}{V_{TR}})/100.$$

Due to the effect of the length of the wire in each bridge circuit it is not possible to use the manufacturer's calibration in this application. Thus, each thermometer is calibrated in a water bath over the range of temperatures to be expected at the observatory, and using this calibration, a temperature is assigned to a resistor composites that is used to scale the electronics at the station. Two or more such composites are needed. They are represented by T_1 and T_2 in the following, and when in place they produce voltages V_1 and V_2:

$$\text{"SCALE"} = 100\ [(T_1-T_2)/(V_1/V_{TR})-(V_2/V_{TR})]$$
$$\text{"OFFSET"} = 100\ [T_1-(V_1/V_{TR}\ (\text{"SCALE"}/100))]$$

The value of V_{TR} is 2.50V DC.

8.2.2 Pressure

The manufacturer specifies the response of the transducer to be 1 in Hg per volt. The calibration is adjusted for the pressure range of the different observatories. For example, for the observatories at 3-km altitude, the scale is referenced at 22.5 in Hg. The calibration factors are as follows:

"OFFSET" = (Presssure at zero volts) x 10^3
"SCALE" = (INST SCALE) (0.002441 X 10^6 volts per bit

As comparisons are made with the mercurial barometer at each observatory it is necessary to adjust the offset to obtain agreement. In most cases the adjustments are within the range ±0.02 in Hg.

Because of the extreme temperatures experienced at the South Pole station, it is necessary to use platimum resistance thermometers with a range to -85°C in place of the linearized thermistors used at the other stations, which have a minimum temperature of -52°C. The platimum resistance thermometer has a nominal resistance of 100 Ω at 0°C and changes about 1 Ω per 2°C. As with the linearized thermistors a resistor composite is constructed and measured, and a temperature is assigned. These are used to obtain the calibration factors in the above equations.

8.2.3 Wind

At the four observatories wind measurements are made with a propeller-type anemometer (Aerovane No. 120, Bendix Corp). This anemometer is of particularly rugged design, and for that reason it is not particularly accurate at low wind speeds. The response of the propeller (impeller) is such that at wind speeds less than 10 mph (~5 m s^{-1}) the inertia of the propeller causes slippage. The effect becomes more pronounced as the wind speed decreases until a starting speed of between 2 and 3 mph (~ 1.5 m s^{-1}) is reached. To approximate this nonlinear response at lower wind speeds a different calibration function is used for winds less than 10 mph (~5 m s^{-1}) that used in the linear portion of the curve at speeds greater than 10 mph (~5 m s^{-1}). In each case the form of the calibration equation is the same:

"SCALE" = (INST SCALE) (0.002441 X 10^4) volts per bit
"OFFSET" = 10 X (INST OFFSET).

Both the instrument OFFSET and SCALE are determined by computing curves of least-squares fit to the results of a wind tunnel calibration of the anenometers.

The wind direction scale is set by the fact that the synchro-to-digital converter produces 256 binary for 360°, yielding a resolution of about 1.4° per bit. Thus, the scale for wind direction is fixed. The offset is assumed to be zero in the calibration, but in fact, there are a number of ways the orientation of 0° can be other than true north. Mispositioning of the synchro in the aerovane and its support are the two that occur most often. Using a theodolite, sighting the aerovane to true north, and checking the resulting indication on CAMS is the best alignment methodology. Details concerning the exposure of the individual sensors are tabulated in Nickerson (1986).

The third step in the processing of the data in MO3 involves the compression of the data into useful form. Data reporting requirements themselves fall into three general catagories. First and most important is the hourly average value in scientific units, which is the basic constituent of the GMCC data base. Second, at shorter time increments it is important to display the results on 1-min intervals to support calibration and comparisons with standard instruments such as the mercurial barometer. One-minute values are also used to depict meteorological conditions in association with flask sampling of atmospheric constituents. Third, in between the 1-min and 1-h average values much variation in weather conditions can occur. Since the 1-min values are not recorded, it was decided to record 10-min averages to allow the study of within-hour variation when necessary. All the above are recorded, displayed, or printed in scientific units using calibration factors described previously.

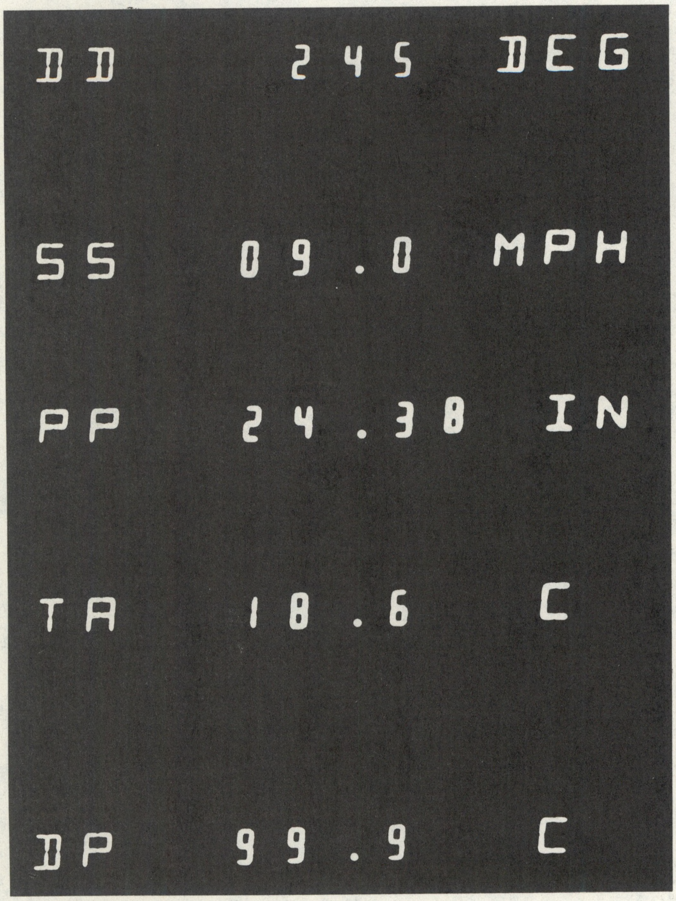

Figure 9.-- A multiple exposure of the microterminal display on the MO3 CAMS showing the sequence in which the meteorological measurements are displayed each minute. (DD-wind direction, SS-wind speed, PP-station pressure, TA-air temperature, DP-dew point temperature, RAIN-precipitation.)

8.3 Data Quality Assurance

Data quality assurance in the acquistiion of meteorological observations has been described by Acheson (1980) as requiring a balance between automation and observer input. Thus in a research environment the primary responsibility for data quality rests with the observer at each station. Two methods of displaying the data provide for data quality evaluation: the continuous display of 1-min average values of all the sensors attached to the CAMS and a printout of the hourly average values for the previous 24 h. The display on the face of the CAMS shows the average value in scientific units for the previous minute; see Fig. 9 for a sample of the display format. The LED display cycles through the ID data channels that change each minute; in addition the precipitation amount and data quality flags for the previous hour are displayed for 4 s each. The remaining 16 s are used to display the time. At any time it is possible for the observer to validate the CAMS measurements by making independent observations or direct comparisons with alternate recording or display devices. The aerovane signals, wind direction, and wind speed are recorded on a strip chart adjacent to CAMS. Dew point temperature and ozone are displayed on the face of the sensor, for easy comparison. The clock display, which accounts for the last 6 s and the first 10 s of each minute, is compared against a standard, usually WWV, daily. Flags are useful in the monitoring of irregularities in data acquisition that can cause errors in the data, but only the previous hour is displayed. The 1-min average values are only available on the display; no recording is made.

