# AUSTRALIAN UNMANNED GEOPHYSICAL OBSERVATORIES IN ANTARCTICA

I. G. BIRD* and P. H. SULZBERGER**

*Abstract:* The development and performance of a very low power consumption unmanned geophysical observatory are described. The observatory, now in operation south of Casey, Antarctica, includes instrumentation for the study of auroral morphology, ionospheric opacity, geomagnetism, and micrometeorology; average power consumption is 0.75 watts and operation to ambient temperatures of −85°C is feasible. Reliable performance for periods up to one year has been achieved.

## 1. Introduction

The cost and difficulties of supporting manned stations on the Antarctic icecap have stimulated, over the past decade, increased attention toward the possibility of using automatic stations (JENNY and LAPSON, 1968; JENNY *et al.,* 1969; BIRD and HUMPHREYS, 1971; SITES, 1973; HEIKKILA, 1973). An adhoc Working Group of the U.S. National Academy of Sciences recently expressed the view "the technology for cost effective implementation of such stations is now available" (BARCUS, 1974).

Significant advances in technology during the past 5 years have paved the way for the development of practical automatic stations which consume small amounts of electrical energy and are capable of reliable operation in Antarctica. Feasibility studies and field trials conducted by the Antarctic Division over a number of years provided background experience for the development of an observatory to support research in auroral morphology, geomagnetism, the ionosphere and micrometeorology (BIRD and HUMPHREYS, 1971).

The observatory, described in the present paper, has been designed for unattended operation for periods up to one year. It consumes an average power of 0.75 watts and records data on digital magnetic tape and photographic film; reliable operation at site temperatures as low as −85°C is feasible. Observatory instrumentation is housed within a shelter buried beneath the snow surface. Only those instruments and structures necessary for data collection and power generation are exposed to the surface environment (Fig. 1). Field trials of the new observatory have been conducted at a site 80 km southeast of Casey (66°38′S, 112°16′E) near the summit of Law Dome.

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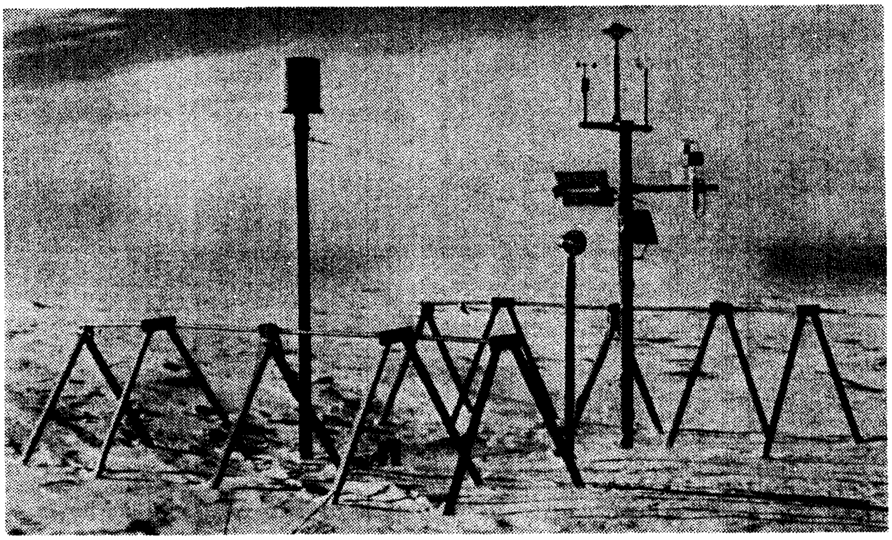

*Fig. 1. Unmanned geophysical observatory installation.*

This paper discusses the design philosophy for reliable low-power unmanned observatories and field experience in their use since 1971. Attention is drawn to recent developments such as low-power solid-state devices, solid-state image sensors, and data transmission via satellite.

## 2. Engineering Background

There are many problems in the design of an unmanned observatory for operation in Antarctica, where surface temperatures to −88°C and winds to 50 $\mathrm{ms}^{-1}$ have been recorded and drifting snow is common. The generation of electric power is one of the foremost. To generate even a few watts can be difficult and costly. The success of the present observatory can be ascribed largely to the low-power consumption achieved by instrumental design and avoidance of thermal control.

The factors discussed in this section of the paper were more comprehensively reported in an earlier paper (BIRD and HUMPHREYS, 1971) and are included here for completeness and for discussion of more recent experience.

### 2.1. *Power supply*

For a 1 watt observatory, the total energy requirement is 9000 watt hours per annum, *i.e.* 1500 amp hours for a 6 volt supply. Experience has shown that this level of power can be conveniently and economically provided from precharged lead-acid batteries with some wind and solar energy support.

Field trials have confirmed the expected efficiency of special lead-acid cells at low temperature. Self discharge is negligible and discharge efficiencies of 75% at −20°C have been established in recent trials at low discharge currents (10,000

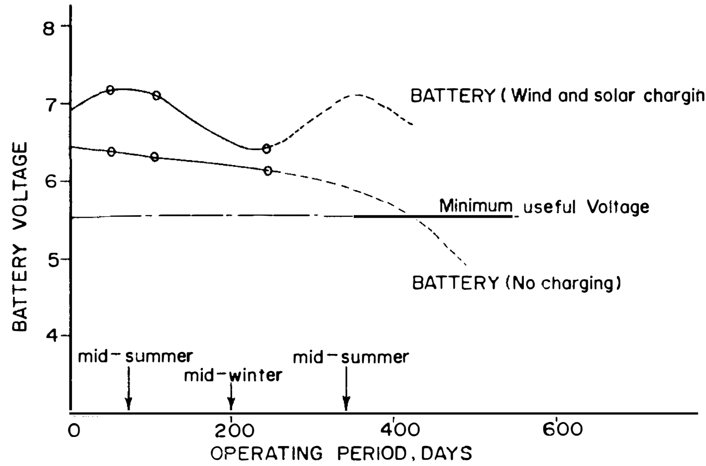

*Fig. 2. Long-term discharge performance of two lead-acid batteries.*

hour rate). These cells are supplied with excess electrolyte; specific gravity is 1.310 which provides the maximum freezing point depression of −72°C for a sulphuric acid-water mixture.

The long-term performance of two 6 volt lead-acid batteries each with a capacity of 500 amp hours is shown in Fig. 2; the discharge was 0.91 amp hours per day, at −20°C.

Battery 1 is powering the logic components of the observatory and is not receiving charge. Battery 2 is powering the various motors and is being charged from a solar panel and wind driven generator.

The life of Battery 1 before recharging is required is projected to be 430 days while that of Battery 2 is indefinitely long.

