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1979 A P BALL, J L CLARKE, M J O'BRIEN

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THE DESIGN AND IMPLEMENTATION OF AN OPERATIONAL,
COMPUTER-BASED WEATHER RADAR SYSTEM

Authors: A P Ball, J L Clarke, M J O'Brien
A H Shaw, S E Trigg and T A Voller

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ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 3151

THE DESIGN AND IMPLEMENTATION OF AN OPERATIONAL, COMPUTER BASED WEATHER RADAR SYSTEM,

A P/Ball, J L/Clarke, M J/O'Brien, A H Shaw, S E Trigg and T A Voller

SUMMARY

This memorandum describes the work of the RSRE Weather Radar Division in the Ground Radar and ATC Group who in co-operation with the Meteorological Office Radar Research Laboratory (Met O RRL) at RSRE have installed an operational weather radar system at Camborne, Cornwall. This is the first of a number of installations soon to be installed by the Meteorological Office. These will form an operational network of weather radars to enable quantitative rainfall data to be made available to meteorologists, hydrologists and others remote from the radar stations.

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THE DESIGN AND IMPLEMENTATION OF AN OPERATIONAL, COMPUTER BASED WEATHER RADAR SYSTEM

A P Ball, J L Clarke, M J O'Brien, A H Shaw, S E Trigg and T A Voller

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1 INTRODUCTION

The ability of radar to measure the intensity and distribution of rainfall has long been recognised by meteorologists, hydrologists and others. The widespread exploitation of techniques for the timely transmission of radar derived data has been greatly hindered by technical and economic limitations. However, with advances in technology and the ever decreasing cost of data processing and transmission equipment, several experimental weather radar systems have been developed in recent years. One such system has been demonstrated at Llandegla, Clwyd (Ref 1), as a part of the Dee Weather Radar Project (Ref 2). The design principles of this system form the basis of the further work described in this memorandum. An extension to the Llandegla system was the incorporation of 3 similar computer based weather radars with overlapping cover into a network system. This was controlled from a central computer at RSRE Malvern. This system, termed "The Mini-Network", using the manned weather radars at Llandegla, Clwyd; Castlemartin, Dyfed; and Defford, Worcestershire; successfully demonstrated the feasibility of the operation of a network system. In May 1977 the Director General of the Meteorological Office gave his approval for a "Pilot Project", centred at RSRE Malvern to "Develop techniques to improve short period forecasts of rainfall and wind and to optimise the impact of such techniques on the short period forecasting capability of the Meteorological Office" (Ref 3). A network of radars similar in design to those operated during the "Mini-Network" will be included as part of the "Pilot Project". This memorandum describes the design and implementation of the first operational radar site for this project at the Meteorological Office Radio Sonde Station at Camborne, Cornwall. Some results are given and future developments of the system are discussed.

2 PREVIOUS WORK WITH A COMPUTER BASED WEATHER RADAR SYSTEM

The single site computer based weather radar system (Ref 1) used a narrow beam, continuously rotating aerial to collect data at a low ("surface beam") elevation. The radar amplitude signals received were digitised and then processed by an on-site PDP-11/40 computer to produce a colour coded cartesian map of rainfall rate and distribution and displayed on a modified colour television (ctv) via a special data store. Radar derived rainfall totals of some river sub-catchment areas of interest close to the radar were also displayed and recorded, for off-line analysis with respect to rain-gauges in the same areas. Control of this system was at the radar site itself via a 'Teletype'. Data was transmitted over the GPO DATEL 600 service to users remote from the radar and displayed on a similar modified ctv and data store as used at the radar site.

2.1 The 'Mini-Network' System

The software system as described briefly above was modified to make the radar site computer part of a dispersed packet switched network. The design principle of this system was that a central computer at RSRE Malvern would control computers and their associated radars over GPO DATEL 2400 lines connected in radial configuration on a master-slave basis. A unique packet switching technique was developed using a minimal computer configuration in order to pass radar control commands and data amongst all sites with full error checking to ensure confidence, (Refs 4, 5 and 6). An operator at the network centre computer could then change and optimise parameters and programs at any remote site in the network. This avoided the need for trained computer

staff at each radar site during the experimental phase of the project. Data from each radar site was transmitted to RSRE Malvern, where the network centre computer composited the data from all available radars. This produced an overall network picture of rainfall rate and distribution which was displayed on a modified CTV via a computer updated display store immediately the data became available. The computer had the additional facility to record 10 composited pictures on disc and replay them in an 'action replay' mode at various rates. This was to assist in the study of the direction of motion of the rainfall areas displayed. Other features of this network system included software to duplicate the communications in a delta type configuration and timing out facilities in the event of radar site hardware or communication equipment malfunction.

2.2 "Mini-Network" Results

The "Mini-Network" was in operation on many occasions between Autumn 1975 and Spring 1976, using the 3 sites stated.

Data from this network was transmitted in real-time to several users for evaluation. These users included the Main Meteorological Offices at Gloucester and Preston and the Severn Trent Water Authority offices in Malvern. The staff of Met O RRI at RSRE Malvern evaluated the network centre composite data in comparison with raingauge results off-line.

The network system was further extended during this time, by the addition of a spur from the computer at Llandegla, to a PDP-11/35 computer at the Bala office of the Welsh National Water Development Authority. This spur connection provided real-time radar-derived information to the Bala computer for river control purposes and provided the 'Mini-Network' system with additional real-time raingauge information. This information was derived from a number of telemetering raingauges over the upper reaches of the River Dee and collected by the Bala computer.

Fig 1 shows some results of composite data obtained with the 'Mini-Network' system. The colour coding of the rainfall values was, at this time, a simple binary progression from the minimum value of $\frac{1}{8}$ mm/hr to 8 mm/hr. This gave a confusing multi-coloured picture which was improved by collapsing the number of colours to the 3 shown in Fig 1. Subsequently, a different colour coding was used (see section 6 and Fig 3).

2.3 'Mini-Network' Conclusions and other developments

The operation of the Mini-Network System demonstrated to a variety of users the feasibility and usefulness of a dispersed packet switched network of computers controlling weather radars and collating the data at a central computer site to derive an overall network picture of all the radars coverage. This was demonstrated at a Symposium on Weather Radar and Water Management in December 1975 (Ref 6). However it became apparent that there were considerable difficulties in meeting all the needs of the various users of such a system. Some of the users could be served by improved forecasts via the existing Meteorological Office data dissemination services such as radio, facsimile recorders etc but other users would require more detailed information pertaining to their particular requirement.

In November 1975 the Director General of the Meteorological Office set up a working group to study means of improving short period weather forecasts over the next decade. This working group reported in August 1976 recognising that "the ability to observe the mesoscale (Medium Scale of the order of a few tens of kms) structure and motion of clouds and rainfall has been greatly improved by recent advances in radar and satellite imagery and that these improvements hold considerable promise for improving local forecasts for periods 0-12 hours ahead". One of the several specific recommendations of this working group was that a 'Pilot Project' should be instituted, the terms of reference of which were "To develop the foundations for improved short period forecasting systems exploiting these new forms of data". Approval in principle to this 'Pilot Project' was given in May 1977.

3 METEOROLOGICAL OFFICE 'PILOT PROJECT'

Detailed below are the objectives of the 'Pilot Project' as described in reference 3.

"The Pilot Project is a 5 to 8 year scheme which is intended to be from the outset a balanced program of fundamental and applied research. The following broad objectives can be identified:

- i To establish and operate facilities to provide mesoscale observational fields of cloud and precipitation (albeit at first over only a part of the country in the case of some of the data); and, in the light of practical experience, to optimise the accuracy, reliability, and the clarity and timeliness of presentation of the data.
- ii To exploit these data to improve our understanding of the structure, mechanism, evolution, and predictability of precipitation and associated wind systems.
- iii To develop simple analytical procedures to optimise the use of these data for the provision of improved forecasts of precipitation and wind (initially over a period of a few hours but with a view to extending the period of improved forecasts up to 6 to 12 hours).
- iv To assess from practical experience the utility of the actual and forecast fields of precipitation to users (such as the Water Industry for example).
- v To assess the desirability, and most cost-effective way, of extending the mesoscale observational network and forecasting techniques.

Progress with implementation of basic facilities (Objective (i)) is expected to be such that Objectives (ii), (iii) and (iv) can begin to be pursued in 1978 in parallel with continuing work on Objective (i).

Although progressive advances in forecasting capability can be expected with the accumulation of experience and understanding (Objective (ii)) built up over the entire period of the Pilot Project, it is considered that a fairly simple application of suitably processed forms of radar and satellite data (developed as part of Objective (i)) will lead to worthwhile improvements in forecasting capability even at an early stage in the work."

One of the major data inputs to the 'Pilot Project' is to be from a network of operational weather radars broadly similar to the previously developed 'Mini-Network' system. Modifications to meet the requirements of the 'Pilot Project' are detailed in Section 4. Another data input is weather satellite data from the 'METEOSAT' satellite which is geostationary at 0° longitude. Cloud or surface data from this satellite in the visible and IR spectra, after suitable signal processing at Met Office, Bracknell is transmitted to RSRE, Malvern where Met O RRL staff use this data to provide a context for the interpretation of the radar derived rainfall information. The data is displayed on a development of the original computer updated store that was used previously in the 'Mini-Network' but with increased data storage capacity and display facilities (Ref 9). This store was developed and constructed at RSRE. The radar/satellite data analysis work is the responsibility of the Forecasting Techniques Group at Met O RRL.

4 SYSTEM DESIGN FOR THE METEOROLOGICAL OFFICE 'PILOT PROJECT'

This system has resulted in many hardware and software changes from the 'Mini-Network' concept but the resulting design evolved maintains the high degree of flexibility that was inherent in the original design. At the same time it meets the present and expected needs of its various users. The functional design of the radar site to meet these requirements of the 'Pilot Project' is as follows.

