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A SOLAR-POWERED AUTOMATIC WEATHER STATION

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SUMMARY

This Technical Note contains functional descriptions of the hardware and software of a solar-powered automatic weather station developed by the Royal Observatory under a joint project between the Royal Observatory and the Guangong Meteorological Bureau of the State Meteorological Administration of the People's Republic of China. Detailed circuit and program descriptions have not been included for the sake of brevity.

Procedures for installing and maintaining the automatic weather station 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 station of this type.

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FIGURES

1. INTRODUCTION

Plans for setting up a network of automatic weather stations in Hong Kong began in 1981. At that time, there was a total of five meteorological stations in Hong Kong which were instrumented and staffed to provide a full set of surface meteorlogical observations. These stations essentially covered the urban areas of Hong Kong Island and Kowloon and the coastal waters south of Hong Kong Island. Because of topographical effects, weather observations at these manned stations did not provide adequate meterological coverage for the whole of the territory of Hong Kong. With the development of new towns and the redistribution of population and industrial centres especially in the New Territories, the manned stations could no longer meet demands of the public for weather information, nor satisfy requirements of consultants for meteorological data to be used in land development and civil engineering design. There was also a steady increase in demand for warnings of localized severe weather phenomena like squalls, thunderstorms and heavy rain which were difficult to forecast without adequate weather observations. To meet these demands, the Royal Observatory decided in 1982 to set up a network of automatic weather stations in Hong Kong. The initial plan was to have five stations set up and put into operation by 1985.

Development of the hardware and software of the automatic weather station network began in early 1983. At that time, it was anticipated that all the automatic stations would be located near new towns and hence would be served by domestic electricity supply. The automatic weather stations were therefore designed to run on domestic electricity supply and transmit data continuously to the central station at the Royal Observatory Headquarter. In the summer of 1984, hardware and software development were both completed, and the first two automatic weather stations were set up and put into operation at Chek Lap Kok and Sha Tin. In the autumn of 1985, two more stations were set up at Lau Fau Shan and Ta Kwu Ling.

During the early planning stages of the automatic weather station network, it was recognised that an automatic weather station on a remote island south of Hong Kong would be very useful for monitoring severe weather systems such as tropical cyclones approaching Hong Kong from the south. After a series of correspondence and meetings in 1983 and in early 1984, the Royal Observatory and the Guangdong Meteorological Bureau eventually entered into an agreement in February 1984 to jointly set up an automatic weather station at Huangmao Zhou, which is a small uninhabited island about 70 km southeast of Zhuhai and 50 km south-southwest of Hong Kong.

As there is no electricity supply on Huangmao Zhou, the station has to be powered by solar energy. As such, the automatic weather station which was at that time already under development and intended for use within Hong Kong could not be easily adapted for use at Huangmao Zhou. Therefore, a new version of automatic weather station, of much lower power consumption, had to be developed.

Hardware and software development of the solar-powered automatic weather station (abbreviated as SPAWS hereafter) began at the Royal Observatory in 1984 and was completed by the end of 1984. This was followed by system integration, testing and debugging which lasted two months. Finally, all parts of the equipment were transported to Huangmao Zhou and installed on 10 July 1985. The station began operation on 11 July 1985.

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

Although the SPAWS was designed as part of the automatic weather station network in Hong Kong, the possibility of stand-alone operation had also been taken into consideration in the design of the station. The data transmitted from it can be received by a modem and displayed on an ordinary video terminal or line printer. The receiving and processing equipment actually in use at the Royal Observatory will not be described in this Technical Note.

2. SYSTEM CONFIGURATION

The features of SPAWS are shown in Appendix 1. The SPAWS is composed of six main functional blocks. They are the solar power supply unit, the DC to DC converters, sensors and associated signal conditioners, the microcomputer, the transmission section and supporting structures for various sensors and equipment. A system block diagram is shown in Figure 1. The relation between these six functional blocks will be described below. The main components of each functional block, as well as the relation between these blocks, will be described in this chapter. More detailed descriptions of these functional blocks are given in Chapters 3 and 4.

The solar power supply unit provides the power to run the entire SPAWS. It consists of three solar panels, a shunting regulator, three re-chargeable batteries and a low-voltage disconnect circuit. The number of solar panels and batteries have initially been designed to supply 6 W of power continuously when the global solar radiation is only 25% of the maximum possible in Hong Kong throughout the year. This corresponds to mostly cloudy skies in the vicinity of Hong Kong (based on solar radiation data at King's Park, Hong Kong). As the SPAWS only consumes an average of 2 W of power (including dissipation in the DC-to-DC converters), the solar power supply unit has adequate capacity to power additional sensors and processing equipment when the need arises. As a means to prevent permanent damage of the batteries should failures in the components of the SPAWS draw excessive current from the batteries, the low-voltage disconnect circuit senses the battery voltage and cuts off power to the entire SPAWS, except itself, when the battery voltage falls below 10.9 V,

The sensors and various electronic circuits in the SPAWS requires more than one supply voltage to operate. Three DC-to-DC converters are used to convert from the 12-V battery voltage three additional voltages to power the sensors and various electronic circuits.

The SPAWS has been designed to accommodate up to a maximum of sixteen sensors. At Huangmao Zhou, five meteorological sensors are used to measure the wind direction, wind speed, air temperature, atmospheric pressure and rainfall. The outputs from the sensors are of different forms and have to be conditioned to suitable analogue voltages before further processing can be done. As a house-keeping function, the battery voltage and the temperature inside the main electronic rack are also sensed and the readings are transmitted back to the Royal Observatory together with the meteorological data. Humidity is not measured at Huangmao Zhou because commercially available humidity sensors are easily contaminated when operated in a coastal environment and may therefore produce inaccurate readings. Furthermore routine maintenance visits are planned to be no more frequent than once every six months. With the existing design, it is easy to include a humidity or dew point sensor in the automatic weather station, should the environment be more agreeable and the station is more easily accessible.

The heart of SPAWS is a modular microcomputer based on the NSC800 microprocessor. Two CIM-bus microcomputer boards, viz. the CIM-802AC CPU board and the CIM-210C parallel input/output board, together provide 2 KB of RAM, 4 KB of EPROM space, two 16-bit timer/counters and seven 8-bit parallel input/output ports. An analogue-to-digital converter board interfaced to three parallel input/output ports has sixteen multiplexed analogue input channels to take in the conditioned sensor outputs. The microcomputer samples all the conditioned analogue signals in sequence once every second. The data are stored in buffers and processed once every minute to produce 1-minute average, extreme or accumulated values. Based on these 1-minute values, average, extreme or accumulated values over longer periods are computed every half an hour and composed into a report message, which is output to the transmission section serially through one of the parallel input/output pins.

A date/time clock is implemented using a timer channel of the microcomputer. It controls the timing of all control and data processing functions and provides the date/time information in the transmitted data stream. Setting of the date/time clock is done via a detachable hand-held diagnostic unit interfaced to three parallel input/output ports of the microcomputer. The diagnostic unit has four input keys, a 9-digit 7-segment LED display and two 7-segment LED displays to act as the operator's console. Using the diagnostic unit in conjunction with a special diagnostic program, various components of the SPAWS can be tested by the operator during calibration and maintenance. The diagnostic unit may be detached from the microcomputer after the station is put into normal operation.

To prevent trapping of the microprocessor by voltage surges caused by near-by lightning strikes, a fail-safe auto-reset circuit is used to reset the microprocessor when the circuit does not receive the regular strobing signal generated by software. However, when this occurs, the date/time clock will be reset too and the station will not report exactly on the 00th and 30th minutes. Then the time contained in the transmitted report message will not be correct. This should not be a problem if the receiving station can furnish its own time, as is the case at present.