For the prototype 1.5 watt observatory (1971) it proved difficult to maintain the batteries for long-term operation on the basis of an installed capacity of 1500 amp hours with wind and solar charging. However, for the new observatory deployed in December 1974, the power consumption is 0.75 watts and long-term

*Table 1. Observatory power and energy summary at −30°C.*

| Instrument | Average power requirement (watts) | Annual energy consumption (amp hours) |
|---|---|---|
| Data logger | 0.25 | 362 |
| Chronometer | 0.184 | 265 |
| Riometer | 0.078 | 114 |
| Magnetometer | 0.16 | 234 |
| All sky camera | 0.05 | 75 |
| Meteorological sensors | 0.032 | 47 |
| Total | 0.754 | 1097 |

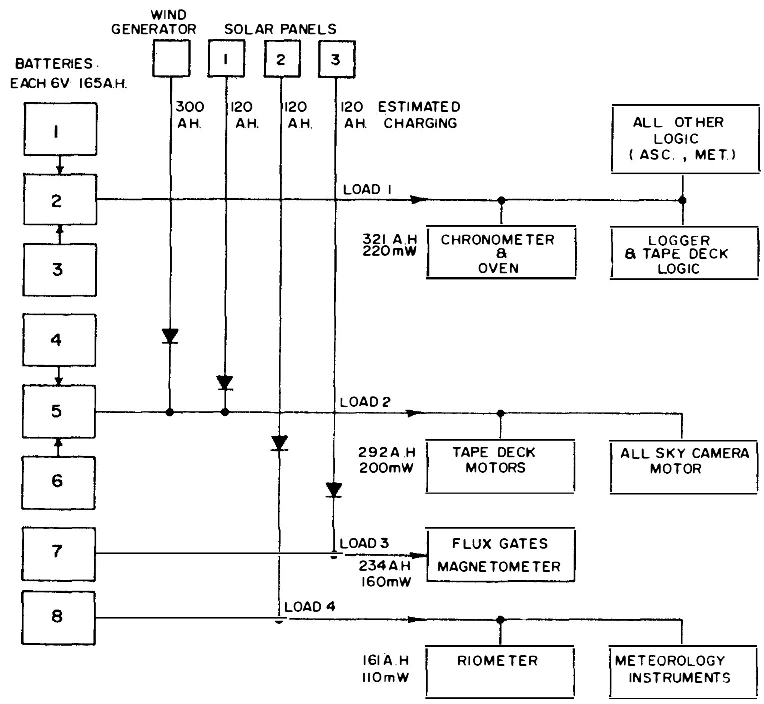

*Fig. 3. Power supply configuration for unmanned observatory.*

operation presents no problem. The total weight of the 1300 amp hour lead-acid battery bank now installed is 400 kg.

The power summary for the observatory instrumentation is tabulated above (Table 1); annual energy requirement is 1097 amp hours at an ambient temperature of −30°C (0.75 watts) and 1278 amp hours at −50°C (0.87 watts). This temperature dependent increase is due to the demands of the chronometer quartz crystal oven.

The observatory power supply arrangement is segmented into four separate battery banks; three banks receive charge (Fig. 3).

Lead-acid cells are of the Faure-X type, 165AH, 2 volt; the plate assembly is mounted within the case normally supplied for 200AH cells to provide the required excess electrolyte. Faure-X cells are specifically designed for long life, low loss service in telephone exchange applications; reliable performance for periods in excess of 20 years has been reported (Exide, 1972).

The recent availability of lithium primary cells (Lyman, 1975) has provided a source of non-aqueous electrolyte batteries discussed in the earlier report. These cells have a capacity of 50 watt hours per kilogram (compared with 20 watt hours per kilogram for Faure-X cells) and supply 60 percent of capacity at −40°C. Lithium cells could, therefore, provide a convenient source of energy where weight is critical, for example where observatories are deployed by air.

### 2.1.1. Wind driven generator

The Antarctic Division turbine wind driven generator supplies a current of 0.5 A to a 6 volt battery in a 10 m $sec^{-1}$ wind; its starting wind speed is 4.5 m $sec^{-1}$. This generator has effectively maintained one battery bank, supplying 300 amp hours of charge per annum. A 25 cm diameter fan of aerofoil blades is direct-coupled to a permanent magnet rotor; the stator is series wound. A minimum of cowling, set forward from the blades, is used.

### 2.1.2. Solar generator

Silicon solar panels have provided a highly reliable source of power. In midsummar a particular solar panel, area 0.07 $m^2$, generated 4 watts of power but by late April this had fallen to 1 watt at mid-day.

Ideally, the elevation of the solar panel should be adjusted periodically for optimum results during the various seasons. Good average results have been obtained by directing the panels towards the snow surface rather than skywards.

### *2.2. Instrumentation for low power and low temperature operation*

For most existing geophysical instruments and recording systems used in upper atmosphere research little attention has been paid to minimising the power consumption and alleviating some of the fundamental causes of thermal instability.

For unmanned observatory applications power economy is achieved by using a nominal 6 volt battery system regulated to 5 volt; this voltage is the minimum generally to operate solid state devices and electric motors. The decision to design the observatory for operation from a single polarity 5 volt supply was made in 1969 when it was becoming evident that future development of linear and digital integrated circuitry was likely to be towards the 5 volt system. Many such elements now exist, including microprocessors (MOTOROLA, 1975), analog-digital

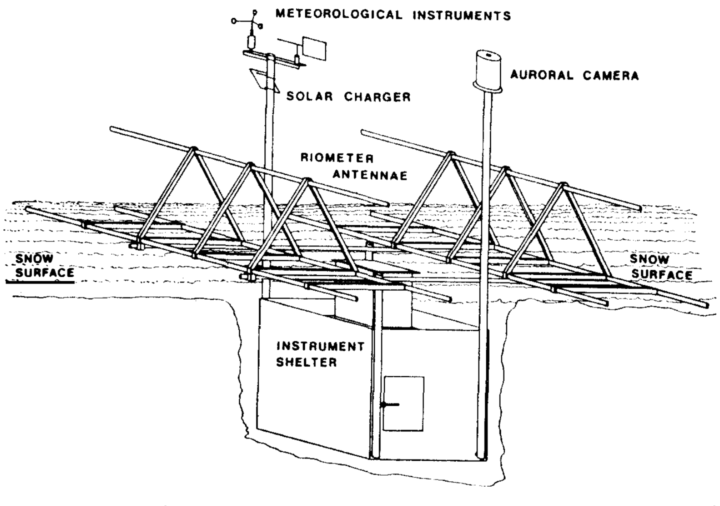

*Fig. 4. A sectional diagram of the unmanned observatory installation.*

converters, operational amplifiers, and comparators. Resistive power losses in CMOS logic elements are in the nanowatt region.