Each radar site will operate with the same signal processing software as was used in the 'Mini-Network' phase. The main differences are in the control and data transmission software and are:

- (1) Overall control of each radar site operation is at the radar site itself.
- (2) The radar and computer system is accurately timed by a crystal clock time-referenced to GMT, in order that the radar can execute a pre-set pattern of aerial elevations during a fixed time interval (typically 15 mins). Data collection begins and ends at any azimuthal quadrant. There is then a 90° azimuth interval while the aerial elevation is changed in preparation for the next data collection revolution and other house-keeping tasks on the computer are completed. The aerial rotation time is set at approximately 55 secs, thus allowing a sequence of 4 different elevations at 5 minute intervals repeated three times at 15 minute intervals. The 15 minute interval occurrence initiates a "surface beam" task regardless of the existing sequence. This caters for the danger of an erratic aerial rotation rate causing a lack of the vital picture data at the expense of the odd higher elevation beam data. This is the main operational task of the system and is termed the 4-Beam task.
- (3) The processed data output of rainfall intensity and distribution data from the surface elevation revolutions is output continuously from the radar site in a fixed data format. It is the responsibility of the users to handle the data as received. There are 4 types of data output by the radar site:
 - i TV picture data of rainfall rate and distribution to a 3-bit accuracy, covering a radius of 210 km from the radar site. This is derived from the surface beam elevation at 15 minute intervals (See Appendix 5).
 - ii Rainfall totals to an 8-bit accuracy, over selected sub-catchment area. These totals are updated at hourly and daily intervals from surface beam elevations at 5 minute intervals (see Appendix 6).

iii Rainfall rate and distribution data to an 8-bit accuracy, suitable for transmission to the network centre computer at RSRE Malvern for compositing with data received from other radars in the network. This is collected from the surface beam elevation as in i and output at 15 minute intervals.

iv The option of on-site archiving of multiple elevation data (as iii) on magnetic tape. This will be used for the off-line assessment of the usefulness of a limited amount of information of the vertical structure of rainfall systems, for the forecasting of certain types of rainfall conditions.

The function of the network centre computer will be to accept the standard 8-bit data format from all available radars in the network. During a fixed time interval, all the time-referenced radars should have executed a surface beam data collection revolution. Composited data of rainfall rate and distribution from all the available radars coverage can then be produced and displayed.

This simplified system retains the essential features of the previously used and well-proven signal processing system used in the 'Mini-Network' but at the same time offers the following major advantages:

(1) No special purpose communications software is required to be resident in the radar site computer. This gives a saving in program size and complexity. It also permits the use of any other manufacturer's or agencies computer and/or software at the radar site providing they meet the timing and standardised data format required by the network computer. Other compatible weather radars can then be included simply in the weather radar network. The network computer can then accept data from all relevant radar sites and forms a composite picture irrespective of the signal processing hardware, or software that has produced this data.

(2) The decision not to adopt a dispersed packet switched network system of computers initially for the 'Pilot Project' will allow a greater freedom in the design of the system. The initial emphasis will be on the development of a suitable data collection and dissemination system using existing equipment and experience.

The first radar installation by the Met Office for use in the 'Pilot Project' is at their Radio-Sonde Station, Camborne, Cornwall. As this radar and computer systems design are similar to the two other systems soon to be installed by the Meteorological Office at other sites, a full technical description of this system should suffice for the other sites.

4.1 Camborne Radar and Computer System overview

The equipment in use at the radar site has not changed conceptually to that used in the "Mini-Network". It consists of an on-site PDP-11/40 computer used to process digitised radar data from a narrow beam, fully steerable radar aerial. The data is collected at several low elevation angles. The radar amplitude signals received are digitised and transferred to the computer by a special purpose Radar Signal Averaging Unit (RSAU). After processing, the signals are displayed as a colour coded, cartesian map of instantaneous rainfall rate and distribution on a modified CTV via a special data store. Similar data can be transmitted via the GPO DATEL service to users remote from the radar and to a network centre computer at RSRE Malvern where a composited CTV picture of Camborne and future radar sites data can be displayed.

each 0.75 km x 1° polar range cell, ie LIST2 ÷ SCANS, is held in list LIST3. Some modifications are now made to this list with program P3 mainly to compensate for the effects of fixed clutter by reference to a previously collected clutter map. This map for the particular elevation angle in use is collected in the absence of rain, and stores in memory all polar cell(s) (0.75 km x 1°) in which the mean signal amplitude exceeds a pre-set threshold value. The clutter cancellation program in P3 then ignores the amplitude signal in the cluttered cell(s) and derives an estimate of amplitude by interpolating between uncluttered cells either side in range. Program P4 now operates on LIST3 to further average the polar cell values (0.75 km x 1°) to polar bins (1.5 km x 1°) in order to reduce the processing time in the later polar to cartesian co-ordinate transformation. The LIST3 signal amplitudes are then converted to rainfall rate (mm/hr) firstly by reference to a table labelled POWERLAW, containing 1024 values. The assumed relationship between amplitude (a), the output of the RSAU and rainfall (R) is

$$a^2 = kR^{1.6} \text{ where } k \text{ is a constant normally assumed to be } 200.$$

The output of the POWERLAW table is the solution of:

$$R = \frac{1.6\sqrt{a^2}}{8} = \frac{a^{1.25}}{8} \text{ where } 8 \text{ is a scaling factor.}$$

The final rainfall rate calculation is then a function of this solution, a look up table named RCORRECTION which allows for the $1/r^2$ dependance of the signal beyond the maximum range of the PIN diode (see Appendix 2) and the value of the word SENSITIVITY. This word is derived from a knowledge of the receiver characteristics and is directly related to the programming of a 12-bit anti-logarithm generator in the RSAU and to POWERLAW (see Appendix 8). The co-ordinate system is changed in real time using programs P5, P6, P8 and P9 (see Appendix 9) into a cartesian co-ordinate system based on the National Grid. When the aerial has completed one complete revolution the processed data of rainfall rate and distribution is suitably formatted for dissemination to the various users. Program PICOUTPUT converts the 8-bit data into 3-bit colour coded TV pictures. Program MODEM transmits this data via the GPO DATEL 600 service. Program SUBCATCHMENT derives rainfall totals from the surface beam elevation, at 5 minute intervals, over selected sub-catchment areas served by the radar, formats the data and appends it to the TV picture data for transmission via program MODEM. Program DATATRANSMIT formats the data into the standardised form for transmission to the network centre computer at RSRE via the GPO DATEL 2412 service. Program MAGTAPE records the multiple elevation, 8-bit data on a magtape unit at the radar site.

4.3 PDP-11 Computer and Software

The PDP-11 computer was chosen originally as the on-site data processor for several reasons, including processing speed and comprehensive program development software. The capital investment in hardware and proven software and the general popularity of this machine family has determined its continued use for the Met Office "Pilot Project". There are 3 generations of PDP-11 computers in use, PDP-11/20 and 11/34 disc based, program development machines at RSRE and a PDP-11/40 as the on-site data processor at Camborne. Further installations will have PDP-11/40 or 11/34 computers. Radar site software has been developed to operate with all configurations of the above computers.

Software written for the system is in PDP-11 assembler. A macro processor is included in the PDP-11 program development system and a macro based "PSEUDO" high level language has been developed for this specific real-time application (Ref 8). This allows the writing of high level source text statements which are interpreted as macro calls and then expanded by the PDP-11 assembler. This system provides some of the features normally associated with a high level language and also such features as the uninhibited use of assembly language statements, good source text readability, self documentation and high efficiency in terms of run-time, storage and code generation. Signed integer arithmetic is used throughout.

Conversion of the software to a high level language such as CORAL 66 would be possible but is not considered to be feasible at the moment when consideration is given to the present machine configurations, the existing amount of proven software and the aims of the "Pilot Project".

4.4 Radar Site Hardware Detailed Description

(A block diagram of the hardware configuration is shown in Fig 2).

4.4.1 Radar

The radar used at Camborne is a PLESSEY 43S Weather Radar that was originally installed at Changi, Singapore; for Met Office storm warning purposes and was returned to the UK recently when the British Armed Forces withdrew from their Far Eastern commitment. The mechanical and electrical modifications, and the installation have been the responsibility of the installation group of the Met Office. The radar aerial system is mounted on a 10 metre tower. The modified azimuth drive system rotates the 3.7 metre diameter aerial continuously at approximately 1.1 rpm. A servo controlled elevation system moves the aerial between -5° and $+36^{\circ}$ with an accuracy of $\pm 0.1^{\circ}$ on command from the computer. The radar transmitting and receiving equipment is housed at the base of the tower along with the associated computer, interfaces, display and communications equipment. The radar transmitter operates at 2880 MHz with prf of 275 Hz. The peak power is 650 kW with a pulse width of 2.0 μ sec. The original Plessey Mk V PPI display equipment is retained, chiefly for monitoring and photographic purposes.

4.4.2 Radar Receiver

To ease the stringent dynamic range requirements of the radar receiver system a logarithmic receiver was used with the original PLESSEY 43S equipment, plus a swept attenuation system to compensate for the $1/r^2$ range dependance of rainfall echoes. Extensive modifications to the original Plessey design have been devised by RSRE to incorporate the latest 'state of the art' solid state components in order to improve the dynamic range, linearity, accuracy and reliability of the system. A full description of this work is covered in Appendix 1.

The swept gain attenuation system to remove the $1/r^2$ dependance of the signal over the first 50 km range uses an S Band PIN diode attenuator with digitally derived bias current, as outlined in REF 1. A detailed description of the digital equipment provided for the Camborne radar, which has been the responsibility of Met O RRL, is given in Appendix 2.

4.4.3 Radar/Computer Interface Unit

This unit is designed to interface between the PLESSEY 43S radar and the PDP-11 computer, to give all the necessary data and control signals for the correct operation of the software (see Appendix 4). These include:

- i 4 decade BCD display of azimuth and elevation and the conversion from BCD to binary for input to the computer.
- ii Interrupt control of the computer by azimuth and elevation least significant bit change.
- iii Control of elevation position (computer activated).
- iv Provision and control of the RSAU 0.8 MHz clock.
- v A 16-bit LED display used as a programmers aid to output from the computer any required data to aid software development and diagnostics.
- vi LED monitoring facility to indicate equipment malfunction.

4.4.4 Displays

Several display options are available to the local and remote user. The "local" user is defined as the person at the radar site while the "remote" user is defined as the person at sites removed from the radar site, who receives data via the GPO Datel 600 Service. The first display option is the Jasmin Mk 3 Store, documented in Appendix 5. This unit has been specified by RSRE (Spec No X6707) and is manufactured by JASMIN ELECTRONICS, LEICESTER. The store displays either on a modified colour television or a colour television display monitor. The displayed data consists of a cartesian representation of the rainfall-rate and distribution as measured by the radar system to a maximum range of 210 km. It comprises a grid of 84 x 84 5 km cells, where each cell can contain one of eight colours to denote rainfall rate. New pictures are normally transmitted at 15 minute intervals from the radar site. The store is capable of replaying 9 successive pictures, at user-selected rates, to examine past events.

