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The Telemetry of Hydrological Data by Satellite

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Preface

The author of this handbook, Dr Ian C. Strangeways, was head of the Applied Physics section at the Institute of Hydrology (IH) until 1989. During the period 1982 to 1989 the section installed a network of ten satellite telemetering outstations and a base receiving station. The handbook is based on the experience gained at the Institute of Hydrology in establishing and operating the network. Mr Max Beran of IH assisted Dr Strangeways with the production of the report and Dr Gordon Bridge of EUMETSAT and Mr Ian Polley of Space Technology Systems also provided useful input. All enquiries concerning the handbook should be addressed to the Director of IH.

While there are many comprehensive publications describing meteorological satellites, available from the European Space Agency, the European Organisation for Meteorological Satellites, the World Meteorological Organisation and others, the type of basic information a prospective user of satellite telemetry will want is spread widely through this large collection of literature.

This handbook aims to bring together the essentials required by those investigating the usefulness, cost and techniques of environmental data collection via satellite. It also includes a review of commercial hardware and of international co-operation in satellite operation. By detailing the performance of a satellite telemetry network operated in the UK, the reliability of the technique is demonstrated.

Although the report assumes a hydrological user community, a large part of the material contained here is applicable to a much broader user base concerned with the transmission of environmental data, or indeed other types of time varying data, from a remote site to a central location.

1. Telemetry

1.1 GENERAL PRINCIPLES

Readers familiar with the basic principles of telemetry should go directly to section 2 and omit the introductory outline given in this first section.

1.1.1 Transmitting data

Telemetry involves transmitting a measurement from its source, in hydrology usually from a remote field station, to a base station where it may be processed, displayed, stored and used. The data can be sent continuously or at intervals. In hydrology it is usually sufficient to receive measurements at set times, on demand from base, or as an alert message when set limits are exceeded.

Measurements will usually be made not just at the instant of transmission, but as sets of readings taken at intervals between transmissions. An example might be three-hourly transmissions of river level data, measurements being taken at half-hourly intervals and held in a local store until transmitted.

Transmission can be via telephone or by a variety of radio techniques, including ground-based radio, meteor-scatter and satellite techniques. Communication can be two-way, with the base calling the outstation, which responds by sending its data. This is called a polling system. Alternatively, communication can be one-way only, with the outstation sending its data automatically, at set times, or randomly in an alert mode.

All communication media can work in either one-way or two-way modes, even satellite telemetry. However, polling methods are more common when ground-based communication is used, while the alert mode is quite common in satellite applications. Although polling methods have obvious advantages, they are more complex and more likely, therefore, to malfunction. They are also more expensive.

1.1.2 Why telemeter?

There are two principle reasons for telemetering hydrological measurements. The first, and obvious, case is where data are needed in real-time, for example in flood forecasting, in the management and control of rivers or dams, or for drainage or irrigation schemes.

Telemetry can, however, sometimes have advantages even where the data are not required urgently. There are many outstations equipped with data loggers measuring rainfall, river level, climate, water quality and other variables, the data being retrieved through detachable memories, tape cassettes, or by transfer to a portable PC during periodic visits to the site by an operator. In the UK, where most sites are easily accessible over good roads, a logging approach is perfectly satisfactory, although labour costs are high.

In much of the world however, access is not easy and outstations can be very remote. Even in the UK some upland sites can be difficult to reach, and overseas it can be a days trip to one outstation, or it may only be accessible by helicopter. In such a situation telemetry can have advantages over logging, despite there being no need for rapid access to the data.

A further advantage of telemetry over in-situ logging concerns quality control and network maintenance, since failure can often be detected as soon as it occurs, minimising data loss; loggers left unattended for long periods can result in the loss of much data.

While it still remains necessary to visit telemetering stations from time to time for maintenance purposes, much information relevant to station condition can be gleaned from the incoming data. A sudden halt to changes in river level or a permanent wind direction can be used to infer the condition of the sensors and of the telemetry equipment. Visits are, therefore, no longer compulsory at set intervals; they can be made much less often and can be better targeted.

Telemetry systems can, of course, fail, and while this is detected at once, the remoter sites may not be immediately accessible. To prevent data loss, a logger can be included as back-up and can often form part of the telemetry system, doubling-up on many of the functions.

With logged systems, field visits were often necessary just as much to change batteries as to collect data. With the advent of very low power microelectronics this need is largely removed. Lithium batteries extend the period yet further and solar power can remove the need to change batteries completely; even in the UK there is sufficient solar power to operate a satellite telemetry system throughout the year.

Ten years ago telemetry was considered only when it was essential. With improved electronics, and particularly with the advent of satellites, it may now be the better option. Cost is no longer a factor always favouring logging, since telemetry can now often equal or better it, especially if the cost of field visits is included in the comparison.

1.1.3 The mechanisms of telemetry

Whatever the media of transmission, the basic units of a telemetry system are the same, and comprise the following items (Figure 1.1).

Sensors

One or more sensors make the actual measurement of the hydrological variable, the electrical signals they generally produce ranging from low to high voltages or resistances in the form of a bridge or a potentiometer; invariably they require some modification before conversion to digital form for telemetry.

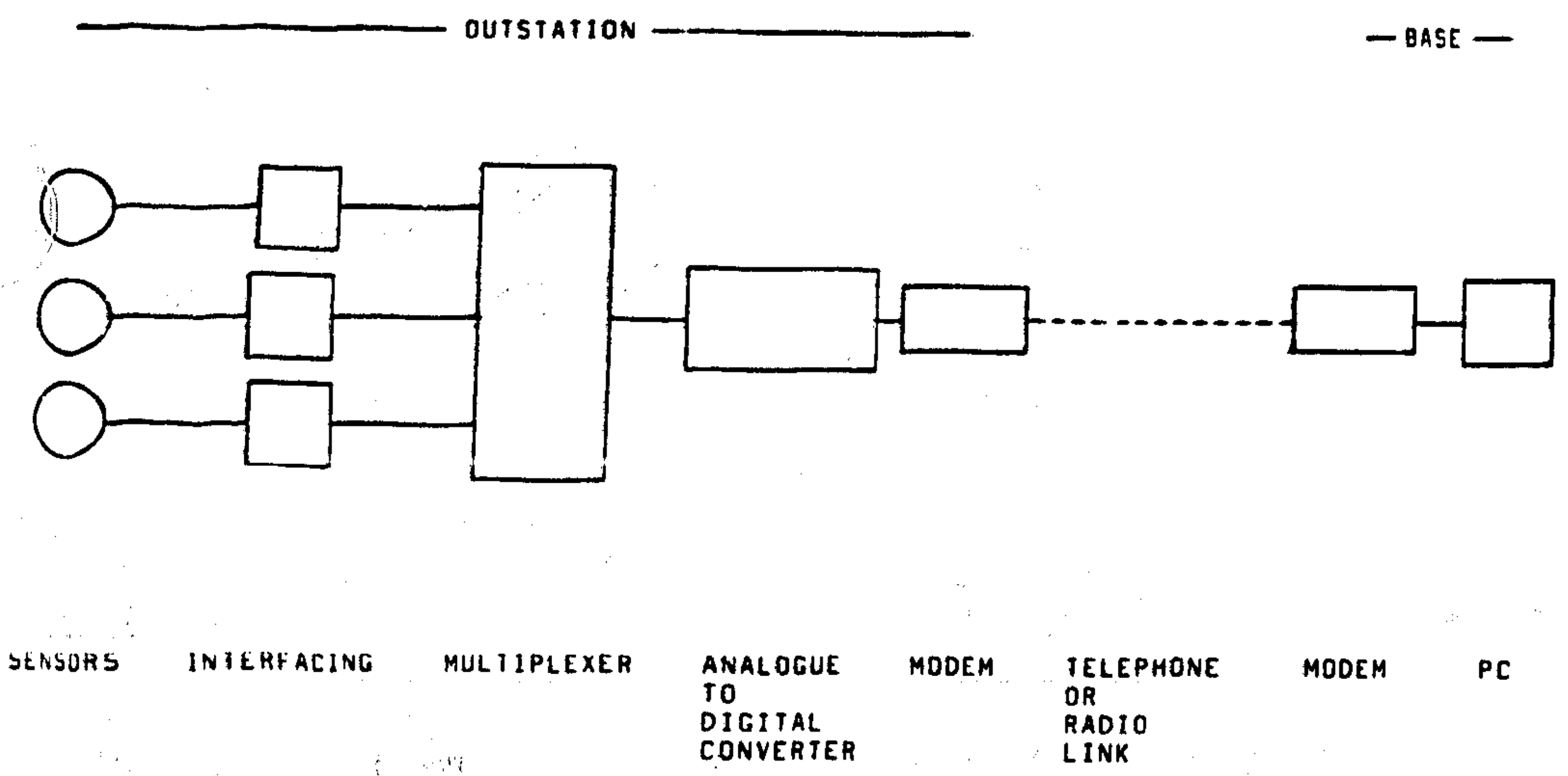


Figure 1.1 Schematic of a telemetry system

Interfacing

Conditioning or interfacing circuits convert the raw sensor signals into a form convenient for analogue to digital conversion (A/D), this usually taking the form of a voltage with a full scale reading of from 1 to 5 volts.

Some of these circuits can be very simple, such as that for a potentiometric sensor, where all that is required is a stable reference voltage applied across it, giving a suitable output, directly. Sensors, such as those for solar radiation, will require an amplifier, while a platinum resistance temperature sensor must form part of a bridge circuit, followed by amplification.

Digital sensors, such as those producing pulses (windspeed, raingauges, etc.) generally require no interfacing and their output can be left in digital form, by-passing the analogue to digital conversion stage.

Analogue to digital conversion

If more than one sensor is involved, as in the case of an automatic weather station (AWS), their standardised voltage signals must be scanned sequentially, by a switching circuit known as a multiplexer, before conversion to digital form. With modern electronics, both switching and A/D conversion can be carried out by single integrated circuit chips.

A/D conversion can be to eight-bit precision or higher, that chosen being dependent on application and on the precision of the sensor. Eight-bit precision divides the scale into 256 steps (0.4%), 10-bit gives 0.1%, 12-bit 0.025%, etc.. Few sensors, particularly when combined with their analogue interfacing circuits, provide an accuracy which merits better than 10-bit precision, and many do not even attain eight-bit.

The output of an A/D converter is a pulse train, representing the analogue input in binary form, a positive voltage representing a "1", a zero voltage a "0" (Figure 1.2). There are universally accepted speeds at which these pulses are produced, known as the baud rate. Those used in telemetry range from 300 bits per second (bauds) doubling at each step increase to 9,600 bauds. Slower speeds are occasionally used, as are 19,200 bauds and even higher for some applications. The better the transmission link, the faster the data can be sent. As a guide, around 37 eight-bit words can be sent each second at 300 baud. In practice the rate may be less, since data words usually have start and stop bits added and possibly parity bits also.

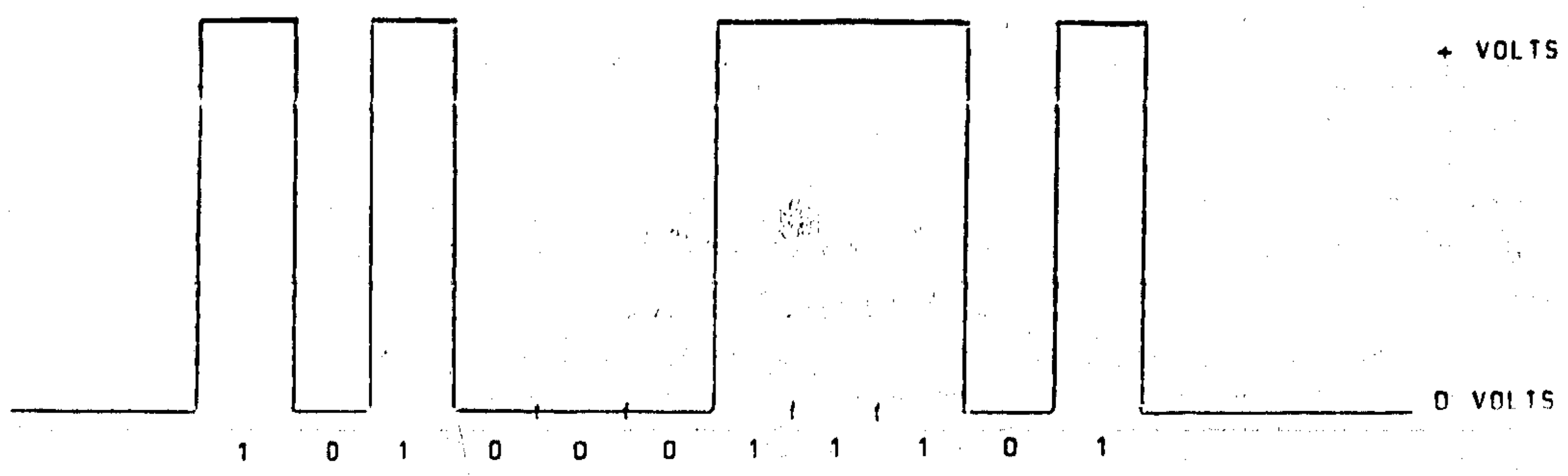


Figure 1.2 Digital voltage signal

Processing

In some applications, in-situ processing of the digitised data may be carried out prior to transmission. This can include the storing of means and totals or of maximum and minimum values, or conversion of the raw data to real units (such as river level in metres). More complex procedures, such as evaporation estimates from climatic data, can also be done in-situ, although it is often preferable to do this in a PC at base after transmission.

Modems

The DC voltage levels, in which the digital words have up to this point been handled (Figure 1.1), cannot be sent over telephone lines or radio links. Before this can be done they must be converted into a form suitable for transmission. There are several methods of modulation available, but in hydrological applications this usually takes the form of conversion of the voltage pulses to tones, which are then used to modulate the radio carrier or telephone line. In a system known as frequency-switch-keying (FSK), one frequency represents "ones", another "zeros". The process of converting between frequency and DC levels is achieved by a MODEM (MOdulate DEModulate).

Intelligent modems not only convert to and from FSK but also perform error checking and convert messages to ASCII characters (American Standard Code for Information Interchange). The latter is universally recognised as a format for data transmission, and in many applications must be adhered to (eg in coding WMO SYNOP and CLIMAT messages).

Modems generally accept serial data in RS232 form, another universally recognised communications standard which specifies the electrical nature that the pulses must take. In brief, a "1" is represented by a negative voltage between -5 volts and -15 volts, while pulses between +5 volts and +15 volts represent "0". The message at the receiver end is demodulated by a further modem and converted back to RS232 DC pulse form. Thereafter, these digital signals can be input to a PC via its serial port and, if in ASCII form, can drive a serial printer.

The received data will then normally be processed - in real time if required for forecasting or control purposes. Software in the PC can be written to handle the data in any way required, producing forecasts and displaying the data in tabular or graphical form.

1.2 TRANSMISSION MEDIA

FSK signals can be transmitted over any suitable media, the most usual being telephone and radio. The merits and problems of the alternatives are discussed below.

1.2.1 Telephone networks

It was said in the past that telephone lines failed just when they were needed most - at times of flooding, heavy rain and gales. Telephone lines are now much improved, although this view still has some force in remote rural areas, exactly where many hydrological outstations will be required.

The cost of sending data by telephone is now low (section 4.6.5) making it a good choice for telemetry, provided the initial connection cost is affordable. It is often this cost that dictates against the use of telephone lines for telemetry, even in the UK with its dense network of lines. Telephone lines are also inflexible in that they cannot be moved once installed, making them unsuited to temporary or short-term applications.

The use of the new portable 'phones is an area worth considering, but whether this would, as yet, be practicable at the remoter, hilly sites is questionable. Calls from such 'phones are also more expensive. It is a possibility for the future in the UK that should be watched, however.

In the remoter parts of the UK, in the technologically less well developed countries and in all large countries, telephone links are usually impractical because the communications infrastructure is not in place. Here other techniques must be used, and these all involve radio in some form.

1.2.2 Ground-based radio

The radio spectrum extends from 3 kHz, with a wavelength of 100 km, down to 1mm (300 GHz). Not unexpectedly all wavelengths do not behave in the same way. Table 1.1 shows their subdivisions.

The lower, long wave frequencies travel great distances by the ground wave, following the curve of the earth. The band-width is narrow, however, so not many stations can be accommodated at these frequencies. The power required is also high.

Short waves extend from 100 m to 10 m, and their long distance capabilities are well known. It is at these high frequencies that radio first becomes useful for telemetry.

High frequency

The ability of high frequencies to span considerable distances is due to their being reflected by the ionosphere, allowing them to reach well beyond the horizon. Subsequent reflection from the ground allows such signals to be propagated completely round the world, by successive reflections. Little power is required, five watts spanning large distances.

HF radio has been used for telemetering hydrological data in remote areas (Strangeways and Lisoni, 1973), (Carvalho, 1987). With modern techniques, but not at small cost, even digital pictures can now be transmitted from remote places at these frequencies (O'Neill, 1990).

Its shortcomings are that, because the ionosphere changes with the time of day and time of year, so too does the propagation of the waves, and fading is common. Interference and multi-path propagation add to the problems. Techniques which combat these add considerably to the cost of HF telemetry.

VHF/UHF

These two frequency bands behave in a similar way. They extend from 30 MHz (10 m) to 3 GHz (10 cm) and are the most commonly used frequencies for telemetry. They do not bend much beyond the horizon - the higher the frequency the less the bending - behaving like light. While this lessens the possibility of interference, communication in one span is possible only up to about 20 km, even with high masts. Repeaters can be used, but this adds to the cost, increases maintenance and also adds to the possibility of failure.

At these frequencies the waves can be directed in a narrow beam using Yagi antenna (as for TV reception). This increases the signal strength and minimises interference. Increased directivity is useful since five watts is the maximum radiated power now permitted in the UK at these frequencies. However, as with all frequencies in the now crowded radio spectrum, it is difficult to obtain a frequency allocation. This acts as a disincentive to their use for telemetry.

If (i) a frequency is available, (ii) line-of-sight paths are possible, (iii) interference is low and (iv) the network is small, VHF/UHF offers a useful and a cost-effective link (Brunsdon and Sargent, 1982).

Meteor-scatter

As meteors enter the atmosphere, the trails they leave are ionised (Figure 1.3). These trails reflect radio waves in the 30 MHz to 200 MHz range, being most effective between 30 MHz and 50 MHz, that is just a little higher than the HF frequencies. Below 30 MHz, problems occur through reflection off the ionosphere, which causes interference. The trails last for only a few seconds, but this is sufficient to send a fast burst of data. The performance of a system is defined as the "Waiting Time" between suitable meteors, or as the average number of words per minute that can be telemetered. This is influenced by operating frequency, data rate, transmitter power, antenna gain and receiver sensitivity.

Data rates up to 5 K bits per second can be used. A transmitter power of at least 300 watts is necessary to be effective. While increasing antenna gain increases signal strength, it also narrows directivity which reduces the number of meteorites usable. Excessive increase in receiver sensitivity results in the detection of manmade signals, of receiver noise and of galactic noise.

A compromise is necessary in all of these, but as a rule of thumb a waiting time of about two minutes is typical. This varies with both time of day and time of year. On average, about 100 words per minute can be telemetered.

The system operates by the base station sending out calls to each outstation. If a suitable trail is in place, the outstation receives the call and immediately sends its data. If these are received correctly, the next outstation is called, if not, calls are repeated until successful.