It was apparent at the outset that no significant amount of power could be provided easily for thermal control of the observatory instrumentation; all equipment, with the exception of the quartz crystal time reference, therefore, is unheated. However, the observatory instrumentation is housed within a 2.2 metre cube instrument shelter beneath the snow surface (Fig. 4), where thermal inertia provided by the snow cover restricts the temperature of the site (WELLER and SCHWERDTFEGER, 1968). Only those systems necessary for data collection and power generation are exposed to the surface environment.

### 2.2.1. Components for unmanned observatories

The performance of various electrical and mechanical components at low temperatures was discussed in detail in the earlier paper; recent field experiences has confirmed the previous conclusions. Provided due account is taken of the drift in logic levels of digital devices, and gain and offset drifts in analog circuitry, adequately stable electronic instruments can be designed for operation at variable low temperatures.

It is expected that the reliability of electronic components should be significantly improved as temperature decreases. This is indicated from the extrapolation of reliability data at elevated temperatures and reported experience at low temperatures (KEYES *et al.*, 1970). During 5 years of field experience with circuitry operating at low temperatures, no electronic failure of a random "wear out" nature has occurred.

Static electricity, generated by drifting snow, has created significant problems, particularly since the widespread use of CMOS logic* elements, and circuit

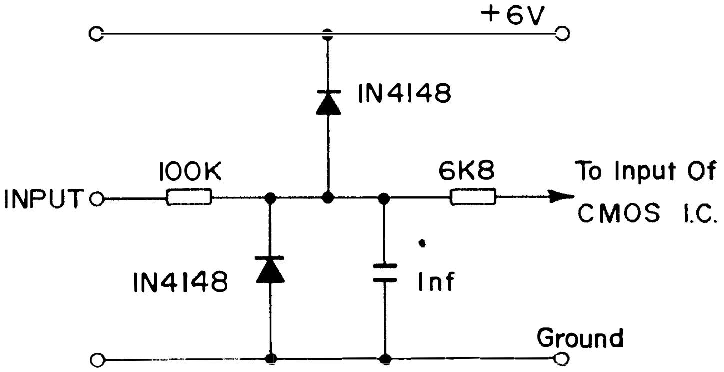

*Fig. 5. Suppression circuitry for snow drift static electricity.*

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* CMOS logic is easily damaged during assembly by static discharge and improperly earthed soldering irons. Damage may not be immediately evident; actual device failure has sometimes occurred several months following installation damage.

failure due to the effects of static electricity has occurred. External cables are now screened and earthed to the instrument rack, and suppression circuits are used on all external sensor lines feeding sensitive inputs (Fig. 5).

The performance of mechanical components is largely dictated by lubrication. Teflon coated surfaces and molybdenum disulphide bonded lubricants (DI SAPIO, 1968), can provide excellent low-temperature performance in bearings and gear trains. Photographic film and magnetic tape are adequately flexible at low temperatures if moved slowly.

### 2.2.2. Sensor performance in the surface environment

The auroral all sky camera, meteorological sensors, and riometer antenna must withstand the extremes of the surface environment.

Despite the unusual and often unknown stress experienced by the exposed components, reliable performance has been achieved. In the prototype station the elements of the riometer antenna projected beyond their end supports and brittle fracture occurred due to vibration. Minor problems have occurred due to icing of the meteorological sensors. The lens of the all sky camera has remained remarkably free of ice although, originally when the camera housing was black, moisture condensed on the inner face of the objective lens. This problem has been largely removed by painting the camera housing with "day-glow" and installing silica gel.

## 3. Scientific Instrumentation

A new generation of standard upper-atmosphere research instrumentation has been specifically developed for unmanned observatory applications.

These instruments are capable of specified operation at ambient temperatures as low as −70°C and consume typically one percent of the power of the standard equipment. The high performance of the new instruments make them attractive replacements for observatory equipment in almost any location.

Individual instruments are broadly discussed below; more detailed descriptions already published or in the course of preparation are referenced. A simplified block diagram of the observatory is shown in Fig. 6.

### *3.1. Riometer*

Riometers measure relative ionospheric opacity by comparing the cosmic noise passing through the ionosphere with a noise reference (LITTLE and LEINBACK, 1959). A servo-controlled receiving system generates noise to balance the incoming signal (Fig. 7).

Active development of riometer systems took place principally during the late 1950's and early 1960's. Although since that time the instrument has gained widespread acceptance, almost no new instrumental development was reported until 1971 when a low-power temperature-stable riometer suited to long-term un-

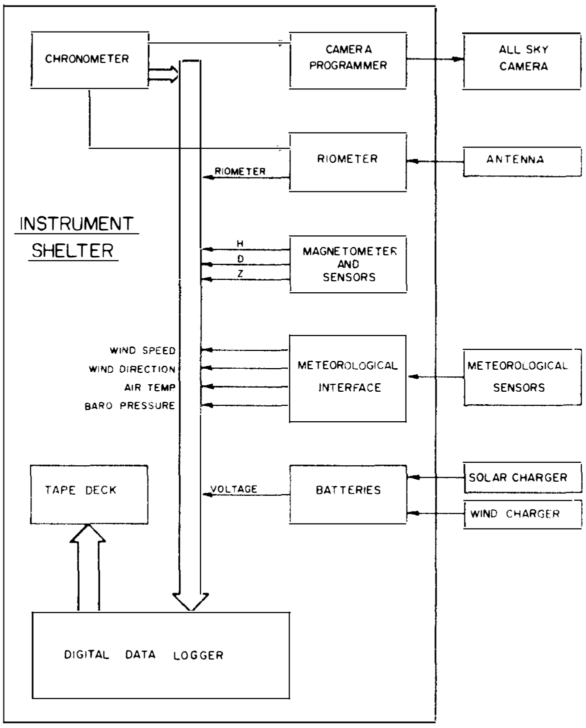

*Fig. 6. Simplified block diagram of the observatory instrumentation.*

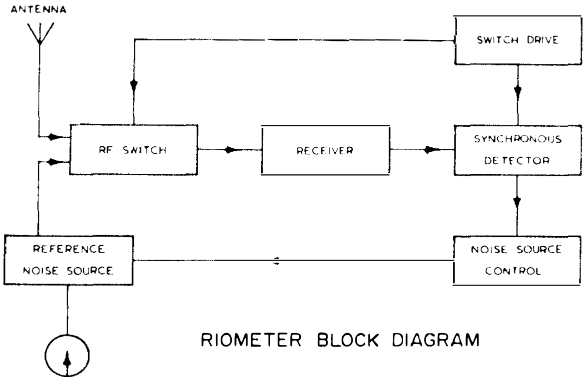

*Fig. 7. Riometer block diagram.*

attended operation was developed at the Antarctic Division (Bird and Humphreys, 1971).