To conserve power, some of the meteorological sensors and electronic circuits are turned off when measurements are not made. Since temperature and atmospheric pressure need to be measured only once every half an hour, the sensors for these two elements and the corresponding signal conditioners are only turned on for three minutes every half an hour to allow measurements to be made. The UHF transmitter in the transmission section, which is the most power-consuming module in the SPAWS, is only turned on at the time of data transmission which lasts about 18 seconds. The switching of the power supplies is controlled by the microcomputer according to a time schedule.

The input stage of the transmission section is a modem. The output of the modem, which is an audio FSK signal, is transmitted to the receiving station by a UHF transmitter coupled to a Yagi antenna.

The site plan of a typical solar-powered automatic weather station is shown in Figure 2. This layout has been used at Huangmao Zhou, with the exception of the concrete foundations for the anemometer mast and its guy wires which were laid out according to a design provided by the Guangdong Meteorological Bureau. The supporting structures for the equipment are designed with the assumption that there is no station building and all parts of the equipment are to be installed outdoors.

Most of the circuit boards are housed in a single 483-mm rack. The rack, together with the pressure sensor, the UHF transmitter and the batteries are placed inside a sealed instrument cabinet. The cabinet is placed on a supporting frame which is covered by a sun-shield to prevent the cabinet from being heated by direct sunlight. The remaining supporting structures consist of a 10-m mast for mounting the wind sensors and the Yagi antenna, a supporting frame for mounting the solar panels and the shunting regulator, and another supporting frame for mounting a Stevenson screen for the temperature sensor. All supporting structures are bolted onto concrete foundations by means of implanted anchor bolts.

Shielded direct-burial cables are used to connect equipment at different locations. These cables are buried in trenches and covered by pre-cast U-shaped concrete blocks.

A lightning arrestor is mounted on top of the anemometer mast to protect the station against direct lightning strikes. The arrestor is connected by a 0.5 cm diameter copper wire to an earth plate buried next to the anemometer mast. Transorbs, which are used to protect the electronic circuits against voltage surges induced by lightning strikes, are installed across the system ground and all power and signal lines that go outside the instrument rack. The system ground is connected at one point to the lightning arrestor ground conductor.

3. HARDWARE FUNCTIONAL DESCRIPTION

3.1 General consideration

The solar power supply unit, the meteorological sensors and associated signal conditioning boards, the two microcomputer boards, the UHF transmitter and the Yagi antenna are directly obtainable from commercial sources. In the description that follows, these modules will be referenced by their model names.

There are six circuit boards specially designed and constructed by the Royal Observatory for the SPAWS. To facilitate description, they will be given the following names according to their main functions.

(a) Low-voltage disconnect board

(b) DC-to-DC converter board

(c) Analgue-to-digital converter board

(d) Signal interface board

(e) Relay control and cable interface board

(f) Diagnostic unit

3.2 Solar power supply unit

3.2.1 Solar panels

Three Solarex SX-120 solar panels are used. Each panel has a peak open-circuit voltage of 22.5 V and is capable of delivering a current of 2.3 A at the peak power voltage of 17 V under an illumination of 1 sun (100 mW/sq cm). A detailed description of the solar panels is given in Reference 1.

At Huangmao Zhou, which is at latitude 21.8 degrees north, the panels are mounted side by side on an aluminium bracket tilted 25 degrees from the horizon towards the south. The angle of tilt has been chosen to maximize the efficiency of the panels for winter and spring operation during which prolonged periods of overcast conditions are expected. The outputs of the solar panels are connected in parallel to the shunting regulator.

3.2.2 Shunting regulator

The shunting regulator, Solarex Model SHO-12-150AFS, controls the charging of the 12 V batteries by shunting away part of the current generated by the solar panels when the batteries are nearly fully charged. The excess power is dissipated by power transistors and load resistors on the shunt path.

Depending on the battery voltage, the regulator operates in one of three different modes.

If the battery voltage is below 12.5 V the regulator operates in a fail-safe mode. In this mode the shunt path is open and the batteries receive the full output from the solar panels. If the initial battery voltage is between 12.5 V and 14.4 V the shunt path is partially turned on to dissipate the excess current and the regulator works in the charging mode. When the battery voltage rises to slightly above 14.4 V, the batteries are almost fully charged and the main shunt path is turned on to divert all the panel output. The regulator now works in the regulate mode. Overcharging of the batteries is thus avoided. Three LEDs on the front panel of the regulator indicate the operating mode of the regulator. Correct operation is verified by the way the LEDs are lit. A detailed description of the regulator is given in Reference 1.

The shunting regulator is housed in a weather-proof aluminium box and mounted on the supporting frame for the solar panels. The box is shielded from direct sunlight by the panels.

3.2.3 Batteries

Three GNB Absolyte 1260 sealed batteries are used. Each battery has a nominal voltage of 12 V and a capacity of 60 Ah. The batteries are connected in parallel and placed inside the instrument cabinet. Based on solar radiation data at King's Park, Hong Kong, it is estimated that the batteries will not be depleted by more than 20% of its its full capacity at any time in the year. At this level of discharge, there should be no release of gas from the batteries. Nonetheless, as a safety measure, some active carbon is placed near their safety vents to absorb any toxic gas which might be released. A detailed description of the batteries are given in Reference 1.

3.2.4 Low-voltage disconnect circuit

The batteries can be permanently damaged if they are excessively drained. This can occur if failure in some components of the SPAWS results in a very large current. The low-voltage disconnect circuit protects the batteries from over-discharging by sensing the battery voltage and cutting off the power supply to the entire SPAWS, except itself, when the battery voltage falls below 10.9 V. Power supply to the SPAWS will resume automatically when the battery voltage rises back to about 11.5 V.

The low-voltage disconnect circuit is located on a small circuit board housed in an aluminium box at the back of the electronic rack.

3.3 DC-to-DC converters

The various meteorological sensors and electronic circuits in the SPAWS require four different supply voltages. The microcomputer and all other digital circuits require a supply voltage of +5 V and draw an average current of 150 mA. The pressure sensor requires a +24 V supply voltage, but draws only 12 mA. The other meteorological sensors and most of the analogue circuits requires two supply voltages, +12 V and -12 V, and draw approximately 60 mA from each one. The UHF transmitter, which is the most power-consuming module in the SPAWS, operates at +12 V and draws 460 mA when turned on.

The +12 V supply is obtained directly from the batteries. The +24 V, +5 V and -12 V supplies are generated from the 12 V battery voltage by three separate DC-to-DC converters which employ switching regulator technique to either step up, step down or reverse the +12 V. The design of each DC-to-DC converter has been optimized with respect to the load current so that it operates near the theoretical maximum efficiency point. Ripples generated by the switching action of the converters on all four supply voltages are suppressed by LC filters.

The DC-to-DC converters are located on a circuit board which is housed inside the same aluminium box at the back of the electronic rack as the low voltage disconnect circuit.

3.4 Sensors and signal conditioners

3.4.1 Wind sensors and processor boards

A Teledyne Geotech Model WS201 Wind System is used to sense the wind direction and wind speed. This system is chosen for its ruggedness in design, low power consumption, light weight and ease of installation and maintenance.

The wind-direction and wind-speed sensors are mounted on a common U-shaped support with the wind-speed sensor below the direction sensor, while the U-shape support itself is mounted on top of a 10-m mast. The direction sensor has a wind vane made of a stainless steel stem and a transparent perspex fin. The vane is balanced by a counter weight and secured to a vertical shaft by a retainer nut such that the vane rotates freely about the axis of the shaft. The shaft is coupled to a potentiometer under a water-proof cover. Output from the potentiometer, in the form of a DC resistance between 0 and 10 k-ohms will thus vary according to the wind direction as the vane aligns itself with the wind. The sensor is interfaced to a Teledyne Geotech Model 21.22-1 wind-direction processor board that applies a +5 V to the direction potentiometer and detects the voltage at its tap. The processor board output is scaled to a DC voltage in the range 0 to 5 V corresponding to 0 to 540 degrees.