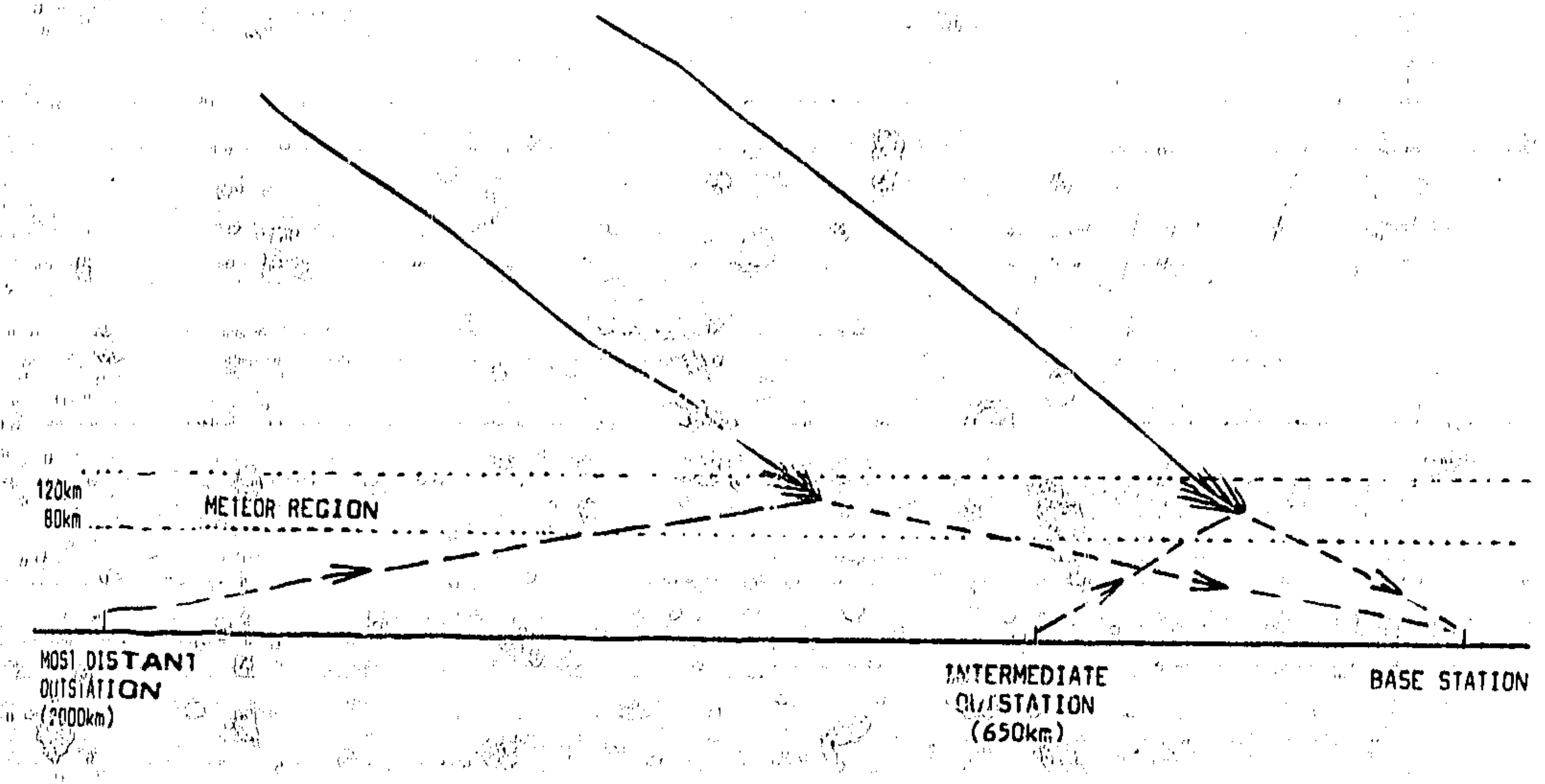


Figure 1.3 Meteor-scatter telemetry

Advantages of the system are that it is secure (private), independent (no satellite) and the meteor trails are free. However, the greatest range which can be spanned is 2000 km and equipment costs are high, (section 4.6.1).

1.2.3 Space-based methods

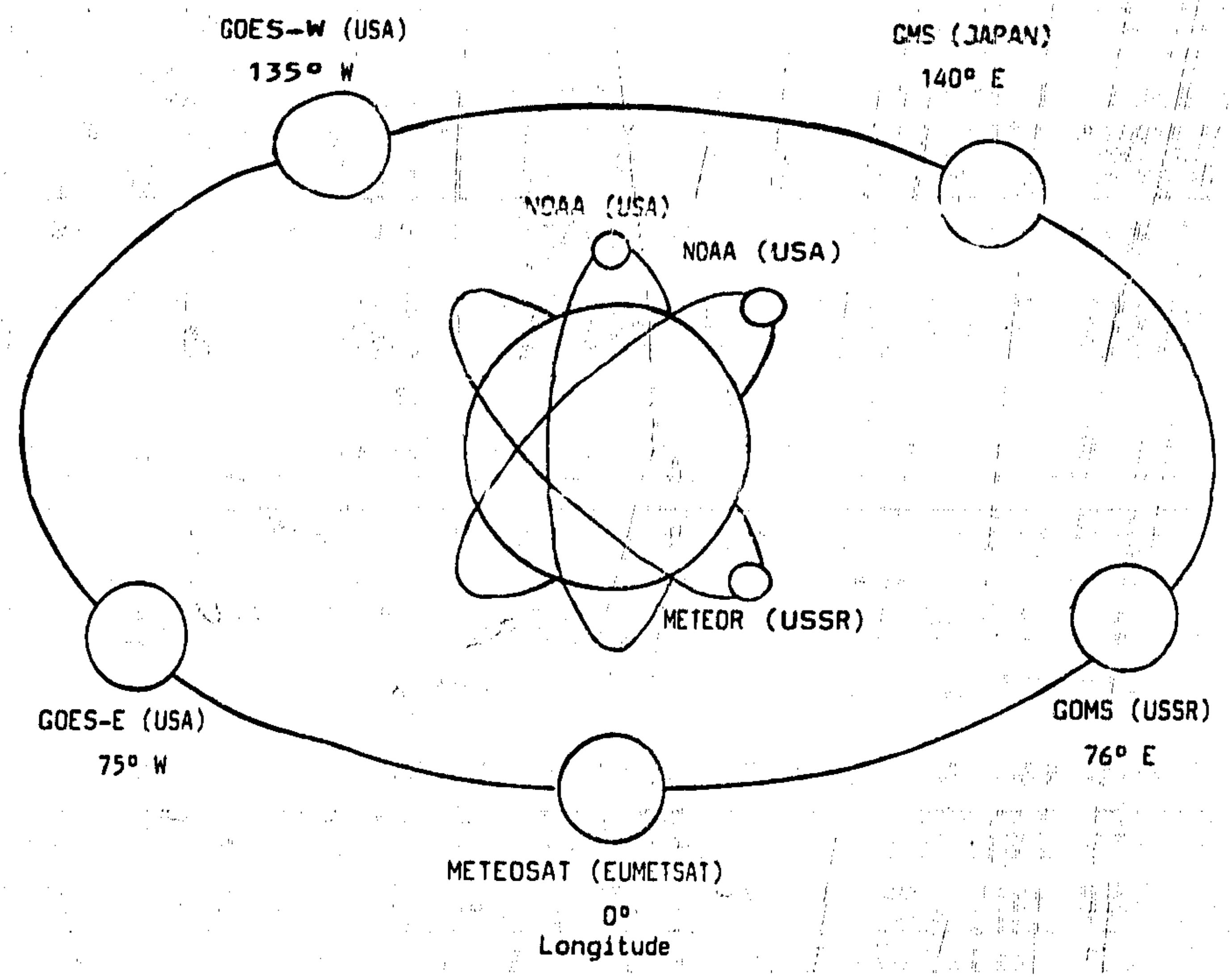


Figure 1.4 The Meteorological satellites

Figure 1.4 illustrates the family of meteorological satellites currently in geostationary and polar orbits. Satellites in both orbits not only have on-board imaging equipment, but also transponders which receive data telemetered to them from data collection platforms (DCPs) at outstations. It is the latter which allows satellites to act as telemetering relay stations.

Geostationary orbits

Satellites in geostationary orbits circle the earth at a distance of 36,000 km above the equator. Their orbital time, at this distance is exactly 24 hours, so they appear to remain stationary over the same point of the earth's surface. Meteosat, GOES and GMS, the European, American and Japanese satellites, are in this type of orbit.

Polar orbits

Satellites in polar orbits circle the earth in a north to south direction, passing close to both poles. They do so at an altitude of around 850 km which results in an orbital time of about 100 minutes. The orbit is sun-synchronous, that is the plane of the orbit always points towards the sun. The earth rotates beneath the satellite, causing it to pass over a different part of the surface at each orbit.

Those currently in use are operated by the USSR and the USA. The former are in the Meteor class, while the latter are Tiros-N satellites operated by NOAA. There are two Tiros satellites in operation, one in an ascending orbit the other descending, together giving 28 passes per day at the poles, with a maximum of six to eight near the equator.

Since they are not geostationary, this type of satellite does not appear stationary at the same position in the sky, but moves across it, being visible for about 10 minutes at each pass.

1.3 THE PLACE OF SATELLITE TELEMETRY IN HYDROLOGY

The advantages that satellite telemetry offers to hydrology are as follows:

1. Repeater stations are not required.
2. Installation of outstations and receivers is simple.
3. Outstations can be moved from site to site with ease.
4. Outstations are unobtrusive; their antennae are small and do not required high masts.
5. There is little restriction through topography.
6. One receiver can receive data from outstations covering over a quarter of the earth's surface.
7. Power requirements are minimal, so solar power is adequate.
8. Equipment reliability is high, both on board the spacecraft and in the field.
9. No frequency licence is required by the user, the satellite operator being licensed.
10. As many receivers as required can be operated, without the need to increase power, or facilities, at the outstations.

These characteristics make satellite techniques attractive for environmental data collection. By mid 1986, the U.S. Geological Survey was operating 1800 DCPs to acquire hydrological data. This is a pointer to the future, elsewhere. Europe lags behind the USA partly because Meteosat has only just entered a fully operational state; around 400 outstations have so far been registered for operation. The proportion of these with hydrological applications is not known, but an authoritative guide as to the future of satellite telemetry in hydrology is obtainable from ESA.

At a recent ESA workshop (Santiago de Compostella, 1987) and in an ESA publication concerning METEOSAT second generation (Sowden et al, 1987), figures were quoted as to their best estimate of the use of satellite telemetry in the 1990s. These figures are reproduced below.

	No of DCPs
1. Meteorology:	
Synoptic - land, ship, aircraft, upper air, drifting buoys	2750
Climatological and agrometeorological	2000
Maritime - coastal stations, rigs, anchored buoys	50
Aeronautical - exchanged between aerodromes	200
Pollution data	300
2. Hydrology	5000
3. Geophysics	2200
4. Oceanography	50
Total	12,550

Of a possible total of 12,550 outstations ESA estimate that 5000 will be used for hydrology. The Japanese satellite, GMS, is also likely to give rise to a large number of applications in the Far East (Cheong, 1987). With the launch of the Russian geostationary satellite in 1991, the region between METEOSAT and GMS will be filled, creating yet further opportunities within central USSR and the Arctic and Indian Oceans.

In the estimate of numbers, no account has been taken of polar orbiting satellites for hydrological data collection. These are at their best at high latitudes, just where those in geostationary orbits are least effective. While hydrological applications using polar satellites will undoubtedly be fewer, there will be situations where this type of satellite offers advantages.

It was in anticipation of the future potential of satellite telemetry in hydrology, that IH began its investigations into its use in 1982, with an expanded programme beginning in 1985 (Strangeways, 1985).

Table 1.1

WAVELENGTH	FREQUENCY	NAME
100,000 m	3 KHz	Very Low Frequency
10,000 m	30 KHz	Low Frequency
1,000 m	300 KHz	Medium Frequency
100 m	3 MHz	High Frequency
10 m	30 MHz	Very High Frequency
1 m	300 MHz	Ultra High Frequency
10 cm	3 GHz	Super High Frequency
1 cm	30 GHz	Extremely High Frequency
1 mm	300 GHz	

2. The Meteosat System

Anyone contemplating satellite telemetry for hydrology will probably use a geostationary satellite. In Europe and Africa, parts of South America and Antarctica, and as far east as central India, this will involve using METEOSAT, although India has its own, somewhat different, satellite system. This chapter describes the METEOSAT system in detail but concludes with a brief look at polar orbiting satellites. The final chapter looks at the other geostationary satellites situated around the globe.

2.1 THE ORGANISATIONS WHICH OPERATE METEOSAT

In 1972 the European Space Research Organisation (ESRO) was given the task of developing, launching and operating a series of "pre-operational" (that is experimental, non-guaranteed) meteorological satellites. The responsibility for this was then passed to ESRO's successor, the European Space Agency (ESA), based in Paris and funded by eight European countries.

In 1981 moves were started to form a European, inter-government organisation for operating meteorological satellites, and in 1983 the concept of the European Organisation for Meteorological Satellites (EUMETSAT) was agreed. The EUMETSAT convention entered into force in June 1986, the first staff taking up duties in the August. It has offices in Darmstadt-Eberstadt, West Germany, and currently there is a staff of about 25. EUMETSAT is funded by the member countries of ESA.

ESA continues to design, launch and operate the satellites but their funding, application, use, exploitation and the maintenance of a continuous service is now the responsibility of EUMETSAT, who are also involved in the planning of future satellite systems.

The practical activity of operating the satellites is the responsibility of the European Space Operation Centre (ESOC), part of the ESA organisation, sited at Darmstadt and employing around 150 staff.

2.2 THE METEOSAT SYSTEM - AN OUTLINE

Figure 2.1 illustrates the METEOSAT DCP telemetry system. The outstation (A) transmits its measurements to METEOSAT (B) along path 1 at set time intervals (hourly, three-hourly, daily, etc.). It has a one minute time slot in which to transmit its data, on a frequency of between 402.01 MHz and 402.20 MHz at a power of five watts (25 to 40 watts for mobile outstations, with omni-directional antenna).

The satellite immediately retransmits these data to ESOC's Ground Station (C), sited in the Odenwald near to Michelstadt, West Germany, along path 2 at a frequency of around 1675 MHz.

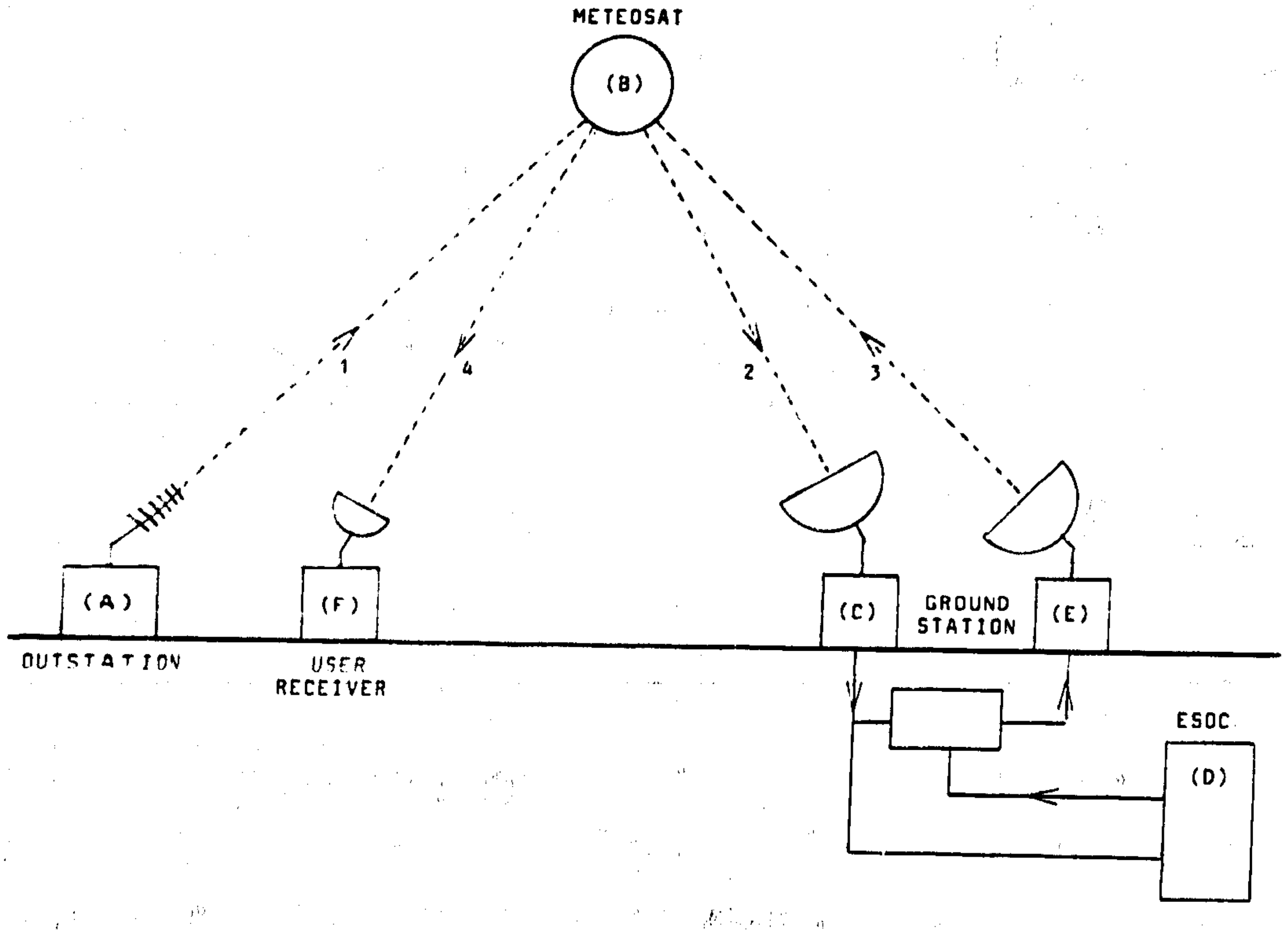


Figure 2.1 The METEOSAT telemetry system

From here the data are sent by land line to ESOC, some 40 km north west of Odenwald in Darmstadt (D). Here they are quality controlled, archived and where appropriate, distributed on the Global Telecommunications Network. They are also retained at the Ground Station and returned to METEOSAT (multiplexed with imagery data) from a second dish antenna (E), along path 3, for retransmission to users via the satellite along path 4.

The signal level is such that it can be received by a 2 m diameter dish antenna, although 1.5 m is often adequate. The dish houses a "down converter", the purpose of which is to convert the incoming signal from 1694.5 MHz to 137 MHz for input to a receiver, which decodes the transmissions, outputting the data in ASCII characters to a printer or PC.

2.3 THE OUTSTATIONS

The unit which forms the heart of an outstation is the Data Collection Platform (DCP). This is an electronic unit, similar in many ways to a logger, which can accept either several analogue voltage inputs directly from sensors, or serial data (RS232) from a processing unit between the sensors and the DCP. It also contains a small memory to store readings taken between transmissions, a processor section for overall management, a clock circuit, the radio transmitter and either a directional or omnidirectional antenna.

Up to 600 bytes can be stored in the memory for transmission at 100 bits per second. This capacity can be doubled, but this requires two one-minute time slots for transmission. The capacity is set by the amount of data that can be transmitted in a one-minute time slot.

