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AN AUTOMATIC RAINGAUGE SYSTEM

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SUMMARY

This Technical Note contains functional descriptions of the hardware and software of a rainfall data acquisition system developed by the Royal Observatory for the Geotechnical Control Office of the Civil Engineering Services Department of the Hong Kong Government. Detailed circuit and program descriptions have not been included for the sake of brevity.

Procedures for installing and maintaining the system are also described in this Technical Note. This is intended to give the reader an idea of the resources and efforts required to actually install and maintain a system of this type.

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1. INTRODUCTION

Real-time rainfall information throughout the territory of Hong Kong is essential for the efficient operation of the Landslip Warning Service provided jointly by the Geotechnical Control Office (GCO) and the Royal Observatory of the Hong Kong Government. In 1978, a network of tipping bucket raingauges was installed at a number of filled slopes in Hong Kong to monitor the rainfall in real-time. Each raingauge was connected through a pair of leased telephone lines to a calculator at the central station in the GCO Headquarters. A DC voltage of the order of 70 V was applied through a resistor to the leased lines. Whenever 0.5 mm of rainfall was collected by the raingauge, the tipping mechanism would cause a reed relay to close momentarily. This closed the DC path between the raingauge and the central station and caused a voltage to appear across the resistor at the central station. The calculator was modified to sense and count such voltage pulses and print out the cumulated rainfall at 15-minute intervals on its built-in printer. There was no electronic circuitry at the raingauge sites. This calculator-based automatic raingauge system was designed and constructed by the Royal Observatory (Reference 1).

To allow for greater flexibility and complexity in processing and displaying rainfall data, the initial system was replaced by a microcomputer-based system in 1982. Reed relay closures caused by rain at the raingauge sites were sensed at the central station by parallel ports of the microcomputer which computed and displayed the cumulated rainfall over specified periods every 5 minutes on a video terminal. The data were archived on magnetic tapes and also sent through modems and leased telephone lines to the Royal Observatory Headquarters for display in the Central Forecasting Office and further processing by the main computer system. This system was designed by the Royal Observatory and constructed by a contractor.

In this microcomputer-based system, the same simple method of sensing a voltage across a closed DC path was employed, and there was no electronic circuitry at raingauge sites. At the central station, it was almost impossible to tell the difference between faulty leased lines and no rainfall. Besides, transient voltages picked up by leased lines during lightning could also trigger the central station electronics and give rise to false rainfall counts. Worse still, the Hong Kong Telephone Company was beginning to phase out telephone lines with physical continuity around 1984. Although existing leased lines could still be retained for some time, lines with physical continuity for new raingauge stations were difficult to obtain. Finally, the power consumption of the system was large, and it was not possible to back up the power supply against long durations of AC outage which occasionally occurred.

In 1987, the Royal Observatory was commissioned by the GCO to upgrade the automatic raingauge system to overcome the above problems. Specifically, the upgraded system was required to (i) operate continuously even during prolonged AC outage (up to 6 hours), (ii) be compatible with existing leased lines with physical continuity as well as new lines without physical continuity, and (iii) be less susceptible to interference by voltage surges on the leased lines. The system that was eventually designed and constructed replaced the entire old system except the raingauges and the leased lines. The new system was installed and put into operation in March 1989. The features of this system is shown in Appendix A.

The design of the automatic raingauge system is described in this Technical Note. The principles of operation of the major hardware and software modules are explained in detail.

2. SYSTEM CONFIGURATION

The automatic raingauge system consists of a number of field stations connected to a central station through leased telephone lines and modems. A block diagram of the entire system is shown in Figure 1. Data and control information are passed between the field stations and the central station by serial asynchronous communication through modems.

Each field station consists of a tipping bucket raingauge and a microprocessor-based electronic package. The microprocessor monitors the tipping of the raingauge and determines the cumulated rainfall for every 5-minute interval. The latest three 5-minute cumulated rainfall values are stored in its memory, and passed to the central station on request. The electronics are powered by a battery, which is charged by a solar panel. There is no requirement for an AC supply, and this greatly reduces the chance of damage to electronic circuitry by lightning-induced surges on the AC line.

The central station consists of two identical processors linked to a supervisor/multiplexer unit, a printer and an off-line microcomputer system. Normally, only one processor will be active while the other is on hot stand-by. The active processor polls the field stations once every five minutes to get the latest three 5-minute cumulated rainfall values. It then computes the cumulated and running total rainfall over longer periods as required for the Landslip Warning Service, and displays the result on a LCD panel. The active processor also (i) prints the results on a printer once every 15 minutes, (ii) sends the latest set of data to a rainfall data receiver at the Royal Observatory Headquarters via leased lines once every 5 minutes, (iii) saves the data in its memory (up to one day's worth of data) and passes them interactively at high speed to the off-line microcomputer system for archival and off-line processing when the latter is ready to receive data, and (iv) passes the latest set of data to the stand-by processor.

If the active processor fails, the supervisor unit will automatically switch in the other processor which is on hot stand-by. There will be no interruption in the operation of the system. This backup feature greatly minimizes the chance of data loss due to failure of electronic components. The two processors and the supervisor unit are constructed of low power consumption components and powered by two independent battery-backed power supply units. Data acquisition, display, transmission and archival will not be interrupted by AC outage lasting up to 24 hours.

Because field units are intelligent and modulated signals are transmitted across leased lines, it is possible to distinguish between failure of leased lines and no rainfall. Errors introduced by noise on the leased lines or intermittent failure of the leased lines can also be detected, and data can be recovered by repeated transmission.

With modems, the telephone lines connecting field stations and the central station need no longer to have physical continuity. Furthermore, the hardware at the field station has even been designed to work in both switched and non-switched telephone networks. Only the software needs to be modified to migrate to a switched network.

3. HARDWARE FUNCTIONAL DESCRIPTION

3.1 Field station

The block diagram of the field station is shown in Figure 2. Its functional blocks include a tipping bucket raingauge, a microprocessor, a modem, a duplexer, a power supply unit and a battery voltage monitor. All electronics, except the solar panel and the battery of the power supply unit, are located on a single printed circuit board (PCB).

Since the field station is powered by solar energy, low power consumption was the prime consideration in the field station hardware design. All components used are of the low power consumption type. Total current consumption of all electronic components is less than 20 mA. To conserve power further, the microprocessor is programmed to enter the "idle" mode (see section 3.1.2) when no processing is required.

3.1.1 Tipping bucket raingauge

The tipping bucket raingauge is a rainfall sensor which has two water collecting buckets balanced on a pivot like a seesaw. When one bucket has collected 0.5 mm of rain, the seesaw tips and temporarily closes a reed relay switch. Counting the number of tips over a certain time period gives the cumulated rainfall over that period.

3.1.2 Microprocessor

The microprocessor is an 80C31 8-bit single-chip microcontroller. It has 128 bytes of RAM, four 8-bit parallel I/O ports, two 16-bit timer/counters, one serial port and two external interrupt inputs. Two of the four parallel ports are used to drive the address and data buses of a 4 kB EPROM which stores the program, and a detachable 2 lines by 20 characters LCD display panel. One of the two ports is also used to sense the value of an 8-bit DIP switch, which is used to set the station number.

The raingauge reed relay output is connected to an external interrupt pin of the microprocessor. Any tip of the raingauge generates a pulse at this pin and causes the microprocessor to execute an interrupt subroutine to add 1 (equivalent to 0.5 mm of rain) to the data buffer.

The microprocessor maintains a real-time clock, which is implemented using one of its timer/counter channels. The main function of the clock is to provide the timing for determining the 5-minute cumulated rainfall. The clock can be set using push-buttons on the PCB or from a diagnostic unit. The detachable LCD display panel is used to facilitate setting the clock via the push-buttons.

The microprocessor keeps count of the number of tips in 5-minute intervals. The latest three 5-minute rainfall values are stored in its memory. When a request for data comes from the central station, the three rainfall values will be passed to the central station. The reason for sending the latest three 5-minute rainfall values instead of just the latest 5-minute value is to allow data recovery when the communication between the field station and the central station cannot be immediately established when the field station is polled due to noise in the leased lines or intermittent faults of the leased lines.

The microprocessor can be programmed to enter an "idle" mode to conserve power. In the idle mode, CPU operation is halted until there is an interrupt from the timer/counters, serial port or external interrupt inputs.

3.1.3 Modem

The microprocessor exchanges information with the central station by asynchronous serial communication through modems. The modem conforms to Bell 212 standard and is operated in 2-wire full duplex mode at 1200 bauds.