### 3.1.1. Recent developments

Further Australian advances in the design of low-power riometers have been reported more recently (Bird *et al.*, 1974). This work has provided a sound theoretical basis for the design of riometers consuming 0.1 watts of power and capable of reliable and stable operation at the ambient Antarctic temperatures.

The heart of these riometers is a solid-state reference noise source of novel design. It utilises the collector shot noise of a bipolar transistor rather than the usual temperature limited thermionic diode. This is the main reason for the low power consumption, reliable operation, and fast response characteristics. Although this noise source is not a fundamental standard like the thermionic diode its noise characteristics for a given frequency are practically independent of temperature, are linear with collector current, and may be calibrated.

### 3.1.2. Riometer performance

The linearity and thermal stability of the riometer is shown in Fig. 8; its output with reference to a standard thermionic noise source at ambient temperatures between +70°C and −70°C is plotted. Field experience at the unmanned observatory and Australian Antarctic stations has demonstrated its performance and reliability.

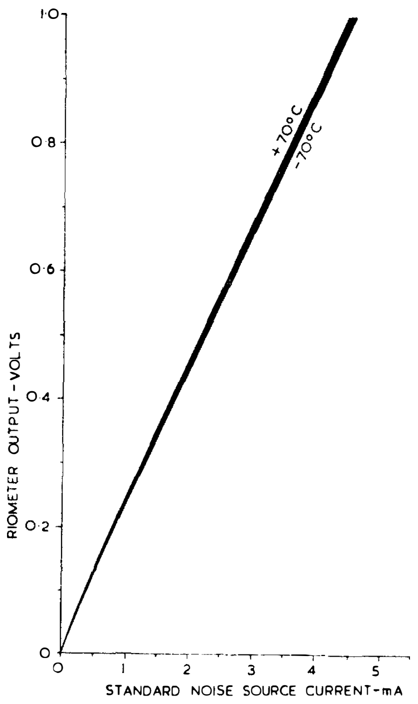

*Fig. 8. Riometer thermal stability.*

### *3.2. Fluxgate magnetometer*

Fluxgate magnetometers are now widely used to measure variations in the intensity of the geomagnetic field. With careful design the fluxgate technique can be made sufficiently stable for observatory applications (Primdahl, 1970). However, the significant temperature drift and relatively high power consumption of existing instruments (Newman and Seers, 1964; Trigg *et al.*, 1971) makes them

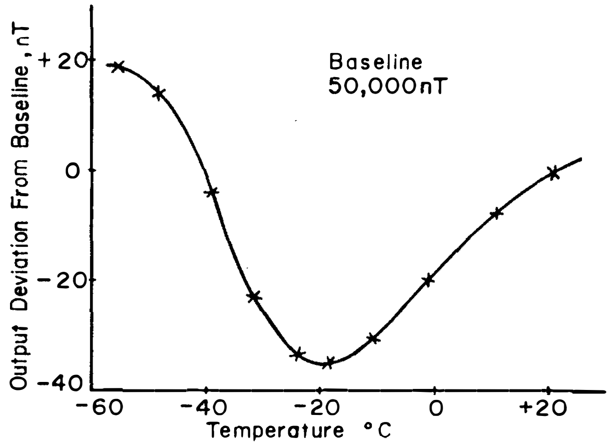

*Fig. 9. Thermal performance of fluxgate magnetometer.*

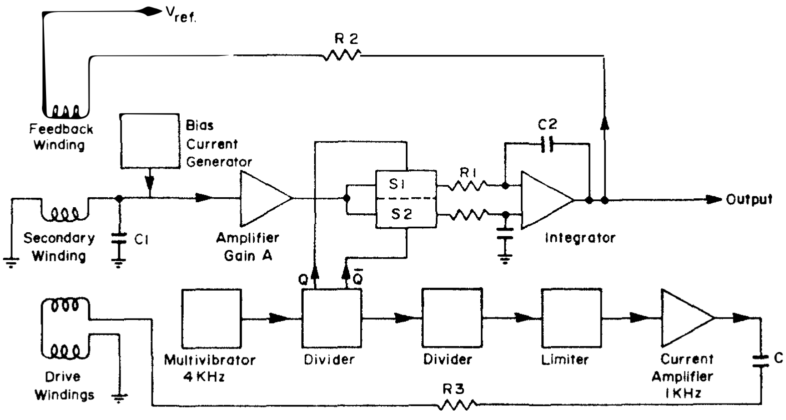

*Fig. 10. Block diagram of fluxgate magnetometer.*

generally unsuitable for the stringent environment and low power requirements of Antarctic field sites.

### 3.2.1. A micropower magnetometer

A new three axis fluxgate magnetometer has been developed specifically for unmanned observatory applications (MORTON and SUCKAU, 1975). It consumes 0.16 watts of power and has stability approaching 1 nanotesla per degree centigrade at temperatures to −60°C (Fig. 9).

To achieve this performance, the phase drift between signal and reference waveforms in the circuitry was largely eliminated. A block diagram of the magnetometer is shown in Fig. 10; CMOS logic elements and low power operational amplifiers are used extensively.

Sensitivity and baseline drift of fluxgate magnetometers are determined not only by the characteristics of the fluxgate sensor (PRIMDAHL, 1970) but also by subtle changes in the electronics drive and demodulation circuitry. One such source of drift originates in the temperature coefficient of the baseline offset current source. For the new magnetometer the source is temperature compensated and the current is defined by feedback circuitry; the temperature coefficient of the sensor is compensated separately. Square wave (rather than sine wave) drive simplifies the electronics and avoids the need for tuned amplifiers which can be a major source of phase drift with ambient temperature variations.

### 3.2.2. Operational experience

Earlier versions of the present magnetometer have operated reliably at the unmanned observatory and the Australian Antarctic stations since 1972. The current design continues to operate satisfactory at the observatory site south of Casey.

### *3.3. Micropulsations magnetometer*

The solid-state three channel micropulsations recorder described in the earlier publication (Bird and Humphreys, 1971) performed satisfactorily and has not been developed further although recent component advances could now profitably be incorporated into the circuitry.

### *3.4. Auroral all sky camera*

The all sky camera design remains essentially as reported in 1971. The camera

*Fig. 11. Auroral all sky camera (Exterior cover removed).*

is illustrated in Fig. 11; simple in-line optics and a cylindrical flat top housing have proved successful in field operation over the past decade. Snow accumulation and condensation on the objective lens has been almost non-existent. Low temperature tests under laboratory conditions have shown the camera will operate at −100°C. An optical arrangement to provide a more linear field is under development.

The earlier electro-mechanical time identification device has been replaced by a light emitting diode array for improved resolution and reliability; each frame is identified by an adjacent time display of days, hours and minutes.