For hydrology, DCPs are marketed that accept just rain or level sensors, or a combination of the two. Where additional sensors are required, such as those making up a weather station, the sensors can be interfaced via a processing unit, similar to a logger, outputting means and totals to the DCP in serial format.

At manufacture DCPs are programmed with their address (an eight digit, octal number) and with their time of transmission, both specified by ESOC. In future designs, these are likely to be programable by the user, to provide greater flexibility.

In operation the DCP's internal clock is set by an operator to GMT (or Z in European terms). This is done either with a "synchroniser unit" or with a portable PC. Up to 15 seconds drift is permitted either way, thereafter it must be reset.

At its appointed times the DCP transmits the accumulated contents of its memory to METEOSAT, and thereafter clears it, ready to receive the next set of data for transmission at the next time slot. This operation repeats indefinitely.

The synchroniser (or PC) can also be used to give the station a name (for example its location) and to carry out a range of tests which include checking the following: clock setting, battery voltage, transmitter state, analogue inputs and the memory contents. It is also possible to speed up the clock to test overall performance, including the making of a test transmission (into a dummy load to prevent interference by transmitting outside of the allocated time slot).

A DCP will fit into a small housing and can be powered by a solar-charged battery. The remainder of the outstation comprises the sensors which are similar to those at a conventional logging station or at a ground-based radio telemetry installation.

2.4 THE SATELLITE

Figure 2.2 shows the construction of METEOSAT. Figure 2.3 shows its field of view for data collection coverage. Geostationary satellites have three roles, firstly to obtain images of earth for meteorological purposes, secondly to disseminate these images and thirdly to relay data from DCPs.

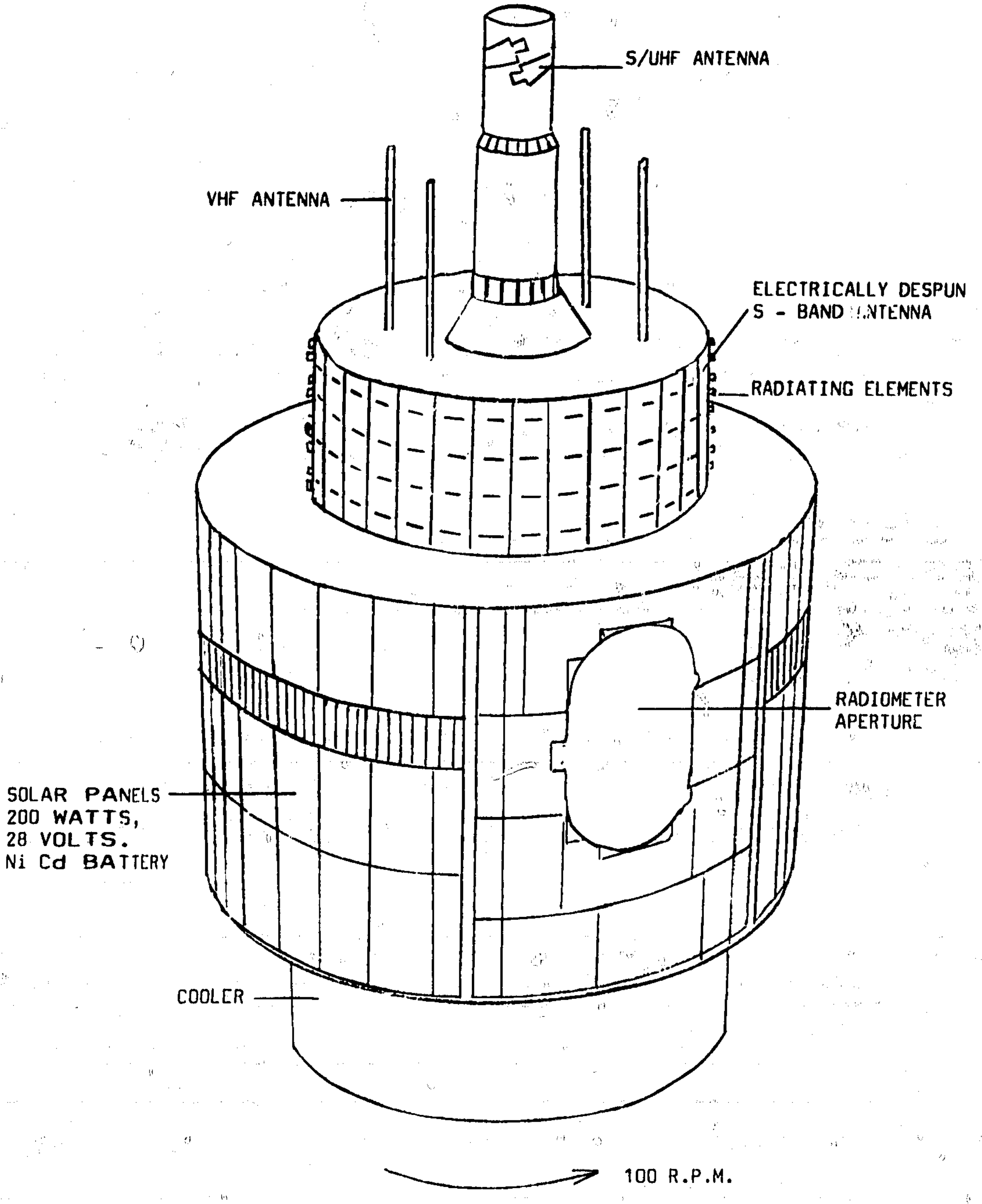


Figure* 2.2 *METEOSAT construction

2.4.1 Images

Although not the main concern of this report, the imaging function of METEOSAT is relevant in that transmissions of DCP data are interleaved with transmissions of low resolution images. Also many users of DCPs may require the images to complement the ground-truth data provided by the DCPs.

The images are built up, line by line, by a multispectral radiometer, producing images in the visible (0.5 to 0.9 um), the infrared for water vapour (5.7 to 7.1 um) and for temperature (10.5 to 12.5 um).

METEOSAT spins on its axis at 100 R.P.M., scanning the earth in horizontal lines from east to west. A mirror makes a small step from south to north at each rotation, building up a complete scan of earth in 25 minutes (including five minutes for resetting the mirror for the next scan).

The visible image is formed of 5000 lines, each of 5000 pixels, giving a resolution of 2.5 km immediately beneath the satellite (less resolution at higher latitudes). The two infrared images each comprise 2500 lines of 2500 picture elements, giving a sub-satellite resolution of 5 km.

The images are transmitted digitally, line by line, at 333,000 bits per second, during the time the scanner is looking at space. These transmissions are not meant for the end user, but go directly to the ground station, where they are processed by ESOC and then disseminated to users, back via METEOSAT, on two separate channels.

The first channel is for high quality, digital image data for reception by a Primary Data User Station (PDUS). The second channel transmits the images in the analogue form known as WEFAX (Weather Facsimile), a standard used by most meteorological satellites (including polar orbiters). These can be received by Secondary Data User Stations (SDUS).

The SDUS receive images covering different sections of the earth's surface in METEOSAT's field of view (Figure 2.3). Transmissions follow a daily schedule, as in table 2.1, one image being transmitted every four minutes. SDUS also receive the DCP transmissions.

2.4.2 DCP data handling

In addition to acquiring and disseminating the images, METEOSAT also has, currently, 66 channels for relaying DCP data from outstations to the ground station. Of these, half are reserved for international use, that is for mobile DCPs passing from the field of view of one geostationary meteorological satellite into that of the next. The remainder are for fixed, "regional" DCPs. Each channel can accommodate as many DCPs as their frequency of reporting and their report lengths permit. Thus, with three-hourly reporting times and one minute messages from all DCPs, and with a 30 second buffer period between each (to allow for clock drift), each channel could accommodate 120 DCPs, making a total of 7920.

2.5.2 The European Space Operations Centre

Figure 2.5 is a schematic illustrating the computing system at ESOC in Darmstadt. It is here that all of the practical activities concerning METEOSAT's operation are carried out. It deals with satellite orbit maintenance, image data and DCPs. The central unit is the Missions Operations Control Computer (MOC), made up of six Siemens R 30 mini computers working in real time. This performs several functions.

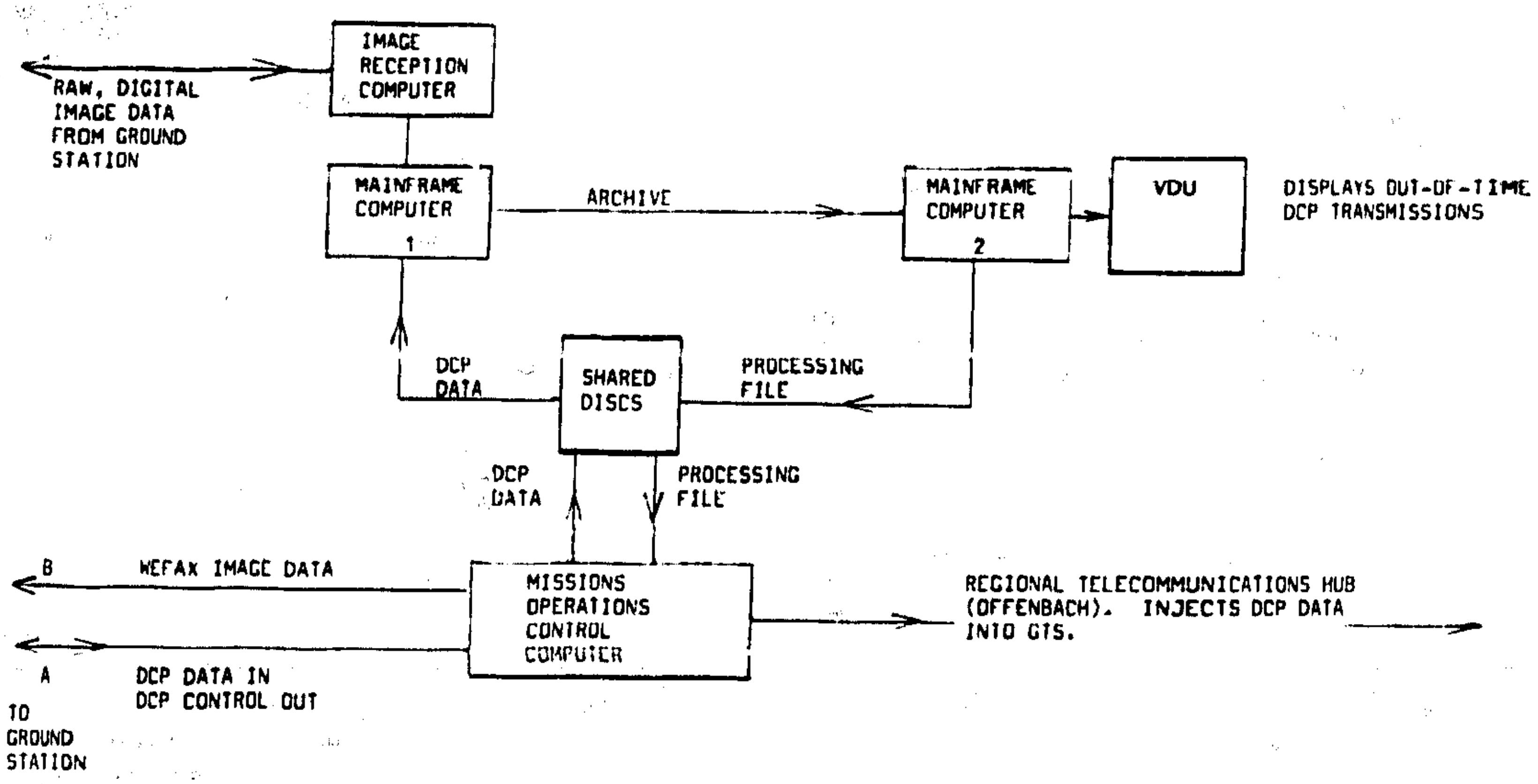


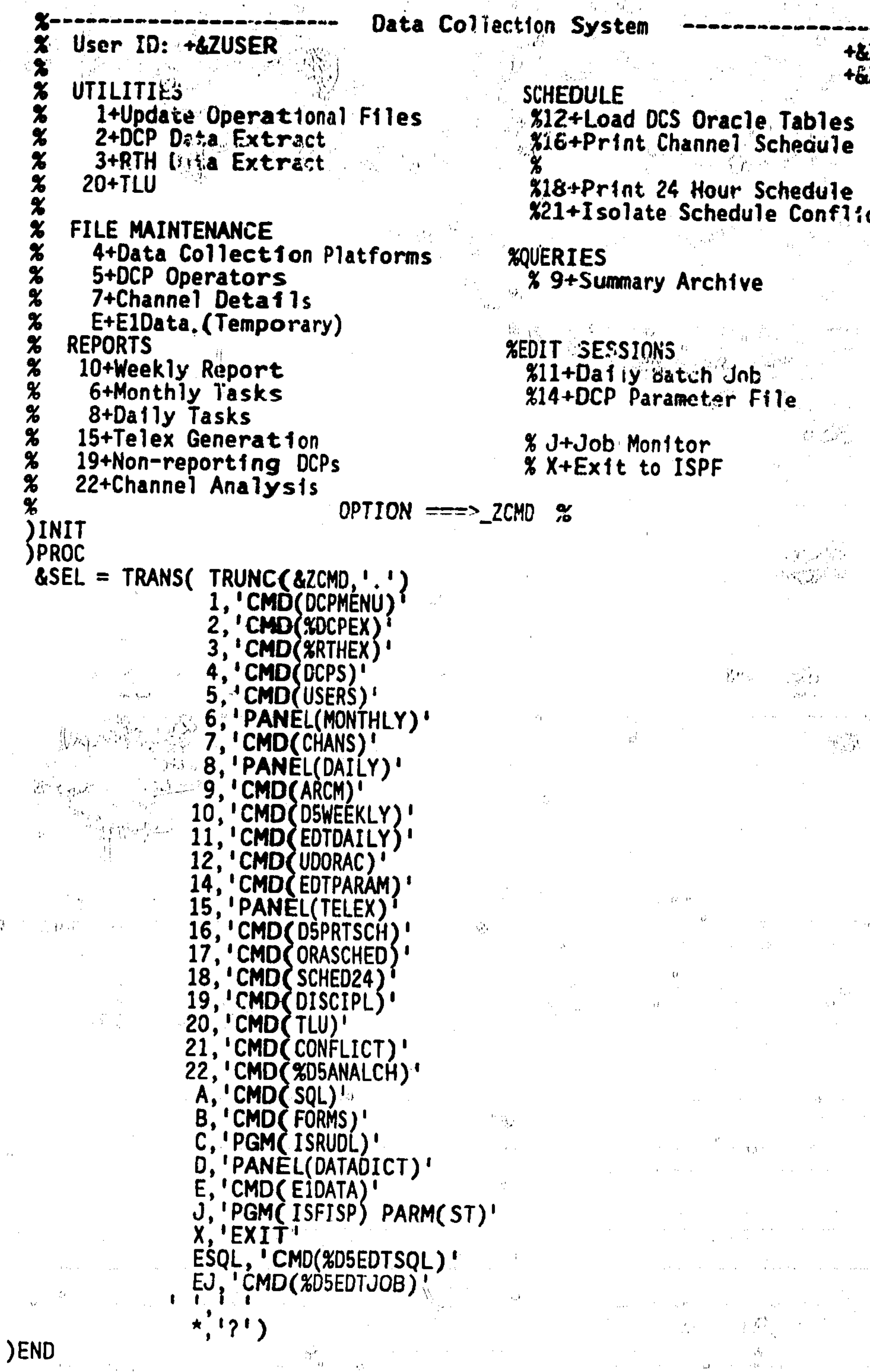
Figure 2.5 METEOSAT ground computer system, Darmstadt

Satellite control

After the launch of a new satellite, the MOC transfers it from low earth orbit to its geostationary orbit. Thereafter it maintains this orbit by periodically firing small attitude-adjusting rockets, controlled from Darmstadt. It is not involved in the actual launching operations.

DCP handling

MOC receives the incoming DCP data on line "A" (Figures 2.5 and 2.6), routing them to the two mainframe computers (both Siemens, type 7865) where they are written to tape for archiving and also for subsequent posting to those users who do not require them in the near-real-time mode provided by retransmission or by GTS. Those required for the latter are transferred to the Regional Telecommunications Hub (RTH) and thence onto GTS. A VDU in the Operations Centre displays any DCPs transmitting out of their allotted time slot. Their operators are then contacted by telex and asked to resynchronise. This occurs in about 1% to 2% of the DCPs in operation per week.



```
%-------------------------  Data Collection System  ---------------
%  User ID: +&ZUSER                                                +&
%                                                                  +&
%  UTILITIES                                    SCHEDULE
%    1+Update Operational Files                  %12+Load DCS Oracle Tables
%    2+DCP Data Extract                          %16+Print Channel Schedule
%    3+RTH Data Extract                          %
%   20+TLU                                       %18+Print 24 Hour Schedule
%                                                %21+Isolate Schedule Confli
%  FILE MAINTENANCE
%    4+Data Collection Platforms                %QUERIES
%    5+DCP Operators                             % 9+Summary Archive
%    7+Channel Details
%    E+E1Data.(Temporary)
%  REPORTS                                      %EDIT SESSIONS
%   10+Weekly Report                             %11+Daily Batch Job
%    6+Monthly Tasks                             %14+DCP Parameter File
%    8+Daily Tasks
%   15+Telex Generation                          % J+Job Monitor
%   19+Non-reporting DCPs                        % X+Exit to ISPF
%   22+Channel Analysis
%                           OPTION ===>_ZCMD  %
)INIT
)PROC
 &SEL = TRANS( TRUNC(&ZCMD,'.')
                 1,'CMD(DCPMENU)'
                 2,'CMD(%DCPEX)'
                 3,'CMD(%RTHEX)'
                 4,'CMD(DCPS)'
                 5,'CMD(USERS)'
                 6,'PANEL(MONTHLY)'
                 7,'CMD(CHANS)'
                 8,'PANEL(DAILY)'
                 9,'CMD(ARCM)'
                10,'CMD(D5WEEKLY)'
                11,'CMD(EDTDAILY)'
                12,'CMD(UDORAC)'
                14,'CMD(EDTPARAM)'
                15,'PANEL(TELEX)'
                16,'CMD(D5PRTSCH)'
                17,'CMD(ORASCHED)'
                18,'CMD(SCHED24)'
                19,'CMD(DISCIPL)'
                20,'CMD(TLU)'
                21,'CMD(CONFLICT)'
                22,'CMD(%D5ANALCH)'
                 A,'CMD(SQL)'
                 B,'CMD(FORMS)'
                 C,'PGM(ISRUDL)'
                 D,'PANEL(DATADICT)'
                 E,'CMD(E1DATA)'
                 J,'PGM(ISFISP) PARM(ST)'
                 X,'EXIT'
                 ESQL,'CMD(%D5EDTSQL)'
                 EJ,'CMD(%D5EDTJOB)'
               ' ' '
                 *,'?')
)END
```

Figure 2.6 ESOC menu of options (for DCP management)

In the case of those DCPs to be retransmitted, the computer holds a list of their addresses and sends control information to the DCP Accumulator at the ground station in Odenwald, instructing it which to retransmit.