3.1.4 Duplexer

The duplexer interfaces the modem to the telephone lines. Its function is to minimize interference between the signal output from the modem and the signal received from the other end. A line matching transformer matches the impedance of the duplexer to that of the telephone lines (600 ohms nominal). A relay controlled by the microprocessor can disconnect the transformer from the telephone lines, which is used to simulate an on-hook condition when the system is used in a dial-up telephone network. When using leased lines, the transformer is always connected to the leased lines.

3.1.5 Power supply unit

The power for operating the electronics is derived from a 6 V battery charged by a 5 W solar panel. A shunting regulator, which is just a zener diode, is used to dissipate excessive energy from the solar panel when the battery is fully charged. From the battery voltage, a DC to DC converter and filter circuits provide a stabilized +5 V and -5 V for powering the electronics.

3.1.6 Battery voltage monitor

The battery voltage monitor is basically a voltage divider circuit which outputs either a logic "1" or "0" voltage depending on whether the battery voltage is above or below a preset threshold. The microprocessor samples the output of the monitor through one pin of a parallel port and reports its status to the central station every five minutes together with the rainfall information. This gives early warning to the operator at the central station of impending power outage at the field station, so that replacement of aged or faulty battery can be carried out promptly.

3.2 Diagnostic unit

The diagnostic unit was designed and built to facilitate installation and trouble-shooting of field stations. It has a mating connector which can be plugged onto the field station electronic package directly for local testing. Remote testing is also possible by connecting the diagnostic unit and the field station through leased lines.

The diagnostic unit maintains a real-time clock. It can request rainfall data from the field station just like the central station. It can also issue two other commands, one to read the field station's real-time clock, and the other to set the field station's real-time clock.

Test functions are initiated via four push-buttons on the front panel. Prompting messages and replies from the field station are displayed on a 2 lines by 20 characters LCD panel.

The diagnostic unit is powered by six AA-size nickel-cadmium batteries. Recharging the batteries is necessary from time to time. Fully charged batteries will give about 10 hour of continuous operation.

The hardware of the diagnostic unit is nearly identical to the field station PCB, but the push-buttons on the PCB are used to activate different functions.

3.3 Central station

The central station has six major functional blocks, namely processor-A, processor-B, supervisor, multiplexer, transformer array and off-line microcomputer system. Some of these major functional blocks can be broken down into smaller functional units. The block diagram of the central station is shown in Figure 3.

3.3.1 Processor-A and processor-B

Processor-A and processor-B are identical both in hardware and software. Each processor is essentially a CIMBUS microcomputer and comprises a CIM-804C CPU board, a CIM-110C universal memory expansion board, a CIM-203C serial I/O board, a LCD panel and controller, a battery and charger, a power supply board, and a power tapping board.

3.3.1.1 CIM-804C CPU board

The NS CIM-804C CPU board is based on the NSC800 8-bit microprocessor. The CPU board has the following functional units:

(a) NSC800 CPU: functionally similar to the Z80 microprocessor but it has three additional re-start inputs.

(b) NSC810 RAM-I/O-Timer: providing three 8-bit parallel input/output ports and two 16-bit timer/counters (with pre-scalars)

(c) Memory circuits (EPROM and RAM): consisting of 2 kB of static RAM, a socket for a 4 kB EPROM, and address-decoding circuits for the system bus.

(d) Interrupt control circuits: providing both timed interrupts for process control and eight asynchronous priorized interrupts to the NSC800 microprocessor.

3.3.1.2 CIM-110C universal memory expansion board

The NS CIM-110C universal memory expansion board allows expansion of the system memory by as much as 128 kB in two overlapping banks, designated A and B, of 64 kB each. Eight sockets on board allow installation of memory chip of different sizes and types including static RAM and EPROM.

As used in the automatic raingauge system, the CIM-110C holds 32 kB of RAM for data, 8 kB of EPROM for program and 4 kB of EPROM for a table referencing field station names and locations to channel numbers.

3.3.1.3 CIM-203C serial I/O board

The NS CIM-203C is a dual channel serial I/O board. Each channel can be configured to operate as RS-232C, RS-422 or RS-423, TTL or +/- 15V I/O levels, DCE or DTE output mode, asynchronous or synchronous. The bit stream format and the baud rates are programmable.

In the automatic raingauge system, only one serial channel is used, and it is configured for RS-232C asynchronous operation at ±15 V level. Through this serial port, the processor sends data to the serial printer, and communicates with the field stations, the Royal Observatory rainfall data receiver, the off-line microcomputer system and the other processor. The port is switched to communicate with each device in turn by a multiplexer controlled by a parallel port of the CPU board. Different baud rates are used when the port is connected to different devices.

3.3.1.4 LCD panel and controller

The LCD panel is a graphic display panel with a resolution of 640 x 200 dots. It is of the TN-FEM positive and reflective type with a viewing angle of about 30 degrees. The panel is driven by a LCD controller which interfaces directly to the CIMBUS. There is a character generator in the controller. In the automatic raingauge system, the panel is used to display 22 lines by 106 characters of text.

3.3.1.5 Battery and charger

The power for the processor is derived from a 12 V battery which is float charged by a battery charger. The battery has a capacity of 30 AH and can provide over 24 hours of backup power during AC outage.

3.3.1.6 Power supply board

The power supply board produces from the 12 V battery voltage stabilized +5 V, +12 V and -12 V for powering the electronics. It consists of a low voltage detector (LVD), a switch-mode regulator and filter circuits.

The LVD controls the power to the regulator. When the battery voltage falls below 10.8 V, the LVD cuts off the current from the battery to the switch-mode regulator. This is to prevent permanent battery damage when the battery becomes over discharged for some reason. The LVD will allow current to flow from the battery to the switch-mode regulator again when the battery voltage rises back to 11.5 V.

The switch-mode regulator converts the battery voltage to +5 V and -12 V, through two different windings of a transformer. The +12 V is obtained by filtering the LVD output to remove ripples introduced by the switch-mode regulator.

The +5V, +12V and -12 V outputs of the power supply board are distributed to other boards of the processor through the CIMBUS.

3.3.1.7 Power tapping board

The power tapping board is used to tap the +5 V, +12 V and -12 V from the CIMBUS of the processor to power the supervisor/multiplexer. It has no electronic components on board. The three supply voltages are brought by a cable from this board to the power board of the supervisor/multiplexer.

3.3.2 Supervisor

The supervisor monitors the status of operation of processor-A and processor-B, and automatically switch in the stand-by one when the active one malfunctions.

By software, a 2 Hz pulse train is generated at one pin of a parallel port of each processor. The presence of this pulse train indicates that the corresponding processor is functioning normally. When a processor fails to execute programs correctly due to component failure or other reasons, it most probably will cease to output the pulse train. This triggers the hardware of the supervisor to switch in the stand-by processor, allowing its serial port to communicate with the field stations, serial printer, Royal Observatory rainfall data receiver and off-line microcomputer system while preventing the other processor from doing so. If both processo'rs are alright, the stand-by one regularly gets the latest rainfall data and status information from the active one so that when the former is switched in, it can carry on the operation of the central station without loss of data.

3.3.3 Multiplexer

The multiplexer is used to switch the serial port of the active processor to various devices (i.e. field stations, serial printer, Royal Observatory rainfall data receiver, off-line microcomputer system and the stand-by processor). It is driven by a parallel port of the active processor under software control.

The multiplexer consists of two stages. First of all, the serial port is switched to one of the serial printer, off-line microcomputer system, stand-by processor and the modem/duplexer circuit. The modem/duplexer circuit is used for communication with the filed stations and the Royal Observatory rainfall data receiver through leased telephone lines. In the second stage of multiplexing, the modem/duplexer line output is further switched between 63 raingauge channels and the Royal Observatory rainfall data receiver.

The supervisor and multiplexer reside on a single PCB.

3.3.4 Line transformer array

Each pair of leased line is connected to the multiplexer through a matching transformer to match the impedance of the telephone lines (nominal 600 ohms). There are eight transformer boards each containing eight transformers.

3.3.5 Off-line microcomputer system

The off-line computer is an IBM/PC AT compatible microcomputer system. It has 1 MB of system memory, a video console with a resolution of 640 x 400 pixels x 16 colours, a 1.2 M floppy disk drive, a 40 MB hard disk drive, a dot-matrix printer and two asynchronous serial ports. One of the serial ports is connected to the multiplexer.