The second aid to maintaining data quality is the daily listing of the hourly average values for the previous 24 to be used as a worksheet, (Fig. 10). In addition to a listing of hourly average values from each sensor for the previous 24 h the Daily Weather Report (DWR) contains a flag to indicate discrepancies that occur within the hour represented. Specifically, flags are set for each measurement when the tally for the previous hour is less than 2880, which is 80% of the number of 1-s readings expected in an hour. This can occur for example when a sensor or the intervening electronics is noisy causing values to exceed the limits set for the "window" filter at input. For ozone alone, a second flag is used when less than 20% of the hour is recorded as well. Flags are also used to call the observer's attention to physical limit violations when they occur, for example, when the dew point temperature is greater than the air temperature at the same level. In addition a flag is raised when the winds are calm for more than 20% of the hour. The last group of flags involves the indication of calibrations. When the data flow is interrupted by the pacer circuit of the dew point hygrometer, a flag is raised. The pacer cycle is an automatic cleaning of the dew point hygrometer mirror by sequentially heating and cooling the mirror. It is typically performed daily, and takes about 20-min to complete. Ozone instrumentation is calibrated weekly, during which time a flag is raised. In addition a flag is raised when the airflow in the temperature radiation shield is interrupted. See Appendix E for a detailed explanation of the form of the flags.

GMCC DAILY WEATHER REPORT

BARROW

YEAR: 1985

DOYHR CUT	FLAGS	RWD DEG	RWS MPH	SF %	PRESS IN HG	TEMPA DEG C	TEMPB DEG C	DEWPT DEG C	RAIN IN
329/00	0	117	13	98	30.25	-10.2	-9.7	-11.2	0.00
329/01	0	123	13	99	30.25	-8.7	-8.6	-9.4	0.00
329/02	0	107	8	97	30.25	-8.9	-8.5	-9.6	0.00
329/03	0	116	6	98	30.25	-8.3	-8.0	-8.9	0.00
329/04	0	112	7	98	30.25	-8.0	-7.8	-8.5	0.00
329/05	0	93	4	93	30.25	-7.9	-7.5	-8.3	0.00
329/06	0	58	4	99	30.24	-7.9	-7.4	-8.5	0.00
329/07	0	49	6	94	30.23	-7.5	-6.8	-8.1	0.00
329/08	0	76	11	99	30.23	-6.3	-6.2	-7.1	0.00
329/09	0	76	11	99	30.23	-6.4	-6.3	-7.1	0.00
329/10	0	84	12	99	30.23	-6.4	-6.3	-7.1	0.00
329/11	0	96	11	99	30.22	-6.7	-6.6	-7.4	0.00
329/12	0	85	10	98	30.21	-6.8	-6.7	-7.5	0.00
329/13	0	72	9	98	30.20	-6.8	-6.7	-7.5	0.00
329/14	0	59	12	99	30.19	-7.1	-6.9	-7.8	0.00
329/15	0	63	13	99	30.19	-7.3	-7.2	-8.0	0.00
329/16	0	65	14	98	30.18	-7.4	-7.3	-8.1	0.00
329/17	0	72	14	98	30.17	-7.4	-7.3	-8.0	0.00
329/18	0	79	15	99	30.16	-7.4	-7.3	-8.1	0.00
329/19	0	81	16	99	30.14	-7.4	-7.4	-8.1	0.00
329/20	0	86	19	99	30.13	-7.6	-7.6	-8.3	0.00
329/21	0	84	19	99	30.12	-7.8	-7.8	-8.5	0.00
329/22	0	84	19	99	30.10	-7.9	-7.9	-8.6	0.00
329/23	1000	86	22	99	30.09	-8.1	-8.1	-10.1	0.00

DAILY WEATHER OBSERVATION

DOY/TIME: 85330 0010 CUT

WIND, AVERAGE FOR PAST HOUR

DIR: 85 DEG, SPEED: 20 MPH

SHELTER TEMP: AIR: -8.0 °C

MAX: -5.8 °C, MIN: -16.0 °C

PRECIP: SNOW IN, VISBY: 3 KM

CLOUD COVER: 100 %, TYPE: St.

WEATHER: SNOWING & DARK

MERCURY BAROMETER READING

DOY/TIME: 85330 0008 CUT

BAROMETER TEMP: 75 °F

BARO. READING: 30.152 INHG.

BARO. & TEMP CORR: -.065 INHG.

CORRECTED VALUE: 30.087 INHG.

CAMS VALUE: 30.09 INHG.

DIFFERENCE: -0- INHG.

Figure 10.-- A typical daily weather report (DWR). At the bottom are the daily weather observation and the mercurial barometer reading, used to validate the above.

The final check of the data is made by comparing conditions as measured by alternate sensors or recording devices against the last hour recorded on the DWR. The observation, known as the daily weather observation (DWO) is made at 0000 GMT. It is reported in the box stamped in the lower left-hand corner of the DWR. The wind comparison is taken from the aerovane strip chart recorder, and an average for the previous hour is determined by eye (±5°, ±1 mph). The temperatures are measured from a maximum and minimum thermometer housed in a Stevenson Shelter in a representative location. The present air temperature, and the maximum and minimum for the previous 24 h are reported (±0.1°C). At the South Pole the values reported by the National Weather Service observer are reported. The observer is also asked to observe the sky conditions and report any precipitation in the lower portion of the form. The observed values are then compared to the printed values. The maximum and minumum temperature should always bracket the measured values. Pressure comparisons are performed twice weekly using a mercurial barometer. The barometer measurements are reported in the form stamped in the lower right hand corner of the DWR. Pressure comparisons are expected to be within a tolerance of ±0.01 in Hg. If any long-term drifting of the pressure transducer is occuring, due to electronic instability or leaks, this comparison will allow the drifts to be removed from the data. At the completion of this comparison the observer must check each column of data for continuity. This check includes the comparison of the sum of the hourly precipitation amounts against the amount in the bucket. The DWR's become the official log of the meteorology measurement at GMCC observatories. They are microfiched at the end of each year for permanant storage.

To avoid confusion by overcrowding the DWR, the hourly average values from a second wind system and the third thermometer were not included. The readings from both these channels do appear on the display of 1-min values and can be printed from the file of meteorological data that contains the 10-min average values. The meteorological data file, (MDF) is recorded every 2 h and can only be recovered from tape. It is a complete listing of all weather data and statistics computed by CAMS (Fig. 11). The time printed in the date-time block is the time the form was printed. The five-digit designation at the top of each column is the day-of-year and hour, DOYHH, of the top row of data. In block A there are two rows with three values in each row, labeled T for tally, H for hourly average and F for flags. Two hours are reported in this box. Items A1, A2 contain the steadyness factor and calm tally respectively for the hours. The B box contains the 10-min averages for each parameter for the two hours represented. The MDF also contains the average voltages measured on channels 0 and 1, in blocks C and D respectively. Channel 0 monitors the voltage on the ground bus of the analog-to-digital converter. The nominal average voltage offset should be 1 m V. Channel 1 records the voltage from a precision 5 V dc reference, so in conjunction with the bus voltage the gain of the analog-to-digital converter can be checked. Block E contains the precipitation amount for the two hours.