The second display option, using the Data Logging Unit is described in Appendix 6 and performs the following functions:

- i Print-out of subcatchment data (both hourly and daily averages). This takes place whenever new data is available; normally at hourly intervals.
- ii An override facility to force print-out at any time. This is to recover any data lost caused by communication errors, power fail etc at the receiving end.
- iii Routine monitoring, by means of a simple block check technique, of data error rates on the communication link.
- iv Print-out of the result of these checks to warn users of error situations. (Thus allowing forced print-out as in ii to examine the data again.)

This unit has been designed and specified at RSRE and two units have been constructed in-house. The development of future units is being undertaken by the Water Research Centre. A further display unit, a "Fast-Update Store", has been developed at RSRE for use at the network centre only. This store is used to display a complete frame of a network picture from the network centre computer immediately it becomes available and is described elsewhere (Ref 9).

4.4.5 Communication Buffer Units

a Radar Site

The radar picture data can be made available to many "remote" users simultaneously. The computer interface and the associated interrupt driven software is, however, designed to drive one modem only. A small transmitter buffer unit has been designed to output this common data from the computer interface to 4 modems. The number of modems can be increased by serial connection of these buffers.

b Remote Site

The remote site user will need a receiver buffer if both the Jasmin display and the Data Logging Unit are installed. A buffer has been designed to output to 4 units and again serial connection of these buffers can extend the user displays.

Both of these units have been produced at RSRE on a one-off basis. Further manufacture is to be undertaken by Met O RRL. Details of the design of the units is contained in Appendix 7.

4.5 Software Description

A detailed description of the software is contained in Appendices 8 and 9. The main functions of the software are summarised below:

a Initialisation of the system, clearing lists, setting up interface parameters etc (program SETUP).

b The program, termed the "baseload program" for the control of the four major data collection tasks, (program TASKMASTER). These are:

i Single revolution PPI (programs PPI 1 and PPI 2)

ii Single revolution clutter map collection and storage (program CLUTASK).

iii Single revolution clutter picture display (program CLUPIC).

iv The "4-Beam Task". This is the normal, time-referenced task to collect data from four different elevations of the aerial during one 15-minute interval. This task is repeated 3 times in a 15 minute time slot. An output picture is produced for the surface beam at 15 minute intervals and detailed sub-catchment data is summed at 5 minute intervals for averaging over hourly and daily periods.

- c Control of the radar aerial elevation angle.
- d Organisation of the digitised radar received signals from the RSAU. This provides for hardware averaging in range. Typically the data is 290 range cells each of 750 metres x 0.1° .
- e Averaging in time over 1° azimuth integration brackets.
- f Cancellation of fixed ground echoes by the interpolation of rainfall information over a previously collected clutter map.
- g Occultation correction for screening of the radar beam by hills, etc (Program P3).
- h Further averaging to 1.5 km x 1° polar bins (Program P4).
- i Conversion from radar received amplitude to rainfall rate in mm/hr (Program P4 and POWERLAW list).
- j Polar to Cartesian co-ordinate conversion. From 1.5° km x 1° polar bins into 2 km and 5 km grids based on the National Grid (Rainfall rates between $1/64$ and 63 mm/hr are held in an 8-bit "float" notation). (Programs P4, P6, P8 and P9.)
- k Conversion of 5 km, 8-bit data to 5 km, 3-bit data for TV display and output to local and remote users. A new TV picture is generated at 15 minute intervals from the surface beam elevation (program PICOUTPUT).
- l Derivation of sub-catchment totals over 1 and 24 hour periods and formatting for output to users (program SUBCATCHMENT).
- m Date and time-keeping (program CLOCK).
- n Storage on magnetic tape of 5 km and 2 km cartesian grid data for all elevations used, and subcatchment totals at hourly intervals plus the appropriate headers of time, date, type, etc (program MAGTAPE).
- o Transmission of 5 km cartesian grid data in 8-bit form via the GPO DATEL 2412 service to the network centre computer for compositing (program DATATRANSMIT).
- p Input and output control of all tasks via the 'Teletype' (program TTY).
- q Decoding of 'Teletype' keyboard instructions via a command string interpreter (program CSI).
- r Control of output messages from a library (program SITEMESSAGE).

5 COMMUNICATIONS

Data is transmitted to the remote users of TV picture and subcatchment data via the GPO DATEL 600 service. This is an asynchronous system operating at 600 baud which transmits the 3-bit TV picture data for storage in the 'JASMIN' store and subcatchment data for the Data Logging Unit. In addition block check characters enable data reliability statistics to be collected.

Data is transmitted to the network centre computer via the GPO DATEL 2412 service. This data is 8-bit, 5 km cartesian grid data of the surface beam elevation and is zero packed to reduce both transmission time and magnetic tape storage requirements (Appendix 11). The DATEL 2412 service is similar to the DATEL 2400 service previously used and described in Ref 1 and operates at 2400 bits per second.

The data is updated at 15 minute intervals by new surface beam data. The GPO DATEL 2412 service operates as a 4-wire, full duplex, synchronous communications link. This has been retained for the "Pilot Project" for reasons of flexibility and development potential. The long term intention is that all weather radar sites should be totally unmanned except for periodic preventive maintenance. Two way communications to each radar site may then be required for control, remote monitoring and calibration procedures (see Section 7 for future developments).

6 CAMBORNE INSTALLATION

The system described above was installed at the Meteorological Office Radio-Sonde Station, Camborne, Cornwall in May 1978. It became operational 24 hours a day from late May and from August it has been transmitting TV picture data of rainfall rate and distribution to the Main Meteorological Office, Plymouth. A similar display facility has been installed at the South West Water Authority offices in Exeter. An addition to this installation will be the provision of a data logging unit (and the appropriate receiver buffer unit). The program in use at Camborne has been provided with a mask of 25 sub-catchment areas of interest to the SWWA and will regularly provide sub-catchment totals of these areas to the data logging unit.

Fig 3 shows a TV picture of data collected with the Camborne system at 0300 hours on 1 August 1978. The coloured symbols in the bottom left hand corner represent rainfall rates as follows:

Black	None	<0.125 mm/hr
White	L	0.125 to <1.0 mm/hr
Yellow	1	1.0 to <4.0 mm/hr
Green	4	4.0 to <8.0 mm/hr
Cyan	8	8.0 to <16.0 mm/hr
Blue	16	16.0 to <32.0 mm/hr
Purple	T	32.0 to <63.0 mm/hr
Red	H	≥63.0 mm/hr

The accompanying meteorological description of events is by a member of Met O RRL staff.

Fig 4 shows the corresponding magnetic tape data collected at Camborne and processed off-line. The print-out is with a modified square format line printer. The symbols shown represent rainfall rates in the range 1/16 to 63.0 mm/hr as shown in the attached table.

Two modifications have been made to the Camborne site software and have been incorporated since November 1978. The first is the use of data from a higher elevation beam for the measurement of rainfall rate at ranges less than 30 km. This greatly reduces the effect of land and sea clutter. The second modification, determined by the geography of the Camborne site, is to elevate the surface beam by 1° in the sector $70-166^{\circ}$ to avoid the hills to the east. (This will reduce the effective performance of the radar at long ranges in this sector but is essential for this particular site.)

7 FUTURE DEVELOPMENTS

Several further installations are planned in the near future. A mobile PLESSEY 43S radar and a PDP-11/40 computer housed in a "Portakabin" will be installed at the Meteorological Office Regional Servicing Centre at UPAVON, Wilts in early 1979. A PLESSEY 43C radar previously used at Llandegla, Clwyd, on the Dee Weather Radar Project and a PDP-11/34 computer and associated equipment will be installed in a radome on Titterstone Clee Hill, Shropshire, in mid 1979. This will provide TV picture data and sub-catchment totals to the Severn and Trent Water Authority Offices in Malvern and TV picture data to the Main Met Office in Gloucester and Birmingham Airport. (The 43C operates in C Band at a frequency of 5.6 GHz.)

A joint project involving the Met Office, Water Research Centre, Central Water Planning Unit, North West Water Authority and the Ministry of Agriculture, Fisheries and Food is purchasing a PLESSEY 45C radar for installation on Hambleton Hill, Lancs. This installation will have the same signal and data processing system as the other sites but will differ in that it is planned to be totally unmanned. Remote monitoring software will be required to maintain this site, the first of the new generation of unmanned sites. Discussions are now taking place between all interested parties to formalise the design and operational requirements of this system.

It is the intention that these radar sites will transmit data to a network centre computer at RSRE Malvern where a composite of the data from all sites will be produced for dissemination to users. This will form a major part of the "Pilot Project" data input. The Forecasting Techniques Group of Met O RRL are responsible for the evaluation of this data in conjunction with the appropriate satellite data to enable fulfilment of their "Pilot Project" objectives.

8 ACKNOWLEDGEMENTS

The authors would like to thank Dr K A Browning, C Met O, Met O RRL Malvern and his staff for their co-operation, assistance and advice without which this work would not have been possible. Thanks are due also to the Met Office Staff at Camborne and at previous sites for their co-operation and forbearance.

Within RSRE, Dr B C Taylor and Mr B Davy were responsible for much of the original design, development and management of the project for the first four years and their work is gratefully acknowledged. Messrs L M Davies and

E W Scott offered considerable assistance and advice on the radar receiver modifications and Mr F E Withers of the Microprocessor Support Unit gave valuable assistance with the design of the Data Logging Unit.

Flt Lt Singleton's contribution (Appendix 10) is also valued and Mrs J Tillson-Willis is given special thanks for her efforts in support of the section.

Appendices 2 and 11 are published with the permission of C Met O, Met O RRL, Malvern.