For most of the time, the microcomputer system is used for analysis of rainfall data and other off-line jobs. Every day, a data archival program has to be executed to archive rainfall data stored in the active processor's memory. The transfer is done interactively with the off-line microcomputer system acknowledging the receipt of every set of data. No data will be lost unless the data buffer in the active processor overflows. This buffer can hold up to one day's data. As the data transfer is done at a high speed (9600 bauds), the time required for archival of data is short.

Normally, data received from the active processor are archived on the hard disk. If the hard disk fails, the data can be archived on floppy disks.

4. SOFTWARE FUNCTIONAL DESCRIPTION

4.1 Field station

4.1.1 Software development

The software of the field station was developed using an IBM PC/AT microcomputer system with a cross-assembler and an emulator for the 80C31 microcontroller. All program codes were written in the 80C31 assembly language.

4.1.2 Software functions

The 80C31 uses the 128 bytes of internal RAM for work area and data storage only. Program codes are stored in an external 8 kB EPROM.

Field station timing is scheduled by a real-time clock. This clock is implemented by programming Timer-0 to operate as a 16-bit timer, which generates an interrupt once every sixteenth of a second. The clock can be set by a diagnostic unit, or with three push-buttons labelled "DIG SLT", "DIG ADV" and "SET/RUN" on the PCB and with the detachable LCD panel. Rainfall cumulation period is 5 minutes, ending at the 0th minute, 5th minute, 10th minute, etc of the hour. The full date and time, i.e. YYMMDDhhmmss, is implemented in the real-time clock, but only mmss (i.e. minutes and seconds) are used for rainfall measurement. When the real-time clock starts running after power on or push-button reset of the microcontroller, it always starts from 00 minute 00 second. Hence, for proper operation of the field station, it is possible to set the real-time clock simply by resetting the microcontroller by the RESET push-button on the 00, or 05, or 10, ..., or 55 minutes of the hour, without using the set clock buttons and the detachable LCD panel. Time-outs are also implemented using Timer-0 interrupts.

Timer-1 is programmed for serial port baud rate generation. This timer does not generate any interrupt. The serial port generates an interrupt after a character is received or sent by it.

Operation of the software begins with the initialization of the program stack pointer and the timer channels, and clearing of the internal memory. Once the initialization is completed, the real-time clock starts running and the field station enters the operation mode. If there is no pending interrupts, the processor enters the power saving idle mode.

Timer-0 interrupts occur sixteen times in one second. On entering the interrupt service routine, the microprocessor updates the real-time clock. It then checks the push-buttons to see if any clock setting service is required, and also checks the time-out counters. These checks result in certain flags to be set. Upon exiting from the interrupt service routine, the microprocessor examines the flags to determine what tasks have to be executed. After executing these tasks, the microprocessor returns to the idle mode.

If the raingauge has collected 0.5 mm rainfall and tips, INT0 will interrupt the microprocessor, waking it from the idle mode. On entering the interrupt service routine, the processor increments the cumulated rainfall buffer of the current 5-minute period. The content of this buffer is the number of tips in the current 5-minute interval. A 1.2 seconds software debounce has been implemented to prevent false counting due to contact bouncing of the reed relay in the raingauge.

When the serial port receives a character from the central station, it will interrupt the processor, waking it from the idle mode. On entering the interrupt service routine, the microprocessor reads the serial port buffer to determine what further actions to take. If the received byte is a request for data <DC1>, the microprocessor sets an enquiry flag. On exit from the interrupt routine, it outputs from the serial port an acknowledge byte <DC2>, followed by a data message of the following format:

<SOH>SS$D_3D_2D_1$BCS<ETX>

where <SOH> = 01H
SS = 2 ASCII bytes for site number in hexadecimal notation (01 to 3F)
D_3 = 2 ASCII bytes for number of tips (in hexadecimal notation) in the 3rd 5-minute interval before current time
D_2 = 2 ASCII bytes for number of tips (in hexadecimal notation) in the 2nd 5-minute interval before current time
D_1 = 2 ASCII bytes for number of tips (in hexadecimal notation) in the last 5-minute interval before current time
B = either an ASCII "+" (2BH) for battery alright or a "-" (2DH) for battery low
CS = 2 ASCII bytes of checksum being the complement of (SS + D_3D_3 + D_2D_2 + D_1D_1 + B)
<ETX> = 03H

After each byte is sent, the serial port generates a transmit interrupt and the processor will load the serial output buffer with the next byte until the entire data message has been transmitted.

After transmission of the last character of the data message, the microprocessor expects to receive a an acknowledge byte <DC3> or another <DC1> from the central station within 5/16 second. When <DC3> is received, or when 5/16 second lapsed, whichever occurs first, the microprocessor enters the idle mode. If <DC1> is received instead, signifying that the central station has not received the correct data message, a <DC2> and data message will be sent again as before. If after nine re-tries the correct message is still not received, the central will know that the communication link is faulty, and it will go to poll the next field station.

Instead of being connected to the central station through leased lines, the modem can be connected to the diagnostic unit for testing or trouble-shooting. The diagnostic unit can request rainfall data from the field station just like the central station. It can also issue two other commands, one to read the field station's real-time clock, and the other to set the field station's real-time clock. The format of the two commands are as follows:

(a) Diagnostic unit requests field station to output date and time information:

<BEL><BEL><BEL>

where <BEL> = 07H

The field station will send the date and time informations as follows:

YMDHmsC

where YMDHms is year, month, day, hour, minute and second in binary notation. C is a checksum equal to the complement of the sum of preceding characters.

(b) Diagnostic unit requests field station to set clock according to date and time embedded in request:

<DC4><DC4><DC4>YMDHmsC

where <DC4> = 14H and YMDHmsC is defined as in (b) above.

The detachable LCD panel can show 2 lines by 20 characters of text. The format of the display is as follows:

YY-MM-DD hh:mm:ss
$SSD_3D_2D_1BCS$ nnnn

where YY, MM, DD, hh, mm and ss are the year, month, day, hour, minute and seconds respectively. SS is the site number in hexadecimal notation (1 to 3F). D_3, D_2 and D_1 are the latest three 5-minute rainfall values (number of tips in hexadecimal notation). B is "+" if the battery voltage is normal and "-" if battery voltage is low. CS is the checksum equal to the complement of the sum of all preceding characters of the second line in hexadecimal notation. Finally nnnn is the number of requests which have been received from the central station or the diagnostic unit since last CPU reset.

4.2 Central station

4.2.1 Software development

The software on processor-A and processor-B are identical, and are developed using an IBM PC/AT microcomputer system, with a cross-assembler for the NSC800 microprocessor. All program codes were written in the NSC800 assembly language. For program testing and debugging, a firm-ware monitor EPROM supplied by the manufacturer of the CIMBUS boards is inserted in the CIM-804C CPU board. With this firm-ware monitor, the application program can be down loaded from the IBM PC/AT microcomputer system through a serial I/O port and debugged.

The data archival software on the off-line microcomputer system was developed on the microcomputer system itself using a BASIC compiler.

4.2.2 LCD panel displays

Most of the software functions of the central station are manifested on the LCD panel display of each processor. The LCD panel is programmed to display 20 lines by 106 characters of text. The format of the display is as follows:

4.2.2.1 Central station status

Line 1 is the system name and program version number:

<< GCO Rainfall Data Acquisition System V 1.0 8811 >>

Line 2 shows the system status:

(1) STATE : The current processing state of the processor:

Scan#nn = Polling raingauge site No. nn.

Process = Polling completed, computation being performed.

O/P CXL = Sending rainfall data to the other processor.

I/P CXL = Receiving rainfall data from the other processor.

O/P R.O. = Outputting rainfall data to the Royal Observatory.

O/P PNTR = Outputting rainfall data to serial printer.

O/P OLP = Outputting rainfall data to off-line microcomputer system.

WAITING = All I/O and computations completed. Watching the time to begin next processing cycle.

(2) SYS : The active/stand-by status of this processor:

on-line = Processor is in active mode to perform all processing tasks including polling raingauge stations and outputting data to various devices

standby = Processor is in stand-by mode. It receives rainfall data from the active processor every 5 minutes to update its own internal data buffers, and is always ready to take over as active processor when the current active processor fails.

(3) SBD : The status of the serial board as determined by loop-back test:

OK = Serial port is serviceable.

U/S = Serial port is unserviceable. Repair is required.

(4) CXL : The status of the communication link between processor-A and processor-B:

OK = Information exchanged correctly.

U/S = Communication breaks down.

(5) RO : The status of the communication link to the Royal Observatory:

OK = Information exchanged correctly.