MET DATA FILE

SOUTH POLE
DATE: 85194
TIME: 1800

ES/RF	PP	TA	TB	TC	DP	WD1	WS1	WD2	WS2
19416	19416	19416	19416	19416	19416	19416	19416	19416	19416
3600 T	3600	3600	3600	3600	0	3600	99 A1	0	0
2 H	19513	-655	-641	-667	9999	1	167	999	999
0 F	0	0	0	0	0	0	0 A2	0	0
C 0						A			
3600 T	3600	3600	3600	3600	0	3600	99 A1	0	0
2 H	19511	-651	-642	-667	9999	359	162	999	999
0 F	0	0	0	0	0	0	0 A2	0	0
1									
3600	19516	-658	-641	-667	9999	4	168	999	999
2048	19513	-657	-642	-667	9999	2	161	999	999
D 0	19511	-656	-642	-667	9999	1	169	999	999
3600	19511	-655	-638	-667	9999	360	171	999	999
2048	19511	-652	-639	-667	9999	359	162	999	999
0	19511	-651	-642	-667	9999 B	359	169	999	999
E 0	19511	-651	-643	-667	9999	358	164	999	999
0	19513	-652	-644	-667	9999	359	165	999	999
	19513	-652	-644	-667	9999	358	154	999	999
	19511	-651	-642	-667	9999	359	166	999	999
	19511	-650	-641	-667	9999	359	161	999	999
	19508	-649	-638	-667	9999	359	163	999	999

Figure 11.-- A typical meteorological data file (MDF). The MDF records data from all channels at 10-min and 1-h resolution, for 2 h. See text for further explanation.

8.4 Data Recording

There are five different files recorded by the M03 CAMS. Three of these contain data, one contains all the calibration factors, and one is a record of the contents of the data tape itself, a directory. The directory is stored on tape block zero and is re-recorded daily from memory. Each file type is identified by a lowercase ASCII character. A printout of the directory is shown in Fig. 12. The calibration factors are housed in a file known as an identification file (IDF), indicated by an I in the directory. Identification files are recorded daily at 0600 GMT. The daily weather report W and the ozone data file O are recorded daily at 0000 GMT. The 10-min average values in the meteorology data file M, are stored for 2-h periods and recorded at even hours throughout the day. It is possible for the station staff to recover any previously recorded data from the tape at any time, including the directory.

```
                       TAPE DIRECTORY

  1 M M M
  4 W O M M I M M M M M M M M M M
 19 W O M M I M M M M M M M M M M
 34 W O M M I M M M M M M M M M M
 49 W O M M I M M M M M M M M M M
 64 W O M M I M M M M M M M M M M
 79 W O M M I M M M M M M M M M M
 94 W O M M I M M M M M M M M M M
109 W O M M I M M M M M M M M M M
124 W O M M I M M M M M M M M M M
139 W O M M I M M M M M M M M M M
154 W O M M I M M M M M M M M M M
169 W O M M I M M M M M M M M M M
184 W O M M I M M M M M M M M M M
199 W O M M I M M M M M M M M M M
214 W O M M I M M M M M M M M M M
229 W O M M I M M M M M M M M M M
244 W O M M I M M M M M M M M M M
259 W O M M I M M M M M M M M M M
274 W O M M I M M M M M M M M M M
289 W O M M I M M M M M M M M M M
304 W O M M I M M M M M M M M M M
319 W O M M I M M M M M M M M M M
334 W O M M I M M M M M M M M M M
349 W O M M I M M M M M M M M M M
364 W O M M I M M M M M M M M M M
379 W O M M I M M M M M M M M M M
394 W O M M I M M M M M M M M M M
409 W O M M I M M M M M M M M M M
424 W O M M I M M M M M M M M M
439
454
469
484
499
```

Figure 12.-- A typical tape directory for the MO3 CAMS. (M-MDF, I-identification file, W-DWR, O-ozone files.)

9. RESULTS

By the end of 1984 the four GMCC observatories were each operating three CAMS continuously. Also by this time most of the problems encountered at the time of installation had been corrected. Although CAMS is programmed to restart automatically after a power interruption, a relatively common occurrence at remote field sites, the fact that an interruption has occurred is reported by an "autorestart" message on the display. If the autorestart is not completed it is usually due to a memory failure, which is denoted a "BRAM LOSS" (loss of the battery-backed random access memory). In the case of a memory loss the operator must restart the system following a fixed procedure that includes entering all the calibration constants. In normal operation with fully charged batteries the BRAM should hold its contents for a week. During 1985, 73 autorestarts were reported for the 12 CAMS in continuous operation. Most autorestarts were attributed to local power failures, and in most cases the power outages were less than 1 min in duration. Eight BRAM failures were also reported. In the case of the MO3 CAMS a total of 371 h of data were lost in 1985. This does not include a tally of hours where less than 20% of the hour is missing. BRAM failures accounted for about 54% of this loss. Later in the year a sharp increase in the number of BRAM failures was observed. Testing revealed that the problem concerned failures in the battery and charging circuits. In some cases the problem was corrected by replacing the batteries. The long-term solution will be to replace all the BRAM boards with new memory technology (ZRAM), which does not require batteries.

In the MO3 CAMS all voltage measurements are made with a unipolar, 12-bit, analog-to-digital converter. The accuracy of this converter is determined by the precision of the initial setting of the offset and gain controls and any drift in these settings in the intervening period. To avoid displacement of the offset to the negative side of zero, which cannot be measured with a unipolar converter, a 1/2-bit positive offset is imposed. This corresponds to a positive offset of approximately 1.2 mV. The gain of the analog-to-digital converter is set by triggering between 4094 and 4095 bits with a voltage of 9.9976 V applied. A presision voltage source, accurate to 0.1 mV is used for this alignment. To account for changes with time in the MO3 CAMS, the bus voltage and a reference voltage (5.000 V DC) are monitored continuously. As a result of our first year of experience it is clear that long- and short-period changes in the reference voltages or analog-to-digital converter setting are significantly less than the specified value of ±1/2 a bit. The most difficult task in maintaining this measurement is obtaining accuracy in setting the initial voltages. The largest changes occurred when the offset and gain were "reset" during the year. The reason for this problem is that while these delicate adjustments are being made the card is extended from the CAMS. The settings change when the extender card is removed. From the printouts it is clear that all MO3 CAMS voltages are accurate to ±1 mV throughout the year.

10. CONCLUSIONS

Between the 1 August and the 1 December 1984, 12 Control and Monitoring System (CAMS) units were installed at the four GMCC observatories. At each, one unit operates the CO_2 system (CO2 CAMS), another measures the result from aerosol and solar radiation instrumentation (ASR CAMS), and a third monitors the meteorological and surface ozone measurement (MO3 CAMS). The systems have operated without difficulty through 1985. The total number of hours of data loss per station was only about one-fourth that of ICDAS in recent years. All indicators show that the analog-to-digital converters are stable and when correctly adjusted yield reliable results within specified limits. The ease with which the observer can initiate calibrations, monitor voltages, change calibration constants, or recover data from tape, through the use of preprogrammed function keys, has greatly reduced the number of errors associated with routine operations. This; in turn, has led to more reliable data acquisition and recording. And, in conjunction with daily printouts and a system of flags, the quality of the data has improved. Changes to both hardware and software are planned to improve the reliability of the random-access memory in power failures and to remove a number of minor errors in the software. Both changes are due to be completed in 1986.

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Appendix A:

CAMS Modules and Subcomponents

Appendix A: CAMS Modules and Subcomponents

Table A1 is a complete listing of the modules and subcomponents required for CAMS as of January 1985. Changes will be made as new requirements are realized and new technology becomes available (early candidates for replacement will be those boards using nickel-cadmium batteries for back-up power, the nonvolatile memory and the battery-backed clocks). A complete listing of all available STD BUS compatible modules can be found in the STD BUS Buyers Guide (Mozanec, 1984). This volume is released twice annually and contains a brief listing of important specifications for each module.

The addresses for the vendors shown in Table A1 are listed below.

Black Box Corp.
5867 N. Broadway
Pittsburg, PA 15241

Burr-Brown
320 E. 3th
Loveland, CO 80537

Corcom
1600 Winchester Road
Libertyville, IL 60048

Data Translation
100 Locke Dr.
Marlboro, MA 01752

Digital Equipment Corp.
36 Cabot Road
Woburn, MA 01801

Epson
P.O. Box 12800
Denver, CO 80216

Lambda
515 Broadhollow Rd.
Melville, Long Island, NY 11747

Mostek
1215 W. Crosby Rd.
Carrollton, TX 75006

Pro-Log Corp.
2411 Garden Rd.
Monterey, CA 92940

Table A1.-- Module and component listing for CAMS as of 31 December 1985.