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TIME 0741

DATE 12th DEC (1975)

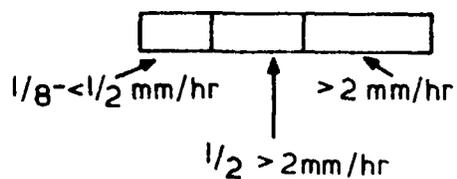
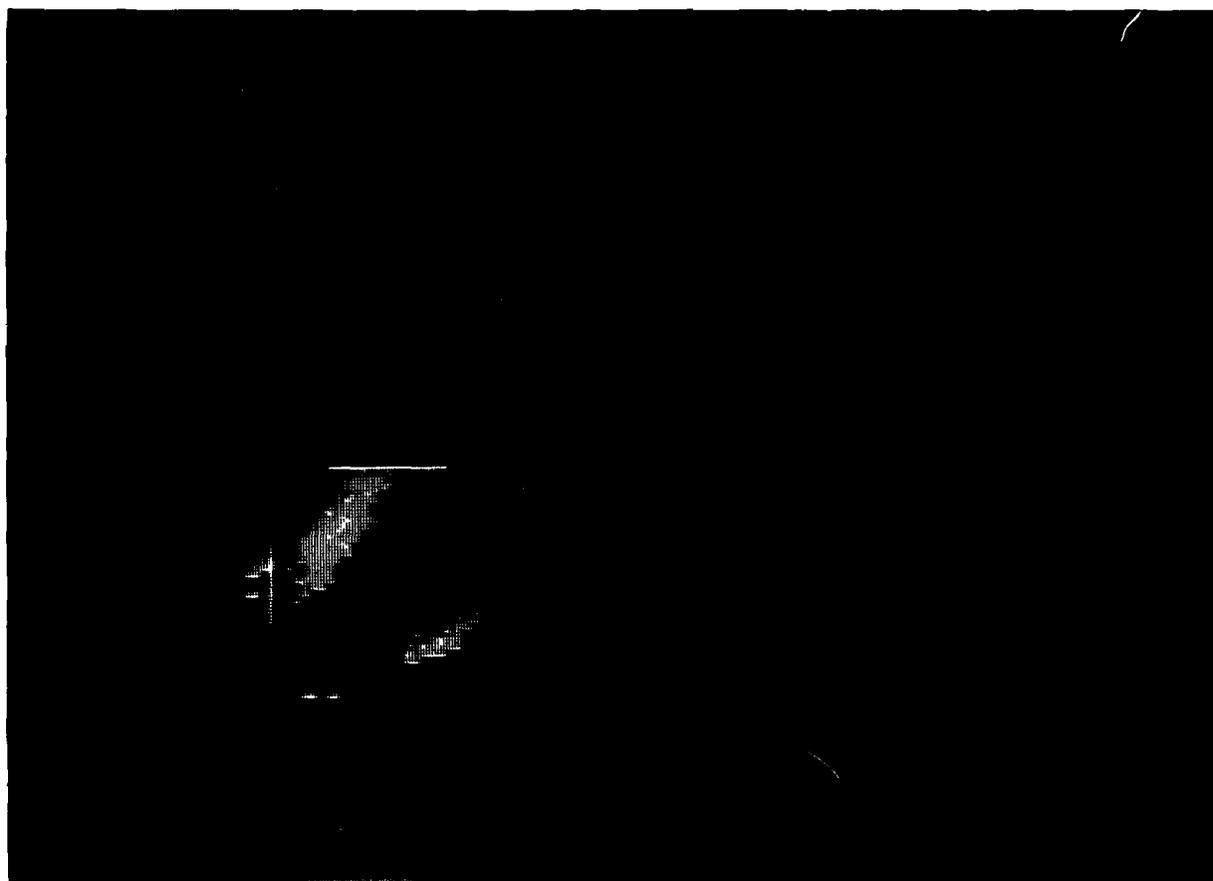


FIG.1

COMPOSITED RADAR NETWORK DATA

THE RADARS WERE AT LLANDEGLA, CLWYD AND CASTLEMARTIN, DYFED.
THE PHOTOGRAPH IS TAKEN FROM A JASMIN MKI STORE / DISPLAY
OPERATING IN THE 128 x 128 x 5 Km RESOLUTION MODE.

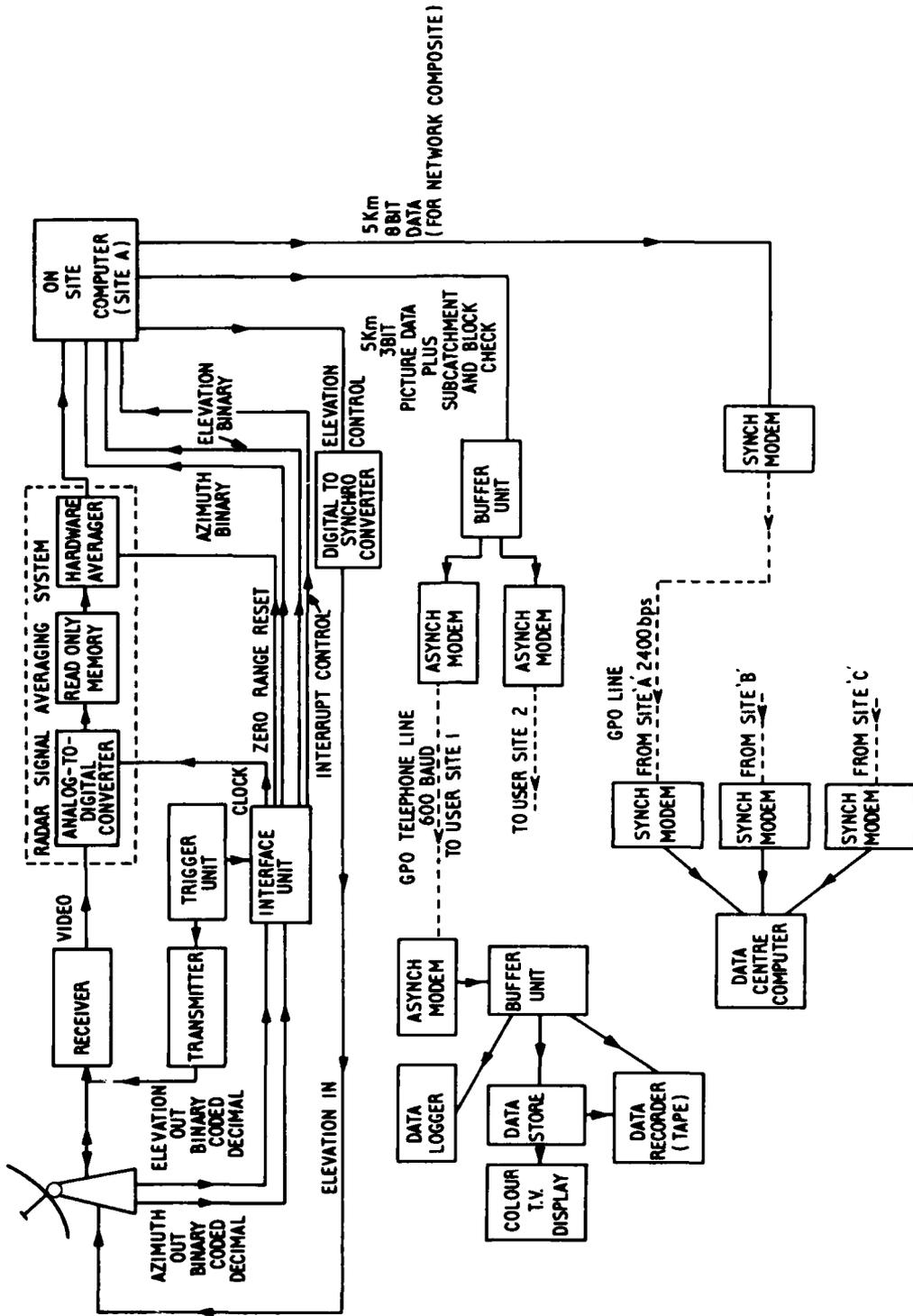
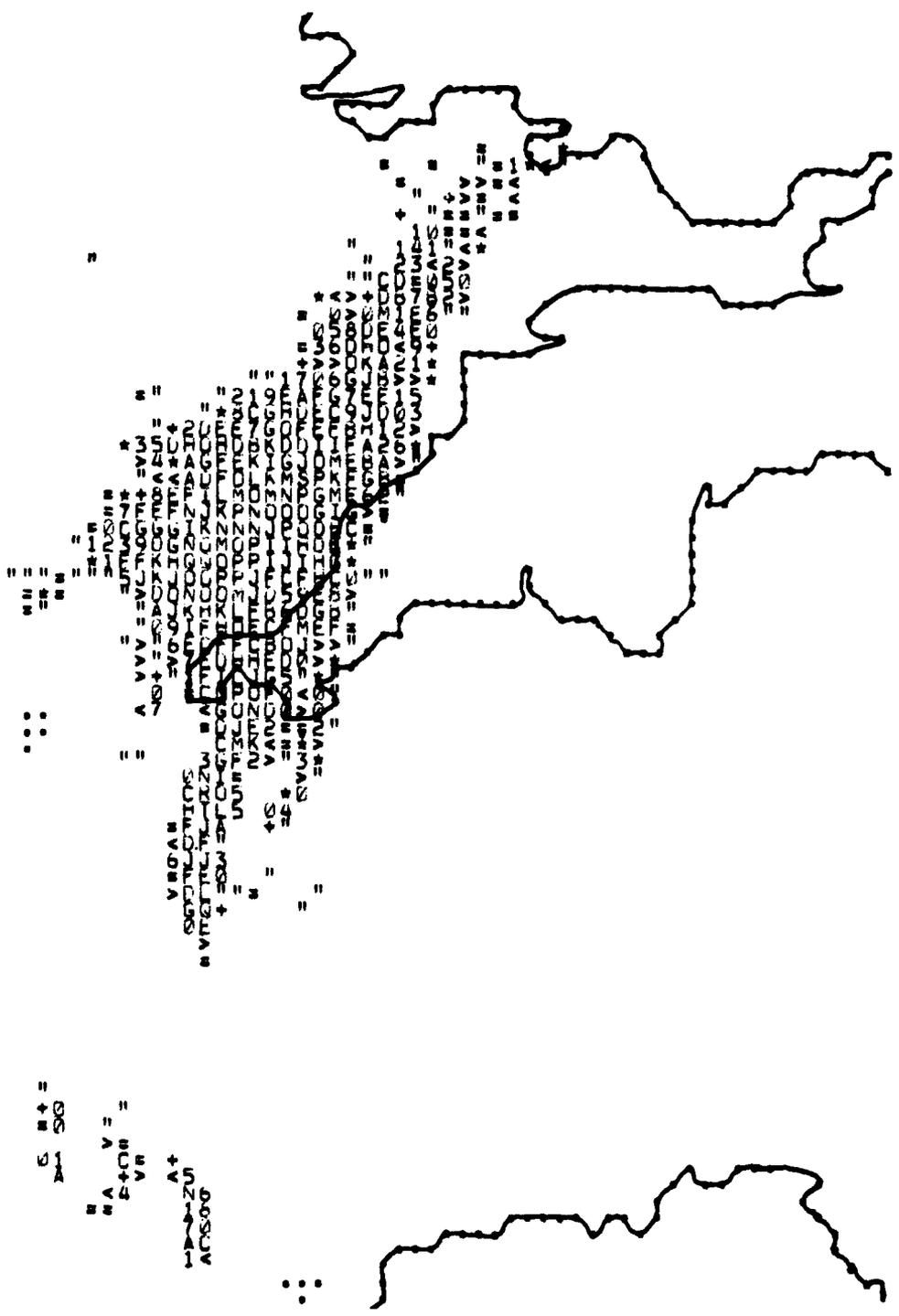