U/S = RO rainfall data receiver busy. U/S lasting over one minute indicates that a fault has occurred. Either the leased line or the RO rainfall data receiver is faulty.

(6) OLP : The status of communication link with the off-line microcomputer system:

OK = Information exchanged correctly.

U/S = The off-line microcomputer system is either not ready to archive data or the link is disconnected.

(7) [nnn] : The number of sets of 5-minute rainfall data to be sent to the off-line microcomputer system. The processor can store up to one day of data (288 sets), beyond which loss of data occurs. Once the off-line microcomputer system is ready to receive data, the processor will send the stored data to it until the latest two sets are left. Not sending the last two sets allow the processor to account for backlog data from the field stations.

(8) TIME: hh:mm:ssH DD-MMM-CCYY WWWWWWWWW

hh = Hour (24-hour clock is used),
mm = Minute,
ss = Second,
H = "H" standing for Hong Kong standard time,
DD = Day,
MMM = Abbreviation of month of year,
CC = Century,
YY = Year,
WWWWWWWWW = Day of the week.

"RO", "OLP", "[nnn]" make sense only when the processor is active.

4.2.2.2 Rainfall and field station status display

Line 3 to 22 of the LCD display shows one of four pages of rainfall data and field station status. The default page shown after polling raingauge stations is page 1. The operator can select other pages by pressing the push-button "NEXT" on the front panel when "STATE" is showing "WAITING".

Page 1 to page 3 shows rainfall data. Page 4 shows the status of field stations. All rainfall values shown have a range of 0 to 999.5 mm. Overflow is denoted by "OVRFW". Values exceeding preset threshold levels will be shown preceded by the character:

- * when the value has just exceeded the threshold in the latest 5-minute interval but not the preceding one.

- " when the value exceeded the threshold in the last two 5-minute intervals.

Current threshold values are:

(a)	1/4HR	15-minute running total	15 mm
(b)	1 HR	1-hour running total	30 mm
(c)	4 HR	4-hour running total	50 mm
(d)	24 HR	daily running total	100 mm
(e)	Q	15-minute accumulated total	15 mm
(f)	H	1-hour accumulated total	30 mm
(7)	D	daily accumulated total	100 mm

The three pages of rainfall data are:

(1) Page 1 : running totals

The column headed by "STN" is station mnemonics arranged in alphabetical order. The columns headed by "1/4 HR", "1 HR", and "4 HR" are running totals for the following intervals:

1/4HR = 15-minute interval;
1 HR = 60-minute interval;
4 HR = 4-hour interval.

(2) Page 2 : cumulated totals

The column headed by "STN" is station mnemonics arranged in alphabetical order. The columns headed by "Q", "H" and "D" are cumulated totals since last data buffer reset:

Q = quarter-hourly reset (when minute is 00, 15 , 30 or 45);
H = hourly reset (when minute is 00);
D = daily reset (when minute is 00 and hour is 00, i.e. mid-night).

(3) Page 3 : daily totals

The first column headed by "STN" is station mnemonics arranged in alphabetical order. The column headed by "LOCTN" are abbreviated site location names. The column headed by "D" is the same as in page 2. The column headed by "24 HR" is the running total for the past 24 hours.

(4) Page 4 : field station status

This page provides information on the operating status of individual raingauge stations. It also contains a look up table for modem channel numbers against station mnemonics and station locations. The columns of this page are defined as follows:

No. = Modem channel number, 01 to 64;

SWp = "SW" is the DIP switch number, 0 to 7, of the eight DIP switch on the supervisor/ multiplexer board. "p" is the switch position of this DIP switch, 1 to 8;

STN = Station mnemonic;

LOCTN = Station location;

CD = latest 5-minute rainfall in number of tips, "xx" if data not received correctly;

CNT = The number of data messages received since last CPU reset. The count is incremented each time a correct data message is received from the raingauge site, up to 288.

b = battery condition: "+" if battery voltage at field station is normal, "-" if battery is low.

If no correct data message is received from a site for three or more consecutive 5-minute intervals, "CD CNTb" will show "<U/S>". If the modem channel has not been enabled at the DIP switch, "<off>" is shown.

It should be noted that for page 1 to 3, the stations are arranged in alphabetical order of station mnemonic (top left to bottom right). For page 4, the stations are arranged in order of channel number.

4.2.3 Active processor

The CIM-804 CPU board is configured to use only one source of interrupt, the Timer-0 interrupt, which is connected to the re-start input RSTA. The timer is programmed to generate one interrupt every one fourth of a second. Since the interrupt is level and not edge driven, and the trigger pulse lasts only 7 μs, it may be missed if interrupt is disabled for too long in the interrupt service routine. So deferred interrupt service is used. On interrupt, the microprocessor sets some flags and exits from the interrupt service routine. On return to the main program, the flags are examined to determine what tasks need to be executed.

In the interrupt service routine, the processor increments the real-time clock, checks the state of the front panel push-buttons, updates the status line (line 2 on the LCD display), and maintains the pulse train to the monostable multi-vibrator on the supervisor. After finishing these tasks, the processor enters the "WAITING" state. Thereafter, every two seconds, it carries out a serial loop-back test, and reports the result on the LCD display in the "SBD" field. Every ten seconds, it interrogates the rainfall data receiver at the Royal Observatory, and sends data if there are data to be sent and the receiver is ready. The off-line microcomputer system is served every second.

On the next 5-minute transition, the processor starts polling the field stations. Processor state "STATE" shows "SCAN #nn" where nn is the modem channel number (01 to 63). As the field station is being polled, the corresponding LED on one of the transformer boards glows. If a modem channel has not been enabled, polling is skipped. The sequence of command and messages between the processor and the field station had been described in Section 4.1.2. Request for data from each field station is repeated, up to nine times, if there is a checksum error, or if there is no response after a certain time-out period. Failing the 10th time, polling will continue with the next station.

The processor stores the data obtained from each field station in its data buffer. After data from all field stations are obtained, the processor performs the necessary computation to update the currently displayed page on the LCD panel, and then enters the "WAITING" state.

When the active processor is in the "WAITING" state, it asks the off-line microcomputer system once every second whether the latter is ready to receive data. The link to the off-line microcomputer system is programmed to operate at 9 600 bauds. The character format is 1 start bit, 8 data bits, no parity bit and 1 stop bit.

The processor first sends an <DC1> to the off-line microcomputer system, and waits for a reply. If no reply is received in 15 ms, it sends another <DC1> and waits for a reply again. If there is still no reply, it assumes that the off-line microcomputer system is out of service and shows "U/S" at the "OLP" field on the LCD display.

The reply from the off-line microcomputer system can be a <DLE>, requesting field station look up table, or a <DC2>, requesting rainfall data. If the reply is <DEL>, the processor will send the station looking up table, and then wait for an acknowledgement of receipt <DC3>.

The format of the station look up table is as follows:

```
<SOH>S##LLLLL,_S##LLLLL,_S##LLLLL,_S##LLLLL<CR><LF>
S##LLLLL,_S##LLLLL,_S##LLLLL,_S##LLLLL<CR><LF>
.....
.....
S##LLLLL,_S##LLLLL,_S##LLLLL,_S##LLLLL<CR><LF>
CS<CR><LF>
<ETX>
```

where S## = station name mnemonics, e.g. H01, N02, etc.
LLLLL = station locations, e.g. Westn, Abden, etc.
CS = checksum being the complement of the sum of all bytes between <SOH> and the checksum itself.
the ",_"s after location names are part of the table.

There are a total of 64 entries for sixty three field stations and a dummy, arranged according to the channel number. This table enables the off-line microcomputer system to keep track of the assignment of station mnemonics to different locations. The off-line microcomputer system always request this table when the data archival program is executed.

If the reply from the off-line microcomputer system is <DC2>, the processor will send the oldest set of 5-minute rainfall data which has not yet been sent to the off-line microcomputer system. The format of the data set is:

```
<SOH>YYMMDDhhmm<CR><LF>
D01D02...D32<CR><LF>
D33D34...D64<CR><LF>
CS<CR><LF>
<ETX>
```

where YY = year in ASCII, 2 bytes,
MM = month in ASCII, 2 bytes,
DD = day in ASCII, 2 bytes,
hh = hour in ASCII, 2 bytes,
mm = minute of the hour in ASCII, 2 bytes,
D01 = number of tips for channel 01, ASCII, 2 bytes,
D02 = number of tips for channel 02, ASCII, 2 bytes,
.. . .
D64 = number of tips for channel 64, ASCII, 2 bytes (dummy)
CS = checksum, ASCII, 2 bytes, being the complement of the sum of all bytes between YY and D64.