Item	Function	Module	Manufacturer				Disposition				
			Name	Model Number	Order Number	Price (1984 $)	Slot	ASR	CO2	MO3	SPARE
1	Processing	Z80 computer	Mostek	MDX-CPU1	MK77850	170	R4	1	1	1	1
2	Memory	RAM/ROM	Mostek	MDX-UMC	MK77759	160	L4	1	1	1	3
3	Memory	Nonvolatile memory	Mostek	MDX-BRAM	MK77760	339	L2 L3	2	2	2	2
4	Clock	Battery clock	Mostek	MDX-BCLK	MK77976	295	L1	1	1	1	1
5	Serial I/O RS 232	Comm. controllers	Mostek	MDX-SIO2	MK77670	250	R2 R3	2	2	2	2
6	Serial I/O RS 422	Comm. controllers	Mostek	MDX-422X	MK77676	280	L5	0	0	1	1
7	Digital I/O	Peripheral controllers	Mostek	MDX-DIOB1	MK77672	195	L5	0	1	0	1
8	A/D converters	Analog input	Data translation	DT2742	Same	495	R5	2	1	1	1
9	A/D converters	Power supply	Data translation	DT2715-1	Same	185	R6	2	1	1	1
10	Digital I/O	Digital gates	Pro-Log	7603	Same	150	L6	0	0	1	1
11	System restart	Monitor board	In-house design & construction	N/A	N/A	300	R1	1	1	1	1
12	Card housing	Card cage	Mostek	MD-CC6	MK77990	219	-	1	1	1	1
13	Power +5V	Power supply	Lambda	LNS-X-5-OV	Same	182	-	1	1	1	1
14	Power ±12V	Power supply	Lambda	LND-X-152	Same	194	-	1	1	1	1
15	System control	Micro-terminals	Burr-Brown	TM 76	Same	450	-	1	1	1	1
16	Recorders	Cartridge tapes	Digital Equip. Corp.	Dectape II	TU-58-BB2	750	-	2	2	2	2
17	Recording media	Tapes	Digital Equip. Corp.	TU-58	TU-58K	20	-	2	2	2	20
18	Printout	Printer	Epson	Dot matrix	FX80	524	-	1	0	0	1
19	RS 232 switch	N/A	Black Box Corp.	SW050	N/A	239	-	1	0	0	0
20	Dasibi interface	Serial I/O RS 422	Mostek	MDX-RIOC	MK78208	279	-	0	0	1	1
21	Relays	Digital control	Mostek	DIOP	MK77673	473	-	0	1	0	1
22	Enclosure	N/A	In house design & construction	N/A	N/A	200	-	1	1	1	1
23	Power line filter	N/A	Corcom	3EFI	N/A	2	-	1	1	1	1

Appendix B:

Wiring of CAMS

Appendix B: Wiring of CAMS

The photograph of the MO3 CAMS in Fig. B1 shows the detail of most of the wiring. Table B1 lists the cable and identifies the connectors required.

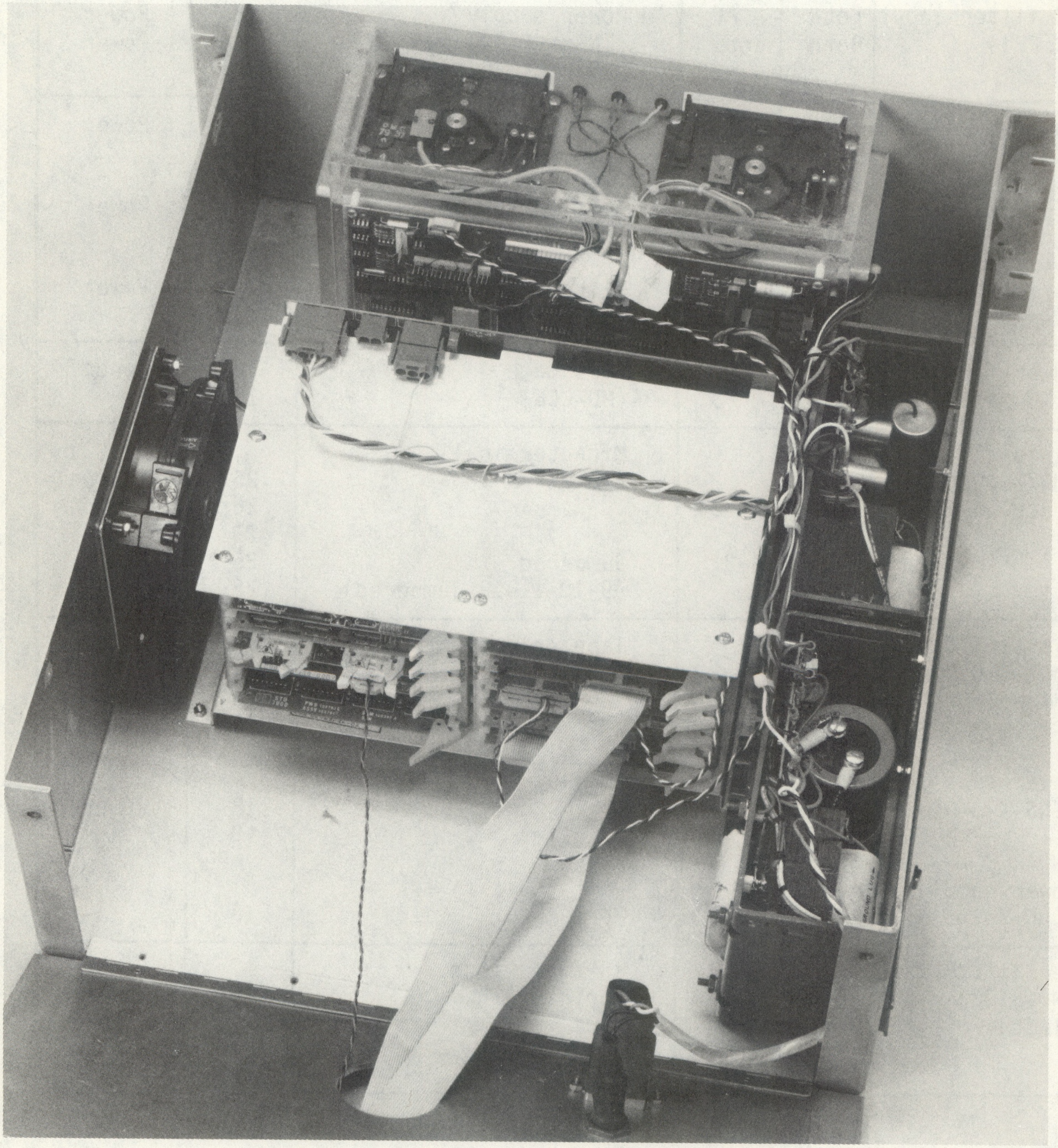
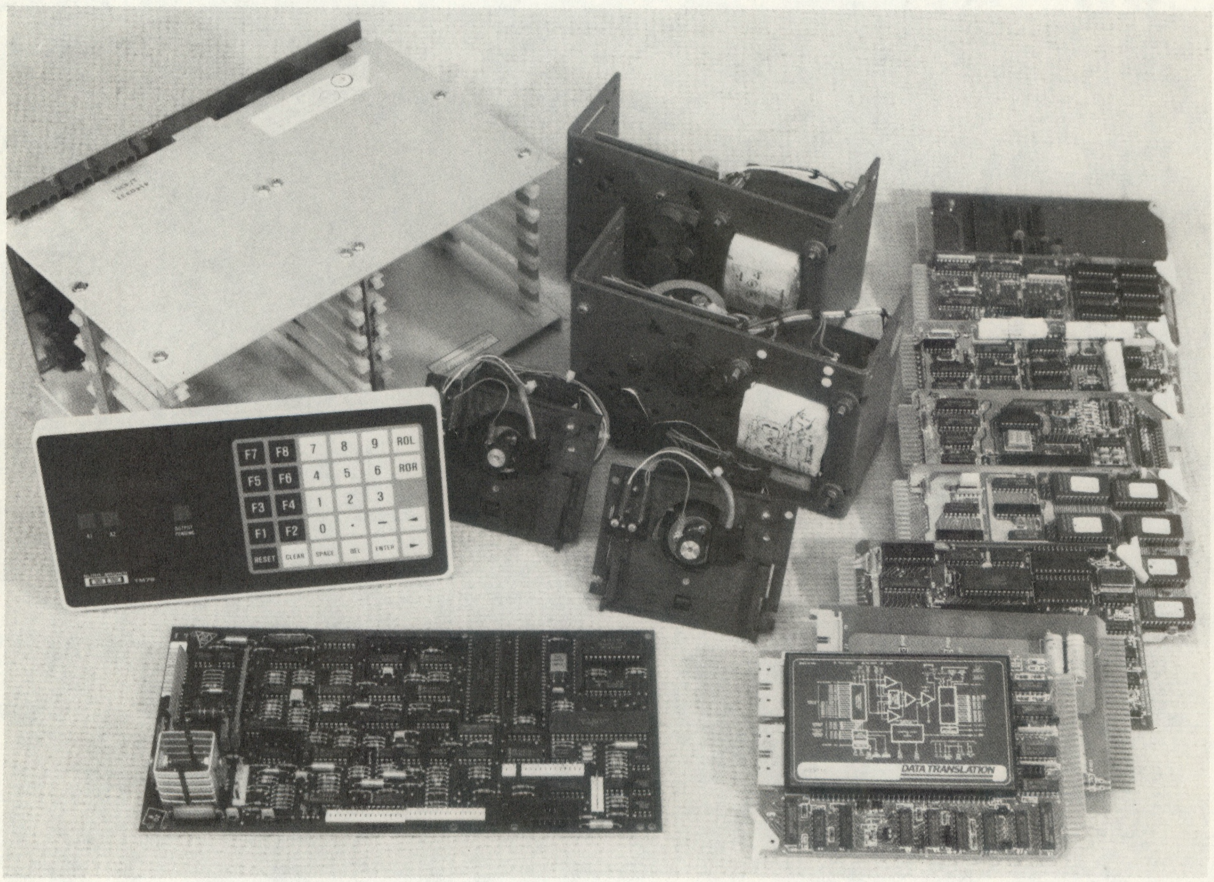