The wind-speed sensor consists of three cups supported on horizontal steel arms spaced 120 degrees apart. The arms resemble the radius of a circle whose centre is fixed to a vertical shaft. The shaft is coupled to a photo-chopper under a water-proof cover. Wind speed above a certain threshold causes the cup assembly to rotate and produces a pulse train whose frequency is proportional to the wind speed. The photo-chopper output is fed into a Teledyne Geotech Model 21.11 wind-speed processor board which converts the frequency of the pulse train to a DC voltage in the range 0 to 5 V corresponding to 0 to 90 m/s.

Details of the wind sensors and processor boards can be found in References 2, 3 and 4.

3.4.2 Temperature sensor and processor board

A Rosemount Model T-200 platinum resistance probe is used to sense the air temperature. It is mounted at eye level inside a wooden Stevenson screen. The sensor is a 4-wire single element type that follows the "International Resistance versus Temperature" curve (DIN 43760 and BS 1904) and operates in the temperature range -10 to +40 degrees Celsius. A matching processor board, Teledyne Geotech Model 21.32, works in conjunction with the sensor to give a 0 to 5 V full scale output corresponding to the specified temperature range.

Details of the temperature sensor and processor board are given in References 5 and 6.

3.4.3 Pressure sensor and level shifter

A Setra Systems Model 270 pressure sensor is used to sense the atmospheric pressure. The sensing element is a vacuum ceramic capsule which deforms proportionally to the atmospheric pressure. The capacitance across two gold electrodes on the inside surface of the capsule is thus also proportional to the atmospheric pressure. The capacitance is converted by charge balance technique to a DC voltage in the +8 to +11 V range corresponding to an atmospheric pressure in the 800 to 1100 hPa range. Details of the pressure sensor can be found in Reference 7.

The output voltage of the pressure sensor is too high to be handled directly by the analogue-to-digital converter. It is therefore offset by -6 V to a value in the +2 to +5 V range by a level shifter circuit located on the relay control and cable interface board.

3.4.4 Rain-gauge and pulse shaping circuit

A Casella 400 cm sq. tipping bucket rain-gauge is used for measuring rainfall. The rain-gauge has a circular funnel under which there are two buckets balanced on a pivot like a seesaw. One bucket will tip if sufficient rain water is collected in it and the alternate bucket will start to collect rain water.

Each tip of the bucket, which corresponds to 0.5 mm of rain fallen, will close a magnetic switch for about 100 milliseconds. This contact closure is transformed to a +5 V amplitude 1.2 seconds wide pulse by a pulse shaping circuit on the signal interface board. The pulse width has to be wider than 1 second because the microcomputer is sampling each analogue input channel only once every second and a pulse narrower than 1 second might be missed. Details of the rain-gauge can be found in Reference 8.

3.4.5 Electronic rack temperature sensor

Most of the electronic circuits of the SPAWS are housed inside a 483-mm electronic rack. The rack itself is placed on the upper compartment of the instrument cabinet which is sealed. Despite the use of the sun shield, the temperature inside the instrument cabinet and the electronic rack can be very high in summer. On the other hand, the temperature inside can be very low in winter. In order to assess the performance of the electronic circuits operating at markedly different temperatures, the temperature inside the electronic rack is measured and reported back together with the meteorological data. The sensor used is a temperature-sensitive integrated circuit on the signal interface board. The output of the sensor is scaled by an amplifier and level shifter to a value in the 0 to 5 V range corresponding to 0 to 100 degrees Celsius. The scaling circuit is also located on the signal interface board.

3.4.6 Battery voltage sensor

The battery voltage is crucial to the operation of the entire SPAWS and it is desirable to have it reported back with the meteorological data. The sensor for the battery voltage is simply a potential divider which divides the +12 V supply voltage on the analogue-to-digital converter board by 3. The potential divider is located on the analogue-to-digital converter board.

3.5 Microcomputer

3.5.1 CIM-802AC CPU board

The CIM-802AC CPU board is based on the NSC800 microprocessor (Reference 9) and is operated at a 2-MHz clock rate. The CPU board has the following functional blocks:

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

(b) NSC810 RAM-I/O-Timer: provides 128 bytes of RAM, three 8-bit parallel input/output ports and two 16-bit timer/counters (with pre-scalers).

(c) Memory circuits (EPROM and RAM): consist of 2 KB of static RAM, a socket for a 27C32 type EPROM, and address-decoding circuits for the system bus.

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

(e) CIM-bus interface circuits: contain the necessary address drivers, data buffers and control signal drivers to allow the CIM-802AC to serve as a CIM-bus master device.

Detailed description of the CPU board can be found in Reference 10.

3.5.2 CIM-210C parallel input/output board

The CIM-210C parallel input/output board is based on two CDP1851 parallel input/output (PIO) chips each having two 8-bit parallel input/output ports (Port A and Port B). Each port can be programmed to operate in one of four modes which are:

(a) Input mode: data input to port only

(b) Output mode: data output to port only

(c) Bi-directional mode: data input and output to port

(d) Bit-programmable mode: individual lines of the port programmed as either input or output

Details of the CIM-210C parallel input/output board can be found in Reference 11.

3.5.3 Analogue-to-digital converter board

The function of the analogue-to-digital converter board is to convert the conditioned analogue signals from the sensors to digital values which the microprocessor can process. Conversion is performed by a 12-bit analogue to digital converter. Analogue multiplexing technique is used to convert analogue signals from as many as sixteen sources sequentially under software control.

The converted data are in 12-bit unipolar straight binary code. 0 V is represented by all bits at logic "0" and full scale (+4.9988 V) is represented by all bits at logic "1".

3.5.4 Power conservation circuit

Atmospheric pressure and air temperature are measured at the 29th and 59th minutes of the hour only. To conserve power, the +24 V supply to the pressure sensor and the ±12 V supply to the temperature processor board are turned on between the 27th and 30th minutes and between the 57th and 00th minutes of the hour only. The power is turned on 2 minutes prior to measurement to allow the sensors and electronic circuits to warm up.

The UHF transmitter is turned on two seconds before data transmission and turned off again one second after the entire data message is transmitted. It is therefore on for only about 18 seconds every half an hour and the average power consumption is very low.

Relays are used to turn on and off the power to the above devices. The relays are controlled by the microprocessor through some parallel input/output pins. The power conservation circuit is located on the relay control and cable interface board.

3.5.5 Fail-safe auto-reset circuit

Voltage surges which are induced by lightning strikes can trap the microprocessor operation and cause erratic program execution. The fail-safe auto-reset circuit is used to reset the microprocessor whenever the latter is trapped. Once reset, the microprocessor will be forced to execute from the beginning of the program. Data currently stored in the microcomputer's memory including the date and time values will be lost or set to the default values. However, subsequent data (except the clock time) will be correct.

The fail-safe auto-reset circuit is triggered into action whenever a pulse is missing from a continuous, software generated pulse train which is the case when the microprocessor is trapped. This circuit is located on the signal interface board.

3.5.6 Diagnostic unit

The diagnostic unit is connected to three parallel input/output ports of the CIM-802AC CPU board. To be used as a hand-held operator's console, it has a 9-digit 7-segment LED display, two 7-segment LED displays and four input keys.

With the normal SPAWS software, the two 7-segment LED displays and three of the four input keys on the diagnostic unit can be used to read and set the date/time clock. The remaining key is used to force the microcomputer to generate and output a report message immediately without waiting for the 00th or 30th minute of the hour. These functions are very useful during the installation and maintenance of the SPAWS. However, once the station is put into normal operation, the power to the diagnostic unit should be turned off since the LEDs draw considerable power.