FIG. 2
CAMBORNE HARDWARE CONFIGURATION

+S



MM/HR	SYMBOL	MM/HR	SYMBOL	MM/HR	SYMBOL
<=0.125	"	<=3.25	B	<=15.0	M
<=0.25	#	<=3.5	9	<=16.0	N
<=0.375	*	<=3.75	A	<=20.0	O
<=0.5	+	<=4.0	B	<=24.0	P
<=0.6875	<	<=5.0	C	<=28.0	Q
<=0.9375	>	<=6.0	D	<=32.0	R
<=1.25	0	<=7.0	E	<=36.0	S
<=1.5	1	<=8.0	F	<=40.0	T
<=1.75	2	<=9.0	G	<=44.0	U
<=2.0	3	<=10.0	H	<=48.0	V
<=2.25	4	<=11.0	I	<=52.0	W
<=2.5	5	<=12.0	J	<=56.0	X
<=2.75	6	<=13.0	K	<=60.0	Y
<=3.0	7	<=14.0	L	<=60.0	Z

FIG 4 CAMBORNE 84² DATA
 DISPLAYED ON LINE
 PRINTER FROM OFF-LINE
 ANALYSIS OF MAGNETIC
 TAPE DATA

0300 1 August 1978
 (As Fig 3)

APPENDIX 1

CAMBORNE RECEIVER SYSTEM

The original Plessey 43S radar receiver used a travelling-wave tube RF amplifier, crystal mixer and valve IF amplifiers which were prone to drift with temperature and time. These RF and IF amplifiers have been changed for solid-state versions. The logarithmic dynamic range of the receiver has been increased and the stability improved. It is expected that the solid-state receiver will give greater reliability and efficiency. A Block Diagram of the improved system is shown in Fig A1A.

The new units in the receiver system are described below:

The AEI Solid-State RF amplifier (Type No DA 5912) provides 30 dB gain with a 6.5 dB noise factor. The unit contains a built-in non-reflecting limiter and mains driven power supply.

The next item in the chain, the Hewlett Packard PIN diode $1/r^2$ attenuator, is a current driven diode providing up to 36 dB attenuation. Its drive current is provided by a digital drive unit described in Appendix 2.

The mixer stage is original Plessey equipment incorporating Mullard components. It has been modified to eliminate an unreliable contact which was affecting its stability.

The IF output from the mixer, at 30 MHz, is fed to the head amplifier, which uses a Plessey SL560 integrated circuit and has a gain of approximately 30 dBs.

The Hatfield variable attenuator which follows the head amplifier has a switched range of 0 to 10 dB, and is used to adjust the sensitivity as required. This procedure is described later in this appendix.

A Texscan passive L-C filter, limits the inherently broadband logarithmic amplifier, and hence the total receiver system, to a -3 dB bandwidth of 1 MHz.

The solid-state logarithmic amplifier is of the successive detection type using 8 Plessey SL521 integrated circuits. It is a modified form of a standard RSRE design used in military radars having accurately balanced positive and negative 12 volt supplies. Modifications have been carried out to increase the stability and logarithmic dynamic range. This has involved changes to the dc amplifier section and provision of a built-in voltage stabiliser on the positive supply so that independent positive and negative power units with output voltages within ± 0.25 V of nominal can be used, and can be replaced in the event of failure, without the need to recalibrate the receiver.

The overall dynamic range is proportional to the number of integrated circuits used and the dynamic range of the head amplifier.

The receiver system is set up using an "S" Band signal generator to inject a signal into the solid-state RF amplifier. This signal generator simulates the calculated power received from a given mean rainfall rate. The logarithmic receiver output voltage is measured using either a digital voltmeter or by printing out the digitised amplitude values using the associated computer system with a special program.

Since the output voltage depends on the load impedance being maintained accurately at the 50 ohm value provided in the Analogue-Digital converter in the Radar Signal Averaging Unit (RSAU), a separate monitoring output is provided on the receiver which feeds a buffer amplifier to enable connection of an oscilloscope.

It was decided to cater for the detection of mean rainfall rates in the range 0.125 mm/hour to 64 mm/hour. A graph of receiver output volts plotted against RF power input is shown in Fig A1B. From this graph it can be seen that the logarithmic dynamic range is 64 dB and the corresponding output voltage range is from zero volts to two volts, a slope of 32 dB/volt. An important aspect of the logarithmic amplifier design is the ability to change the unit without lengthy recalibration procedures. This has the advantage that the logarithmic amplifiers can be set up in the laboratory and are inter-changeable. The theoretical minimum detectable signal is -107 dBm given that the noise-figure of the RF Amplifier is 6.5 dB.

With these receiver parameters it is thought that the best use of available dynamic range is achieved by setting the overall gain, using the variable attenuator, to give an output of one volt for an RF input of -73 dBm, equivalent to a mean rainfall rate of 4 mm/hour. If, at any time, it was thought desirable to change this setting this can be done, using the attenuator, to give an output of one volt for, say, 1 or 2 mm/hour.

The calculated mean rainfall rates and ADC levels are plotted in Fig A1B in addition to output volts. It is desirable to keep the receiver noise output voltage below zero volts so that the full available ADC range is used for signals. The formulae used to calculate power returned from a given mean rainfall rate are given later in this appendix.

Because of the "noise-like" structure of the returns from precipitation it is necessary for the logarithmic response of the receiver to extend below the -97 dBm (0.125 mm/hour) and above the -54 dBm (64 mm/hour) points to provide a good statistical sample. A greater amount of additional dynamic range is required at the high signal end than at the low signal end. In the present design, and using the setting 4 mm/hour equals 1 volt, we have allowed 7 dB below -97 dBm and 14 dB above -54 dBm.

The receiver system has proved to be very stable in use. At the present time gain is checked by injecting an "S" Band signal into a -30 dB directional coupler but in the future we shall incorporate an automatic gain check into the system, using a pulsed noise diode to give a calibration signal beyond maximum radar range, provided the long term stability of the noise diode can be proven to be adequate. It is hoped that this calibration signal will be sufficiently stable to give an indication of any major change. An "S" Band signal would still be used for final calibration.

DETAILED NOTES ON RECEIVER SETTING UP AND OPERATION

The following notes are included as a guidance to personnel using the receiver equipment. (A more detailed block diagram is shown in Fig A1C.)

The variable attenuator is provided to enable the initial setting-up procedure to be carried out and can also be used to compensate for tolerances, and changes that take place in the equipment which precedes it. The latter includes cable attenuation which at Camborne is insignificant but at a site using a mobile 43S may be as much as 2 dB.

The variable attenuator must not be used to take out any changes in the logarithmic amplifier which should be stable and therefore replaced if faulty. A graph of power into the logarithmic amplifier against voltage out is shown in Fig A1D. The graph is taken using the signal generator fed through a 6 dB attenuator to compensate for the attenuation in the passive filter and any cable losses.

It is important that the lead from the logarithmic amplifier to the Analogue to Digital converter is kept reasonably short (<1 metre) and that oscilloscopes, digital voltmeters, etc are not connected to this point in parallel with the amplifier output. The accuracy of the digitised output is affected if the 50 ohm amplifier loading impedance provided by the load within the Analogue to Digital Converter is reduced by other loads or cable capacitance. An auxiliary high impedance output (fed from the main amplifier via a 1 Kohm resistor) supplies a buffer amplifier for feeding non-critical loads. As the buffered output may differ slightly from the main output, precise measurements must always be made on the main output. When the A/D converter is not connected, and a digital voltmeter substituted, the 50 ohm impedance must be maintained by an external accurate 50 ohm load. (A 2% tolerance on impedance produces an error of \approx 0.3 dB at a 1 volt output level.)

If it is necessary to carry out a spot check on the overall gain of the system this must be done with a signal giving about one volt output from the logarithmic amplifier. This is to avoid the effects of noise at lower levels or saturation at higher levels.

Care must be exercised if there is a need to disable the AFC when making measurements. There is an AFC disable button available for this eventuality. Any attempt to disable the AFC by removing the LO feed to the AFC mixer will cause a change in the signal mixer current and affect the conversion efficiency and hence, the gain.

CALCULATION OF POWER RECEIVED FROM A GIVEN RAINFALL RATE

The form of the radar equation used in these calculations is due to Probert-Jones (Ref A1). This formula includes, within the equation, a two-way beam shape loss factor derived from a Gaussian approximation to the aerial main-beam shape, avoiding the use of a separate beamshape loss factor as would be required in conjunction with the usual form of radar equation, for example in Ref A2.