Figure B1.-- A top view of the MO3 CAMS and associated wiring.

Table B1. CAMS enclosure wiring specifications

Source module	Pin-to-pin		Receptor module	Wire size	Purpose
AC filter input	Both	AC	Power supply	18	Power
(3 EFI)	Both	Both	(LNS-X-5-0V)	18	Power
			Fan		
Power supply	AC	AC	Power supply	18	Power
(LNS-X-50V)			(LND-X-152)		
	+5V	1	Card cage	12	Power
	GND	2	(MD-CC6)	12	
	+5V	14	Microterminal	20	Power
	GND	1	(TM-76)	20	
Power supply	+12	4	Card cage	18	Power
(LNO-X-152)	-12	3	(MD-CC6)	18	
Serial I/O			Microterminal		RS-232
(MDX-SIO2)	2	2	(TM-76)	26	communi-
(left)	3	3		26	cation
	7	7		26	
	20	19-21	Jumpered	26	
			(9-10-11-12 jumpered)	26	
Serial I/O			Tape drive control		RS 232
(MDX-SIO2)	1	9	(TU-58)	26	communi-
(right)	2	3		26	cation
	3	8		26	
Power supply					
(LNS-X-5-0V)	+5	5		18	Power
	GND	3		18	
Power supply					
(LND-X-152)	+12	1		18	
Serial I/O #2			RS-232 switch		Communi-
(MD-SIO2)	1	1	(printer)	26	cation
(left)	to	to			
	26	26			


F7 F8 7 8 9 ROL
F5 F6 4 5 6 ROR
F3 F4 1 2 3
F1 F2 0
RESET CLEAR SPACE DEL ENTER
DATA TRANSLATION

Appendix C:

Monitor Board

Appendix C: Monitor Board

Introduction

The monitor board is a custom STD BUS board that performs several important functions in the CAMS system (Fig. C1). Primarily these functions relate to ensuring that CAMS is able to recover from intermittent failures, and is able to detect equipment temperature fluctuations that might compromise the integrity of the data being collected. Also located on this board is a circuit that provides periodic interrupts that are used by the multitasking executive to switch between tasks.

Watch-Dog Timer

The CAMS system uses a watch-dog timer to detect failures. If the watch-dog timer fails to receive a periodic "keep-alive" signal, which is produced by the multitasking executive each time the system status is examined, a hardware reset is generated to force the system into a known start-up procedure. This allows the system to recover from events such as a power fluctuation that are too short to be detected by the system's power failure monitor.

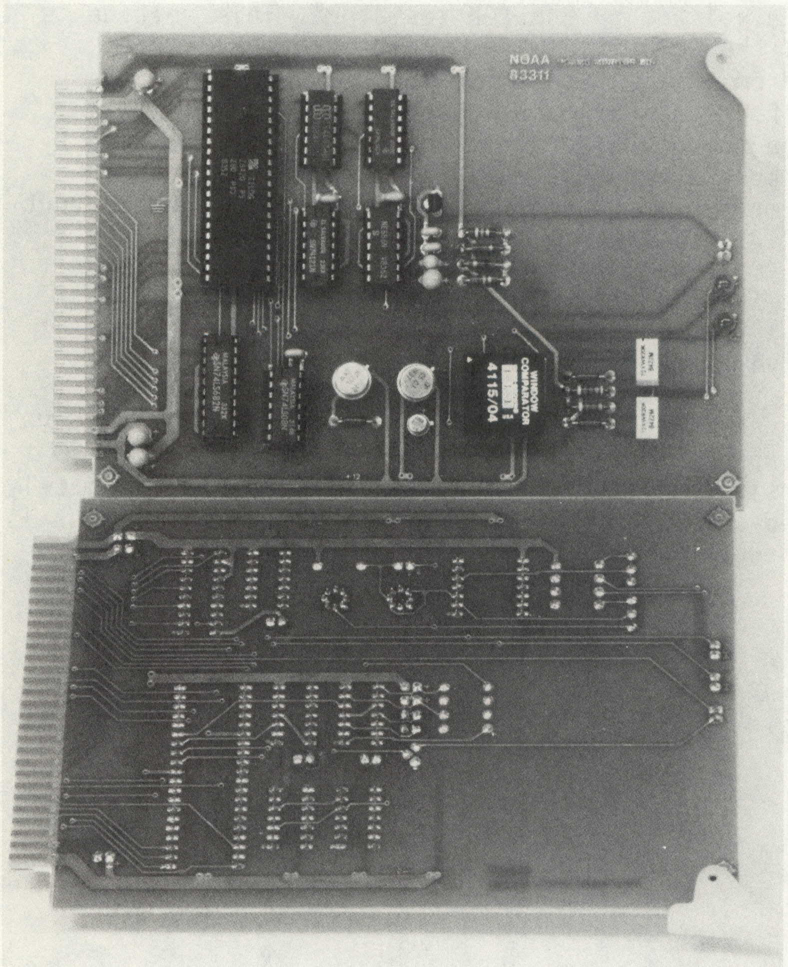


Figure C1.-- The top and bottom sides of the monitor board.