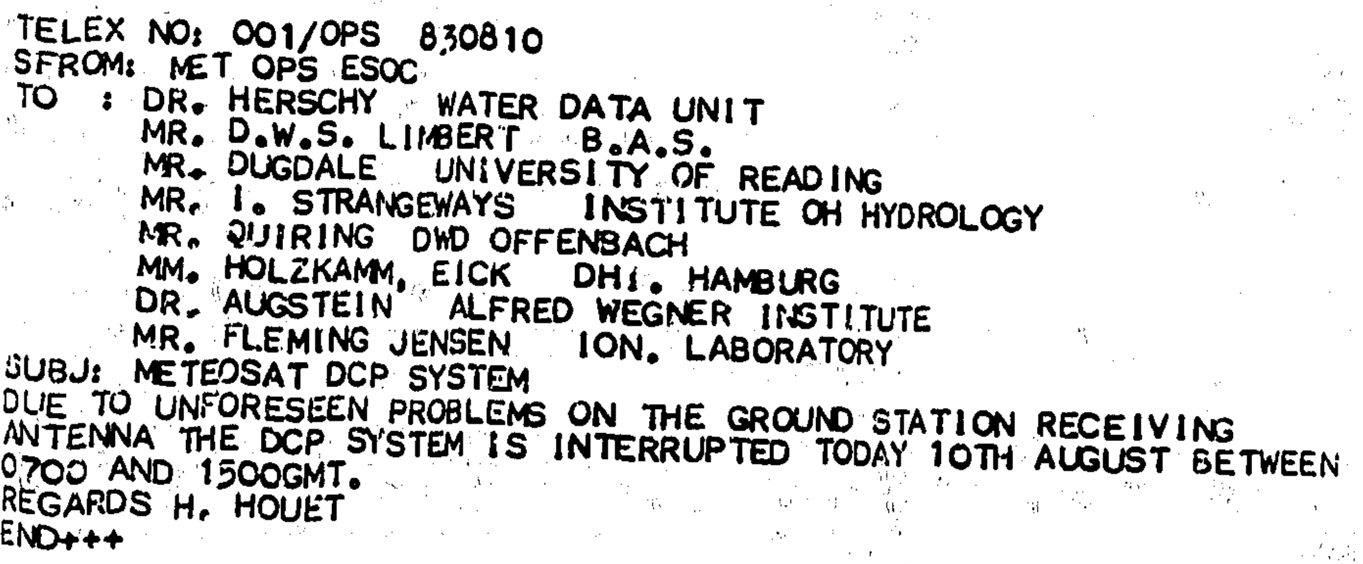
ESOC operates its own DCP, sending hourly messages via the complete system, including retransmission, and enabling overall functioning of the system to be checked continuously.

A terminal gives access to a menu of options for operating the DCP system (figure 2.6). It gives information on such matters as who the DCP operators are (item 5 in the figure) and which ones are not reporting (item 19), and summaries and reports of system performance as well as access to the DCP messages. This is supervised by the "DCP Co-ordinator" (the correct contact for DCP users in case of operational problems).

Image processing

Incoming, raw, digital image data from Odenwald go first to the Image Reception Computer, a separate Siemens R 30 mini, from whence they are transferred to the two mainframes for processing and correction. They are then archived and returned to the Ground Station for retransmission in both digital and WEFAX form. It is with the latter that the DCP data are also retransmitted, in the 27-second gap between pictures.

The WEFAX channel is also used to send text messages, in the form of WEFAX images, to both users of the images and to operators of DCPs. For the latter, notes regarding unexpected downtimes and similar interruptions are useful to have. Such messages are sent during those periods when no image is being transmitted (designated as ADMIN in Table 2.1). ESOC additionally sends telexes to DCP operators if an interruption is anticipated (Figure 2.7).



```
TELEX NO: 001/OPS  830810
SFROM: MET OPS ESOC
TO  : DR. HERSCHY   WATER DATA UNIT
      MR. D.W.S. LIMBERT   B.A.S.
      MR. DUGDALE   UNIVERSITY OF READING
      MR. I. STRANGEWAYS   INSTITUTE OH HYDROLOGY
      MR. QUIRING  DWD OFFENBACH
      MM. HOLZKAMM, EICK   DHI. HAMBURG
      DR. AUGSTEIN   ALFRED WEGNER INSTITUTE
      MR. FLEMING JENSEN   ION. LABORATORY
SUBJ: METEOSAT DCP SYSTEM
DUE TO UNFORESEEN PROBLEMS ON THE GROUND STATION RECEIVING
ANTENNA THE DCP SYSTEM IS INTERRUPTED TODAY 10TH AUGUST BETWEEN
0700 AND 1500GMT.
REGARDS H. HOUET
END+++
```

Figure 2.7 Example of a telex received from the ESOC warning of an interruption to the DCP system

2.5.3 ESOC and EUMETSAT policies

The hardware and software at the ground station and at the operations centre evolved during the 1980s and now provides a fully operational service.

At the start of 1989 there were around 10,500 DCP transmissions per week. By September 1989 this had risen to 15,000, produced by around 240 active DCPs. To cope with this sudden increase and that anticipated in the 1990s, 66 new DCP receivers (Figure 2.5) have been installed and will become operational in April 1990. EUMETSAT has now introduced a policy of asking DCP operators who have not used a particular time slot for three months to either resume transmission or surrender the allocation.

The practice of having DCPs but not operating them is, in part, due to users keeping some DCPs as spares. The problem arises because, to date, DCPs have been preprogrammed, at manufacture, with their allocated address and time slot, both unchangeable except by return to the manufacturer. Some recent DCP designs enable both the transmission time and the address to be changed by the user (via the synchroniser or portable PC). An interim solution is to exchange the EPROM memories that hold this information.

However, this does not help where users may want to operate DCPs intermittently. A policy used at IH was to operate DCPs, if not continuously, then regularly, even if actual hydrological data were not being transmitted. This occupied the slot, but was also a useful means of testing the system. Now that evaluation is complete, however, this is less necessary, and in the event of charges being made for time slots it would also be uneconomic. The cost of operating a satellite telemetry network is the subject of section 4.6.

2.5.4 The METEOSAT launch programme

METEOSAT 1 was launched in November 1977 and performed well until it drifted out of range in August 1985.

METEOSAT 2 was launched in June 1981, but its DCP receiver failed and it could not be used, as intended, to completely replace METEOSAT 1. Its retransmission capability was not affected however, and DCP transmissions were routed up via METEOSAT 1 and retransmitted down from METEOSAT 2.

When METEOSAT 1 became unusable in 1985, METEOSAT 3 had not yet been launched. To fill in, ESA used GOES 4, which was no longer required by the USA, it being moved east in its orbit to 40° West. This placed the satellite in view of both the reception centre and the control centre in the USA. It gave good service until it was replaced, although during parts of 1986 and 1987 there were times of the day when performance was degraded due to increasing movement of the ageing satellite in its orbit (see section 3.4.2).

METEOSAT 3 (originally called P2) was launched in June 1988 and took over the DCP mission from GOES 4, handling both the up and down links.

METEOSAT 3 is now on standby, having been replaced by the first of the METEOSAT Operational Programme's satellites (METEOSAT 4 /MOP 1), launched in March 1989. Thus there are, at the time of writing, two functional satellites in orbit, giving high reliability of service.

METEOSAT 5 (MOP 2) is due for launch in late 1990, after which it will become the primary satellite. MOP 3 (METEOSAT 6) will be launched when required.

These four satellites will provide a service until at least 1995 when a new generation of satellites will take over. This METEOSAT Second Generation (MSG) has been the subject of many international meetings (section 5). The MSG will be an updated design of the present-day satellites, and is aimed at providing cover until 2010, with MSG 1 scheduled for launch in 1998. A further MOP satellite is currently under construction as back-up to MOP 3.

As from 1990, therefore, there will always be at least two satellites in operation. This should remove any reservations about the possible continuity of satellite telemetry.

2.6 USER RECEIVERS

These receive both the WEFAX imagery and DCP data on a 1.5 m to 2 m diameter dish at 1694.5 Mhz. A preamplifier is followed by a down-converter, mounted on the back of the dish, which reduces the frequency to 137 Mhz, allowing cabling of up to 100 m to the receiver.

The receiver is usually switchable to several, (typically six), of the 66 channels, demodulating the RF input from the down-converter and outputting it, as a 2.4 KHz AM sub-carrier, to the processing unit - or "DCP Message Recovery Unit".

2.6.1 DCP data recovery

Data are recovered by a bit-synchroniser, which converts the incoming phase-modulated binary signal into the standard form (HDLC) in which it was originally transmitted from the DCP.

The HDLC data-stream is then converted into a standard asynchronous format in RS232/V24/V28 using 8-bit standard ASCII characters. It also buffers the message and filters out the data according to DCP address. Although capabilities vary from make to make of equipment, the processor usually allows the operator to select which DCPs are to be output to a printer or to a PC and which will just be displayed on a terminal screen. It is usual to print out just those DCPs which the user has in operation but to display all incoming data. The latter is useful in keeping a watch on overall system performance.

All subsequent processing and storage of the incoming data can be handled by the PC, the form this takes depending on the purpose of the data. They may be simply archived for later use or they may be used in real-time for input to a model for forecasting. Once to this stage, the system is indistinguishable from any other type of telemetry system.

For all but the 27 seconds of each four minutes during which the DCP data are handled, the output from the receiver is image data.

2.6.2 Image data recovery

The WEFAX analogue signal is output, line by line, building up a complete picture, much as a TV picture is scanned, but instead of one frame each 1/50 second, each picture takes three and a half minutes to build. These analogue signals can be used to produce a hard copy, by laser or other printing technique, or the images can be displayed on a monitor screen. For the latter, an additional unit, a "Digital Frame Store" is required; a PC can also be used, *suitably programmed*. The digital frame store converts the analogue signal into numbers, each representing the intensity of a pixel.

The pictures are reconstituted at normal TV scanning rates by converting each line back from its stored digital form to an analogue, video form acceptable by a standard monitor. False colour can be added to help differentiate more easily between the various shades of grey.

2.7 POLAR ORBITING SATELLITES

The main topic of this handbook is geostationary satellite telemetry, since this is the more common and more useful form. However, polar orbiting satellites can be used in the same way and have some advantages in certain situations. A note on them is thus appropriate here.

Section 1.2.3. described the orbits of polar satellites, that is, low orbits in the north/south direction with a period of about 100 minutes. In consequence, they do not appear stationary at one point in the sky, but appear over the horizon, pass across the sky, (not necessarily directly overhead), and set at the opposite horizon. They are visible for about 10 minutes at each pass, but this varies depending on the angle at which they are visible.

Such orbits dictate that a different mode of operation is necessary for a telemetry system using them. Unlike geostationary systems, the DCPs used with polar orbiting satellites (called Data Collection Systems - DCS) cannot transmit at set times, nor can their antenna be directed at one point in the sky. Instead, the DCSs are given set intervals at which to transmit, ranging from 100 to 200 seconds. They use a similar, but not identical, frequency to DCPs, and their antenna are, necessarily, omni-directional.

Each outstation is given a slightly different transmission interval so as to reduce the chances of coincidental transmissions from two stations. Further separation of outstations is achieved by the fact that, due to the satellite's a Doppler shift in received frequency occurs. This is different for each DCS because it occupies a different location relative to the satellite.

This last feature is also used to enable the position of moving outstations to be followed. This is one of the useful features of polar orbits, and can enable, for example, a drifting buoy to be both tracked and its data collected. Further, the buoy can move completely round the world and still be followed by the same satellite. While this may not be of much value to hydrological applications, even fixed DCSs can make use of the feature, in that it enables data to be collected from any point on earth via the one satellite.

The transmissions from DCSs are received by the satellite at some point in its overpass. The means of then transferring the received data to the user has to be different to that adopted for METEOSAT. They follow two routes.

In the first, they are immediately retransmitted, in real-time, in the UHF range, and can be received by a user's receiver on an omni-directional antenna. To ensure communication, both receiver and outstation must be within a range of not more than about 2000 km of each other, since both must be able to see the satellite at the same time.

In the second route, the received data are recorded on a magnetic tape logger onboard the spacecraft and retransmitted to ground stations as the satellite passes over. These stations are located in the USA and France. From here the data are put onto the GTS or sent as a printout by post if there is less urgency.

As is shown in section 4.6.5, the cost of using the polar satellites is not small, and while they have some unique advantages over geostationary systems, they are of less general purpose use as telemetry satellites. Their greatest value is that they can collect data from high latitudes, beyond the reach of geostationary satellites.

They can also be of value in those areas of the world not currently covered by geostationary satellites. For example, the Japanese GMS satellite does not currently provide a retransmission facility and users can receive data only via the GTS. Until such a time as all of the earth's surface is covered by geostationary satellites with retransmission facilities, polar orbiting satellites will usefully fill the gap.

Table 2.1 Daily schedule of METEOSAT WEFAX images (See also Figure 2.3)

MINUTES HOURS	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58
0- 1	E3	-	D2	D1	D3	D4	D5	D6	D7	D8	D2	D9	D1	D3	-
1- 2	-	-	D2	D1	D3	-	-	-	-	-	D2	D1	D3	-	-
2- 3	-	-	D2	D1	D3	TEST	-	-	RANG	RANG	D2	D1	D3	-	-
3- 4	-	-	D2	D1	D3	D4	D5	D6	D7	D8	D2	D9	D1	D3	-
4- 5	-	-	D2	D1	D3	E1	E2	E3	E4	E5	D2	D1	D3	E6	E7
5- 6	E8	E9	D2	D1	D3	ADMN	-	-	RANG	RANG	D2	D1	D3	E1	E2
6- 7	E3	-	D2	CO2	CO3	D1	D3	D4	D5	D6	D2	CO2	CO3	C3D	C3D
7- 8	-	-	D2	CO2	CO3	C5D	C60	D7	D8	D9	D2	CO2	CO3	C8D	C9D
8- 9	-	-	D2	CO2	Co3	TEST		-	RANG	RANG	D2	CO2	CO3	TEST	TEST
9-10	-	-	D2	CO2	CO3	D1	D3	D4	D5	D6	D2	CO2	CO3	C1D	C2D
10-11	C3D	C4D	D2	CO2	CO3	C5D	C6D	D7	D8	D9	D2	CO2	O3	C7D	C8D
11-12	C9D	-	D2	CO2	CO3	ADM	-	-	RANG	RANG	D2	CO2	CO3	E1	E2
12-13	E3	-	D2	CO2	CO3	D1	D3	D4	D5	D6	D2	CO2	CO3	C1D	C3D
13-14	C3D	C4D	D2	CO2	CO3	C5D	C6D	D7	D8	D9	D2	CO2	CO3	C7D	C8D
14-15	C9D	-	D2	CO2	CO3	TEST	-	-	RANG	RANG	D2	CO2	CO3	-	-
15-16	-	-	D2	CO2	CO3	D1	D3	D4	D5	D6	D2	CO2	CO3	C1D	C2D
16-17	C3D	C4D	D2	CO2	CO3	C5D	C6D	D7	D8	D9	D2	CO2	CO3	C7D	C8D
17-18	C9D	-	D2	CO2	CO3	ADM	-	-	RANG	RANG	D2	D1	D3	E1	E2
18-19	E3	-	D2	D1	D3	D4	D5	D6	D7	D8	D2	D9	D1	D3	-
19-20	-	-	D2	D1	D3	E1	E2	E3	E4	E5	D2	D1	D3	E6	E7
20-21	E8	E9	D2	D1	D3	TEST	-	-	RANG	RANG	D2	D1	D3	-	-
21-22	-	-	D2	D1	D3	D4	D5	D6	D7	D8	D2	D9	D1	D3	-
22-23	-	-	D2	D1	D3	-	-	-	-	-	D2	D1	D3	-	-
23-24	-	-	D2	D1	D3	ADM	-	-	RANG	RANG	D2	D1	D3	E1	E2

C = Visible. D = Infrared (temperature). E = Infrared (water vapour). ADM, TEST, and RANG = ESOC management

3. Practical evaluation of a satellite telemetry system

3.1 BACKGROUND

The Institute of Hydrology (IH) started its instrument development programme in 1964, beginning with automatic weather station (AWS) design. This expanded over the next two and a half decades (Strangeways, 1985). With the launch of METEOSAT 1 in 1977, satellite telemetry became practicable. Seeing this as important for hydrology, particularly with IH's wide overseas involvements, a practical evaluation of its potential was begun at IH in 1982. This chapter reviews the programme of tests and development.

3.2 FIRST DCP TESTS

In March 1979 the manufacturer McMichael Ltd had their first DCP approved by ESA. Although physically much larger than current designs, it was nevertheless capable of performing most of the functions of a present-day DCP.

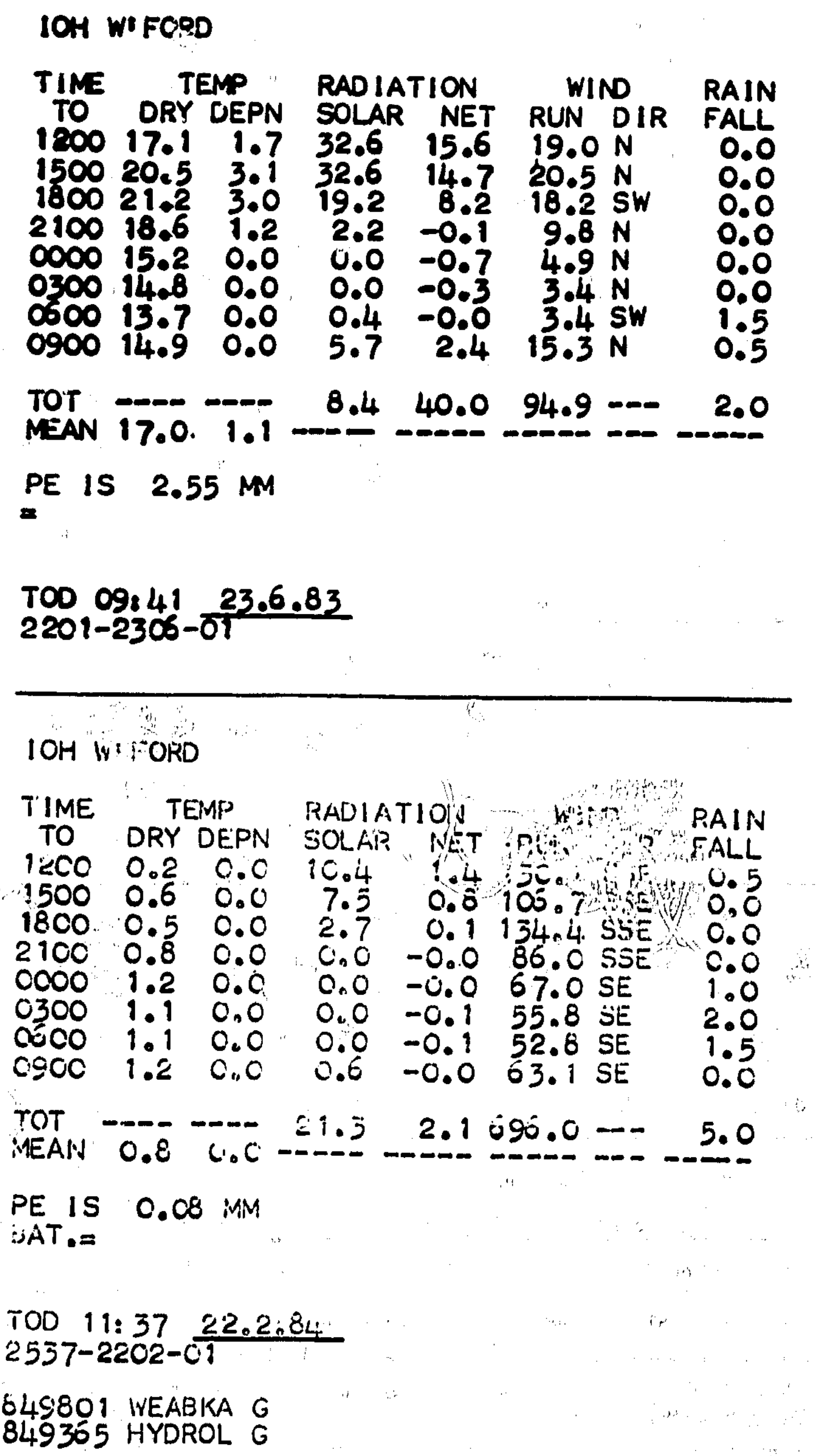
In the first tests, in December 1982, a McMichael DCP was installed on the Wallingford meteorological site, interfaced to an AWS. It transmitted once a day, sending three-hourly means and totals of air temperature, wet bulb depression, solar and net radiation, wind speed, wind direction and rainfall. Data were received at IH by telex over the GTS network, via the Meteorological Office, generally arriving within ten minutes of the DCP's transmission time (Figure 3.1).