The existing 180 metre 16 mm film capacity (15,000 exposures) is proving inadequate for year-round operation and a larger film cassette and camera assembly are now needed.

The camera programmer is preset for the desired periods of operation in multiples of 10 days; a photocell activates the camera during hours of darkness. Auroral photographs are taken at 2 minute intervals at an 8 second exposure. A small DC motor drives the camera mechanism.

### *3.5. Meteorological sensors*

Measurements of wind-speed and direction, barometric pressure, and air temperature are made at one hourly intervals. Table 2 shows the various parameters recorded, range of measurement, and measurement resolution.

The various sensors have a proven performance in the Antarctic environment but the recently available vibration cylinder barometer (Hamilton Standard) could prove more reliable in the long term than the present mechanically read aneroid instrument.

The meteorological sensor arrangement is shown in Fig. 12. A shield prevents solar radiation reaching the unaspirated air temperature sensor. For winds above about 0.5 m $\text{sec}^{-1}$ the temperature measurement accuracy is within 0.2°C of a mercury thermometer within a standard Stevenson's Screen. The design of the static head for the barometric pressure sensor was based on the work of KODAMA *et al.*, 1967. Under conditions of wind and drifting snow, comparisons of pressure

*Table 2. Meteorological sensors and parameters.*

| Parameter | Sensor | Range | Resolution |
|---|---|---|---|
| Wind speed | Cup anemometer (Optical sensing) | 0-63 m $\text{sec}^{-1}$<br>40 sec and hourly average | 0.06 m $\text{sec}^{-1}$ |
| Wind direction | Wind vane (potentiometer sensing) | 0-360° | 1° |
| Barometric pressure | Digital aneroid barometer | 820-880 mb (depends on site) | 0.1 mb |
| Air temperature | Silicon transistor | +20°C to −80°C | 0.1°C |

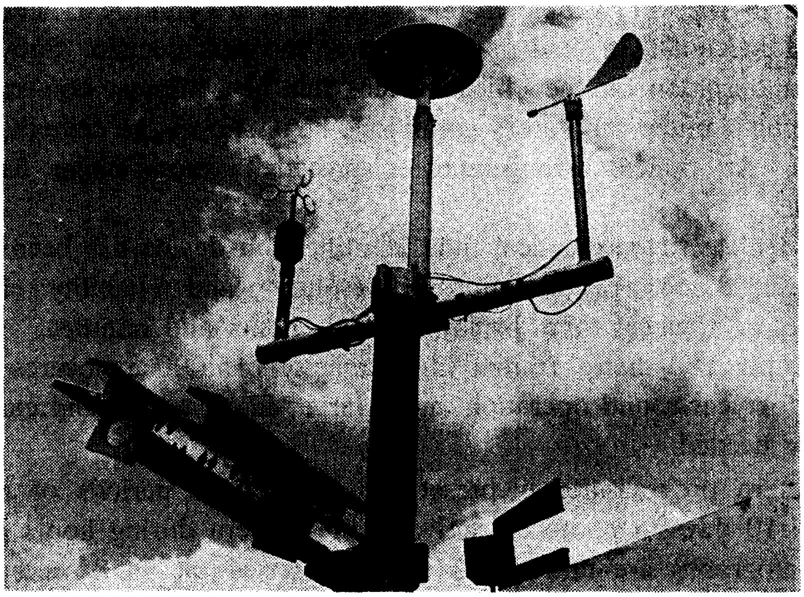

*Fig. 12. Meteorological sensor assembly.*

measurements with an observatory mercury barometer suggest an accuracy of approximately 0.5 mb; sensitivity of the mercury barometer to wind made closer comparisons impossible.

### *3.6. Digital data logger*

The logger developed for the observatory records data in computer compatible format at a maximum rate of one channel per second; thirty-two channels of mixed digital and analog data are catered for. Data are recorded on half inch computer tape, 556 bits per inch, 7 track non-return-to-zero-inverted encoding. Individual channels may be pre-programmed for the following:

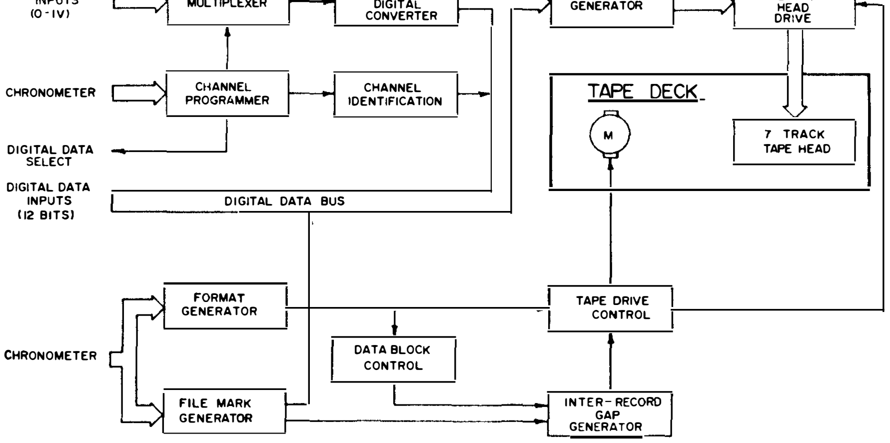

*Fig. 13. Digital data logger block diagram.*

digital or analog data input
required sampling rate: 10 sec, 20 sec, 1 min, 10 min, 1 hour, 1 day, 10 days, skip.

Data samples are recorded sequentially on the tape and channels are identified by an alphabetic character. Data words are formatted into 4 bytes each 7 bits wide; the first byte identifies the channel, the remaining three bytes record the 12 bit BCD data word. A simplified block diagram of the logger is shown in Fig. 13 (HENSTRIDGE *et al.*, 1975).

### 3.6.1. Mode of operation

The channel programmer sequentially activates the pre-programmed analog (0 to +1 V) and digital data inputs (12 bit) at individually selected interrogation rates. All data are converted to a common digital format and gated to the data bus; longitudinal and lateral parity are sensed and recorded.

Analog conversion time is 100 m sec, therefore, sample and hold circuitry is not required as all the instrumental time constants are well in excess of this figure. Data is encoded in BCD format, the maximum analog input being 999 mV. Any over-range input is catered for by utilising the character following the ident character, and employing non-numeric characters.