The watch-dog function is implemented using U4, U5, U7, and U8 in Fig. C2. U5 is a one-shot that produces a short pulse for every positive transition of the keep alive signal. This pulse causes a logical zero to be clocked into U4, a D-type flip/flop. This logical zero gates off the periodic pulses coming from U8, a free-running oscillator. Each occurrence of a pulse from U8 causes the state of U4 to change to a logical one. If U4 is not reset the zero state by a subsequent keep alive signal, the next pulse from U8 will pull the system reset line low by means of U1, reseting the system. The maximum time between keep alive pulses is determined by the period of the oscillator. For this application the maximum time is approximately 1 s.

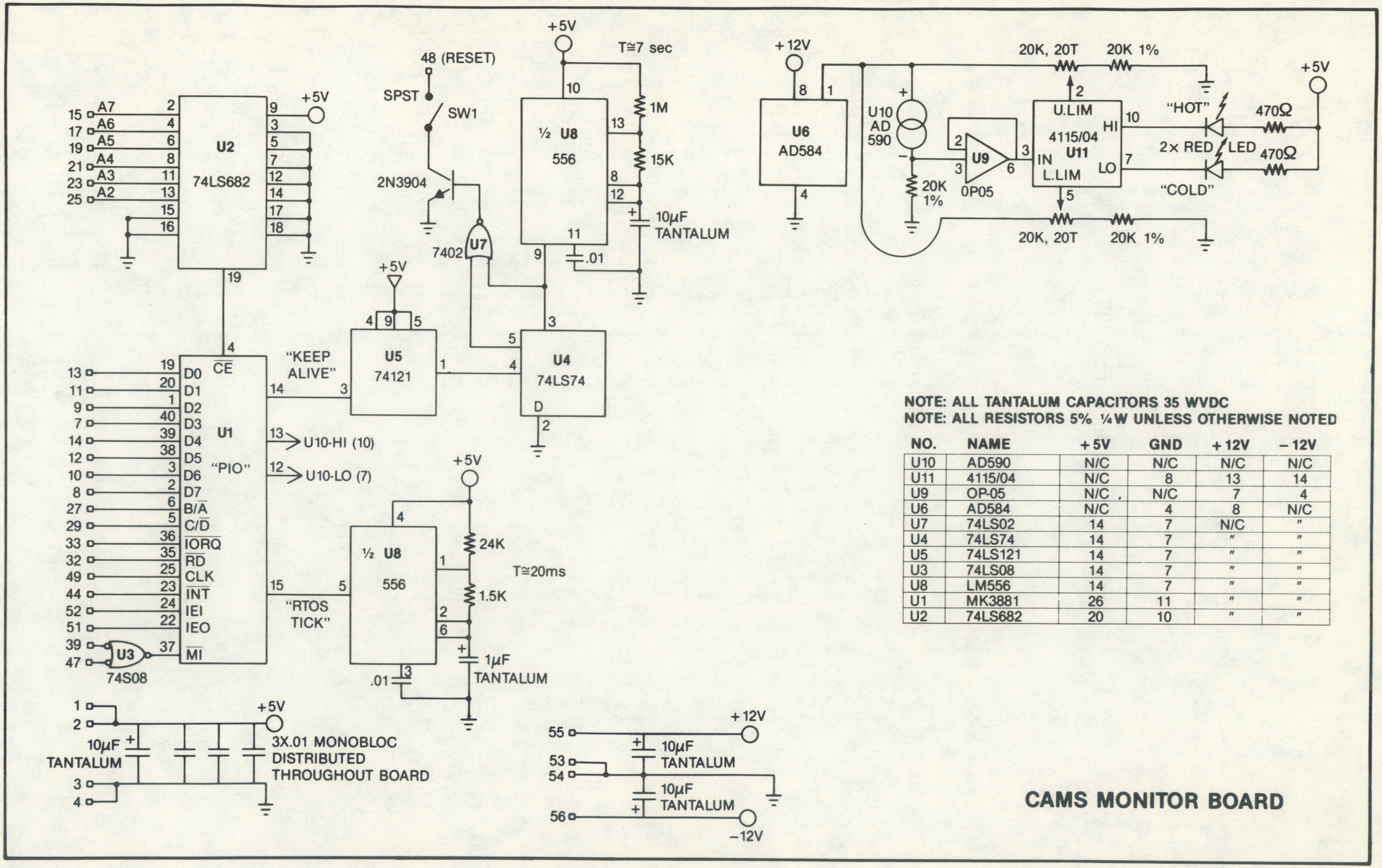
Temperature Alarm

The monitor board includes a temperature alarm circuit to detect enclosure temperatures above and below preset alarm levels. This allows the system to flag data that might be affected by temperature errors in the analog-to-digital convertors, and also alerts the operator to temperature fluctuations that occur when the system is unattended.

This function is provided by U6, U9, U10, and U11 (Fig. C2) and associated components. U6 is a precision voltage source that provides a very accurate, temperature-compensated, voltage reference. U10 is a temperature-controlled current source. The current through U10, which is proportional to temperature, is converted to a voltage by the 20K resistor. This voltage is buffered by op-amp U9, and is then fed into window comparitor U11. U11 compares the voltage signal from U9 against thresholds set by the 20K potentiometers to determine if the temperature is above the upper limit, or below the lower limit. If the temperature is outside the range specified by the potentiometers, the appropriate warning light is turned on, and the condition is reported to the main processor through the parallel input/output controller U1.

Time-Slice Interrupt Circuit

The multitasking executive used to control the CAMS software requires a periodic time-slice interrupt to allow different tasks to share the processor. This interrupt is provided on the monitor board by one-half of U8, and the PIO. U8 is a dual-purpose timer connected as a free-running oscillator that provides a positive pulse train with a period of approximately 10 ms. This pulse, identified as "RTOS TICK," is detected by the PIO which is programmed to interrupt the processor.



NOTE: ALL TANTALUM CAPACITORS 35 WVDC
NOTE: ALL RESISTORS 5% ¼W UNLESS OTHERWISE NOTED

NO.	NAME	+5V	GND	+12V	−12V
U10	AD590	N/C	N/C	N/C	N/C
U11	4115/04	N/C	8	13	14
U9	OP-05	N/C	N/C	7	4
U6	AD584	N/C	4	8	N/C
U7	74LS02	14	7	N/C	"
U4	74LS74	14	7	"	"
U5	74LS121	14	7	"	"
U3	74LS08	14	7	"	"
U8	LM556	14	7	"	"
U1	MK3881	26	11	"	"
U2	74LS682	20	10	"	"

Figure C2.-- The wiring diagram for the CAMS monitor board.

Appendix D:

Operation Procedure for M03

Appendix D: Operation Procedure for M03

Functional operation of the Meteorology-Ozone (M03) CAMS is controlled by the eight black function keys on the microterminal, shown in Fig. D1.