As an example, below is a hexadecimal dump of a set of data transmitted at 14:25 on 30th Dec, 1987.

```
01 38 37 31 32 33 30 31 34 32 35 0D 0A 30 35 31   .8712301425..051
34 30 38 31 32 .. .. .. .. .. .. .. .. .. .. ..   40812...........
.. .. .. .. .. .. .. .. .. .. .. .. .. 0D 0A ..   ................
.. .. .. .. .. .. .. .. .. .. .. .. .. .. .. ..   ................
.. .. .. .. .. .. .. .. .. .. .. 30 37 2D 2D 34   ...........07--4
37 0D 0A 03                                       7...
```

This corresponds to rainfall amounts of:

channel	number of tips	rainfall in mm	
01	05	2.5	
02	14	7.0	
03	08	4.0	
04	12	6.0	
..	..	..	message
63	07	3.5	checksum byte
64	--	(not enabled)	= 47H

It should be noted that channel 64 is a dummy. If a modem channel is not enabled, data for that channel become "--". If data is not available from a channel, data for that channel become "xx".

The off-line microcomputer system is expected to acknowledge receipt of each set of rainfall data by returning a <DC3>. The processor, on receiving the acknowledgement, will send the next set of rainfall data. This is repeated until only the last but two sets of data are left. If a request for rainfall data is received but no more data are available, the active processor will send a <DC3>.

When the active processor is in the "WAITING" state, it asks the receiver at Royal Observatory once every ten seconds whether the latter is ready to receive data. The link to the Royal Observatory is programmed to operate at 1,200 bauds. The character format is 1 start bit, 8 data bits, no parity bit and 1 stop bit.

The active processor first sends an <DC1> and waits for a reply for 100 ms. If no reply comes, the enquiry will be repeated for up to nine times. The reply is either a <DLE> requesting full field station and rainfall information, or a <DC2> requesting the latest set of rainfall data.

Full field station and rainfall information consists of the station look up table, site sorting list, and all rainfall data stored in memory, making up about 30 kB. The data is in fact a segment of system memory designated as data buffers for the above information, and takes about three minutes to be completely transmitted. To allow for error recovery, the data are transmitted in packets of 259 bytes, and the receiving end is required to acknowledge correct reception of each packet by returning a <DC3>. The packet format is as follows:

<SOH>....(256 bytes of data)....CS<ETX>

If the rainfall data buffer is not full, the empty section is filled with <NULL>s, which are also sent. The site sorting list is a sequence of sixty four bytes, which maps channel numbers to the station mnemonics in alphabetical order. This list is used for arranging the order of appearance of stations on the display. The rainfall data receiver at the Royal

Observatory requests and uses this full set of information to initialize its data buffers immediately after it is reset.

If the reply from the Royal Observatory rainfall data receiver is <DC2>, the latest set of rainfall data is sent. The format of the data message is the same as that to the off-line microcomputer system, and no packetization is used. If a request for rainfall data is received but no more data are available, the active processor will send a <DC3> instead.

The serial link to the stand-by processor is programmed to operate at 19 200 bauds. The character format is 1 start bit, 8 data bits, no parity bit and 1 stop bit. When the active processor is in the "WAITING" state, it asks the stand-by processor once every second whether it is ready to receive data by sending a <DC1>. Time-out for no reply is 12 ms and re-try is done twice.

Similar to the link to the Royal Observatory, if the reply is <DLE>, full field station and rainfall information are sent, but without packetization. The stand-by processor requests and uses this full set of information to initialize its data buffers immediately after it is reset. If the reply is <DC2>, the latest set of rainfall data is sent. The data sent is the content of a rainfall data buffer, the current date and time, and the number of data sets which have to be sent to the off-line microcomputer system. The rainfall data buffer has 64 x 4 bytes. Each group of four bytes contains the binary values decoded from the ASCII HEX of the number of tips reported by a field station. The time buffer has nine bytes (packed BCD), being the day of week, century, year, month, day, hour, minute and second. The data set count is a 2-byte binary number. If a request for rainfall data is received but no more data are available for sending, the active processor will send a <DC3>.

On the 00th, 15th, 30th and 45th minute of the hour, the processor composes a table identical to page 2 of the LCD display and send it to the serial printer. The link to the printer is programmed to operate at 9 600 bauds. The character format is 1 start bit, 8 data bits, no parity bit and 2 stop bits.

4.2.4 Stand-by processor

The stand-by processor's main task is to receive rainfall data from the active processor to update its internal data buffers. The received data are also displayed on its LCD panel. Normally page 1 is displayed, but the user can select other pages to display just as for the active processor. Most of the time, the processor is in the "WAITING" state.

4.3 Off-line microcomputer system

The off-line microcomputer system operates in the DOS environment. There are two versions of the data archival program, namely GCO1.EXE and GCO2.EXE for the two serial ports COM1 and COM2. GCO1.EXE should be used if COM1 is connected to the multiplexer, while GCO2.EXE should be used if COM2 is connected to the multiplexer.

For most of the time, the microcomputer is used for analysis of rainfall data and other off-line job. Every day, the data archival program has to be executed at least once to archive data stored in the active processor's memory.

The program starts by initializing array variables for storage and then waits for a <DC1> from the active processor. On receipt of the <DC1>, it will request the station look up table and then the rainfall data set by set. The command and data formats have already been described in Section 4.2.3.

Each set of rainfall data received is stored sequentially in a file. The data format is the same as that received over the serial link (see Section 4.2.3), except that the leading <SOH> and ending <ETX> are stripped. Data for each calendar day is stored in one file, whose name is set by the program to be YYMMDD (YY for year, MM for month and DD for day). The program automatically opens a new file when the first set of data for a day is received.

After the receipt of a set of data, the off-line microcomputer system expects to receive another set within the next 1.5 seconds. If another set of data is not received within that time, the microcomputer will display the last set of data received on its video console. The display can be one of the four pages described earlier. The user can select the desired page by pressing the left-arrow key one or more times.

If the active processor has no data to send when the data archival program is first started, the off-line microcomputer system will prompt the user for a starting date. If a file name which matches the date is found, the microcomputer will read rainfall data from the hard disk beginning with data on that date until it reaches the latest set of data, which is then displayed on the video console. It then monitors the serial port for new data from the active processor.

5. INSTALLATION

5.1 Field station

The filed station requires very little site preparation for installation. All that is required is open space for placing the raingauge and solar panel. Neither of them should be obstructed or shaded by buildings or other structures.

Two flat surfaces, each of size 1 m x 1 m and separated by at least 2 m should be formed for installing the raingauge and the solar panel. The 2 m separation is to avoid splashing of rain from the solar panel to the raingauge.

The tipping bucket raingauge is bolted by three stainless steel bolts on a pre-fabricated concrete slab of dimension 450 m x 450 mm x 200 m (height) as shown in Figure 4. The solar panel is mounted on the tilted surface of an aluminium supporting frame facing south as shown in the same figure. The inclination of the panel is 25 degrees which is optimal for the solar radiation condition in Hong Kong. The frame is made up of two triangular brackets which are held firmly on top of the concrete slab by stainless steel anchor bolts. Four holding screws passing through the sloped portion of the brackets are threaded into the aluminium slot under the solar panel to fix the panel to the brackets.

The re-chargeable battery is fixed on the lower left beam of the solar panel supporting frame by brackets and cable ties. The electronic package, housed in a cast aluminium box of dimension 222 mm x 142 mm x 55 mm, is fixed by brackets on the solar panel supporting frame under the solar panel. There is a clearance of about 5 mm between the bottom of the box and the concrete slab surface to minimize heat conduction between the two, as the concrete slab can be heated to quite high temperatures in the summer. The solar panel also blocks the box from direct solar radiation, while the box itself is painted white to minimize solar radiation absorption.

As a field unit consists of only a few elements, installation is relatively simple. However, strict quality control during the installation process is essential to minimize future maintenance problems.

5.2 Central station

The off-line microcomputer system should be installed according to instructions given in the manuals provided by the manufacturer. The rest of the central station is housed inside one equipment rack as shown in Figure 5.

The equipment rack front view in Figure 5 depicts the mounting locations of three card cages. The top part of the equipment is left empty, then in sequence the processor-A card cage, processor-B card cage and supervisor/multiplexer card cage are mounted. The top of the equipment rack is left empty so that the LCD panel of processor-A is near eye level for easy viewing. The two sets of batteries and chargers are placed on the bottom of the rack.