The original Probert-Jones formula can be expressed as:

$$P_r = \frac{\pi^3}{16 \log_e 2} \frac{P_o h}{\lambda^2} G^2 \theta \phi \frac{1}{r^2} \left| \frac{\epsilon-1}{\epsilon+2} \right|^2 \frac{\Sigma d^6}{64} \quad A1.1$$

P_r = Received Power in watts

P_o = Peak transmitted Power in watts

h = Pulse length in space in metres

G = Gain of aerial system

θ, ϕ = Beamwidths in radians

r = Range in metres

ϵ = Dielectric constant of water

Σd^6 = Sum of the sixth power of raindrop diameters in unit volume
(mm^6/m^3)

λ = Wavelength in metres

We have used this equation in a re-arranged form as suggested by A J Whyman (RSRE) at this uses more readily measurable parameters.

$$P_r = \frac{\pi^3}{16 \log_e 2} \frac{P_{av}}{\text{prf}} \frac{f^2}{c} G^2 \theta \phi \frac{1}{r^2} \left| \frac{\epsilon-1}{\epsilon+2} \right|^2 \frac{Z}{64} \times 10^{-18} \text{ watts} \quad A1.2$$

where $\left| \frac{\epsilon-1}{\epsilon+2} \right|^2 = 0.93$

P_{av} = Average Transmitter Power = 357 watts

f = Frequency = $2,860.10^6$ Hz

G = Aerial Gain = 6310

θ = Elevation Beamwidth in Radians = 0.035

ϕ = Azimuth Beamwidth in Radians = 0.035

r = Range in metres

c = Speed of light = 3.10^8 metres/second

prf = Pulse recurrence frequency = 275 Hz

Z = Σd^6 in units of mm^6/m^3

Z can be expressed in relation to a rainfall rate, R, in mm/hr by the empirical formula

$$Z = AR^B$$

where A and B are constants depending on the type of rain (REF A2). For average rainfall, A can be taken as 200 and B as 1.6. For the radar parameters quoted above, equation A1.2 gives the following results for a range of 50 km, the $\frac{1}{r^2}$ normalised range.

Rainfall Rate (mm/hour)	Power input to RF amplifier (dBm)
0.125	-97
1	-83
4	-73
8	-68
16	-63
32	-58
64	-54
100	-51

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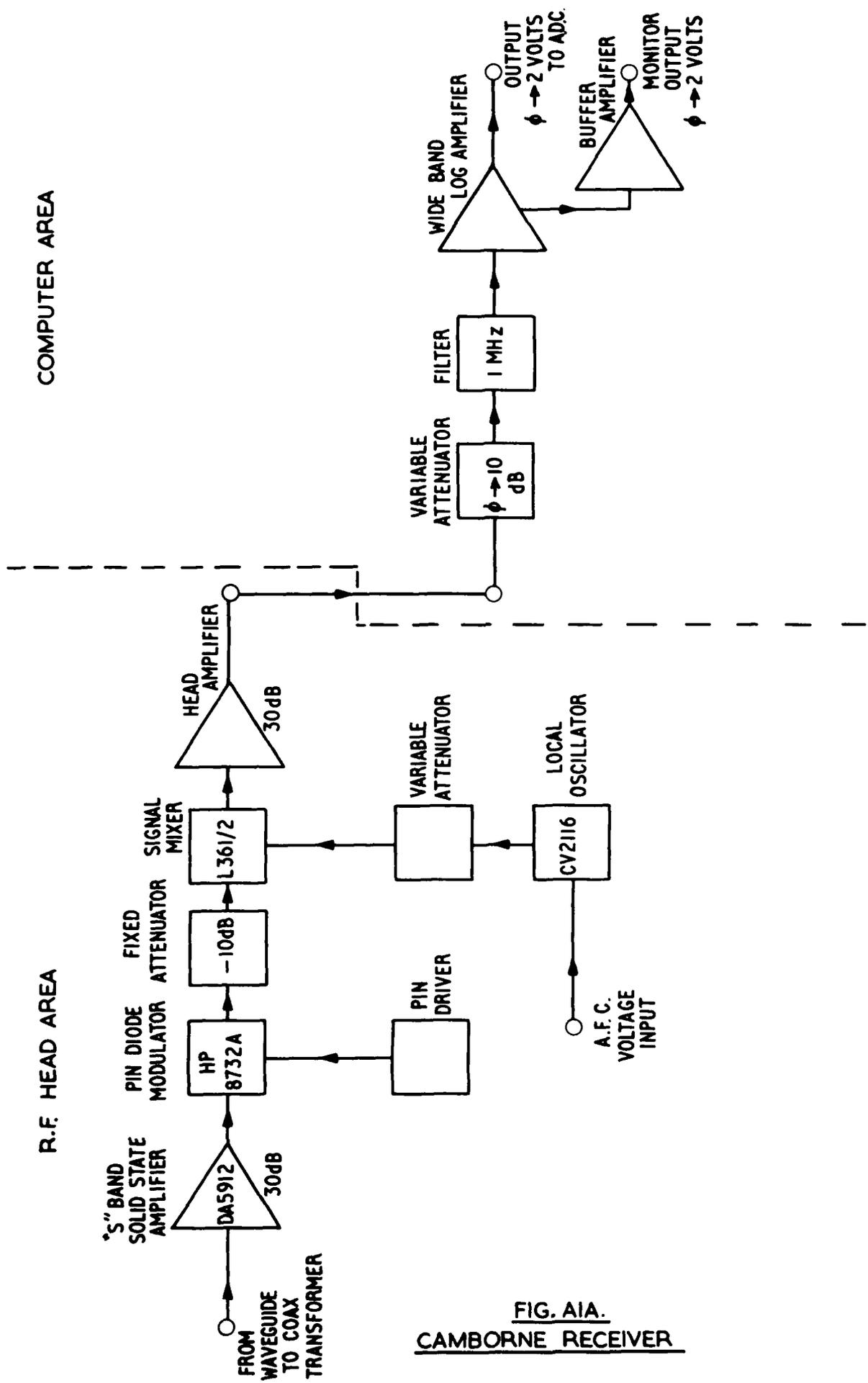


FIG. A1A.
CAMBORNE RECEIVER

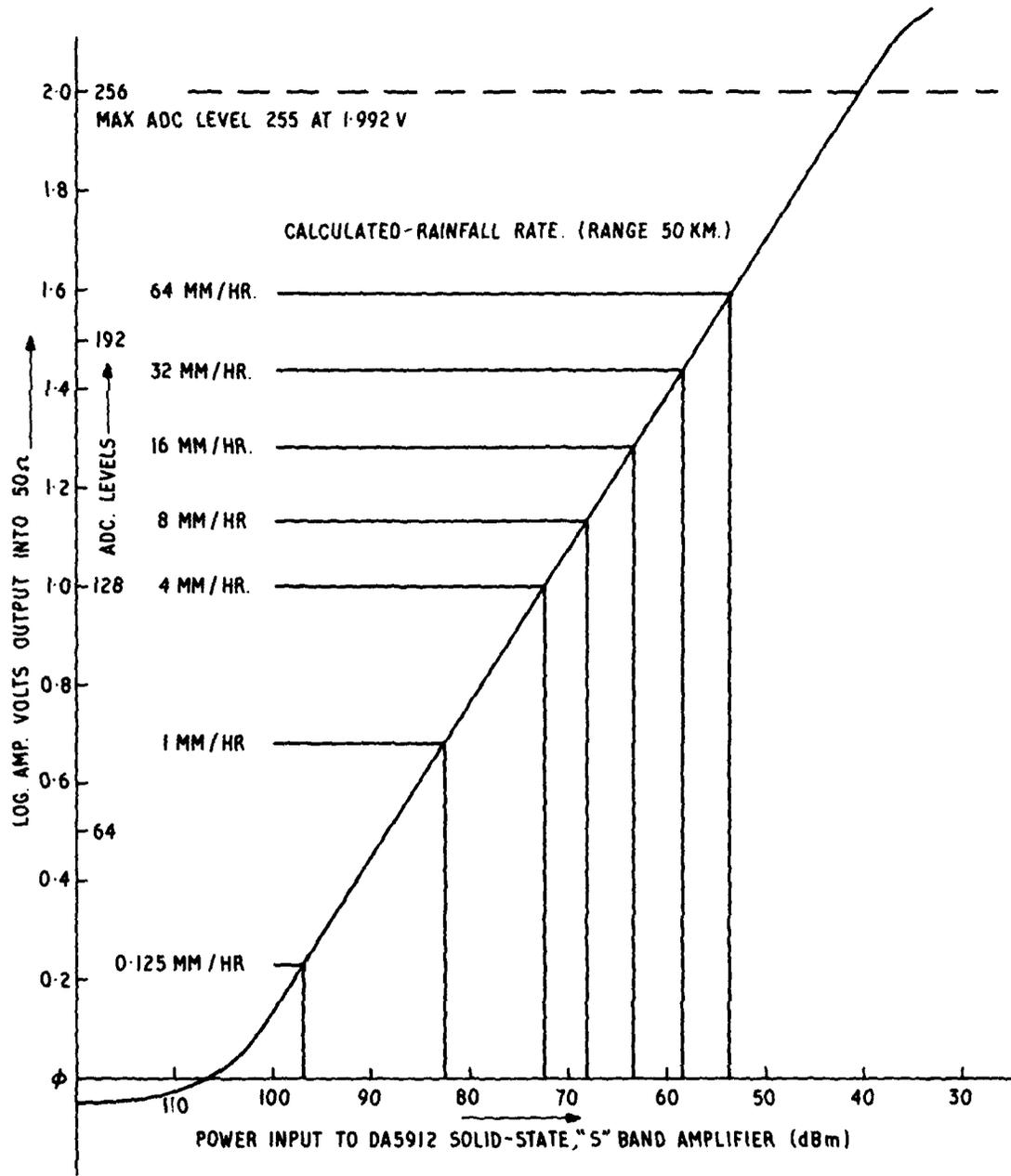


FIG. A1B. RECEIVER OUTPUT VOLTAGE VS POWER INPUT.