After a year's successful operation, it was moved to Coire Cas, a site at 600 m altitude in the Cairngorm mountains, and continued operation there until the end of 1984. The test was then concluded, the system having shown itself to be reliable over the two-year period.

3.3 MAIN TEST PROGRAMME

3.3.1 Equipment purchased

By completion of the first IH tests, McMichael had developed an updated model of their earlier DCP; it was still the only DCP manufactured in the UK. Ten of these, together with a synchroniser for setting up and testing the DCPs, were purchased by IH in 1985 for the next phase of the test programme. A receiver/processor, with dish antenna, and a WEFAX Digital Frame Store were also purchased. Over the next three and a half years the



```
IOH W'FORD

TIME     TEMP      RADIATION       WIND       RAIN
 TO   DRY DEPN   SOLAR   NET    RUN  DIR     FALL
1200 17.1  1.7   32.6   15.6   19.0 N        0.0
1500 20.5  3.1   32.6   14.7   20.5 N        0.0
1800 21.2  3.0   19.2    8.2   18.2 SW       0.0
2100 18.6  1.2    2.2   -0.1    9.8 N        0.0
0000 15.2  0.0    0.0   -0.7    4.9 N        0.0
0300 14.8  0.0    0.0   -0.3    3.4 N        0.0
0600 13.7  0.0    0.4   -0.0    3.4 SW       1.5
0900 14.9  0.0    5.7    2.4   15.3 N        0.5

TOT  ---- ----    8.4   40.0   94.9 ---      2.0
MEAN 17.0  1.1  ----- ----- ----- --- -----

PE IS  2.55 MM
=


TOD 09:41  23.6.83
2201-2306-01
```

```
IOH W'FORD

TIME     TEMP      RADIATION       WIND        RAIN
 TO   DRY DEPN   SOLAR   NET    RUN  DIR      FALL
1200  0.2  0.0   10.4    1.4  150.[illegible] [illegible]E     0.5
1500  0.6  0.0    7.5    0.8  105.7 [illegible]SE     0.0
1800  0.5  0.0    2.7    0.1  134.4 SSE       0.0
2100  0.8  0.0    0.0   -0.0   86.0 SSE       0.0
0000  1.2  0.0    0.0   -0.0   67.0 SE        1.0
0300  1.1  0.0    0.0   -0.1   55.8 SE        2.0
0600  1.1  0.0    0.0   -0.1   52.8 SE        1.5
0900  1.2  0.0    0.6   -0.0   63.1 SE        0.0

TOT  ---- ----   21.5    2.1  696.0 ---       5.0
MEAN  0.8  0.0 ----- ----- ----- --- -----

PE IS  0.08 MM
BAT.=


TOD 11:37  22.2.84
2537-2202-01

649801 WEABKA G
849365 HYDROL G
```

Figure 3.1 Examples of DCP transmissions received via the GTS system by telex

Upper: From automatic weather station at Wallingford
Lower: From the same station relocated in the Cairngorm mountains, Scotland

DCPs were installed at a variety of locations, with a range of sensors, creating one of the largest DCP networks in Europe. In 1985, Space Technology Systems Ltd acquired the proprietary design rights to the GEC/McMichael DCP products (see 4.1.2).

Of the ten DCPs purchased, four accepted analogue voltage inputs (up to a total of five inputs each, with a full scale reading of five volts). The synchroniser was used to program the DCPs regarding which of the five inputs were to be used and how often they should be sampled and stored, ready for the next transmission. Three-hourly transmission time slots were obtained for all ten DCPs. The remaining six DCPs accepted serial RS232 data inputs. These required only an input of the current time via the synchroniser. Details of the 10 DCPs are given in the table below.

Table 3.1

DETAILS OF DCPs USED IN TESTS

ADDRESS	ESA REFERENCE	TRANSMISSION TIME (MINUTES PAST HOUR)	SERIAL NUMBER
1680 1686	GB/10H 1	36	69
1682 1372	2	38	77
1682 26E8	3	40	78
1682 359E	4	42	79
1682 430E	5	44	80
1682 5078	6	46	81
1682 65E2	7	48	82
1682 7694	8	50	83
1682 8610	9	52	84
1682 95E6	10	54	85

Transmission hours: 1, 4, 7, 10, 13, 16, 19, 22 GMT

At purchase, GB/IOH 1 to 6 were of the digital input type, and GB/IOH 7 to 10 were of the analogue input type.

In June 1988 GB/IOH 7 to 10 were converted to digital inputs.

3.3.2 The receiver/processor

The dish antenna was installed on a flat roof with a clear, uninterrupted view of the satellite. A cable of 50 m length connected it to the receiver which was installed in the writer's office, making it possible to gain experience of its performance throughout the test programme. Such hands-on experience was an important element in gaining an overall feel for the performance of the complete system: looking only at printouts of the received data, in isolation and not in real-time, would have been less informative.

The processor section of the receiver was programmed, via a permanently connected terminal, to display all incoming DCP data on the terminal's VDU (not just those from IH's DCPs). This enabled a more precise judgement to be made as to where problems lay - DCP, dish, receiver, processor, satellite, ESOC or ground station.

In addition to displaying all of the incoming DCP data on the terminal screen, the processor was also programmed to output incoming IH DCP data via its serial port to a printer. This gave a permanent record and also allowed performance overnight and at weekends to be followed. Later in the test programme, the data were also input to a PC and stored on disc, appropriate software being developed. To guard against PC failure, however, a printer was always operated as back-up. The above programming of the processor was carried out by means of its built-in software, supplied as part of the system by the manufacturer.

The WEFAX digital frame store was also operated throughout the test programme, alongside the terminal. It gave a display of 256 lines by 256 pixels per line in 16 grey tones with a false colour capability. The simultaneous reception of the images was a useful, additional aid in assessing overall system operation, since any problems could be more easily diagnosed and located in the system. The imaging equipment performed without fault throughout the test period.

3.3.3 DCP installations

Figure 3.2 gives a summary of when the ten DCPs were in operation, what their applications were, and where they were sited. Details of these installations are given below, followed by a brief analysis of the performance of the overall METEOSAT telemetry system based on their operation.

(i) Analogue DCPs

Constant voltages

As a first test, the analogue DCPs were set to telemeter fixed voltage levels, derived from their internal reference voltage, using a resistor chain. Figure 3.3 illustrates one such transmission. The figure also illustrates a number of features common to all DCP retransmitted messages. These are as follows:

1. ESOC insert the day number and the exact time of reception of the transmission (plus 10 seconds). The retransmission illustrated thus starts at six seconds past the minute.
2. The DCP address is included in the retransmission.
3. "VOLTAGES AT WALLINGFORD T 2" is the station identification, programmed into the DCP by the operator via the synchroniser.

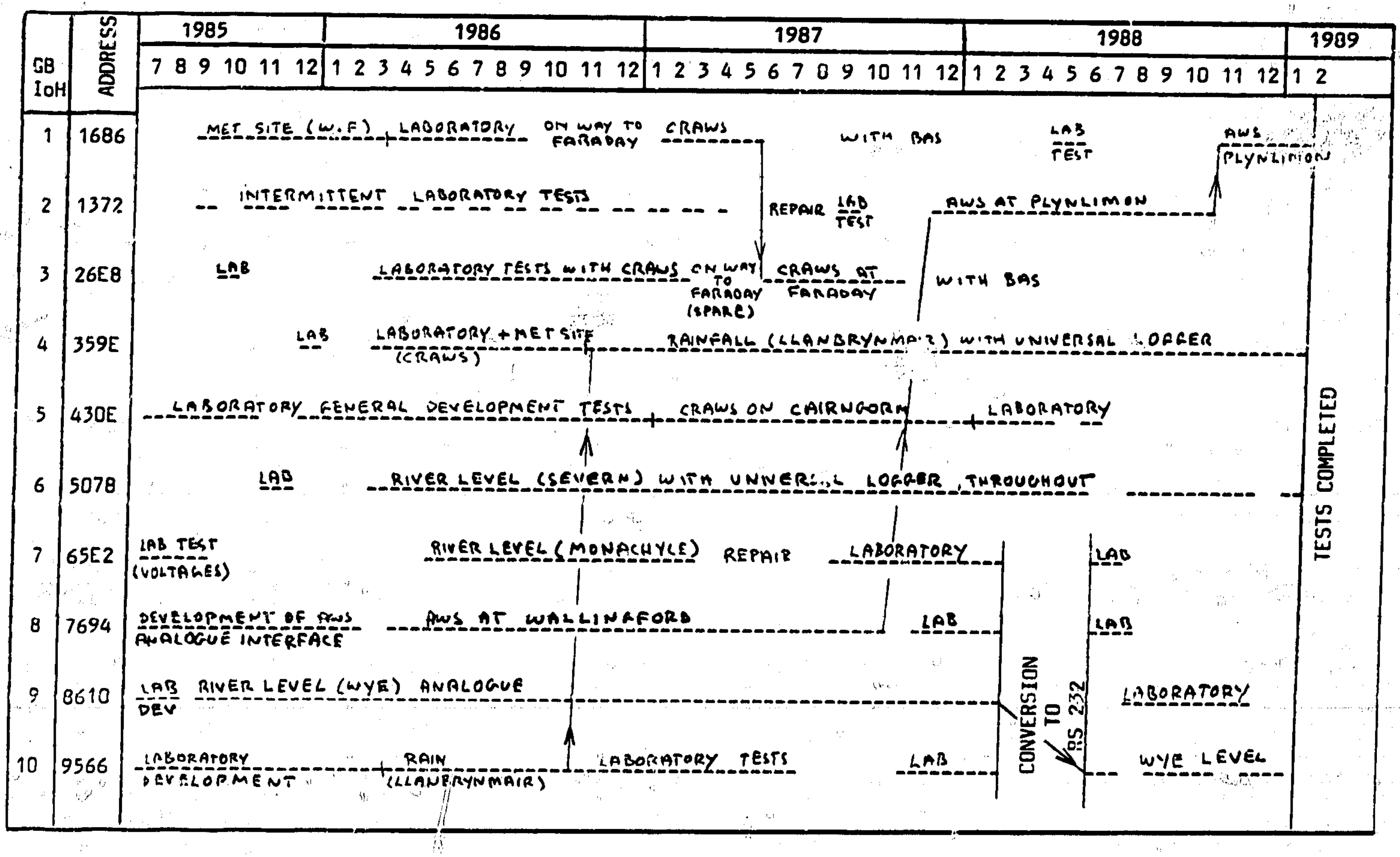
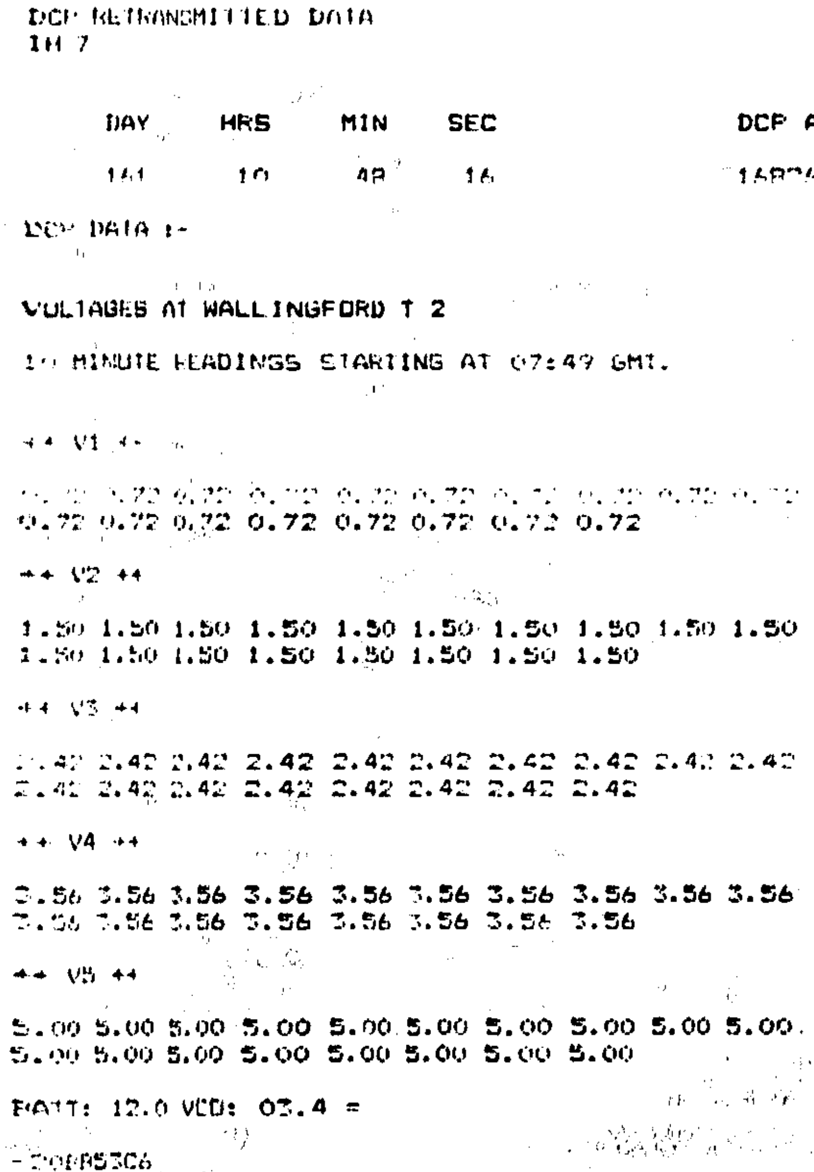


Figure 3.2 Record of DCP operations (IH tests)

4. The DCPs automatically transmit a measure of their on-load battery voltage. It should be between 11.0 and 15.0 volts.

5. "VCO: 03.4" is further housekeeping data, referring to a test point in the transmitter circuit. It should be between 2.0 and 6.0 volts.

6. -20BB53C6 is a code which ESOC insert when their automatic checks on quality show no errors of a nature verifiable by them, such as garbled words, etc., (but not erroneous hydrological data).



```
DCP RETRANSMITTED DATA
IH 7

      DAY     HRS      MIN     SEC                DCP ADDRESS

      141      10       48      16                1AB7A5E2

DCP DATA :-

VOLTAGES AT WALLINGFORD T 2

10 MINUTE READINGS STARTING AT 07:49 GMT.

++ V1 ++

0.72 0.72 0.72 0.72 0.72 0.72 0.72 0.72 0.72 0.72
0.72 0.72 0.72 0.72 0.72 0.72 0.72 0.72

++ V2 ++

1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50
1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50

++ V3 ++

2.42 2.42 2.42 2.42 2.42 2.42 2.42 2.42 2.42 2.42
2.42 2.42 2.42 2.42 2.42 2.42 2.42 2.42

++ V4 ++

3.56 3.56 3.56 3.56 3.56 3.56 3.56 3.56 3.56 3.56
3.56 3.56 3.56 3.56 3.56 3.56 3.56 3.56

++ V5 ++

5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00
5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.00

BATT: 12.0 VCO: 03.4 =

-20BB53C6
```

Figure 3.3 Retransmission of constant voltage test data via a DCP

River level

The potentiometric level sensor, developed for use with the Microdata logger (Strangeways and Templeman, 1974), is well suited to use with analogue DCPs, its three potentiometers being energised by the DCP's internal stabilised five volt rail, available externally during sampling. The resulting potentiometer outputs are compatible, without any processing, with the DCP's signal input requirements. Two gauging stations were installed, one at Plynlimon in September 1985, using GB/IOH 9, and one at Balquhidder in May 1986, using GB/IOH 7.

Rainfall

A tipping bucket raingauge was interfaced to an analogue DCP using a count-to-voltage converter circuit, each tip incrementing the voltage output by 0.25 volts. The voltage levels were stored every 10 minutes by the DCP, the resulting 18 readings being transmitted at three-hourly intervals. GB/IOH 10 was installed with such an interface at Llanbrynmair, a remote Plynlimon site, in March 1986.

Automatic weather stations

AWS required the most complex of the interfaces developed for the analogue DCPs, involving amplifier and bridge circuits. Using such interfacing, an AWS was operated at both Wallingford, using GB/IOH 8 in March 1986, and later at Carreg Wen, an upland Plynlimon site.

(ii) Digital DCPs

Analogue DCPs are particularly useful where sensors produce suitable voltage signals directly, such as the level sensor described above. Indeed such an arrangement offers the simplest and most economic means of operating a DCP.

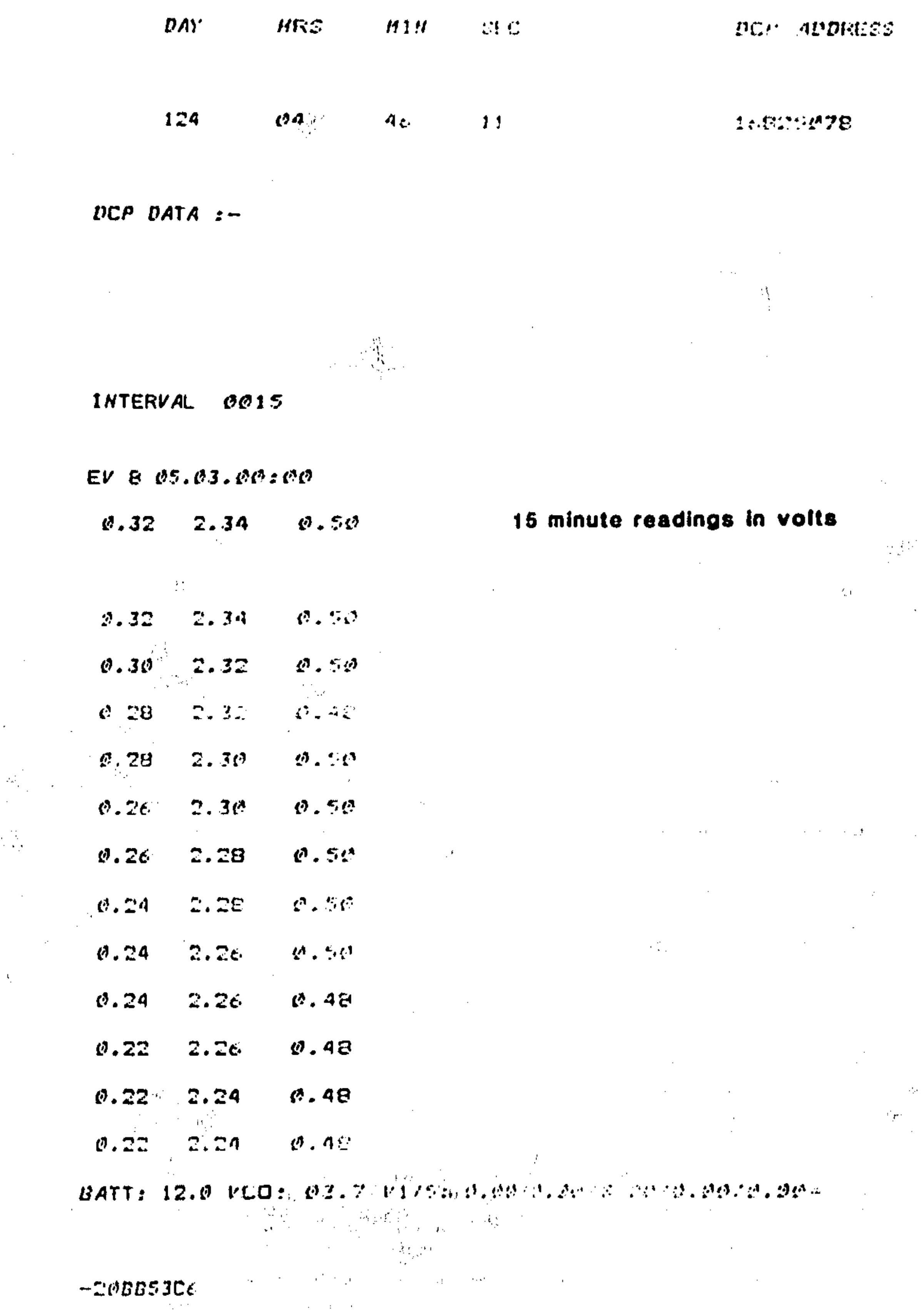
DCPs accepting serial, digital inputs (RS232), however, provide the best means of enabling some pre-processing of the measurements to be carried out prior to inputting to the DCP. This allows the most efficient use to be made of the limited amount of data that a DCP can send in its one-minute time slot.