6. MAINTENANCE

6.1 Field station

The electronics of the field station had been designed for maintenance free operation, but regular maintenance of the mechanical parts is required to ensure proper operation.

The solar power supply unit is the key component for prolonged operation and must always be maintained in its best condition. Dirt accumulated on top of the solar panel decreases the solar energy input. For most locations in Hong Kong, cleaning once every two months should be sufficient. In dusty locations, the cleaning should be done more frequently; In any case, maintenance should be performed as soon as field station battery status shown on page 4 of the processor LCD panel is low. If possible, after passage of a tropical cyclone or severe rain storm, the field stations should be inspected for structural damage or water leakage. Due to site limitation, some stations, for example those on lee side of a hill, may not have good exposure to sunlight. Such sites should be observed more closely. Frequent occurrence of low battery state necessitates addition of another solar power unit in parallel with the existing one, otherwise frequent replacement of the battery may be required.

6.2 Central station

The off-line microcomputer system and the serial printer will be maintained by the supplier. The remaining part of the central station does not have wearable parts so little maintenance is required. Preventive maintenance of the electronics in the equipment rack should be done once a year just prior to the start of the rainy season.

7. CONCLUDING REMARKS

Development of the automatic raingauge system began in April 1987 and was completed in December 1988. By March 1989, the central station and forty field stations were installed. The operation of the system has been satisfactory up to the time of the writing of this manual. The only problem that has been encountered so far is water leakage into either the electronic package and/or the connector at the field station. This happened at a few raingauge stations, and was found to be due to improper sealing of the electronic box or the connector.

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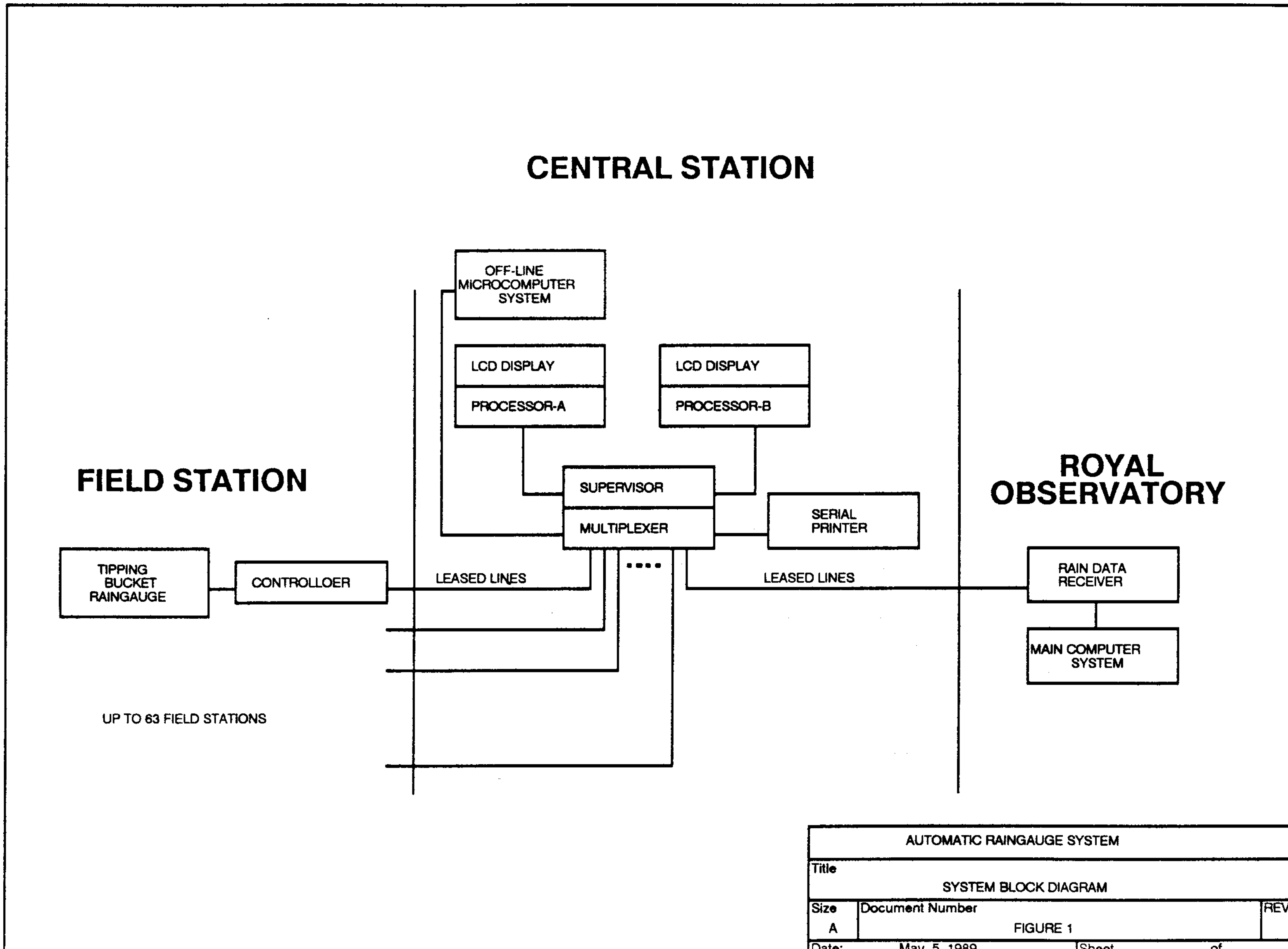