A diagnostic program has been written for testing out the various components of the microcomputer during maintenance and repair of the SPAWS. To run the program, the EPROM containing the normal SPAWS software has to be replaced by one containing this special software. The operator can enter commands through the input keys, while prompt messages and results are displayed on the 9-digit 7-segment LED display.

3.6 Transmission section

3.6.1 Modem

The microcomputer outputs the data message serially through one of its parallel input/output pins at 300 bauds. This is a digital signal consisting of rectangular pulses and hence cannot be input directly to the UHF transmitter. A TCM3101J single-chip modem is used to modulate the digital signal to a sinusoidal one.

Using the FSK method, the modem outputs a sinusoidal signal at one of two frequecies, viz 1300 Hz for logic "1" and 2100 Hz for logic "0". A buffer circuit is used to provide DC isolation and gain adjustment to allow optimum coupling to the UHF transmitter. The modem and buffer circuit are located on the signal interface board.

3.6.2 UHF transmitter and antenna

Choice of the transmitter output power and antenna gain has to be optimized for signal intensity at the receiving point, against power consumption and antenna size. For the automatic weather station at Huangmao Zhou, which is about 50 km from the UHF relay station at Stanley, Hong Kong, a Monitron Model T46F33 UHF transmitter with an output power of 2 W is used. The antenna used is a SCALA Model 114 Yagi antenna of 10-dB gain mounted with its dipoles in the horizontal plane to produce horizontal polarization so as to minimize scattering of the electromagnetic wave by the sea surface. A detailed description of the transmitter and antenna can be found in Reference 12.

3.7 Circuit board positions and cabling plan

Most of the circuit boards of the SPAWS are housed inside a 483-mm rack (Figure 3). There are three types of circuit boards and each type has its own edge connector backplane.

Five boards are installed vertically in one card cage. They are, from left to right, the CIM-802AC CPU board, the CIM-210C parallel input/output board, the analogue-to-digital converter board, the signal interface board and the relay control and cable interface board. There are two spare slots for housing additional CIM-bus boards and one spare slot for housing an additional custom-made circuit board.

The Teledyne Geotech signal conditioning boards are mounted horizontally in another card cage at the right of the rack. From top to bottom, they are the wind-direction processor board, the wind-speed processor board and the temperature processor board. There is one spare slot for an additional signal conditioning board such as a humidity sensor processing board.

The DC-to-DC converter board and the low-voltage disconnect circuit board are housed in an aluminium box at the rear left of the card cage.

Headers, plugs and sockets are used as far as possible to make connections between different modules of the SPAWS to facilitate assembly and dissembly during installation and maintenance of the station. In addition, the cable interface section of the relay control and cable interface board helps to route the power and signals between various circuits boards inside the electronic rack to minimize the number of stray wires.

4. SOFTWARE FUNCTIONAL DESCRIPTION

4.1 Software development

The software for the SPAWS was developed using a Philips PMDS II microprocessor development system equipped with a NSC800 microprocessor emulator. All program modules have been written in assembly language to achieve compactness and speed in execution. The program which normally runs in the SPAWS has a size of less than 4 KB and can be accommodated in just one EPROM on the CPU board. Interrupts are used to ensure that all time critical tasks such as data acquisition and baud rate generation are executed strictly according to schedule. Notwithstanding the requirement for compactness and efficiency, due consideration has also been given to readability of the program source code and ease of modification of the programs.

Altogether two programs have been developed for the SPAWS, one for normal operation of the station and another one for testing out the various components of the microcomputer during calibration and trouble-shooting of faults. The diagnostic program may be looked at as an assortment of subroutines of the normal SPAWS program, each of which can be initiated by the operator through the input keys of the diagnostic unit rather than automatically according to a time schedule. For this reason, only the normal SPAWS program will be described here.

4.2 Overall function

Operation of the SPAWS is scheduled by a date/time clock implemented using a timer channel of the microcomputer. The clock controls the timing of all data processing and peripheral control functions of the microprocessor and provides the date/time information in the transmitted report message.

In normal operation of the SPAWS, the microcomputer is programmed to sample all the conditioned analogue signals in sequence once every second. The data are stored in memory and processed once every minute to produce 1-minute average, extreme or accumulated values. Based on these 1-minute values, average, extreme or accumulated values over longer periods are computed every half an hour and composed into a report message. The message is then output serially to the transmission section at 300 bauds via a parallel input/output pin. The baud rate is generated by software using another timer channel of the microcomputer. As a means to conserve power, the microcomputer is programmed to turn on and off the power supplies to the temperature processor board, the pressure sensor and the UHF transmitter according to a time schedule.

As a means to accept operator's command, the microprocessor reads the key status of the diagnostic unit once every second to determine which key is being depressed. The status is interpreted and the corresponding function is executed.

The microprocessor also generates a 0.5 Hz clock to operate the fail-safe auto-reset circuit. It does so by outputting a "1" and a 0" alternately to a parallel input/output pin at the beginning of every second.

4.3 Specification of output products

At the automatic weather station at Huangmao Zhou, the meteorological parameters shown in Appendix 2 are computed and transmitted to the receiving station every half an hour. The computation of each parameter is handled by one or more program subroutines. Insertion, deletion or modification of any of these subroutine requires minimum modification of other parts of the program.

4.4 Format of report message

The SPAWS transmits report messages to the receiving station on the 00th and 30th minutes of the hour. The data are in ASCII format so that they can be displayed directly on an ordinary video terminal or printer at the receiving station after the FSK signal is demodulated by a modem.

The format of the report message is as follows:

<NUL><NUL><NUL><NUL><NUL><NUL><NUL><NUL><NUL><NUL>
]]]]]]]]<SOH>SSS<CR><LF>
<STX>YYMMDDhhmmss<CR><LF>
DxxxxExxxxFxxxxdxxxxexxxxfxxxxgxxxxhxxxxixxxxGxxxxHxxxxIxxxx
JxxxxSxxxxUxxxxuxxxxVxxxxyxxxxzxxxx
<CRC0><CRC1><CRC2><CRC3><ETX><CR><LF>
&&&&&&&&<SOH>SSS<CR><LF>
<STX>YYMMDDhhmmss<CR><LF>
DxxxxExxxxFxxxxdxxxxexxxxfxxxxgxxxxhxxxxixxxxGxxxxHxxxxIxxxx
JxxxxSxxxxUxxxxuxxxxVxxxxyxxxxzxxxx
<CRC0><CRC1><CRC2><CRC3><ETX><CR><LF>
<EOT><EOT><EOT>

where: <NUL> = 00H, <SOH> = 01H, <STX> = 02H, <ETX> = 03H,
<CR> = 0DH, <LF> = 0AH, <EOT> = 04H,

SSS = Station name (eg HMZ),

YYMMDDhhmmss = Year, month, day, hour, minute and second,

'D', 'E', 'F', ... etc, are data identifiers as defined in Appendix 2,

xxxx = Data. Leading blanks are filled with ASCII zeros.

Negative values are preceded by '-'. '9999' stands for variable wind or overflow, '////' for error, and

<CRC0>, <CRC1>, <CRC2> and <CRC3> are the ASCII equivalent of the 16-bit cyclic redundancy code for that part of the message enclosed by <STX> and <ETX>, excluding <CRC0> to <CRC4> themselves.

It can be seen that apart from some headers, the report message is made up of two identical halves. Each half carries the name of the station, the date and time of the report, the full set of data and a cyclic reducdancy code. The duplication of information in the message is aimed at reducing data loss due to noise in the transmission path which might invalidate part of the report message. The several <NULL> characters at the beginning of the message is intended for synchronization at the receiving station.

The serial bit format is 1 start bit, 8 data bits and 2 stop bits. There is no parity bit.