The observatory chronometer programs the data logger. Data input sensing, record format, and file mark generation are activated from chronometer BCD time signals. Inter-record gaps are automatically initiated after the recording of a preset quantity of data. Data block size may be preset in the range 1 k to 40 k

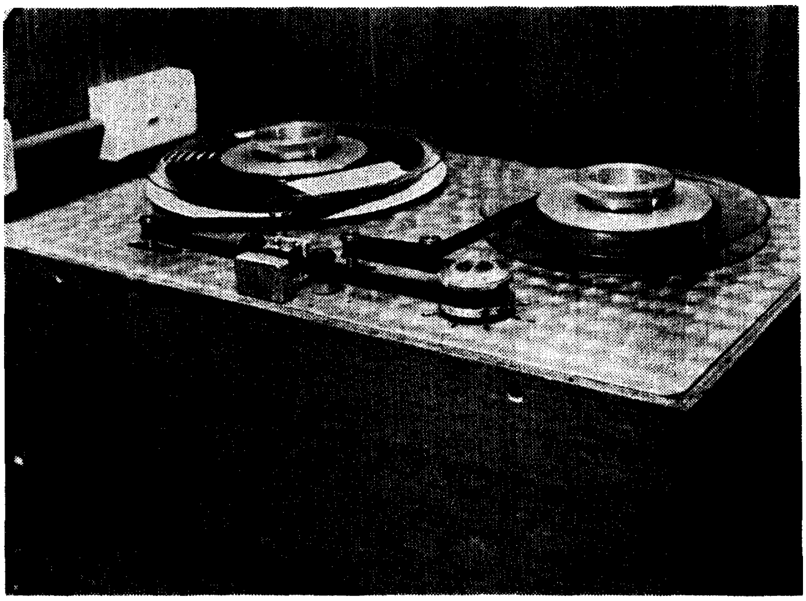

*Fig. 14. Digital tape deck.*

bytes depending on the requirements of the computer processing facility; a block size of 10 k bytes (5 hours of data) is used in the present observatory. File gaps may be manually initiated to allow for loading the tape onto the recorder.

The components of the digital tape recorder are mounted on a precision machined cast aluminium plate. The capstan and recording head assembly are purchased commercially; a stepping motor and gear reducer increment the capstan at a rate of 10 steps per second. Tape feed and take-up loops are sensed by reed switch-magnet arrangements; small DC motors and associated gearing drive the tape spools. The tape deck is illustrated in Fig. 14.

### 3.6.2. Data capacity

Data recording capacity is defined by the length of magnetic tape; the tape deck will accept a 267 mm ($10\frac{1}{2}''$) spool; a tape length of 975 m (3200 feet) is used.

This capacity allows the recording of 5.2 million data samples and the requisite inter-record gaps, *i.e.* 590 samples per hour for one year of operation. For the present observatory, data are recorded at a rate of 500 samples per hour and these samples are apportioned as detailed in Table 3.

*Table 3. Data recording details.*

| Parameter | Details | Sample rate |
|---|---|---|
| Chronometer | Days ; hours ; minutes ; seconds | 1 per hour |
| Meteorological sensors | Wind run, speed, and direction ; baro pressure ; air temperature | 1 per hour |
| Riometer | Cosmic noise | 3 per minute |
| Magnetometer | Components $H$<br>Components $D$ and $Z$ | 3 per minute<br>1 per minute |
| Housekeeping | Shelter temperature ; reference voltage and zero ; battery banks (4) ; wind generator ; solar panels (3). | 1 per hour |

### 3.6.3. Performance

The primary design criteria for the data logging facility was for low power consumption, adequate low temperature performance, and versatility of programming.

The logger circuitry is based on CMOS medium scale integration digital logic devices (Fig. 15). Standby power is 30 m watt and operate power is 1.3 watts; at a sample rate of 500 per hour the duty cycle is 14 percent and average power consumption for the system is 180 m watt.

In laboratory low temperature tests the data logger circuitry and tape recorder performed satisfactorily at temperatures down to −70°C. Field experience has

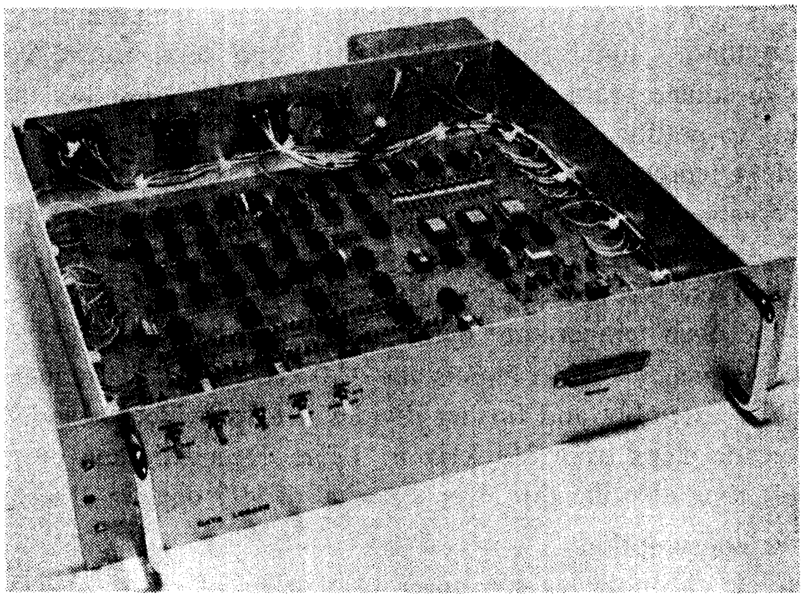

*Fig. 15. Digital data logger electronics assembly.*

shown the system to be reliable in the long-term.

### *3.7. Chronometer*

The earlier publication considered the requirements and feasibility of various quartz crystal chronometers in detail. The prototype observatory used a DT crystal operating at 100 kHz, and a discrete component frequency divider; an accuracy of around 30 seconds per year was achieved.

Improved technology in low power frequency division now allows the use of

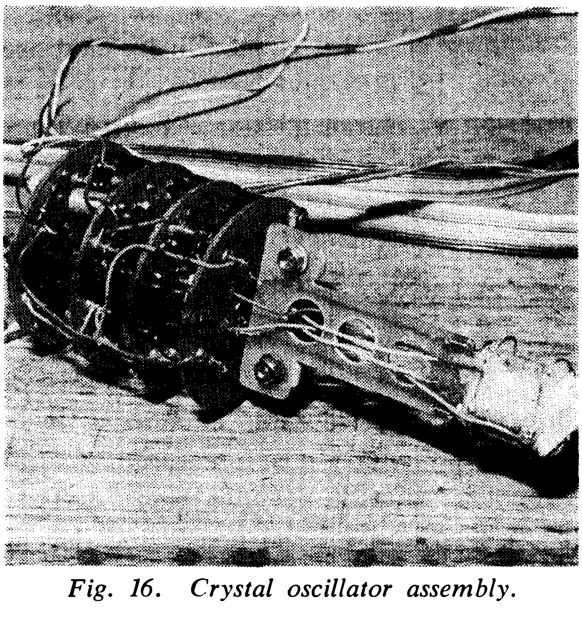

*Fig. 16. Crystal oscillator assembly.*

a 4 MHz AT Crystal specially manufactured for zero temperature coefficient at 0°C. The oscillator, initial frequency divider, and temperature controller are potted in polyurethane foam within a dewar flask. Fig. 16 shows the electronics assembly prior to potting.