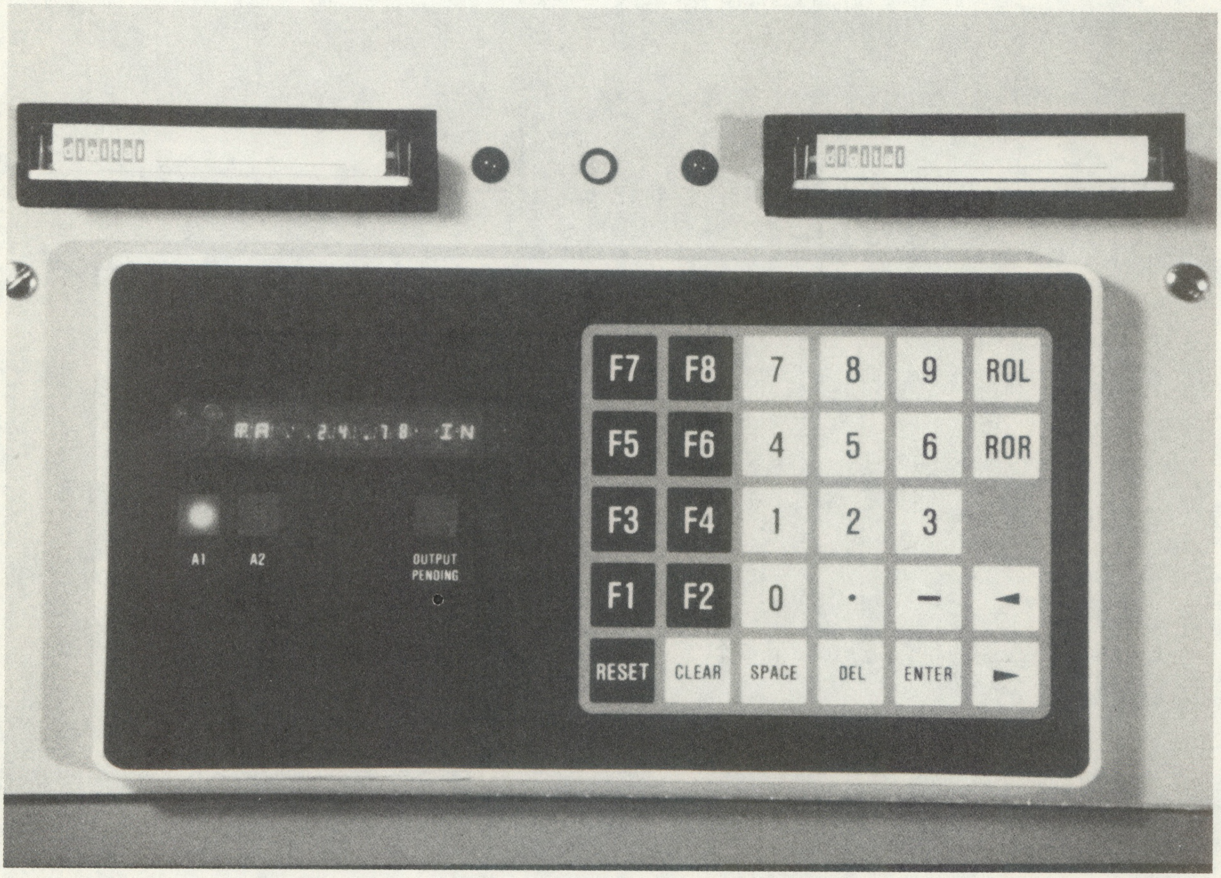


Figure D1.-- A closeup photograph of the front panel of CAMS showing the cartridge tape drives and the microterminal.

Function keys are assigned to operate the clock (F1); monitor the analog-to-digital converter (F2); operate the tape recorders (F3); pass data to the printer (F4); display and clear error messages (F5); input identification and calibration factors (F6); initiate ozone calibrations (F7); and reset the CAMS after a memory failure (F8) see Fig. D2. Pressing any one of these keys causes an immediate response on the microterminal

```
                         M03 CAMS
                    Function Operation

Function -->
   Options
      !
      !
      V

F1
Clock Control
--------------
[ SET CLOCK ?]
[1=YES, 0=NO ]
0: exit
   --------------
1:
   [CLOCK  CNTRL]
   [DATE-       ]
       yyddd
   [TIME-       ]
      hhmmss
   [PRESS ENTER ]
   ==============

F2
A/D Readouts
--------------
[A/D MONITOR ]
[CHANNEL ?   ]
 enter channel
[1=VLT, 2=BIT]

    formats:
[CHnn = v.vvv]
[CHnn = dddd ]
==============

F3
DECtape Access
--------------
[TAPE CONTROL]
[ENTER OPTION]
0: exit
   --------------
1:
   [ NEW TAPE ? ]
   [1=YES, 0=NO ]
       0: exit
     1:
   [ENTER DRV#  ]
     0 or 1
   --------------
2:
   [ CLOSE TAPE ]
   [1=YES, 0=NO ]
       0: exit
     1:
   [ TAPE  FULL ]
   --------------
3:
   [ BAD TAPE ? ]
   [1=YES, 0=NO ]
       0: exit
     1:
   [REMOVE  TAPE]
   [  1=READY   ]
     1:
   [TAPE VALID ?]
   [1=YES, 0=NO ]
   0: xeq F3.1
   1:
   [ACTIVE DRV #]
       0 or 1
   --------------
4:
   [DRV0-ACTIVE ]
   [DRV1-VALID  ]
   ==============

F4
Printouts
--------------
[ PRINTOUTS  ]
[PRINTER ON ?]
0: exit
   --------------
1:
   [SELECT TYPE  ]
0: exit
   --------------
1: Daily Weather
   --------------
2: Ozone Report
   --------------
3: ID array
   --------------
4:
   [ENTER BLK#  ]
     (0..511)
   [ENTER DRV#  ]
     (0 or 1)
   --------------
5: Tape Directory
   ==============

F5
Error Handling
--------------
[ERR HANDLING]
[ENTER OPTION]
0: exit
   --------------
1: last error
   [###-dddhhmm ]
   --------------
2:
   [ CLEAR MSG? ]
   [1=YES, 0=NO ]
     (0 or 1)
   [OK TO RECORD]
   [1=YES, 0=NO ]
     (0 or 1)
   ==============

F6
Cal Factors
--------------
[CAL  FACTORS]
[1=YES,  0=NO]
    0: exit
    1: cont
[ENTER CH#   ]
 enter channel
[aa CH OK?   ]
[1=YES,  0=NO]
   1: change
   0: skip

[BEGIN        ]

[nn aa        ]
[0=CHG,1=CONT]
     1:
[ENTER CHG-  ]
      .
      .
      .
 enter factors
for all channels
==============

F7
Ozone Cal
--------------
[ OZONE CAL  ]
[PRINTER ON ?]
[1=YES,  0=NO]
    0: exit
    1: cont
[NEXT  SOURCE]
[1=READY     ]
  15 min wait
[OZONE  CHECK]
      .
      .
      .
 cycle repeats
press 0 to quit
==============

F8
# Box Reset #
--------------
[  9 = RESET ]

9: reset
   [INITIALIZE]

     xeq F1
     xeq F3.3
     xeq F6

[INPUT STA ID]
 (station id)
[nn OK?      ]
[1=YES,  0=NO]
 0: redo
 1: continue
==============
```

Figure D2.-- Listing of M03 CAMS functions and operations.

display, which identifies the operation or peripheral to be implemented. The example shown in Fig. D3 is for the most commonly used printout function. After pressing F4 the