4.5 Program modules functional description

The SPAWS program is composed of a number of modules each performing some specific functions. The program modules are separately assembled and then linked together to form the complete SPAWS program. The functions of each module are described below:

(a) LPAWS: It is the main program module of the SPAWS. It initializes memory and input/output devices and activates different subroutines to acquire and process data according to a time schedule. The 1-minute mean wind direction, wind speed and maximum gust, 1-minute cumulated rainfall and 1-minute means of other sensor outputs, the 15-minute and cumulated rainfall and the 60-minute cumulated rainfall are computed within this module. This module also calls external subroutine WIND10 and WIND60 (see below) to calculate the 10-minute and 60-minute wind parameters. The algorithms for calculating the various wind parameters are given in Appendix 3.

(b) ISR: It is activated once every second by timer interrupt. Analogue input channels are scanned and the raw data (12-bit binary format) will be converted to a 32-bit floating point format, scaled and added to the respective 1-minute data buffers.

Also, the content of a control counter is incremented by one which is used for various input/output device time-outs.

(c) TXISR: It is activated once every 1/300 second by timer interrupt. It outputs the report message serially through one of the parallel input/output pins of the microcomputer. The timer interrupt is enabled by LPAWS when the report message is ready for transmission. The timer interrupt is disable by TXISR itself when the entire report message is transmitted.

(d) WIND10: It is a subroutine called by LPAWS to calculate the 10-minute mean wind and maximum gust. The algorithms are given in Appendix 3.

(e) WIND60: It is a subroutine called by LPAWS to calculate the 60-minute mean wind and maximum gust. The algorithms are given in Appendix 3.

(f) GENRPT: It is a subroutine called by LPAWS to compose the processed data into a report message in the format described in Section 4.4.

(g) RTC: When this subroutine is activated by ISR, the date/time clock is advanced by one second. It contains a set clock sub-module to enable the operator to set the date/time clock using the diagnostic unit.

(h) LIB: It contains various small subroutines used by other program modules. Most of the constants and tables are defined in this module.

(i) MATHS: It is a mathematical package for floating point and decimal arithmetic operations.

(j) RAM: This subroutine performs memory assignment for various variables during system initialization.

5. INSTALLATION

5.1 General considerations

The order in which the various pieces of equipment of the SPAWS are installed is not very important. However, if the time available for installation is limited, the equipment should be installed in an order that enables each to be tested immediately after it is installed. Therefore, it is preferable to install the solar power supply unit before the electronic rack so that the DC-to-DC converters can be tested before power is applied to the electronic circuit boards. Also, the UHF transmitter and antenna should be installed before the sensors, so that testing of transmission and reception can be carried out while the sensors are being installed.

All the equipment of the SPAWS are to be mounted outdoors on specially designed steel supporting structures. These structures are secured on top of concrete bases using embedded anchor bolts, which are set in the concrete with the help of templates to ensure exact alignment of the bolts and the holes on the legs of the supporting structure. Except the anemometer mast, all supporting structures and anchor bolts are made of stainless steel to resist corrosion. Lock washers are used throughout to prevent nuts from loosening as a result of vibration at high winds.

5.2 Solar panels and shunting regulator

The solar panels and the shunting regulator are mounted on a single supporting frame. A tiltable aluminium bracket supplied with the solar panels is first bolted on the supporting frame, and then the panels are bolted side by side on the bracket. The bracket is further held at its top end by guy wires fixed at the anchor bolts of the supporting frame. The shunting regulator are mounted on two parallel bars near the middle of the supporting frame. Cables from the solar panels and the batteries are connected to the appropriate junction terminals inside the shunting regulator.

5.3 Instrument cabinet and sun shield

The instrument cabinet stands on two horizontal parallel bars of another supporting frame. It is held onto the bars by four hooks bolted on the bottom of the cabinet. Five stainless steel sheets are bolted by butterfly nuts onto the four sides and the top of the supporting frame to act as a sun shield for the instrument cabinet.

The instrument cabinet is divided into two compartments by a removable PVC board supported on four small plates welded on the side walls of the cabinet. Batteries are placed in the lower compartment while the electronic rack is placed in the upper compartment. Cables run between the two compartments at the back of the cabinet. Connection of cables between equipment inside and outside the cabinet is made via three water-proof sockets fitted on the front bottom of the cabinet. A hole on the front bottom of the cabinet allows the pressure sensor venting tube and the UHF antenna cable to pass through. The hole has to be sealed by silica gel after the tube and antenna cables were put in place. The hinged door on the front of the cabinet is fitted with rubber rims to make it air-tight.

5.4 Electronic rack

In installing the electronic rack, all circuit boards must first be inspected for visible damage and then inserted into the proper slots (Figure 3). After application of power, an ammeter should be used to check the current consumption. The normal consumption is approximately 150 mA. If the set clock operation can be performed correctly through the diagnostic unit, the installation of the electronic rack is completed.

5.5 Meteorological sensors

The wind sensors are mounted on an adaptor which is bolted on the top of the anemometer mast. The wind sensors should be tested both mechanically and electrically before they are mounted on the mast. Electrical connections to the instrument cabinet are made through a plug and socket assembly on the mounting adaptor.

The temperature sensor is mounted at eye level inside a wooden Stevenson screen (Reference 13) affixed on a stainless steel supporting structure. The output leads of the sensor are fixed onto a terminal block inside the screen.

The pressure sensor is mounted by bolts on the upper left side of the instrument cabinet. A nylon venting tube attached to the sensor inlet protrudes outside the instrument cabinet through a hole at the bottom of the cabinet. The tube is fitted onto the air inlet of a static pressure head (Reference 14) standing next to the instrument cabinet. The static pressure head is used to minimize the dynamic wind effect on pressure measurement. It is mounted on a pole stuck in the ground and is higher than the instrument cabinet so that wind flow around it is not disturbed by the cabinet.

The tipping bucket rain-gauge is mounted on a concrete slab by means of two anchor bolts. Level screws are provided on the rain-gauge to bring it to a horizontal position for best accuracy. A 2-core cable is connected across the sensor switch and brought to the terminal block inside the Stevenson screen. A multi-core cable then carries the signals from the temperature and the rainfall sensors to the instrument cabinet.

5.6 UHF transmitter and antenna

The UHF transmitter is mounted by bolts near the pressure sensor inside the instrument cabinet. The co-axial antenna cable passes outside the cabinet through the same hole on the bottom of the cabinet as for the venting tube of the pressure sensor.

The Yagi antenna is clamped on a mounting bracket which is attached to the anemometer mast. The antenna is mounted at about 2.5 m above ground level with the antenna pointing at the receiving station. The dipoles on the antenna are aligned horizontally to produce horizontal polarization so as to minimize the scattering of the electromagnetic wave by the sea surface.

5.7 External cables and connectors

There are a number of multi-core cables running between equipment at various locations. Shallow trenches are dug on the ground to bury the cables. Pre-cast U-shaped concrete blocks are used to cover the trenches to prevent the cables from being blown about by strong winds.

All cable routes are made short and smooth. Surplus cables are coiled into loops and secured onto the nearest supporting structures by cable ties.

All exposed connectors are wrapped with fusible tape to resist moisture and to provide mechanical strain relief on the cable joints.

6. MAINTENANCE

6.1 General considerations

The electronics of the SPAWS has been designed for maintenance-free operation. In choosing the solar power supply unit and sensors, ease of maintenance of the mechanical parts is one of the prime considerations. Routine maintenance is required no more than once every six months. The maintenance work required in each maintenance trip will be described below.

Field repair and calibration of sensors and circuit boards should be avoided. In case of failure, faulty boards and modules should be replaced with good and pre-calibrated ones. It is therefore necessary to have a full set of spare sensors and circuit boards ready for replacement.