The ambient temperature within the instrument shelter will always be below $-5$°C; a precision proportional controller and heater maintains the crystal at $-5 \pm 0.01$°C. Operation of the crystal on the sloping portion of its frequency-temperature characteristic gives improved accuracy. The frequency error is partly cancelled as the oven temperature cycles above and below $-5$°C.

A CMOS frequency divider inputs the 100 kHz standard frequency from the oscillator-divider assembly and further divides it to provide 6 standard frequency outputs in decade steps from 100 kHz to 1 Hz. Decoded time outputs in BCD format provide time identification over a period of 999 days in 1 second intervals.

### 3.7.1. Power consumption

The complete chronometer consumes 34 m watts of power at $-5$°C, increasing at a rate of 6 m watts per °C for lower temperatures due to oven load. At $-30$°C the overall power consumption is 184 m watts.

The dewar flask and crystal oscillator assembly is mounted within a block of expanded polystyrene for additional insulation. Experiments to further reduce the oven power requirements by a dual dewar flask arrangement, use of reflective foil, and additional external insulation, were unsuccessful.

### 3.7.2. Frequency stability

The present observatory chronometer was designed for an absolute timing accuracy within 1 second per year. This precision requires the oscillator frequency to be maintained within $1 \times 10^{-9}$ per week.

Prior to service the quartz crystal was aged in its final oscillator configuration for a period of six months. Its drift and ageing rate were determined by phase comparisons with a precision VLF transmission (North-West Cape) and by observations of its digital time readout compared with HF standard time transmissions (WWV and VNG).

These measurements and subsequent field performance over an 8 month period indicate an absolute accuracy of 0.7 seconds per year should be achieved.

## 4. Operational Experience

During the past four years considerable experience has been gained in the design and deployment of unmanned observatories. The prototype observatory operated almost continuously during the two year period 1971–72 and this provided an invaluable background for the continuing development program. A considerably upgraded observatory deployed on Law Dome in December 1974 has continued to operate normally. Data from the new observatory is being analysed and some preliminary results are presented below (Section 4.4.).

### *4.1. Prototype operation, 1971*

The prototype observatory was installed at a site 80 km south of Casey on the summit of Law Dome (Fig. 17) in May 1971.

Installation commenced in early May and manual excavation of the snow pit to house the instrument shelter presented no physical difficulty. However, drifting snow tended to refill the hole. A bulldozer finally made short work of the exercise by excavating a pit of depth 2.5 m. The shelter was manoeuvred into the pit and snow packed around it and levelled to avoid the generation of snow drifts.

Observatory assembly was straightforward, although site temperatures down to −30°C made outdoor work unpleasant; the desirability of summer time installation was evident. The system was fully operational by 20 May 1971. Instrumentation included a riometer, 16 mm all sky camera, geomagnetic micropulsations recorder, and micrometeorological equipment.

A chronometer with an accuracy of about 30 seconds per year programmed the instrumentation; data was recorded on slow speed frequency modulated magnetic tape.

The installation was first revisited in mid-September and the effects of four months of mid-winter operation observed. Snow accumulation over the site was around 0.3 m and all instruments except one channel of the micropulsations recorder were operating normally. Lack of suitable on-site test equipment made it impossible to assess chronometer accuracy. However, the crystal oven was at the correct temperature and all chronometer circuitry was operating normally.

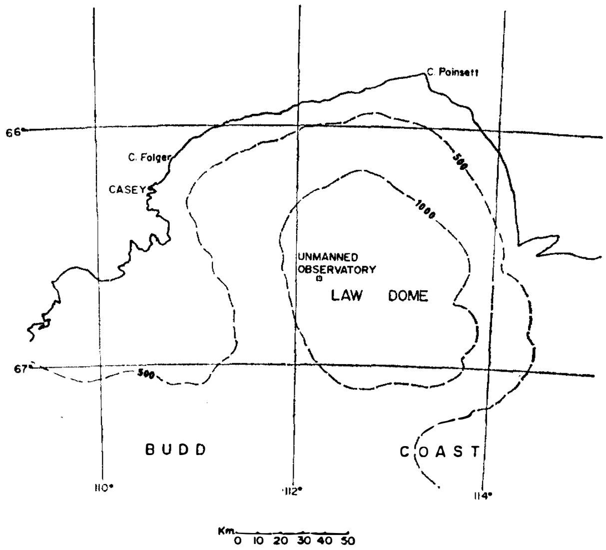

*Fig. 17. Casey region, showing the location of the unmanned observatory.*

Data had been recorded on the magnetic tape recorder. The lead-acid batteries had been maintained at an adequate level of charge by the wind and solar generators; electrolyte level had fallen about 5 mm.

Further visits were made to the site in mid-December 1971 and at the end of January 1972. "Faultless operation" was reported on both occasions.

The generally satisfactory performance of the prototype observatory during 7 months of operation in 1971 (including the mid-winter period) provided confidence in the potential for the techniques and principles involved in the system design. Concepts such as the viability of low-power electronics, use of special lead-acid batteries as the power source, and subsurface installation of the instrument shelter, proved to be well founded. The need for an improved data logging capability and chronometer test facilities was evident (Hope, 1972).

### 4.2. *The continued operation of the prototype, 1972*

A CMOS chronometer with inbuilt test facilities, digital data logger, and fluxgate magnetometer, were installed in the observatory in February 1972. A visit to the site in April confirmed the continuing normal operation of the previous instruments and the satisfactory performance of the three new instruments under field conditions.

A further visit in mid-July found the station to be inoperative; the battery supplying the electronics was discharged. The additional electronics installed earlier had increased the average power consumption from 1 to 1.5 watts and this power level could not be supported by the installed battery capacity (1500 AH) with the available wind and solar charging. The new digital data logger accounted for 80 percent of the electrical load on the electronics battery bank. Although the logger made use of low power TTL logic elements readily available at the time the need for improved power performance ultimately provided by the CMOS logger then under development was apparent.

The observatory was revisited in early October and again the batteries were near discharged, although the instruments were still functional.

The performance during the second year of operation was, therefore, marred by the incapacity of the power supply to meet the demands of the new data logger. The remainder of the observatory performed satisfactorily (Henstridge, 1973).

### 4.3. *Observatory program, 1973*

No new experiment was added to the observatory in 1973 but a renewed instrumental development effort was initiated at the Antarctic Division. Two useful years of field trials had provided valuable engineering background for a broad reconsideration of observatory design.