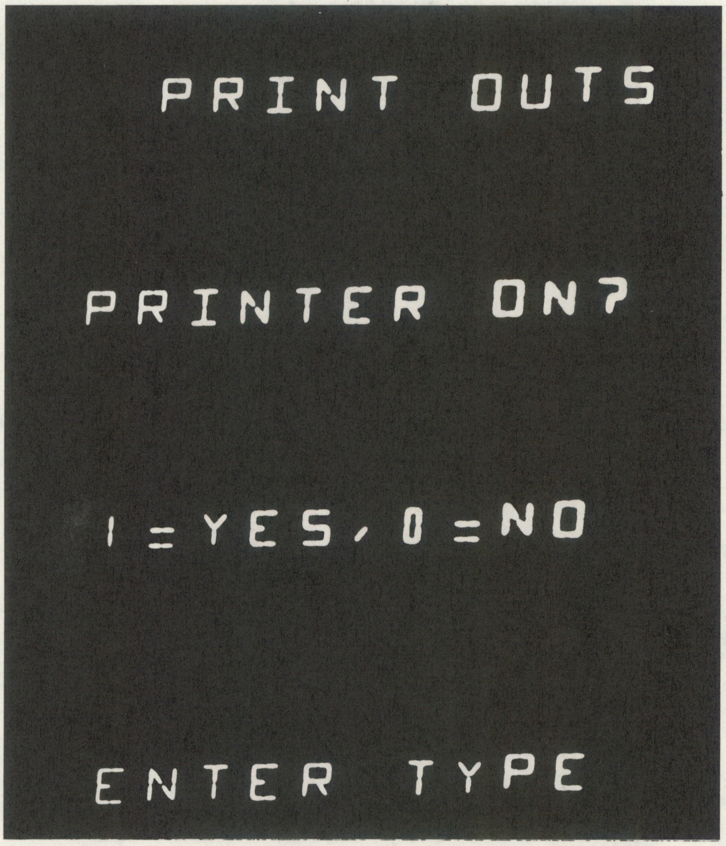


Figure D3.-- A multiple-exposure photograph of the LED display in the microterminal on the M03 CAMS showing the sequence of promps issued at the request for printout.

display shows "PRINT OUTS" followed by "PRINTER ON?" followed by "1=Y, 0=N" to which the operator must respond. This cue allows the operator to turn the printer power on and switch the printer input to the M03 CAMS if necessary. The printer is to be turned off at all times it is not in use. Following two yes responses, achieved by pressing "1" and "ENTER," the CAMS responds by displaying a request for the type of printout desired "ENTER TYPE." The various printout types are listed in Fig. D2, column F4. A "0" response to the "PRINTER ON?" request causes CAMS to exit this function. Printout will begin immediately after the type is entered. Printout does not interrupt the flow of data into CAMS or the recording of data, because the transfer is directly into a printout buffer in the printer at a rate of 2400 baud. The other function switches operate in much the same way as the printout function.

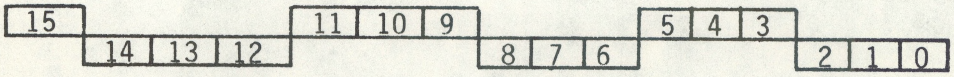
Appendix E:

Data quality Assurance Flags

Appendix E: Data Quality Assurance Flags

A system of flags, which call the observers attention to irregularities in the data set, are a necessary part of any program to maintain data quality. In the case of the meteorological variables, which are represented on the Daily Weather Report (DWR), there are three types of tests that must be made. The first involves accounting for the loss of data within the hour. Tallies are not printed on the DWR, so a critical level was set at 80% to cause a flag to show that for the specific hour more than 20% of the data from a specific channel is missing, for any reason. In the case of power interruptions and the failure of the analog-to-digital converter, a separate flag is set to denote these significant events. Interruption to the aspirator airflow to the thermometers is also flagged. The second class of flags denote hours when calibrations are conducted. In this case the normal flow of data is interrupted. The third class concerns the occurrence of data discrepancies that can be generally limited by the physical nature of the measurement. These include dew point temperatures that exceed the air temperature, tower top temperatures that are cooler than the temperature at the base of the tower, and prolonged periods of calm winds. The flags are updated hourly. They are displayed on the microterminal LED display and printed alongside the data/time column on the DWR.

The flag consists of a five digit number in a binary-coded-decimal format. It takes the form shown below with the bits numbered from right to left.



0. Ozone calibration occurred.
1. Ozone data tally <80% of complete hour.
2. Ozone data tally <20% of complete hour.

3. Pacer circuit on this hour.
4. Dew point temperature > air temperature, TA.
5. Dew point temperature tally <80% complete.

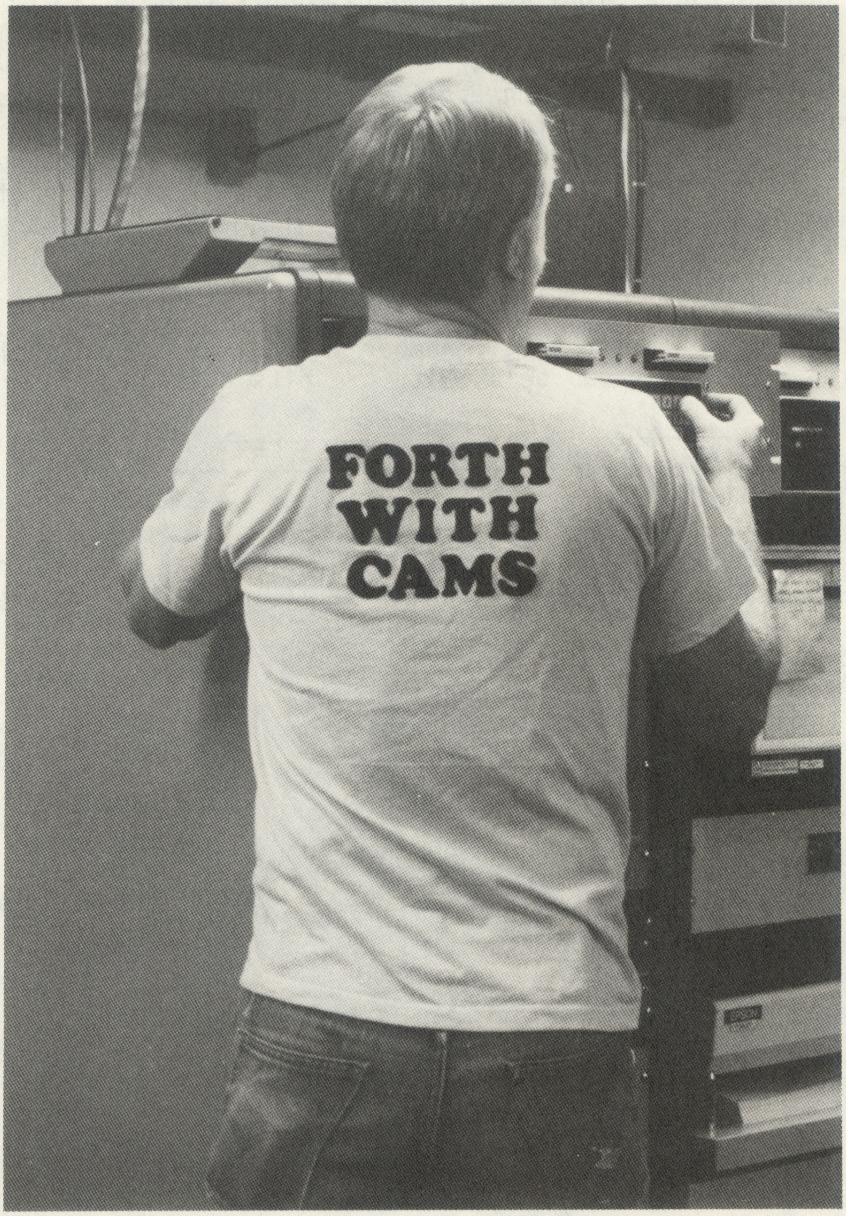
6. Temperature aspirator inoperative.
7. Air temperature TA > TB.
8. Air temperature TA or TB tallies <80% complete.

9. Primary wind values <1 mph (~0.5 m s^{-1}) for >20% of hour.
10. Secondary wind values <1 mph (~0.5 m s^{-1}) for >20% of hour.
11. Primary wind tally <80% complete.

12. Secondary wind tally <80% complete.
13. Pressure tally <80% complete.
14. Autorestart occurred this hour.

15. Analog-to-digital converter out of registration.

The flags are grouped so that the most significant errors are left justified thus attracting the most attention. The more routine calibration features are on the right-hand side. The variables are generally grouped by digit so the operator can quickly determine the measurement causing the flag. The observers are trained in the approprate action to take as a result of each flag.



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