6.2 Electronic rack

Metal contacts should be examined for corrosion which might happen if the instrument cabinet has not been sealed properly. If that happens, the entire electronic rack might have to be replaced.

6.3 Solar power supply unit

The solar panels should be cleaned to remove dust and dirt which decrease the efficiency of the panels. Bolts and guy wires should be checked for loosening.

6.4 Meteorological sensors

The wind sensors require almost no maintenance. All electronic as well as movable parts are essentially sealed and hence do not require cleaning. Routine maintenance includes visual inspection for physical damage, and checking the sensor mounting and alignment. The mounting adaptor should be painted once a year.

The temperature sensor should be cleaned to remove any dust accumulated on the surface. The terminal block and cable connection should be examined. The screen box should be painted annually.

The tipping bucket rain-gauge should be inspected for physical damage. Any dirt or grass inside the funnel should be cleared. Tipping of the buckets should be verified by pouring a known amount of water into the rain-gauge and counting the number of contact closures.

6.5 Supporting structures

The guy wires for the anemometer mast should be examined and tightened if necessary. The mast should be painted once every two years.

As stainless steel is weather-resistant and requires no painting, the only maintenance required for the other supporting structures is the examination of the bolts and nuts to make sure that none is loosen.

6.6 External cables and connectors

All external cables and connectors should be inspected for physical damage, loosening and bad contact. Any fault discovered should be repaired immediately. The joints of broken cables should be wrapped with plastic tapes and then fusible tapes. Bad connectors should be replaced.

7. CONCLUDING REMARKS

The automatic weather station at Huangmao Zhou described in this Technical Note is the first solar-powered automatic station developed and deployed by the Royal Observatory. Since its installation in July 1985, the station has functioned satisfactory without any interruption up to the present time (September 1986). It survived the passage of Typhoon Tess (8515) in September 1985, which came within 140 km of the station and gave rise to a maximum hourly mean wind of 32.4 m/s and a maximum gust of 41.7 m/s at the station. In comparison, the SPAWS was more reliable than the automatic weather stations set up within Hong Kong, which were occasionally damaged by voltage surges induced by lightning on the power line. It is therefore planned that future automatic weather stations would also be of the solar-powered type whenever possible.

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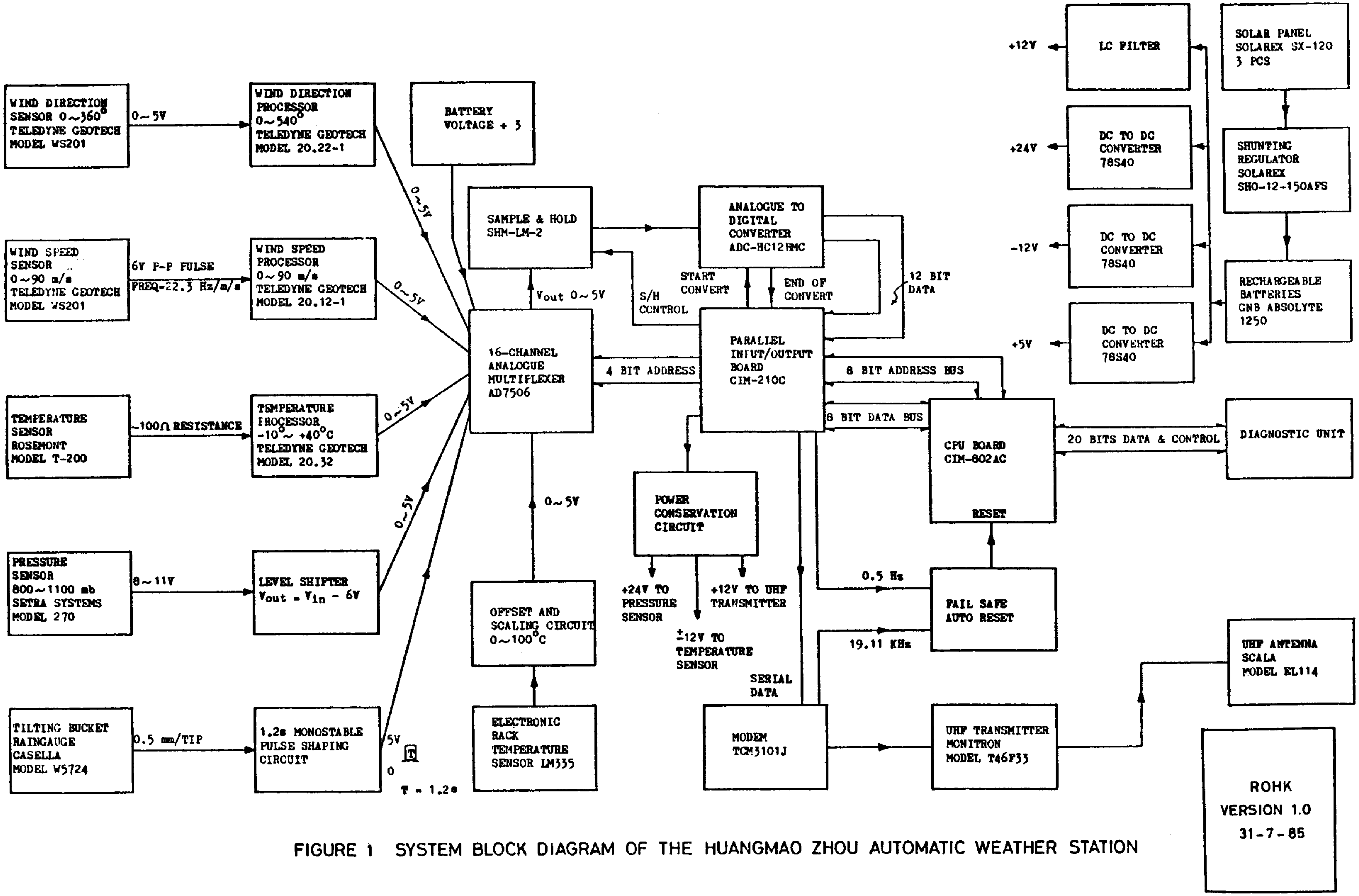
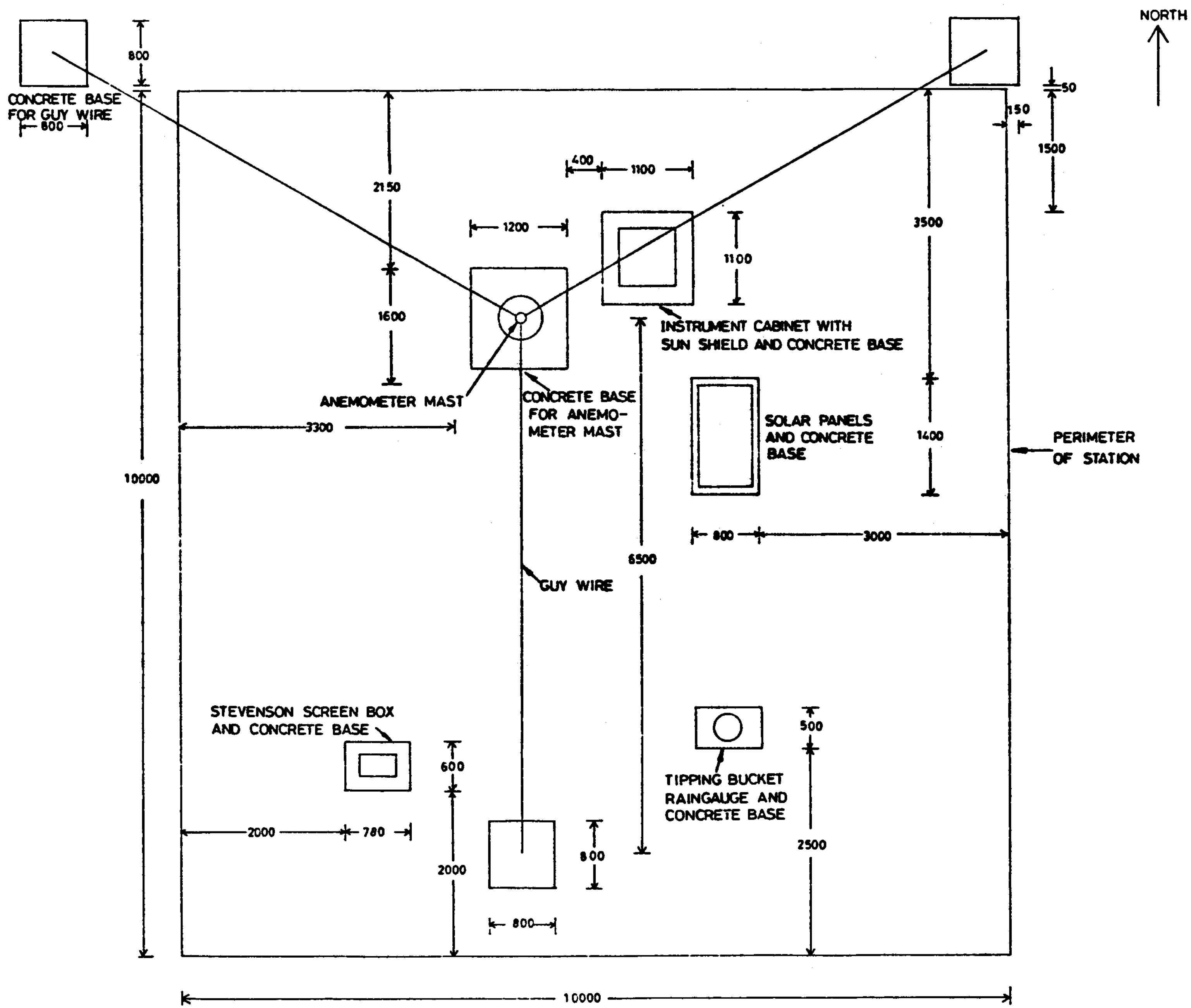