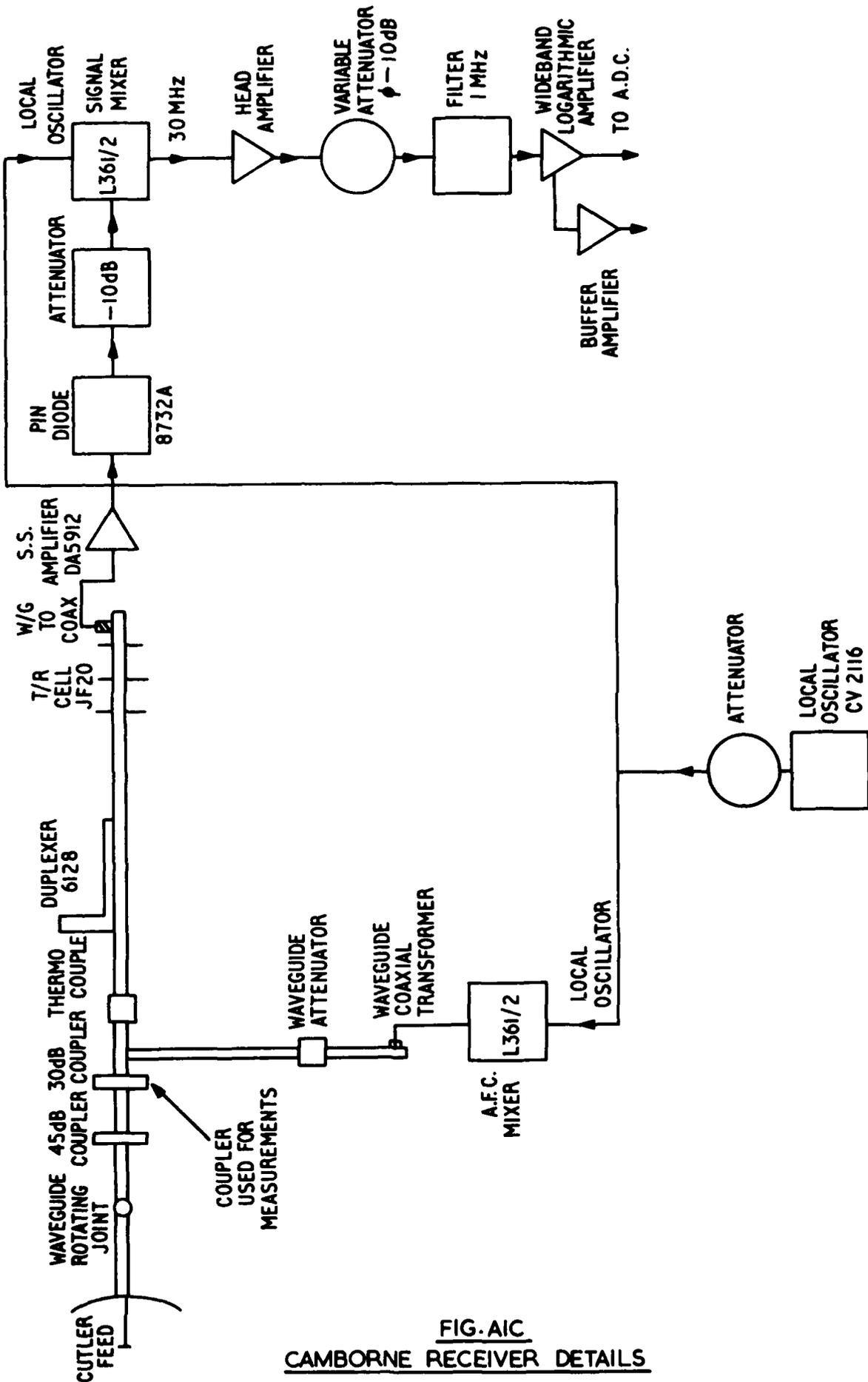


FIG. A1C
CAMBORNE RECEIVER DETAILS

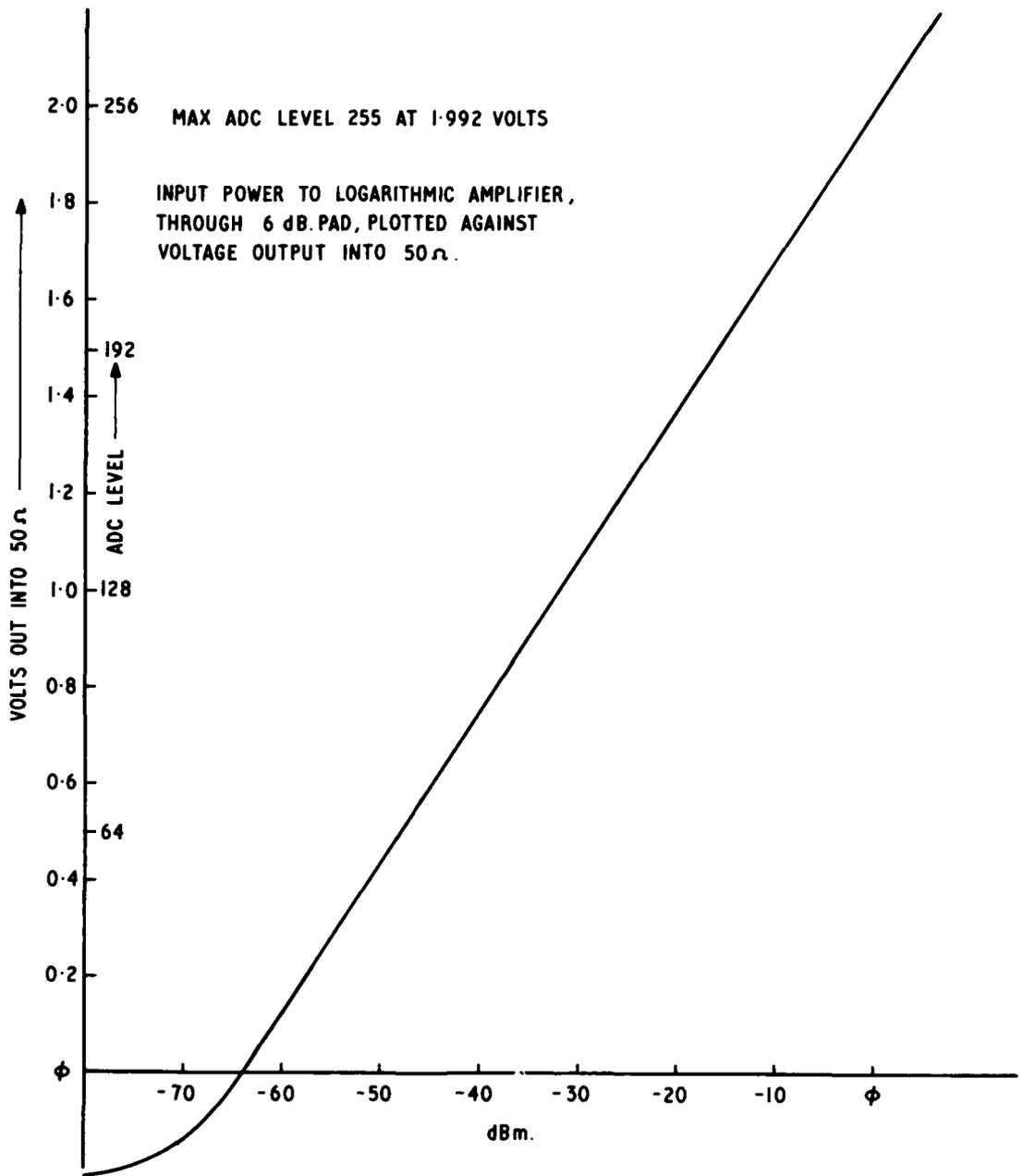


FIG. A1D.

APPENDIX 2

$\frac{1}{r^2}$ (programmable) swept attenuator

M J E CAWLEY MET O RRL MALVERN

The $1/r^2$ dependance of signal strength with range imposes a stringent requirement on the overall receiver dynamic range. A hardware correction using a standard PIN diode gives a range-independant signal return over a dynamic range of 36 dB for a penalty of a 2 dB insertion loss. This rf attenuation thus reduces the requirement of the receiver components which follow the PIN diode.

The required attenuation at any point on the $1/r^2$ curve is calculated from:

$$r \text{ (km)} = \sqrt{\frac{r_o^2 \text{ (km)}^2}{\text{antilog} \left(\frac{\text{required attenuation}}{10} \right)}}$$

where r = range point on $\frac{1}{r^2}$ curve

r_o = normalisation range ie range at which attenuation is to be 0 dB.

The total range of interest is divided into range cells and information on the bias current required for the appropriate attenuation in each cell is held in a Programmable Read-only memory (PROM). The number of range cells required is determined by the accuracy demanded of the curve and in the present case 256 cells are used corresponding to a maximum error of ± 0.6 dB.

Referring to Fig A2A the system is triggered on receipt of a transmitter pulse. In the normal state the reset bistable holds both the binary rate multiplier (brm) and the 8 bit binary counter in the reset condition. On receipt of a transmitter pulse the reset bistable changes state allowing the brm to pass clock pulses at a rate determined by the range setting. The 8 bit binary counter counts these pulses on a "ripple through" basis until the counter is full. At this point the 8 input NAND gate triggers the 1.4 mS monostable which in turn switches the reset bistable. The brm is now reset so inhibiting further clock pulses but the 8 bit counter remains in its full state for a further 1.4 mS at which point it too is reset to 0. Thus, commencing with each transmitter pulse the counter counts from 0 to 255 in a time:

$$\text{time} = \frac{\text{brm rate} \times 255}{\text{clock frequency}}$$

so giving ranges of 200 km, 100 km, 50 km and 25 km respectively corresponding to brm rates of $\div 32$, $\div 16$, $\div 8$, and $\div 4$. The counter then remains at 255 for a further 1.4 mS (210 km) before returning to 0. This count is applied to the address inputs of the PROM and the PROM is programmed so that the corresponding word outputs follow the $1/r^2$ law. The PROM outputs are latched in order to avoid the glitches which occur during memory access time, the latch being enabled by the delayed pulse generator during count time and by the 1.4 mS monostable when count goes from 255 to 0. To further ensure that minimum attenuation is obtained between r_o and $r_o + 1.4$ mS the monostable is

also used to disable the PROM during this period. ON/OFF control by external line is also obtained by disabling the PROM since this method is both immediate and does not disturb the count sequence. The voltage output from the digital to analogue converter is fed to the PIN diode (current operated) via a series load.

The test bistable enables single pulses to be fed to the counter by pressing the button the number of times corresponding to the required address. Thus:

Address	-	Attenuation
0		36 dB
7		30 dB
15		24 dB
31		18 dB
63		12 dB
127		6 dB
255		0 dB

A preset is provided to allow for the adjustment of the output current to suit individual HP diode units.