When IH began its evaluation of the ten DCPs in 1985, no suitable, intelligent, programmable unit was available commercially to perform the task of accepting several sensor inputs, and of outputting their processed measurements in RS232 form, for acceptance by a DCP. It was partly to fill this gap that the Universal Logger was developed at IH based on earlier, simpler, loggers in the IH low cost instrument series. This unit enabled a variety of sensors to be interfaced to serial DCPs and it also provided a logger back-up facility.

Prior to the logger becoming available in 1986 however, the digital DCPs were operated without any data input - to evaluate the overall telemetry system as fully, and as quickly, as possible.

River level

For the same reason that the river level sensor was simple to interface to an analogue DCP, so too was it simple to interface to a logger. For this reason it was the first sensor to be tested with a digital DCP, being installed at a Plynlimon gauging site in March 1986, using GB/IOH 6. Figure 3.4 illustrates a retransmission of its data. It remained in operation until the end of the tests in 1989.



```
      DAY      HRS      MIN      SEC                    DCP ADDRESS

      124      04[illegible]      46       11                     1[illegible]78

   DCP DATA :-



   INTERVAL  0015

   EV 8 05.03.00:00
    0.32   2.34    0.50

    0.32   2.34    0.50
    0.30   2.32    0.50
    0.28   2.32    0.42
    0.28   2.30    0.50
    0.26   2.30    0.50
    0.26   2.28    0.50
    0.24   2.28    0.50
    0.24   2.26    0.50
    0.24   2.26    0.48
    0.22   2.26    0.48
    0.22   2.24    0.48
    0.22   2.24    0.48
   BATT: 12.0 VCO: 03.7 V1/5[illegible]


   -20BB53C6
```

15 minute readings in volts

Figure 3.4 Retransmission of DCP data from a river gauging station operating on the Severn at Plynlimon, central Wales

Rainfall

Pulse-producing sensors, such as the tipping bucket raingauge, connect directly to the Universal Logger's digital inputs. In November 1986 such a system, using GB/IOH 4, replaced the analogue model installed earlier. It too remained in operation until the end of the tests. Figure 3.5 is an example of its retransmitted data.

```
DCP RETRANSMITTED  DATA
RAIN PL
     DAY     HRS      MIN     SEC                      DCP  ADDRESS


     125     07       42      09                       1682359E


DCP DATA :-




INTERVAL  0060


0000              Hourly totals of tips of raingauge bucket
0000
0000

0000
0001
0001

0001
0006
0000

0007
0002
0001
BATT: 12.3 VCO: 03.2  V1/5: 0.00/0.00/0.00/0.00/0.60=


-20BB53C6
```

Figure 3.5 Retransmission of DCP data from a raingauge station operating at Llanbrynmair, Plynlimon, central Wales

Automatic weather stations

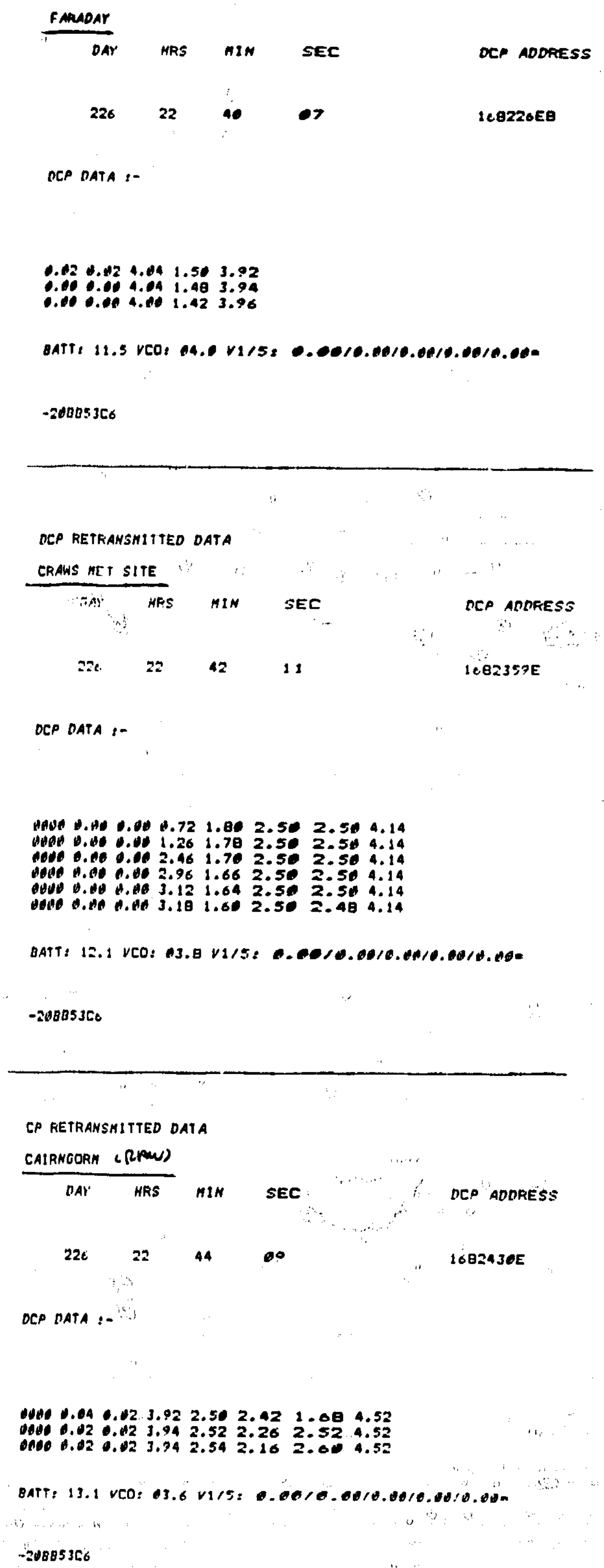
The AWS interfacing, developed for use with the analogue DCPs, was, with very little modification, compatible with the Universal Logger's input requirements. With the modification completed by November 1987 it was possible to replace the analogue DCP, operating with the Carreg Wen AWS, with a digital version (Figure 3.6). This also continued in operation until 1989. Its installation completed the change-over to digital DCPs.

```
DCP RETRANSMITTED DATA
OFFICE
     DAY      HRS     MIN     SEC                      DCP ADDRESS


     125      10      38      13                       [illegible]


DCP DATA :-




INTERVAL   0060                          Hourly totals/means in volts
   0.00    4.06
0071   0004    3.20    0.34    3.52    0.00    3.28


0087   0008    3.18    0.34    3.52    0.00    3.02
0088   0005    3.16    0.32    3.50    0.00    3.04
0099   0007    3.18    0.36    3.48    0.00    2.50


0109   0001    3.18    0.34    3.48    0.00    2.26
0125   0005    3.16    0.32    3.50    0.02    1.74
0191   0006    3.14    0.38    3.52    0.00    2.00


0196   0001    3.18    0.42    3.58    0.00    2.24
0192   0001    3.18    0.58    3.74    0.00    2.16
0179   0000    3.22    0.68    3.86    0.00    2.00
BATT: 11.7 VCO: 03.0 V1/5: 0.00/0.00/0.00/0.00/0.00=


-20BB53C6
```

Figure 3.6 Retransmission of DCP data from an automatic weather station operating at Carreg Wen, Plynlimon, central Wales

Cold regions AWS (CRAWS)

An interesting application of digital DCPs was the transmission of data from Antarctica. CRAWS is an AWS developed at IH for operation in mountainous and polar regions (Strangeways, 1989). Developed on Cairngorm over 10 winters, a joint IH/BAS evaluation of its ability to stay ice free for an Antarctic winter was carried out in 1987 at BAS's Faraday base.



```
FARADAY
        DAY     HRS     MIN     SEC                     DCP ADDRESS


        226     22      40      07                      16822 6EB

DCP DATA :-



0.02 0.02 4.04 1.50 3.92
0.00 0.00 4.04 1.48 3.94
0.00 0.00 4.00 1.42 3.96

BATT: 11.5 VCO: 04.0 V1/5: 0.00/0.00/0.00/0.00/0.00=

-200053C6
```

```
DCP RETRANSMITTED DATA
CRAWS MET SITE
        DAY     HRS     MIN     SEC                     DCP ADDRESS


        226     22      42      11                      1682359E

DCP DATA :-



0000 0.00 0.00 0.72 1.80 2.50 2.50 4.14
0000 0.00 0.00 1.26 1.78 2.50 2.50 4.14
0000 0.00 0.00 2.46 1.70 2.50 2.50 4.14
0000 0.00 0.00 2.96 1.66 2.50 2.50 4.14
0000 0.00 0.00 3.12 1.64 2.50 2.50 4.14
0000 0.00 0.00 3.18 1.60 2.50 2.48 4.14

BATT: 12.1 VCO: 03.8 V1/5: 0.00/0.00/0.00/0.00/0.00=

-20BB53C6
```

```
CP RETRANSMITTED DATA
CAIRNGORM (RAW)
        DAY     HRS     MIN     SEC                     DCP ADDRESS


        226     22      44      09                      1682430E

DCP DATA :-



0000 0.04 0.02 3.92 2.50 2.42 1.68 4.52
0000 0.02 0.02 3.94 2.52 2.26 2.52 4.52
0000 0.02 0.02 3.94 2.54 2.16 2.60 4.52

BATT: 13.1 VCO: 03.6 V1/5: 0.00/0.00/0.00/0.00/0.00=

-20BB53C6
```

Figure 3.7 Retransmission of DCP data from Cold Regions AWS operating at Faraday (Antarctica), Cairngorm summit (Scotland) and a Wallingford test site

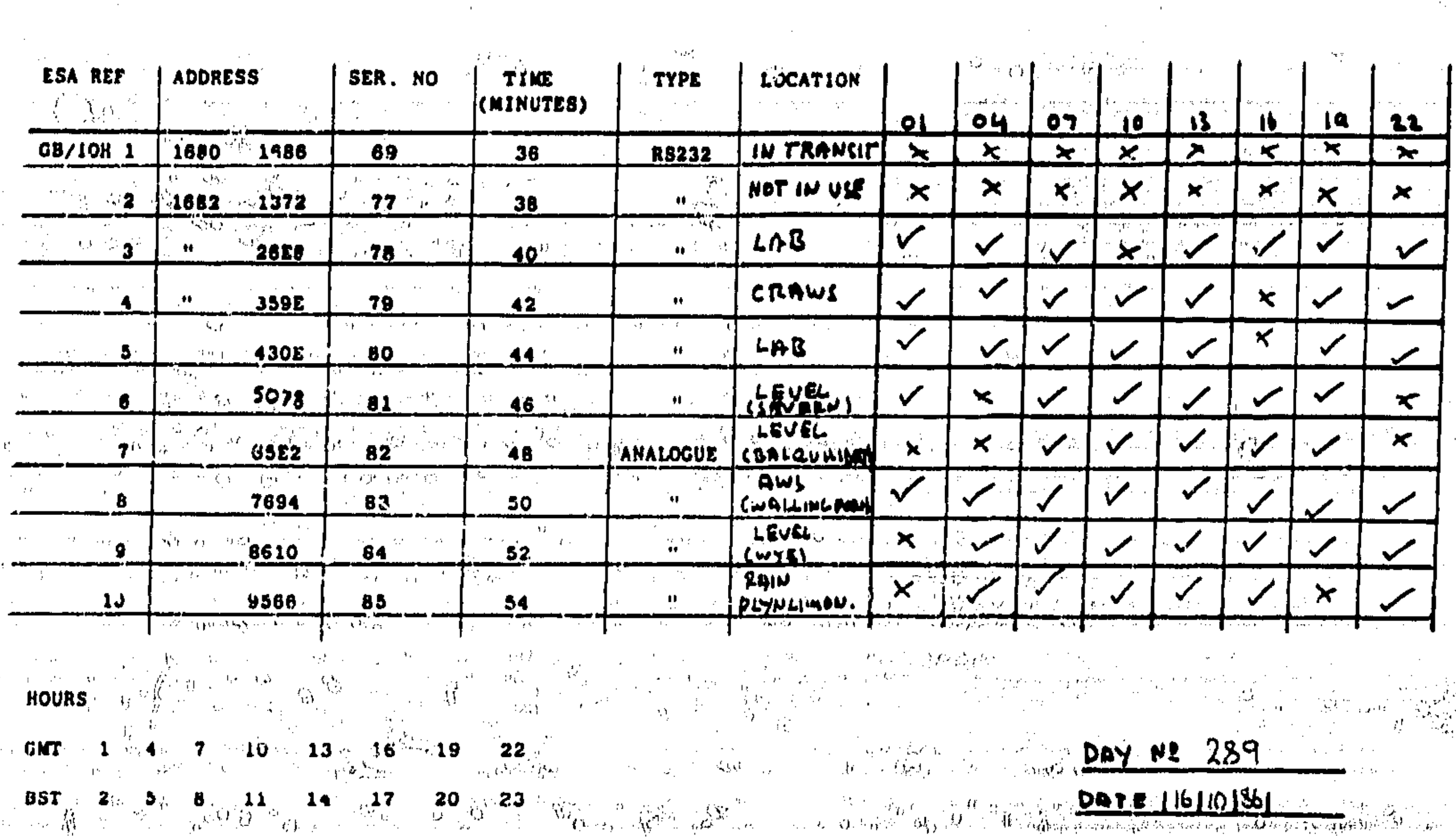
Prior to the availability of DCPs, such an evaluation would have had to rely on in-situ logging, introducing a long delay before the data could be seen. It was possible, instead, to telemeter the data from Faraday, using a digital DCP, giving sight of the data every three hours in Wallingford (Figure 3.7).

3.4 PERFORMANCE

3.4.1 Method

In estimating the performance of the overall telemetry system, each element must be considered separately - DCP, satellite, ESOC activities and the receiver. This was approached through keeping two sets of records.

A daily record was kept, throughout the three and a half year test period, of every transmission made from each DCP, Figure 3.8 being an example for one month. The second set of records were supplied by ESOC (Figure 3.9) in the form of routine monthly tables for each DCP, showing whether a transmission had been received or not.



DCP TRANSMISSIONS

ESA REF	ADDRESS		SER. NO	TIME (MINUTES)	TYPE	LOCATION	01	04	07	10	13	16	19	22
GB/IOH 1	1680	1986	69	36	RS232	IN TRANSIT	✗	✗	✗	✗	✗	✗	✗	✗
2	1682	1372	77	38	"	NOT IN USE	✗	✗	✗	✗	✗	✗	✗	✗
3	"	26E8	78	40	"	LAB	✓	✓	✓	✗	✓	✓	✓	✓
4	"	359E	79	42	"	CRAWS	✓	✓	✓	✓	✓	✗	✓	✓
5		430E	80	44	"	LAB	✓	✓	✓	✓	✓	✗	✓	✓
6		5078	81	46	"	LEVEL (SEVERN)	✓	✗	✓	✓	✓	✓	✓	✗
7		65E2	82	48	ANALOGUE	LEVEL (BALQUHID	✗	✗	✓	✓	✓	✓	✓	✗
8		7694	83	50	"	AWS (WALLINGFOR	✓	✓	✓	✓	✓	✓	✓	✓
9		8610	84	52	"	LEVEL (WYE)	✗	✓	✓	✓	✓	✓	✓	✓
10		9566	85	54	"	RAIN PLYNLIMON.	✗	✓	✓	✓	✓	✓	✗	✓

HOURS

GMT 1 4 7 10 13 16 19 22

BST 2 5 8 11 14 17 20 23

DAY Nº 289

DATE 16|10|86

Figure 3.8 Example of IH daily table of DCP transmissions

```
DCP : GB/IOH 8          ADDRESS : 16828610     CHANNEL : R10                    USER : I.STRANGEWAYS
                                                                                       WALLINGFORD, OXON

                     MESSAGES RECEIVED DURING THE MONTH OF : OCTOBER

--------------------------------------------------------------------------------------------------------
                                                  HOUR
 DAY |  0    1    2  3  4  5   6   7  8  9  10 11 12 13 14 15 16 17 18 19 20 21 22 23  SUM
--------------------------------------------------------------------------------------------------------
   1 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
   2 |  0    0    0  0  1  0   0   1  0  0  0  0  0  1  0  0  1  0  0  1  0  0  1  0   6
   3 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
   4 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
   5 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
   6 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
   7 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
   8 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   7
   9 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   7
  10 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  11 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  12 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  13 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  14 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  15 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  16 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   7
  17 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   7
  18 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  19 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  0  0  0  1  0  0  1  0   7
  20 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  21 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   7
  22 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   8
  23 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  1  0   7
  24 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  0  0   7
  25 |  0         0  0  1  0   0   1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0   2
  26 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  0  0   6
  27 |  0    0    0  0  0  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  0  0   5
  28 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  0  0   7
  29 |  0    1    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  0  0   7
  30 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  0  0   6
  31 |  0    0    0  0  1  0   0   1  0  0  1  0  0  1  0  0  1  0  0  1  0  0  0  0   6
--------------------------------------------------------------------------------------------------------
                                                                                      TOTAL    222

NO MAJOR OUTAGES DURING THE MONTH OF SEPTEMBER
OWING TO SOFTWARE PROBLEMS NO MESSAGES WERE ARCHIVED ON:
DAY 25 BETWEEN 07.55 AND 21.57 GMT
DAY 27 BETWEEN 01.23 AND 06.11 GMT
ALL MESSAGES RECEIVED WERE PROCESSED
```

Figure 3.9 ESOC monthly table of DCP transmissions

From these, a third table was produced, combining their information (Figure 3.10). This shows:

- Transmissions received at both Wallingford and Darmstadt;
- Transmissions received at Darmstadt only;
- Transmissions received at Wallingford only; *
- Transmissions received at neither place.