Figure 1. System Block Diagram

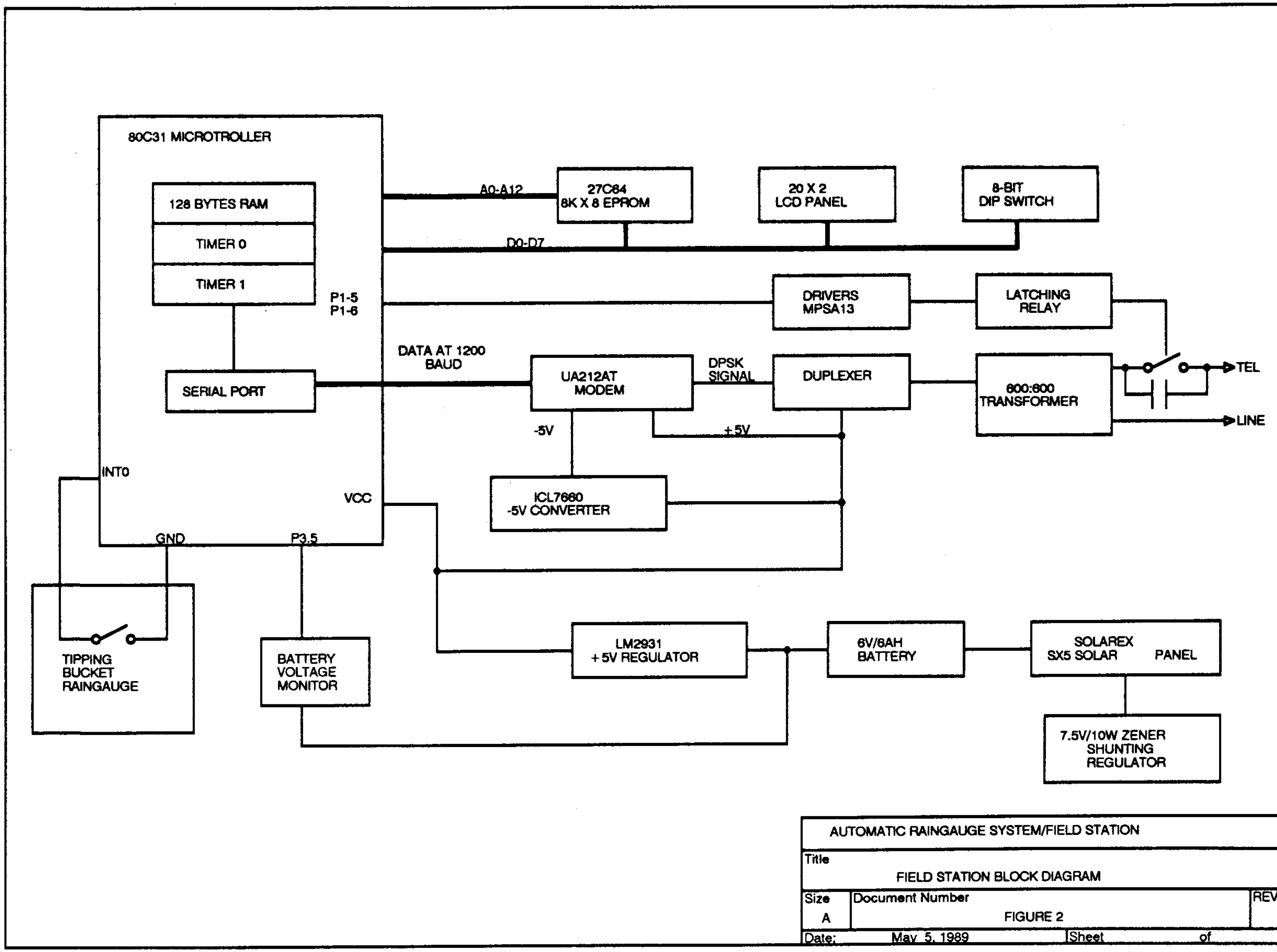

Figure 2. Field Station Block Diagram

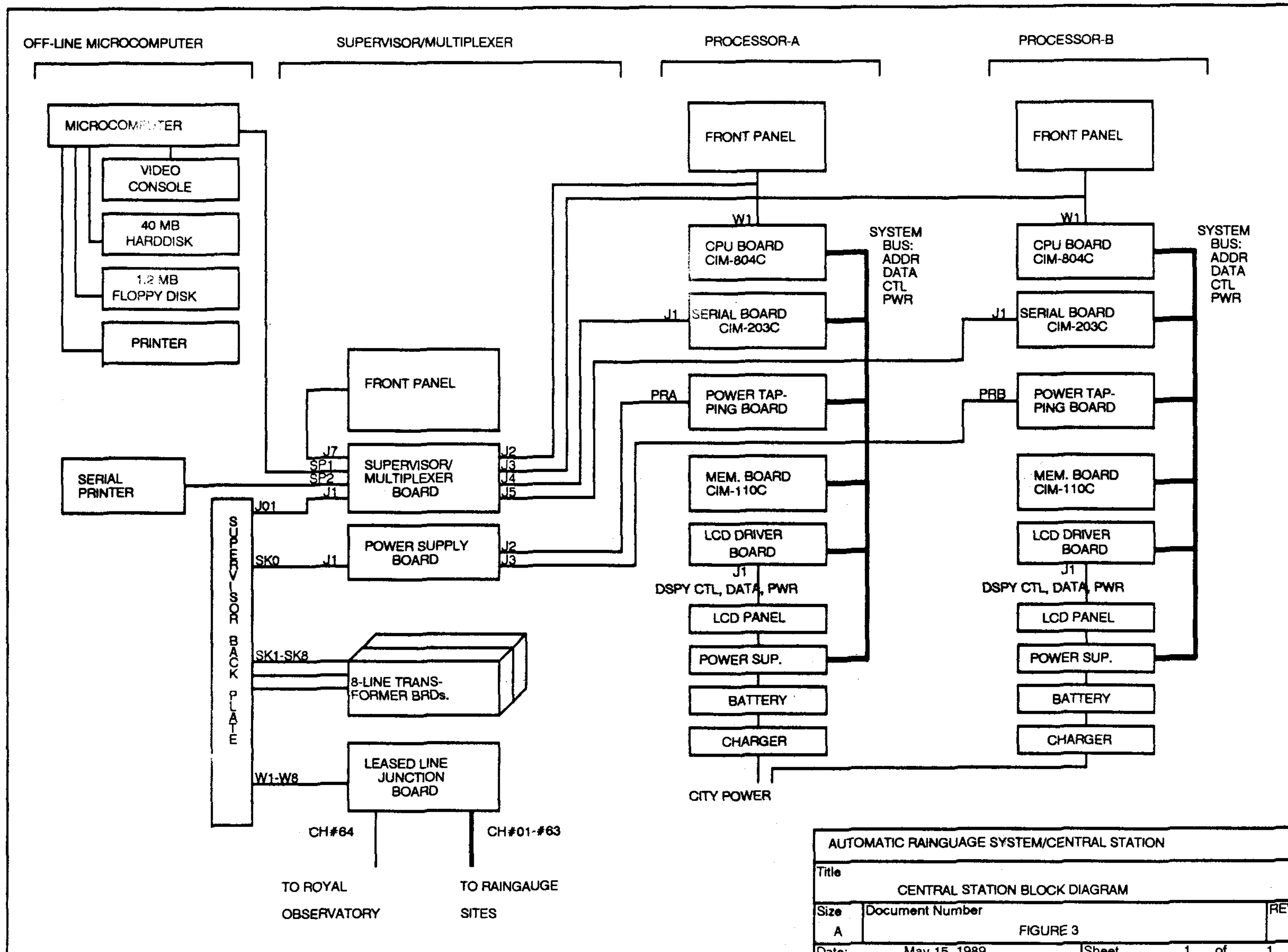

Figure 3. Central Station Block Diagram

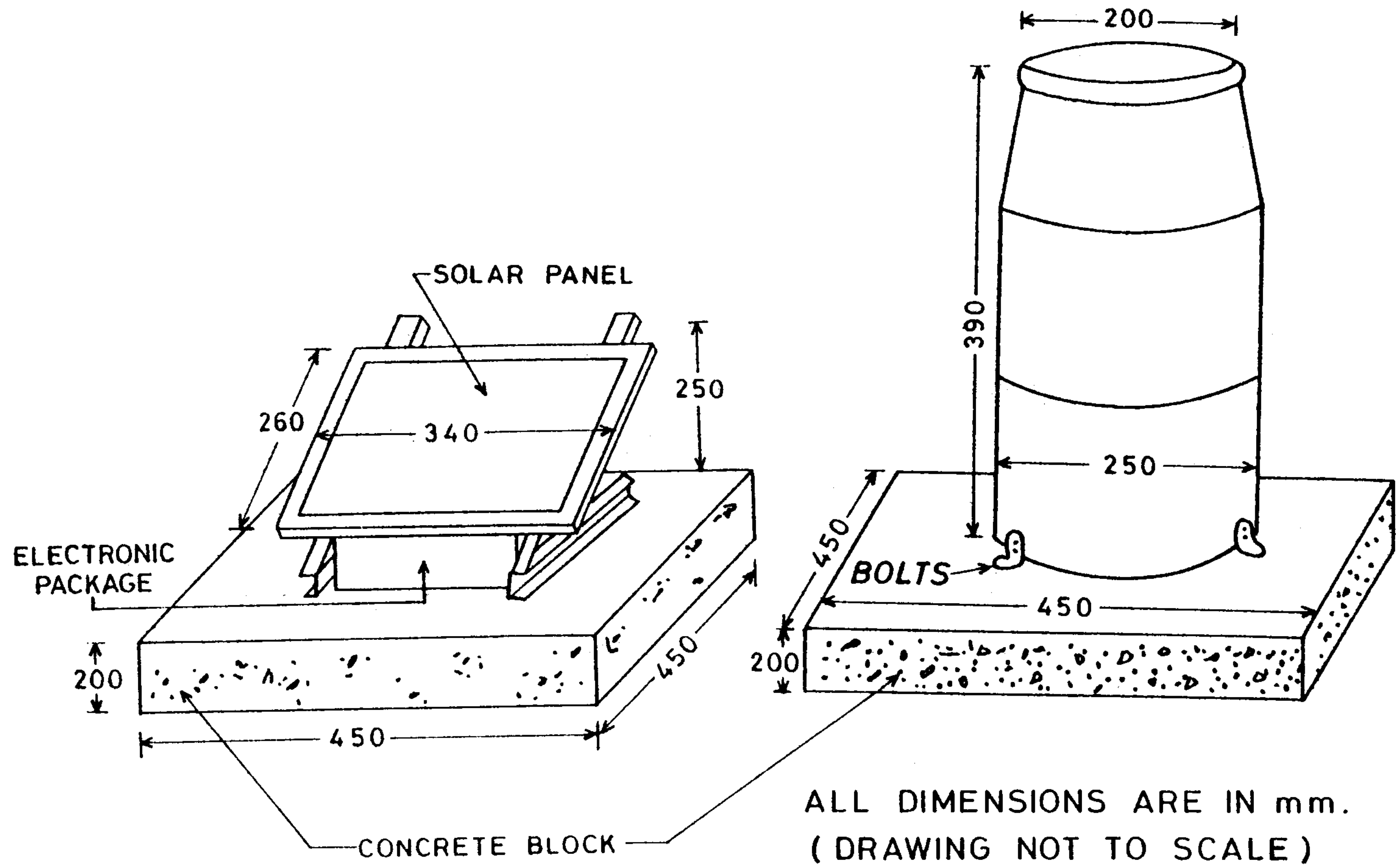

Figure 4. Field Station Perspective View

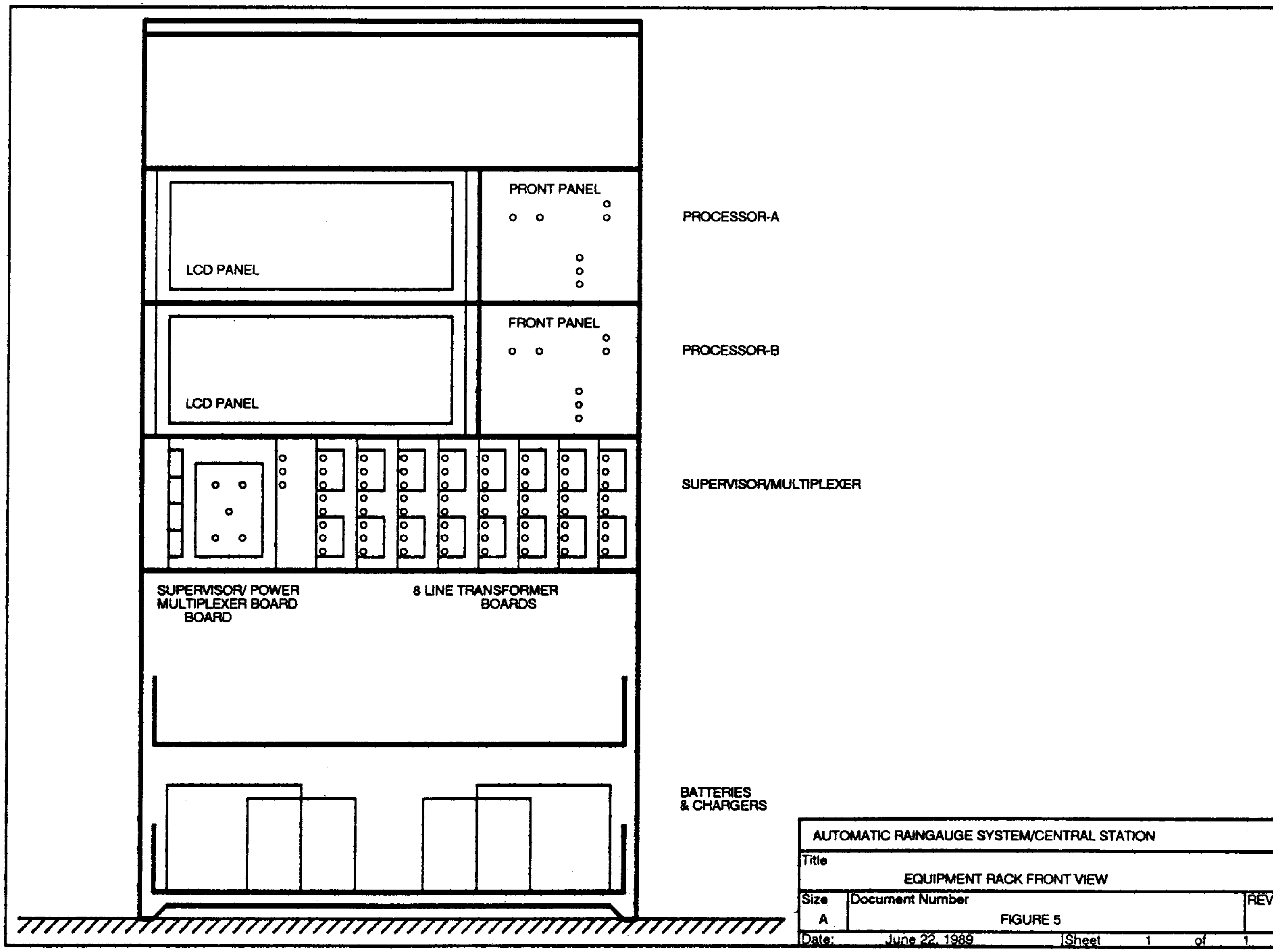

Figure 5. Equipment Rack Front View

APPENDIX A - FEATURES OF THE AUTOMATIC RAINGAUGE SYSTEM

A.1 Field station

1. Sensor

(a) Rainfall sensor

Diameter	- 400 cm^2 tipping bucket raingauge
Resolution	- 0.5 mm per tip
Output	- contact closure of about 100 ms duration with multiple bouncing

(b) Battery monitor - battery voltage is sensed and reported back to central station

2. Processing

(a) Processor	- Intel 80C31 microcontroller running at 11.059 MHz clock
(b) Program	- contained in one 8 kB EPROM
(c) RAM	- 128 bytes on-chip RAM
(d) Operator interaction	- hand-held diagnostic unit
(e) Date/time clock	- software generated real-time clock with year, month, day, hour, minute and second. Accuracy about 10 seconds/month
(f) Output products	- 3 latest 5-minute cumulated rainfall values together with battery status per report to central station
(g) Report frequency	- determined by central station. Currently once every 5 minutes
(h) Report format	- ASCII codes
(i) Serial format	- 1200 bauds, 1 start bit, 8 data bits, no parity bit, 1 stop bit

3. Modem

(a) Type	- Fairchild UA212AT modem
(b) Communication standard	- Bell 212A/103

(c) Modulation method - DPSK for 1200 bauds

4. Power supply unit

(a) Solar panel

Type	- Solarex SX-5, 6 V/5 W panel
Open circuit voltage	- 11 V
Voltage at peak power	- 8.5 V
Current at peak power	- 580 mA

(b) Regulator

Type	- 7.5 V/10 W zener diode shunting regulator
Regulation voltage	- 7.5 V

(c) Battery

Type	- lead-acid sealed
Nominal voltage	- 6 V
Capacity	- 6.5 AH

(d) Supply voltages - ±5 V from DC to DC converter

5. Power requirement

(b) Current consumption - 18 mA (nominal) from battery

6. Supporting structures and cables

(a) Supporting structure - aluminium frame for bolting on concrete base

(b) External cables - direct burial type