FIGURE 1 SYSTEM BLOCK DIAGRAM OF THE HUANGMAO ZHOU AUTOMATIC WEATHER STATION



ROHK
VERSION 2.0
16-12-85

FIGURE 2 SITE PLAN OF AUTOMATIC WEATHER STATION AT HUANGMAO ZHOU

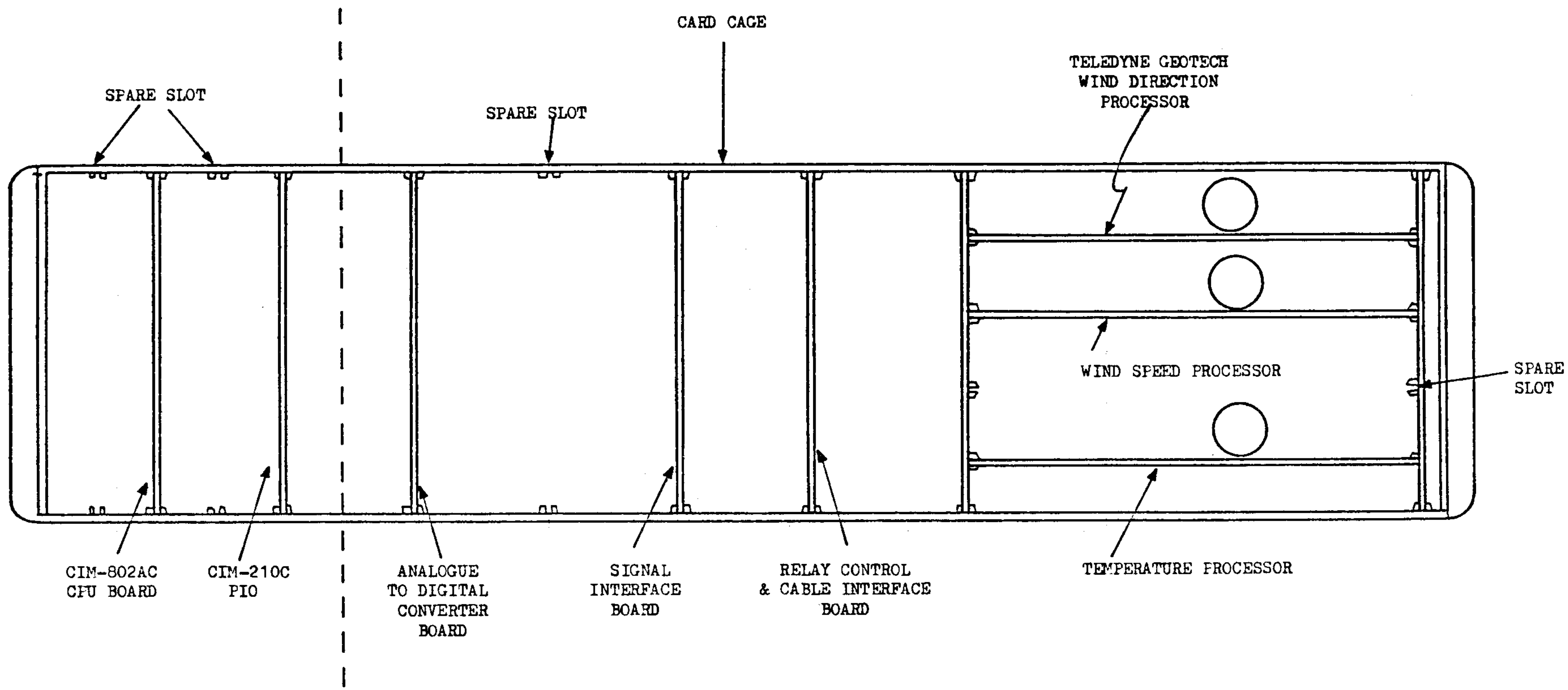


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FIGURE 3 CIRCUIT BOARD POSITIONS INSIDE ELECTRONIC RACK

APPENDIX 1 -
Features of the Solar-powered Automatic Weather Station

1. Sensors and supplied signal conditioners

(a) Wind direction

Sensor	-	Counterweight-balanced vane
Threshold	-	1 m/s
Distance constant	-	1.5 m maximum
Output	-	0 - 5 V corresponding to 0 - 540 degrees
Accuracy	-	±3 degrees, 5 degrees maximum gap
Power required	-	+5 V, 0.5 mA. ±12 V, 15 mA each

(b) Wind speed

Sensor	-	3-cup generator
Threshold	-	1 m/s
Distance constant	-	5 m maximum
Range	-	0 - 90 m/s
Output	-	0 - 5 V corresponding to 0 - 90 m/s
Accuracy	-	±0.5 m/s or ±2% of true air speed
Power required	-	+12 V, 15 mA. -12 V, 6 mA.