Also shown, for the occasions when the IH receiver was not in operation, are:

- Transmissions received at Darmstadt;
- Transmissions not received at Darmstadt.

To highlight different features, the same information was also tabulated in time-groupings, as well as the illustrated grouping by DCP.

3.4.2 Analysis

Hardware failure

Two DCPs failed and were returned to the manufacturer for repair. One was

---

* While it would seem contradictory to receive data at Wallingford while not at Darmstadt, ESOC did sometimes fail to record reception, even though transmission had occurred correctly - as evidenced by data being received at Wallingford.

✓ are omitted in this section to provide a clearer display, an empty square representing a ✓.

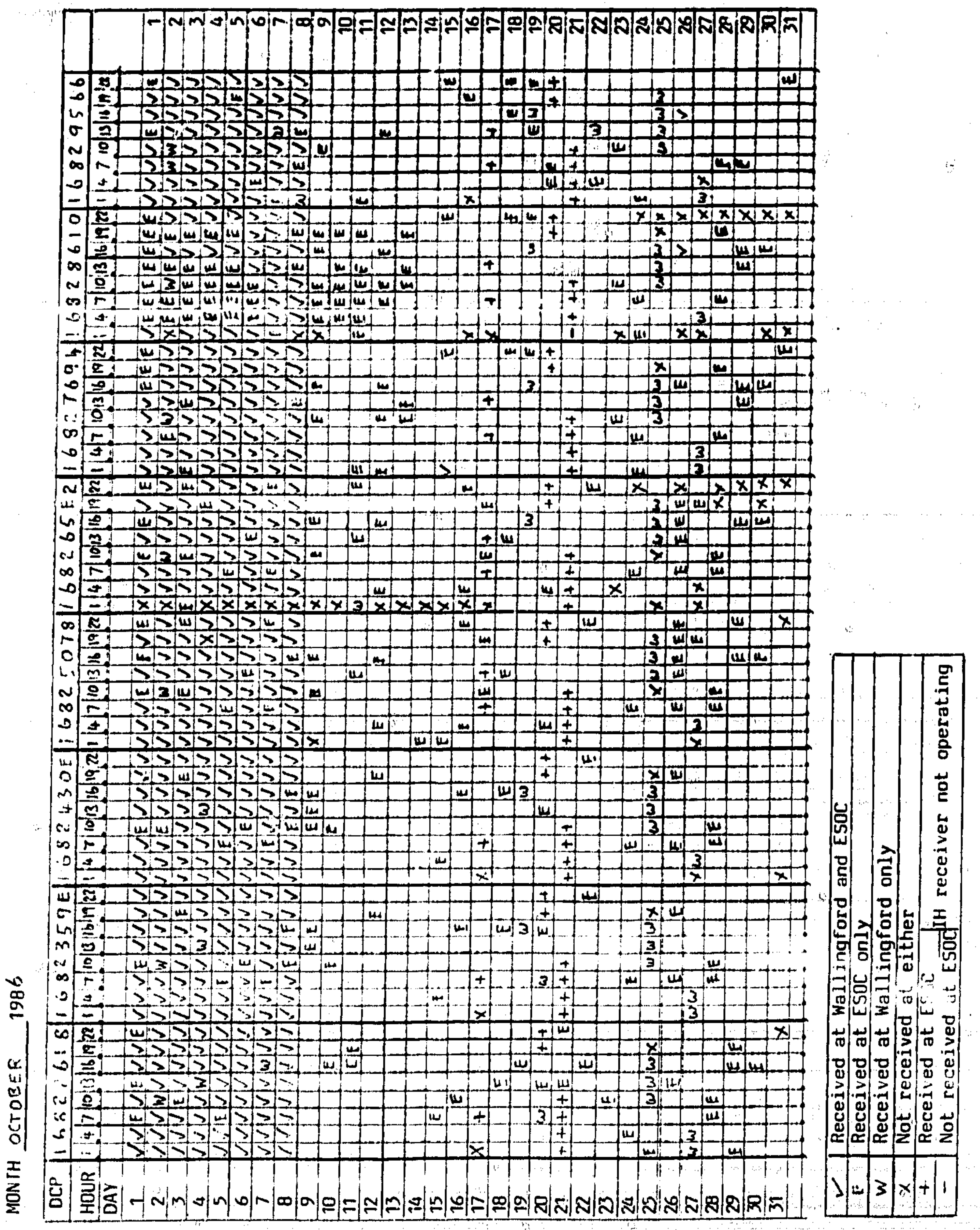


Figure 3.10 Combination of previous two tables (Figures 3.8 and 3.9)

due to the failure of the processor chip, which was changed, the second was due to corrosion of a circuit board where it joined the battery input plug. The cause of this could not be established by the manufacturer, but it appears to have been a one-off event. It was repaired and the fault did not recur. The DCPs involved were GB/IOH 2 and 7 respectively.

The down-converter, (not a Space Technology System's product), on the receiver antenna dish developed a temperature-dependent fault, introducing noise on the WEFAX pictures and unreliability in DCP reception. The unit was exchanged and the fault did not occur again during the test period.

Data return

The questions to be addressed are how many transmissions that the DCPs should have made did they fail to make, and how many that they did make were lost somewhere along the way, and through what causes.

In interpreting performance, account must be taken of the following:

(i) Throughout the test period, with the exception of a few months at the end, GOES 4 was the satellite in use. As explained earlier, this gave problems from time to time due to its position in orbit - a problem now removed with the launch of P2 and MOP1.

(ii) Throughout the test period ESOC were updating their hardware and software, working towards providing a fully operational system. These activities caused occasional interruptions to the retransmission service.

(iii) The processor section of the receiver occasionally failed to recognise DCP addresses, and lost the message as a result. This was overcome in more recent designs and is therefore excluded from the assessment.

Despite these provisions, it will be seen that performance was good.

In all, around 750,000 DCP transmissions were made and it was not, therefore, possible to include all of them in the analysis made here. Instead, two sample months were taken, when as many as possible of the DCPs were in operation for the whole period. The first month, October 1986, was about a year into the tests. The second period, August 1988, was towards the end, and followed the launch of P2 (METEOSAT 3).

(i) October 1986

Eight DCPs were operational throughout October 1986. The total number of transmissions made was therefore 1984. Of these, 64 were not received at ESOC (or IH), representing a loss of 3.2%. All but 12 of these losses occurred during the 22.00 and 01.00 time slots, times when reception was poor every day due to GOES 4 orbit problems. (In 1987 this effect drifted slowly to 04.00 and 07.00, and later to 07.00 and 10.00.)

Of the 12 lost transmissions that were outside of these time slots, all but one were in the adjacent slot, suggesting the same cause, although over half of the 12 occurred on the 25th day, suggesting an additional factor.

A further factor can also be seen if the DCPs are considered separately:

GB/IOH	3	4	5	6	7	8	9	10
% Loss	1.2	0.8	1.6	1.2	11.2	0.4	7.7	0.8

This shows that the "orbit effect" was also DCP-dependent. The two DCPs with the greatest losses, Nos. 7 and 9, were both being operated at mountainous sites with hills to the south - 7 being in Scotland and 9 at Plynlimon. Both of these were in valleys at river gauging sites, the worst performer of the two being that at the higher latitude where the angle of elevation of the satellite was smaller. This suggests that the orbit of the satellite took it just beyond sight of these two DCPs. During times other than around these critical periods, the performance of these two DCPs was as good as that of the others, all of which were at open, lowland sites.

There were 58 occasions when ESOC did not record reception but IH did. From the table it is seen that these, too, occurred mostly on the 25th of the month and to lesser extents on the 2nd, 4th, 19th and 20th, all between 10.00 and 16.00. This was due to activities at Darmstadt interfering with the automatic record-keeping, but not with retransmission (see ESOC's note, bottom Figure 3.9).

It would appear, therefore, that GOES 4's problems accounted for 52 of the 64 data losses, while the remaining 12 were due either to a spread of this effect and/or activities at ESOC, mostly on the 25th day. This suggests that the DCPs probably performed without fault.

(ii) August 1988

Five DCPs were in operation continuously during this month (GB/IOH 2, 4, 6, 9, 10), producing 1240 transmissions. Of these, 33 were not received by ESOC or IH, a loss of 2.7%. However, ESOC's notes show that five were lost on the 15th due to power failure and eight on the 25th due to software problems, leaving just 1.7% unaccounted for. ESA have always stated that about 1% of transmissions will be lost, through a wide variety of causes.

3.5 CONCLUSION

From this brief look at performance, the following points emerge:

1. Data return was 96.8% in the first month considered and 97.3% in the second.
2. The great majority of the losses, if not all, can be attributed to GOES 4's orbit problems and ESOC's development activities on certain days.
3. The DCPs appear to cause no detectable losses.
4. With the new operational satellites now in orbit, a 99% data return can be expected.

4. Commercial equipment and operating costs

The following is not an exhaustive list of suppliers, but includes all of those who have displayed equipment at exhibitions accompanying meteorological and hydrological conferences, or those known of through word of mouth or by brochure. Any manufacturer who wishes to be added to the list given below, should write giving technical details to the Institute of Hydrology; any omission is through lack of knowledge.

The previous chapter concerned an evaluation of DCPs manufactured by Space Technology Systems Ltd. These were adopted in 1982 (and their updated model in 1985), because they were the only UK firm making such equipment. Neither this explanation, nor their use, should be interpreted as either criticism or as promotion.

4.1 DCPs FOR GEOSTATIONARY SATELLITES

4.1.1 Typical specification

Although DCPs differ from make to make, it is possible to give a typical specification:

Power output	5-6 watts with directional antenna 40-50 watts, omnidirectional
Transmission interval	1 minute to 24 hours
Transmission duration	1 minute maximum
Number of channels	1 self-timed, 1 alert
Type of inputs	5 analogue or 1 event counter or 1 serial (RS232)
Data sampling interval	1 minute to 24 hours (analogue and event only)
Transmission format	WMO code Plain text, ASCII, 8-bit binary
Operating temperature	-30°C to +60°C
Power supply	12 volts, DC 10 ma, quiescent, 1-2 amps transmit
Data storage	1 K bytes

4.1.2 Suppliers

In alphabetical order:

CEIS Espace
rue des Freres-Boudes, Z.I. Thibaud
31084 Toulouse Cedex, France

CEIS Espace manufactures a wide range of satellite telemetry equipment and is very active in the field. Products for both geostationary and polar orbiting satellites are available. They also market complete turnkey systems with their DCP/DCS for hydrology, meteorology and seismology.

Didcot Instruments Ltd
Station Road
Abingdon
Oxon OX14 3LD, UK

This company is best known to hydrologists for its AWS and soil moisture neutron and capacitance probes. However, during 1990 they plan to market a DCP (and receiver). Initially the DCP will accept RS232 inputs, but there will be provision for the later addition of analogue inputs.

Handar
1380 Borregas Avenue
Sunnyvale, CA 94089-1094, USA

There are currently 1300 Handar DCPs in operation in the USA, reflecting the US's earlier entry into the use of satellite telemetry. As with CEIS, complete packages are available for meteorology and hydrology, including conventional, ground-based UHF/VHF telemetry systems.

Space Technology Systems Ltd
Technology House
Station Road
Alton
Hants GU34 2PZ, UK

This company acquired the proprietary design rights to the GEC/McMichael DCP products in 1985. GEC/McMichael had been manufacturing DCPs since 1979, although the 1985 product was an updated version of that of 1979. (It was the 1985 model that was the subject of the IH tests described in chapter 3.) STS now offers a further updated model, and also a service for upgrading/refurbishing their 1985 design. DCPs are supplied either as stand alone units, as parts of integral STS systems, or to other manufacturers for inclusion in their own systems.

Sutron
2190 Fox Mill Road
Herndon
Virginia 22071, USA

The Sutron 9000 series is a modular system comprising a variety of rack-mounted electronic boards, allowing systems to be built to specific needs. One of the boards is a satellite transmitter, and others include memory, input/output, A/D conversion and conventional UHF radio units. Data logging can be incorporated with satellite telemetry.

Synergetics
6565 Odell Place
PO Box E, Boulder
Colorado 80306-1236, USA

Their series 3400 system is made in modular form, comprising boards for sensor interfacing, control functions and the transmitter.

4.2 DCS FOR POLAR ORBITING SATELLITES

The equivalent organisation to EUMETSAT for the NOAA polar orbiting satellites is:

Service Argos
Centre Spatial de Toulouse
18 avenue Edouard-Belin
31055 Toulouse Cedex, France

Application to use the satellites must be made formally through Argos, the decision to allow their use being taken jointly with NOAA and NASA.

Data Collection Systems (DCS) are very similar to the DCPs used with geostationary satellites.

4.2.1 Suppliers

A full list of manufacturers of certified DCSs is obtainable from Argos, and no details are given here beyond noting that CEIS Espace, Sutron and Synergetics, already listed as manufacturers of DCPs, also manufacture DCSs.

4.3 RECEIVERS

Most manufacturers of DCPs (and DCSs) also supply suitable receivers, and no separate list of suppliers need be given. All receivers will receive data from any make of DCP, and all DCPs can transmit to any receiver, since the retransmission signals are in ESOC standard form.

Receivers, and the associated processing unit, vary in their complexity from make to make, but all include the basic essentials of antenna, down-converter, receiver, phase demodulator and the means to convert the signal back to asynchronous data in ASCII characters. Most systems today include a PC with suitable software to store the incoming data on disc.

All receivers also output the WEFAX image signals, which take a standard form for all satellites. These can be decoded and displayed by adding a digital scan converter to the receiver.

4.4 WEFAX EQUIPMENT

Most WEFAX systems are marketed as complete, self-contained, systems. Indeed receivers solely for the purpose of image production are in far wider use than those for DCP data reception, and there are many suppliers, some examples being:

Feedback Instruments Ltd
Crowborough, East Sussex UK

using the Apricot Microcomputer, and

NCS Ltd
Newcastle NE20 9BD, UK

using the Apple Macintosh II.

However, only those units which can be added on to a receiver installed specifically for DCP/DCS data reception, or which combine the two functions, are relevant here. Examples of this type of product include:

Space Technology Systems, (listed earlier), and

Microwave Modules Ltd
Brookfield Drive
Liverpool L9 7AN, UK.

It was the latter that [illegible] used during the tests described in section 3.

The field is also one that is popular with amateurs, since it is not difficult to make a suitable receiver and digital frame store quite cheaply, and a competent home computer enthusiast can obtain or write software able to handle the digitised images.

4.5 METEOR-SCATTER

Inclusion here of this type of equipment is for the purpose of comparing costs and also to provide contacts for those wishing to follow up the technique further.

4.5.1 Suppliers

Hollis International
17 Clinton Drive
Hollis
New Hampshire 03049, USA

Meteor Communications
Unit 12, Long Spring
Potters Wood
St Albans
Herts AL3 6EN, UK

Vaisala
Cambridge Science Park
Milton Road
Cambridge CB4 4BH, UK

4.6 COSTS

4.6.1 Equipment Costs

Since there is a great variety of facilities offered by manufacturers, and because prices change, individual products are not priced. Instead, typical ranges are quoted, valid at 1990. The price of DCPs has tended to fall slightly over the period 1982 to 1990.

DCPs and DCS	£2,500 - £3,000
Synchronisers	£1,000 - £2,000
Receivers	£5,000 - £15,000
WEFAX Digital Frame Store	£600 - £1,000
Meteorscatter Outstation	£5,000 - £25,000
Base station	£25,000 - £80,000

4.6.2 Installation costs

One of the advantages of satellite telemetry is its simplicity of installation compared with other telemetry methods. The cost of sensor installation will be the same as that for any system, whether logging or telemetering. The cost of installation of the DCP, however, involves only that of providing a simple