The field program virtually ceased during 1973 and the station was recovered in November of that year and returned to Australia for examination.

### 4.4. *The deployment of a new observatory, 1974*

A new observatory was constructed in 1973, it included upgraded versions of all instrumentation, particularly the data logger and chronometer. The average power consumption for the new configuration was 0.75 watts, half that of the prototype.

The observatory was temporarily assembled for trial in the Casey station area in early July and was subject to a severe blizzard shortly afterwards. Extensive damage to the external components resulted. Adequate repairs were soon completed and the system performed satisfactorily through to early November 1974 when it was finally installed at its field site on Law Dome. Partial failure of two CMOS logic devices due to the effects of snow drift static electricity was the only malfunction; installation of the suppression circuitry discussed earlier (Section 2.2.1.) eliminated the problem (MORRISSY, 1975).

Completely satisfactory operation has been observed during two subsequent visits to the site. The most recent visit was made in early August following the mid-winter period of operation when temperatures to −50°C were experienced. The power distribution of the observatory is now entirely satisfactory for the 0.7 watts consumption.

Computer programs are being developed for the analysis of the recorded data.

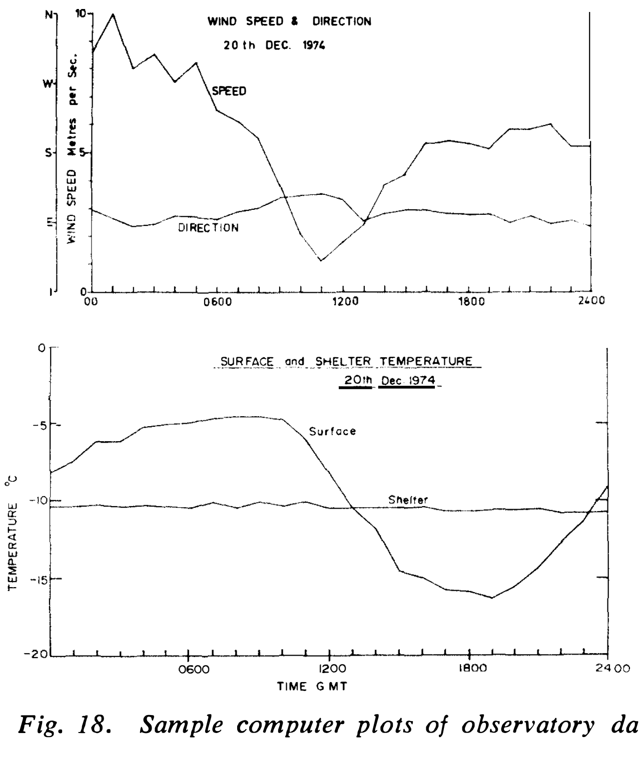

*Fig. 18. Sample computer plots of observatory data.*

At this time sample segments of data have been read, tabulated and plotted by computer. Typical results for a 24 hour period are reproduced in Fig. 18.

## 5. Future Program

The success with the two low power observatories fielded to date has provided a basis for confident continuation of the program; possible future activities are discussed below.

### *5.1. Deployment schedules*

The Antarctic Division is presently constructing two further observatories for deployment in the polar cap region during the International Magnetospheric Survey in 1977, possibly near the Auroral Pole (74.05°S, 126.51°E) and midway between this site and Casey.

Also a small observatory consisting of an all sky camera, three-axis magnetometer, data logger and chronometer, is scheduled for deployment on the Amery Ice Shelf in the summer 1975/76.

### *5.2. System development*

The present generation of instrumentation is sufficiently developed to provide adequate performance in most circumstances. Future developments are expected in the areas of data logging and transmission, and sensors.

### 5.2.1. Satellite data channels

The feasibility of a data communications link from an unmanned observatory via a satellite was convincingly demonstrated by SITES (1972). Synchronous satellites are visible to a latitude of 80°S in some areas of Antarctica (JENNY and LAPSON, 1968).

For the transmission of small amounts of data the NIMBUS F random access and measurement system is attractive. This satellite data gathering system is designed to randomly access large numbers of relatively simple low power data transmitters on a twice daily basis. The average power consumption of the remote data encoder and UHF transmitter is 300 milliwatts (LIVINGSTON *et al.,* 1975).

HEIKKILA (1973) has proposed the use of VLF (100 kHz) transmissions to communicate data from several slave stations relaying data to a main station. The Antarctic Division is planning a field trial of this proposition in the Casey area.

### 5.2.2. Power generation

The need for reliable and economic generation of electric power will become increasingly evident as the complexity and capability of observatories increases. Isotope power generators are feasible but very costly; sunlight can provide useful power for periods up to six months of the year depending on latitude (LOFF *et al.*, 1966). To power observatories during the mid-winter period poses a considerable challenge; the reliability of propane thermo-electric generators in the environment of inland Antarctica is unknown but laboratory tests carried out by the Antarctic Division at −50°C were not encouraging. Below −40°C propane has no vapour pressure and must be driven to the burner, loss of efficiency due to the latent heat of the liquid gas can be considerable. For example, at a gas temperature of −40°C it is no longer possible to boil water on a propane gas burner.

A scaled version of the Division's turbine wind driven generator could provide a significant increase in generation capability above the existing 5 watt with good reliability. This generator has proved its reliability during a decade of operation at various Antarctic sites.

### 5.2.3. Solid-state image sensors

Investigations on charge-coupled solid-state image sensors demonstrated the significant potential of such devices for auroral imagery (SUCKAU, 1975). The sensitivity of available devices is about one order short of that required for auroral applications. However, technological advances are being made rapidly in the image sensor field and ultimately it is expected that these sensors could replace film records of auroral displays and allow for radio transmission of auroral images.

### 5.2.4. Data logging

The present CMOS data logger is the most complex component of the observatory. A CMOS microprocessor system recently announced (SWALES and WEISBECKER, 1974), could open a new horizon in low power data logging and processing at remote sites.

A Central Processing Unit with associated memories and input-output buffers based on this development could significantly simplify the hardware and provide for processing flexibility not feasible with a hard-wired logic system. The Antarctic Division has now initiated development in this area.

Although data transmission links could reduce reliance on logging, it is believed that there will be a continuing need for an efficient on-site capability to provide redundancy for the communications channel.

## 6. Conclusion

The feasibility and potential for low power unmanned geophysical observatories operating in the environment of inland Antarctica has been demonstrated. To achieve the present level of efficiency it was necessary to develop a new generation of standard geophysical instruments along with companion data logging and chronometer techniques. Expansion of the existing capability appears to depend critically upon the availability of a suitable power source. Wind driven generators might well supply this need.

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