(c) Temperature

Sensor	-	4-wired platinum resistance
Linearity	-	in accordance with International Resistance vs Temperature Chart
Output	-	0 - 5 V corresponding to -10 to 40 degrees Celsius
Accuracy	-	±0.1 degree Celsius
Power required	-	±12 V, 20 mA each

(d) Pressure

Sensor	-	variable capacitance ceramic capsule
Range	-	800 - 1100 hPa
Output	-	8 to 11 V corresponding to 800 - 1100 hPa
Accuracy	-	±0.3 hPa at room temperature
Power required	-	+24 V, 12 mA

(e) Rainfall

Sensor	-	400 cm sq. tipping bucket rain-gauge
Resolution	-	0.5 mm per tip
Output	-	contact closure of about 100 ms duration with multiple bouncing

(f)	House keeping	-	Battery voltage and temperature inside main electronic rack also sensed and reported back

2. Processing

(a)	Microcomputer	-	CIM-bus CPU and parallel I/O boards running at 2 MHz clock
(b)	Program	-	contained in one 4 KB EPROM on CPU board
(c)	RAM	-	2 KB static RAM on CPU board
(d)	Operator interaction	-	hand-held diagnostic unit
(e)	Date/time clock	-	year, month, day, hour, minute and second. Accuracy 2 seconds per month
(f)	A/D	-	12-bit binary. 0 - 4095 corresponding to 0 - 5 V
(g)	Sampling rate	-	1/sample/analogue channel/second
(h)	Output products	-	18 parameters per report (see Appendix 2)
(i)	Report frequency	-	once every half an hour at 00th and 30th minutes
(j)	Report format	-	ASCII codes in format shown in Section 5.7
(k)	Serial format	-	300 bauds, 1 start bit, 8 data bits, no parity bit, 2 stop bits

3. UHF transmitter and antenna

(a) UHF transmitter

Transmitter type	-	frequency modulation
Frequency	-	400 - 470 MHz, factory set at 465.425 MHz
Bandwidth	-	5 kHz
Deviation sensitivity	-	5.0 kHz/1.0 V_{rms} input
Distortion	-	3% at 1 kHz and 2/3 deviation
Output power	-	2.2 W

Input impedance	-	100 k-ohms minimum
Output impedance	-	50 ohms
Power required	-	12 V, 460 mA

(b) Antenna

Type	-	Yagi with 7 dipoles
Bandwidth	-	450 - 470 MHz
Gain	-	10 dB at 460 MHz
Impedance	-	50 ohms

4. Solar power supply unit

(a) Solar panels

Number of panels	-	3 connected in parallel
Open circuit voltage	-	22.5 V
Voltage at peak power	-	17.25 V
Current at peak power	-	2.3 A per panel
Wind loading	-	60 m/s

(b) Regulator

Type	-	shunting
Power handling	-	150 W
Regulation voltage	-	14.4 V at 25 degrees Celsius, temperature compensated and adjustable
Shunt path open voltage	-	12.5 V
Housing	-	weather-proof aluminium box

(c) Batteries

Number of batteries	-	3 connected in parallel
Type	-	lead-acid, sealed
Nominal voltage	-	12 V
Capacity	-	59 AH down to 10.5 V

5. Power requirement

(a) Supply voltages	-	+12 V direct from batteries, +5 V, -12 V and +24 V from switch-mode DC to DC converters

(b) Ripple - less than 50 mV at all supply voltages using LC filters

(c) Current consumption - average consumption including dissipation at DC-to-DC converters 2.0 W; peak consumption 7.5 W when UHF transmitter is turned on.

6. Supporting structures and cables

(a) Anemometer mast - 10 m high, 89 mm outer diamemter G.I. pipe

(b) Other supporting structures - stainless steel frames for bolting on concrete foundations. All equipment can be mounted out-door.

(c) External cables - shielded direct-burial type

APPENDIX 2 Specification of output products

Product Name	Data Identifier	Resolution	Range
GPW(A)*			
10-min mean wind direction	D	1.0 deg	0-360 deg
10-min mean wind force	E	0.1 m/s	0-90 m/s
10-min maximum gust	F	0.1 m/s	0-90 m/s
GRW(B)*			
10-min mean wind direction	d	1.0 deg	0-360 deg
10-min mean wind force	e	0.1 m/s	0-90 m/s
10-min maximum gust	f	0.1 m/s	0-90 m/s
GPW(C)*			
10-min mean wind direction	g	1.0 deg	0-360 deg
10-min mean wind force	h	0.1 m/s	0-90 m/s
10-min maximum gust	i	0.1 m/s	0-90 m/s
60-min mean wind direction	G	10 deg	0-360 deg
60-min mean wind force	H	0.1 m/s	0-90 m/s
60-min maximum gust	I	0.1 m/s	0-90 m/s
1-min mean temperature	J	0.1 deg	-10-40 deg
1-min mean MSL pressure	S	0.1 hPa	800-1100 hPa
GPR(A)*			
15-min cumulative rainfall	U	0.5 mm	0-225 mm
GPR(B)*			
15-min cumulative rainfall	u	0.5 mm	0-225 mm
60-min cumulative rainfall	V	0.5 mm	0-900 mm
Battery output voltage	y	0.1 V	0-15 V
Cabinet temperature	z	0.1 deg	0-100 deg

*NOTE: (a) The three sets of 10-minute mean wind/maximum gust are designated by GPW(A), (B) and (C). GPW(A) is the latest and GPW(C) is the earliest.

(b) The two sets of 15-minute cumulative rainfall are designated by GPR(A) and (B). GPR(A) is the latest.

APPENDIX 3 -
Algorithms for calculating various wind parameters

1. 1-minute mean wind and maximum gust

Since wind direction values have a discontinuity at 360 degrees, the mean value cannot be calculated by simply taking the arithmetic average. The algorithm used for calculating the 1-minute mean wind direction is as follows:

(a) The sixty wind direction readings taken within the minute are sorted into two groups, one group for directions greater than 180 degrees and another group for directions less than 180 degrees. The number of samples and the scalar mean of these two groups are represented by variables (m, M) and (n, N) respectively.

(b) If (M - N) > 180 degrees, the mean wind direction will be [m(M -360) + nN]/(m + n); otherwise it will be [mM +nN]/(m + n).

The 1-minute mean wind speed is the scalar mean. The 1-minute maximum gust is the largest of the sixty wind speed readings taken within the minute.

2. 10-minute mean wind and maximum gust

The 10-minute mean wind direction is calculated from the ten latest 1-minute mean wind direction values.

(a) The ten 1-minute mean wind directions are represented by variables D0, D1, ..., D9 with D9 being the latest.

(b) The wind is classified as steady if the deviation of the wind direction (comparing consecutive 1-minute means) is less than 30 degrees, otherwise it is classified as unsteady.

(c) If the wind in the latest three minutes is unsteady, the wind direction is classified as variable and is represented by the value 9999.

(d) If counting from the end, the number of consecutive minutes with steady direction is greater than or equal to three, the scalar mean is calculated for the entire period (starting from the end) for which the wind is steady.

(e) If (c) and (d) do not apply, the scalar mean is calculated only for the last time period with steady wind direction lasting more than three consecutive minutes and such that this period ends within D5 to D9. Otherwise the wind is classified as variable.

The 10-minute mean wind speed is the scalar mean of the ten latest 1-minute mean wind speed values.

The 10-minute maximum gust is taken to be the largest of the 1-minute maximum gusts in the past ten minutes.

3. 60-minute mean wind and maximum gust

The 60-minute mean wind direction is calculated from the sixty latest 1-minute mean wind directions values.

(a) The sixty 1-minute mean wind direction values are sorted into 10-degree sectors centred at 010, 020, 030, ... , and 360 degrees.

(b) The number of samples within each sector is smoothed by a "1 4 6 4 1" weight as follows:

Let N(X) = number of samples in the 10-degree sector centred at X degrees

On smoothing,

$$Ns(X) = 1N(X-20) + 4(X-10) + 6N(X) + 4N(X+10) + 1N(X+20)$$

(c) If there exists a unique maximum Ns(Xm), then the mean wind direction = Xm degrees.

(d) If more than one maximum exist and the difference in direction of the two widest separated maxima is greater than or equal to 90 degrees, the wind direction is classified as variable. Otherwise the mean direction equals the average direction of these 2 extreme values.

The 60-minute mean wind speed is the scalar mean of the sixty latest 1-minute mean wind speed values.

The 60-minute maximum gust is taken to be the largest of the 1-minute maximum gusts in the past sixty minutes.