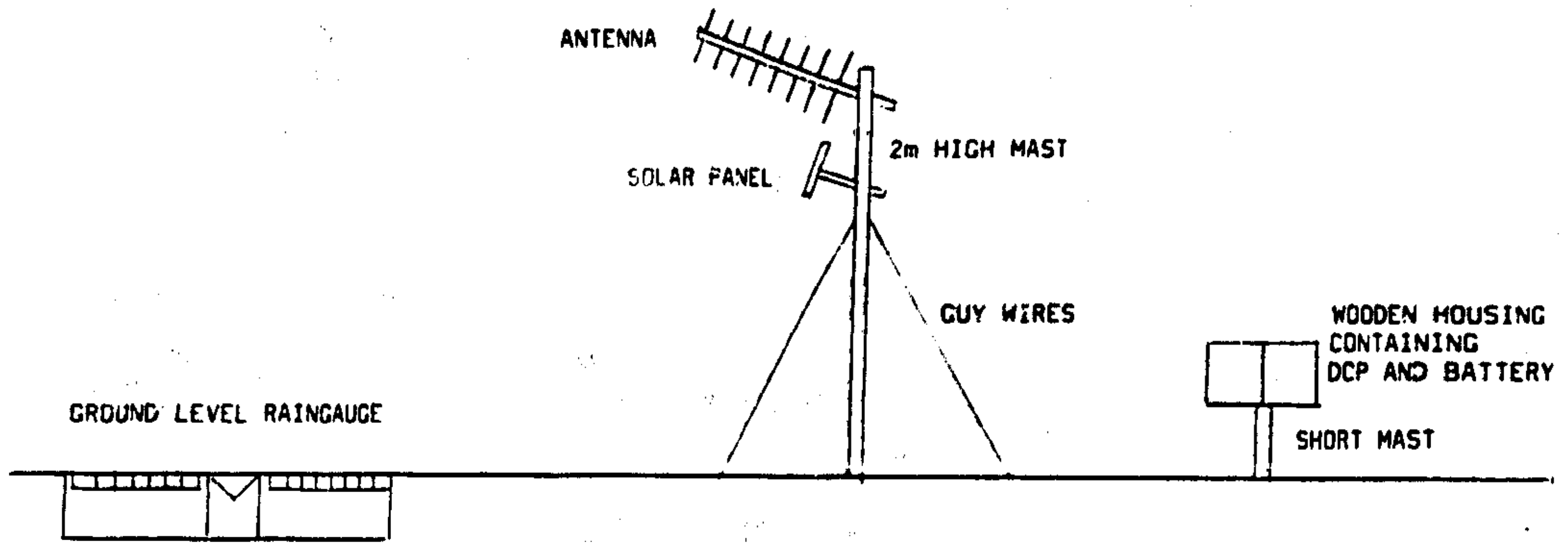


Figure 4.1 Components of a satellite telemetering raingauge outstation

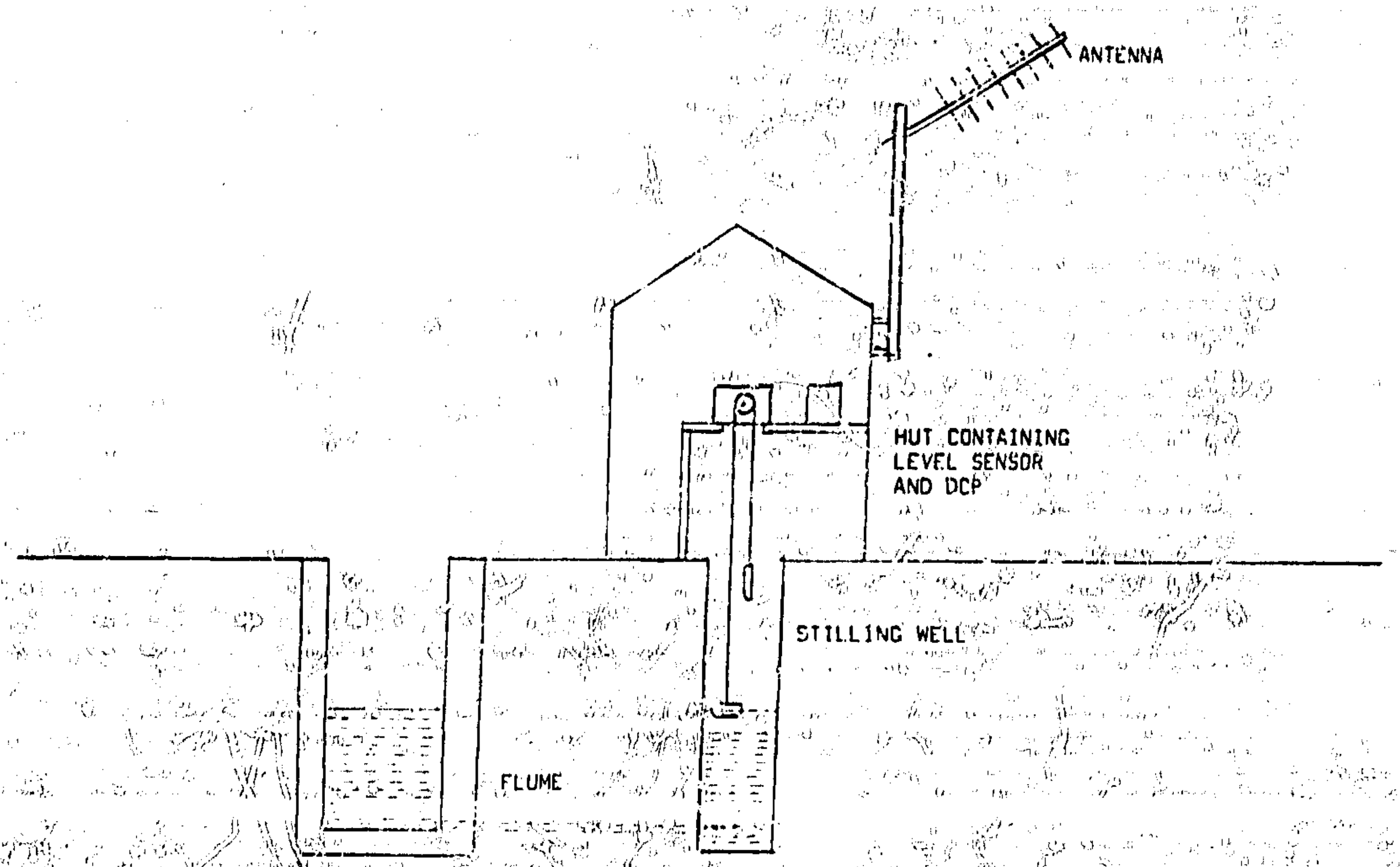


Figure 4.2 Satellite telemetering river gauging outstation

housing for the DCP and its battery. This need be no more than a wooden housing with sides of 50 cm, and a 2 m high pole from which the antenna is deployed. Some guying may be necessary in exposed places. Figure 4.1 illustrates a rainfall telemetering outstation. Alternatively, if there is already a housing for a stilling well for example, the DCP can be sited within it and the antenna fixed to a pole on its wall (Figure 4.2). The cost of installation is thus minimal.

The receiver requires only desk space, while the 1.5 m diameter dish can be installed on the ground or on a flat roof with simple fixings. Figure 4.3 illustrates the installation at Wallingford. The installation procedure is also simple, and involves directing the dish until the maximum signal level is indicated on the receiver's signal level meter. Directivity is not highly critical, although positioning the antenna is eased with a portable meter.

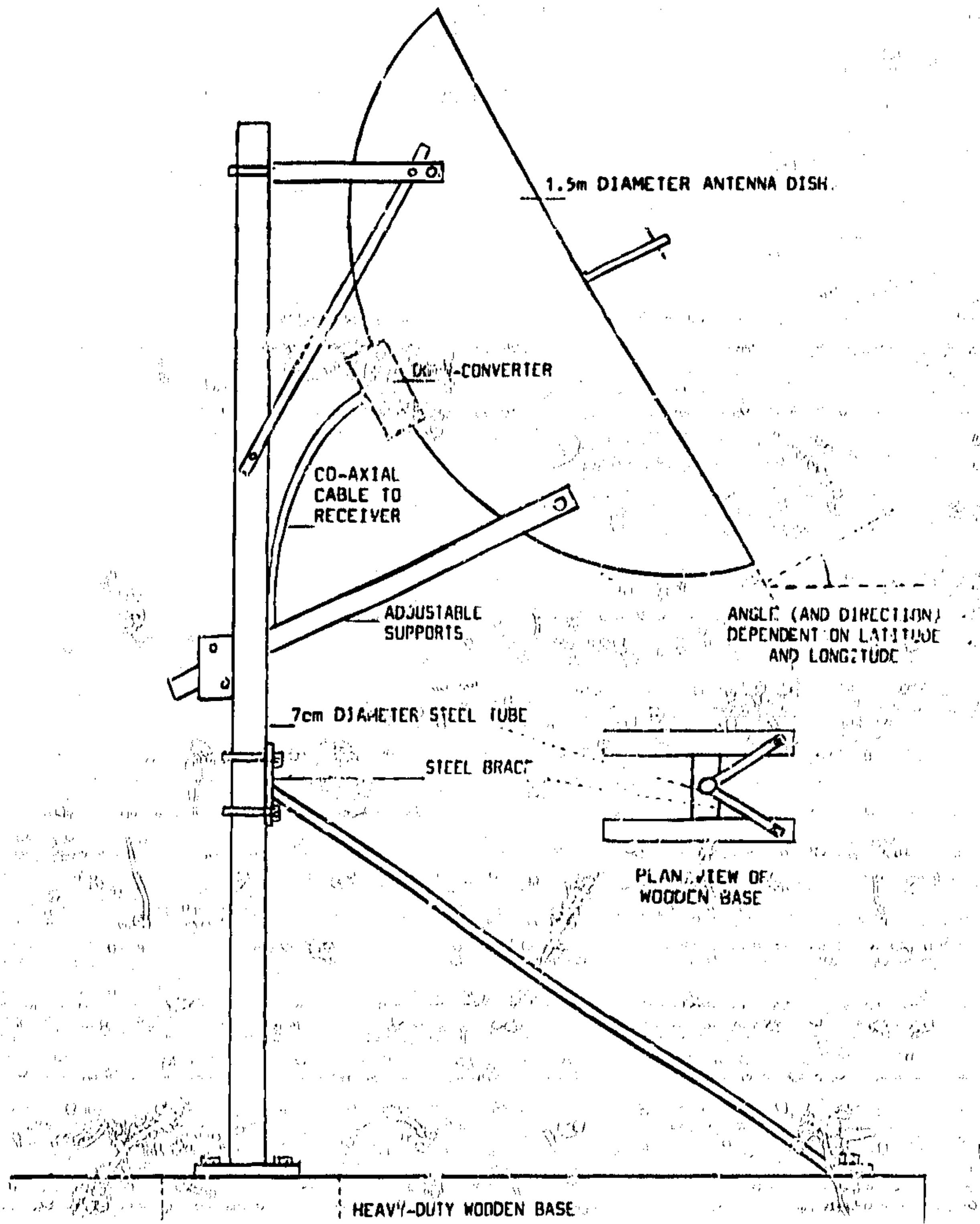


Figure 4.3 Antenna for the reception of retransmitted DCP (and WEFAX) signals

4.6.3 Operational costs

The cost of running a satellite telemetry system is low. Apart from occasional visits to carry out routine maintenance it is only necessary to visit outstations after a breakdown. The cost of travel is thus much less than that incurred with logging systems and the staff time involved is also considerably less. Even a periodic inspection can often be done by local personnel and a "checked" message sent, via DCP, along with the data.

Operations at base are largely automatic. There is no requirement to physically handle any data, as is necessary with the cassettes or solid state memories of logging systems. Software can alert an operator to the failure of a DCP, or to when its battery voltage or reporting time are drifting out of range. Even processing of the incoming data can be largely automatic. This is a considerable improvement on the operating techniques necessary with manually-tended logging systems, which in comparison are highly labour intensive.

4.6.4 Maintenance costs

The parts of the system requiring maintenance by the user are the outstation and the receiver, the remainder being the concern of ESA.

DCPs have to meet precise standards set by ESA before they can be used with METEOSAT and this results in instruments of quality. Maintenance visits to outstations are thereby kept to a minimum. As was shown in the previous section, in over three years of IH testing, only two failures occurred amongst ten DCPs. Visits to outstations were necessary to attend to sensors, power supplies or wind damage, but not to DCPs.

The receiver, of which only one is usually required, operates in a more benign environment than the DCPs and is thus subject to less environmental stress, such as temperature extremes. Being operated at a manned base, it is also open to immediate tests if performance is in doubt. Maintenance costs are thus restricted to the repair of hardware failures of the one unit at an accessible site.

During the IH tests no receiver or processor failure occurred, the only maintenance required being the replacement of the down-converter on the receiver dish. This is the one part of the base system which is subject to the same environmental extremes as the DCPs, and this came to light during high summer temperatures.

4.6.5 Cost of using the satellites

METEOSAT

EUMETSAT have introduced the following policy regarding charging for the use of METEOSAT for the telemetry of DCP data.

If data are relevant to the National Meteorological Service, or when messages are transmitted over WMO's GTS, there is no charge. Other users will pay as follows:

For each regional DCP transmitting one, one-minute duration message every three hours, a charge of 3.5 K ECU will be made for the first year. This is approximately equivalent to £2390 at 1990 rates of exchange. Subsequent years will be charged at approximately £1020. Assuming three-hourly time slots, this amounts to 2920 transmissions per year, or 35 pence for each one-minute message. Comparing this with telephone telemetry, one-minute calls currently cost five pence for a local call in the cheap rate in the UK, rising to 20 pence at peak rates over 56 km. Rates [illegible] range from 86 to 137 pence per minute.

However, up until the time of [illegible] use of the METEOSAT telemetry facility free [illegible] assurance in writing (1984) from ESA that there [illegible] rations, to charge users such as IH for data co[illegible] that research organisations, collecting mete[illegible] it forms part of a national Meteorologic[illegible] authorised programme of the WMO, can expec[illegible] system.

Before a user can operate a DCP, initial application must be made to EUMETSAT by completing an admission questionnaire. Enquiries should be directed to:

The Director, EUMETSAT
Am Elfengrund 45
D-6100 Darmstadt-Eberstadt
Federal Republic of Germany.

Tel Int + 49 6151 53 92 0
Fax 49 6151 53 92 25.
Telex 4197335 (EMET D)

Polar orbiting satellites

For application to use a polar orbiting satellite the address given above in section 4.2 should be used. Charges for the use of the Argos system are currently in the region of:

Commercial tariff: 24,520 French Francs per station per year. This is equivalent to about £2,452 per year.

Reduced tariff (WMO) for meteorological applications: 8173 FF (£817) per year.

5. The International Situation

5.1 EUROPE

5.1.1 ESA meetings

The three functions of METEOSAT - image generation, image dissemination and data collection - are generally treated separately, with user meetings being organised by EUMETSAT for both image and DCP aspects. For imagery and their applications, regular "Scientific User" meetings, hosted by different countries, are held. The most recent meeting was in Spain in 1988, the previous one in the Netherlands in 1986, with the eighth planned for August 1990 in Sweden.

There are also meetings concerned specifically with DCP use. The First Meteosat DCP Users Conference was organised by ESA and held in Portugal in 1986. At this meeting, papers fell into groups covering DCP applications in meteorology (eight papers), hydrology (two), oceanography (two), seismology and geophysics (two), and technical details of DCPs (four). A second meeting is planned for 1991 in Greece.

Receiving most attention at present is the Second Generation of METEOSAT. The first of the meetings concerned with this was held in France in 1984 and resulted in several studies being set up, subsequently reviewed at Workshops in Ravenna and Hokenschwargau, both concerned entirely with imagery.

The second meeting was held in Santiago de Compostela (Spain) in 1987 and was concerned as much with DCP telemetry as with imagery. It was at this meeting that the importance of DCPs to hydrology was stressed and the estimate of 5000 DCPs being in use in hydrology from 1995 onwards was made by ESA. The author attended this workshop and was the only hydrologist present. European hydrologists need to become more aware of the value of satellite telemetry if good use is to be made of METEOSAT's capabilities.

5.1.2 EUMETSAT plans

In addition to fulfilling the METEOSAT launch programme outlined in section 2.5.4, EUMETSAT also plans to make a contribution in the area of polar orbiting satellites. At present this is provided by the USA from its two NOAA satellites. A European polar satellite is, however, planned for the late 1990s and this will add a further DCP/DCS option to that of METEOSAT. (A question worth raising is whether DCS data, telemetered via future European polar satellites, could be retransmitted via METEOSAT as well as via the polar satellite, direct, or over the GTS. Such a facility would enable data from areas beyond the 2000 Km range of such satellites to be received directly by users on the same hardware that receives DCPs. This would allow data to be collected from any point on earth.)

5.2 WORLD-WIDE

The co-ordination of the international system of geostationary satellites is achieved through a number of paths, in particular through EUMETSAT and WMO.

5.2.1 EUMETSAT

EUMETSAT acts as the secretariat for an informal group known as the Co-ordination Group for Meteorological Satellites (CGMS) which meets about once a year. It has established international standards for image dissemination and for DCP systems. It includes ESA, EUMETSAT, Japan, India, the USA, the USSR and the People's Republic of China.

EUMETSAT also attends the meetings of The International Polar Orbiting Meteorological Satellites group (IPOMS), and is now seeking to develop its own contributions in this area.

5.2.2 WMO

WMO also co-ordinates satellite operational activities at meetings held at regular intervals. The most recent meeting was held in Geneva in November 1989 and the following is a brief review of the international aspects considered in the report of the meeting (WMO 1989).

Japan

GMS-3 is the current operational Japanese satellite, at 140° longitude. GMS-4 was launched in September 1989 and was being tested at the time of the meeting. It was due to become operational in December 1989. GMS-3 will then be moved to 120°, as back up. GMS-5 is due for launch in 1994 to replace GMS-4.

Currently GMS satellites do not offer a retransmission service for DCPs, making it impossible for users to receive their DCP data directly. Data can only be received over the GTS and must be in the standard WMO format. There are no plans to provide retransmission in the forseeable future, and the absence of this feature has already proved problematic to this author in connection with a telemetry project in Malaysia. This must surely limit the usefulness of GMS satellites; Japan is urged to reconsider the matter.

USA

The GOES series of geostationary satellites have been in operation for the longest, and GOES-I is to be launched in 1991, with GOES-J at an unspecified later date, as required.

The polar orbiting NOAA-10 (AM) and NOAA-11 (PM) are those currently operational. NOAA-D (PM) will be launched 1n 1990 and NOAA-I (PM) in 1991, with more to follow every 15.5 months. The next generation, NOAA-K, L, M, N and O, will start a new series and will be able to handle 1200 platforms in the Argos DCS system.

Brazil

The Space Research Institute (INPE) and the Institute for Space Research Activities (IAE) will have two satellites launched, one in 1991 and one in 1993, in low equatorial orbit. They will carry DCS transponders, compatible with the Argos system. There are also plans to launch two polar orbiting satellites, one in 1994 and and one in 1996 for high resolution IR land resources applications. Brazil's Centre for Environmental Studies (CSA) also currently participates with Japan, the USA and more recently with EUMETSAT.

China

There is a co-operative effort between China (60%) and Brazil (40%) to design, construct and launch two polar orbiting satellites in 1993 and 1995, for land resources studies. They will carry DCS transponders.

USSR

To date, the USSR has not operated any geostationary meteorological satellites. They plan to launch the first GOMS satellite in 1991 and it will have the capability of handling DCPs. A retransmission facility will be available. Its orbit will be at 76°, providing effective cover for the first time over the Indian Ocean.

There are also plans to operate two to three new polar orbiting satellites in the Meteor-2 series. Meteor-3, a new series, is on test following the first launch in 1985.

5.2.3 INSAT

While India does operate a meteorological geostationary satellite (INSAT) it differs from the others in that its transmissions are beamed, being receivable only in the Indian continent; so far its images have not been widely available outside of the country. INSAT also has a DCP facility but it, too, is limited to within the continent. In addition it is linked to the national telecommunications system and the satellite is also used for educational transmissions. INSAT is, therefore, a special case and not of wide international concern, especially as regards DCP operation.

At 74° E, it is close to the position which GOMS will occupy (76° E) when launched, shortly, by the USSR, which will then provide cover for that region of the world. For this reason INSAT is not shown in Figure 1.4.

5.2.4 Indonesia

Indonesia operates a domestic satellite (PALAPA) for its own telecommunications purposes. This can also be used for environmental data collection, but since it uses different frequencies and data rates to those of satellites designed specifically for meteorological purposes, conventional DCPs cannot be used via it. As with the Indian satellite it is, therefore, a special case and is not shown in Figure 1.4.

5.2.5 Continuity

Assuring continuity is a high priority of the WMO panel of satellite experts and they would urge national satellite operators to make their systems compatible with each other. The group felt that this was so important that they put out a general statement about the continuity of service of polar and geostationary satellites. Its importance was stressed in particular for WMO's World Weather Watch and World Climate Programme.

WMO stated that the operational components of the satellite systems must have "staying power", with every reasonable effort being made to avoid breaks in service. The importance of co-operation between satellite operators in maintaining continuity was also stressed: this was typified by the moving of a GOES satellite over the Indian Ocean in 1979, controlled by ESA, and the repositioning of GOES-4, in 1985, to maintain DCP services when METEOSAT-2's transponder failed. WMO urge satellite operators to co-operate by moving any of their spare geostationary satellites to adjacent longitudes, if they would be more effective in the global sense, while still retaining full control.

WMO and EUMETSAT are, therefore, working to ensure the future continuity of satellite services, and with the comprehensive international launch programme planned, a reliable and continuing service seems ensured.

6. Conclusions

Because technology is advancing rapidly it is difficult to keep abreast with what instrumentation is available for hydrological data collection. Hydrologists have long been used to collecting data with conventional instruments, such as cup-counter anemometers, and these still have an important place. Since the mid 1960s, however, data logging has become an increasingly used technique, and telemetry via telephone lines or ground based UHF radio has been in use for several decades. To these, satellite telemetry has now been added.

Despite involving some of the most advanced technology available, in the form of spacecraft and space communications equipment, satellite telemetering systems are extremely simple to install, operate and maintain from the user point of view. Overall costs are also comparable with, or less than, those of operating a UHF ground based telemetry network or a network of in-situ data loggers, with the latter's reliance on field visits to collect the data.

Satellite communication requires no repeaters and only simple outstation construction. Large antenna masts are not required. One third of the Earth's surface can be covered by one receiver, outstations being sited anywhere within this area. Systems can operate for extended periods without attention. Faults can be detected rapidly and automatically. Power requirements are minimal, solar power being adequate. Outstations can be moved easily from site to site. At base, incoming data can be handled automatically. As many base stations can be operated as required, without changes to outstations being necessary.

Satellite telemetry is now a viable alternative to ground based telemetry and in-situ data logging. While data may be collected with advantage, via satellite, from remote parts of the UK, the technique becomes uniquely important in larger countries and where large distances are to be spanned. This handbook is intended as an introduction to the new techniques and as an encouragement to use them.