A.2 Central station

A.2.1 Real-time processors

1. Processing

(a) Configuration - two identical processors with one active the other on hot stand-by, switch-over under hardware supervisor control

(b) Processor - CIMBUS system based on NSC800 microprocessor running at 4 MHz

(c) Program storage - one 8 kB EPROM

(d) RAM - three 8 kB RAM chips

(e)	Operator interaction	- push-buttons and toggle switches on front panels
(f)	Display	- LCD panel programmed to display 20 lines of 106 characters. Positive type. Tiltable mounting
(g)	Date/time	- software implemented real-time clock with year, month, day, hour, minute, second and self-adjusted day of week. Accuracy about 10 seconds per month
(h)	Polling frequency	- 5 minutes
(i)	Number of field stations	- 63
(j)	Output products	
	On LCD panel	- running and cumulated totals, system and field station status organised in 4 pages updated every 5 minutes. Pages selectable by push-button
	To serial printer	- running totals once every 15 minutes via RS232C serial interface
	To off-line microcomputer	- 5-minute cumulated rainfall via RS232C serial interface. Interactive transfer
	To remote receiver	- 5-minute cumulated rainfall via modem once every 5 minutes. Interactive transfer
(k)	Data format	- all serial outputs in ASCII codes
(l)	Character format	
(m)	Serial format	
	To serial printer	- 9600 bauds, 1 start bit, 8 data bits, no parity bit, 2 stop bits
	To off-line microcomputer	- 9600 bauds, 1 start bit, 8 data bits, no parity bit, 1 stop bit
	To remote receiver	- 1200 bauds, 1 start bit, 8 data bits, no parity bit, 1 stop-bit
(n)	Modem	- same as field station

2. Power supply

(a) Charger	- 13.6 V, maximum current 4 A
(b) Battery	- 12 V (nominal), 30 AH
(c) Supply voltages	- ±12 V and +5 V from DC to DC converter

3. Power requirements

(a) Power consumption	- 600 mA (nominal) from each battery. Battery back up time over 24 hours on fully charged up batteries.

A.2.2 Off-line microcomputer systems

1. Processing

(a) Hardware	- IBM PC/AT compatible microcomputer with at least one serial port
(b) Data archival	- once a day, for about 3 minutes