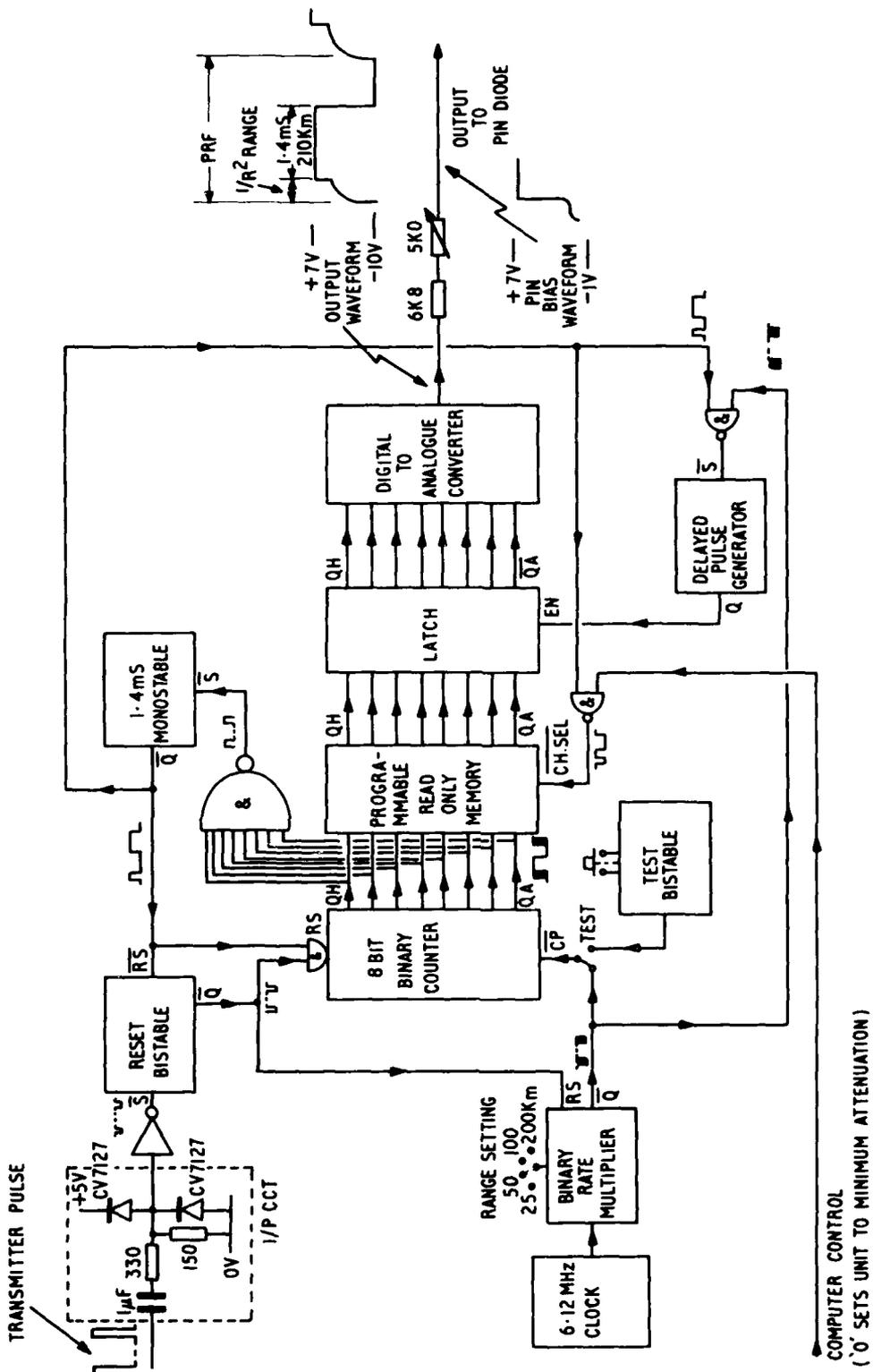


FIG. A2A
R2 LOGIC DIAGRAM

APPENDIX 3

RADAR SIGNAL AVERAGING UNIT (RSAU)

A3.1 INTRODUCTION

This unit was designed and manufactured by MICROCONSULTANTS LTD for the digitisation of radar analogue video signals, the averaging of successive amplitudes and the transfer of the result to a PDP-11 computer. It effectively performs the function of radar signal averaging in range.

The RSAU consists of an 8-bit analogue to digital convertor, a digital anti-logarithm generator using electrically alterable programmable read only memories, averaging logic to average up to 16 successive amplitudes and control logic to transfer the result to a PDP-11 computer by direct memory access.

A3.2 SIGNAL PROCESSING

A3.2.1 Analogue to Digital Convertor (ADC)

The video signal from the radar receiver is converted to an 8-bit parallel digital form in a MICROCONSULTANTS analogue to digital convertor type AN-D1 802 VID. The rate of digitisation is determined by externally applied clock pulses derived from the radar/computer interface unit (See Appendix 4). The clock frequency is normally 0.8 MHz which is equivalent to sampling the radar signal at range intervals of 187.5 metres.

The ADC is modified by the manufacturers to make the 0 to 2 V input of the unit compatible with the radar receiver output.

A3.2.2 Anti-Logarithm Generator

A programmed read-only memory is used to generate a 12-bit anti-logarithm output that is proportional to the amplitude of the signal present at the logarithmic amplifier receiver input. This comprises a 256 word, 12-bit look-up table implemented in two 8 x 256 bit electrically alterable programmable read-only memories (Ultra-violet erasable type NS MM5203Q). The input-output relationship for the read only memories is derived from a knowledge of the receiver characteristics.

A3.2.3 Averaging Logic

Successive output words from the anti-logarithm generator are summed in a 16-bit storage register. The number of samples to be summed and then scaled to derive the average value is preset by a computer output instruction. After this number of samples has been summed the content of this storage register is transferred to a holding register for scaling and transfer to the computer, and the storage register is then cleared and a new summation commenced. The holding register content is scaled by right shifting to give the average of 1, 2, 4 or 8 samples (or, by alteration of a scale link board in the unit, an average of 2, 4, 8 or 16 samples can be obtained). The average of the number of samples selected is then transferred to the 12 least significant bits of a 16-bit computer work via a direct memory access interface (type DR11-B) to the computer.

A3.3 COMPUTER INTERFACE SIGNALS

The radar zero range trigger pulse (PREPULSE) is used to initiate a sequence of averaged values from the RSAU to the computer. The rate of transfer is determined by the ADC clock rate (CLOCK) and the number of samples averaged. Typically a clock of 0.8 MHz is used and 4 successive samples are averaged thereby giving a DMA rate of 0.2 MHz or a 16-bit computer word every 5 μ secs. Computer instructions transferred through the DR11-B interface determine the number of samples to be averaged, the total number of averaged samples to be transferred to the computer and the area in computer memory where the data is to be placed.

APPENDIX 4

RADAR/COMPUTER INTERFACE UNIT

This unit is designed to interface between an existing Plessey 43S radar and a PDP-11 series computer in order to give all the necessary data and control signals between equipments for the correct operation of the software.

The data provided by the radar equipment is as follows:

- 1 AZIMUTH - output in a $3\frac{1}{2}$ decade binary coded decimal (BCD) parallel form in the range 0 to 359.9° in one-tenths of a degree units.
- 2 ELEVATION - output in a $3\frac{1}{2}$ decade BCD parallel form in the range 0 to 359.9° in one-tenths of a degree units.
- 3 A zero range trigger pulse, marked as PREPULSE on the RSAU, coincident with the firing of the radar transmitter.
- 4 The radar logarithmic receiver output video signal (in the range 0-2 volts).

This data is routed to the radar/computer interface unit which operates on the data from the radar to supply it to the computer in the required form and also to provide control signals from the computer to the radar equipment as follows:

- 1
 - a Azimuth is displayed on the front panel in BCD on a 4 decade, 7 segment LED display.
 - b Azimuth is converted from BCD to 12-bit parallel binary for input to the computer on the data input lines of a 16-bit general purpose input/output interface type DR11-C. The 16-bit output lines of this interface are available within the unit to output signals to accurately position the aerial at a fixed azimuth via synchro control transformers.
 - c The least significant bit (lsb) of the BCD azimuth signal is connected to the interrupt request line of the DR11-C interface of the computer. When the computer responds to this request it clears the request line in readiness for the next lsb azimuth change. The signal processing of the whole system is initiated when an lsb azimuth change is detected.
- 2
 - a Elevation is displayed on the front panel in BCD on a 4 decade, 7 segment LED display.
 - b Elevation input is handled in exactly the same way as azimuth but in a separate DR11-C interface. Lsb elevation change interrupts are used to continuously monitor the aerial elevation angle. The 16-bit output lines of the elevation DR11-C interface are used to output discrete elevation settings from the computer to an elevation synchro control transformer.

3 The zero range trigger pulse (PREPULSE) is used to initiate the count down of an 8.0 MHz crystal clock to derive a 0.8 MHz clock for use in the RSAU in order to determine the rate of digitisation of the radar video signal. The delay between the zero range trigger pulse and the first and subsequent 0.8 MHz clock pulses can be up to one 8 MHz clock cycle (equivalent to 18.75 metres in range). This will be a fixed range delay error for this one particular zero range trigger pulse and hence azimuth interrupt. Further inputs will create differing range delay errors up to a maximum of 18.75 metres in range. This is considered to be acceptable to within the accuracy of the whole system particularly as the RSAU provides data to the computer integrated over 750 metres in range.

This clock signal (CLOCK) and the associated zero range trigger pulse (PREPULSE) are routed to the adjacent RSAU to continue the signal processing after an azimuth lsb change has been detected (lc above).

4 A third 16-bit general purpose input/output DR11-C interface is used to output 16-bit data from the computer to a 16-bit LED display on the front panel of the unit. This is used as a programmers aid and software exists to output to these lights any data within the computer that is required to be examined. It is particularly useful for continuously examining data that is changing (ie azimuth) and is considerably quicker and easier to use than repeated requests via the teletype.

5 In order to quickly ascertain equipment malfunction a simple display facility is incorporated in the unit that indicates on LED displays on the front panel in the absence of the appropriate signal. The signals monitored are zero range trigger pulse, RSAU clock, azimuth and elevation lsb change, azimuth and elevation interrupt request and acknowledgement, and direct memory access taking place between RSAU and computer.

Additional features of the radar/computer interface unit not fully implemented at the present time are:

1 Parallel operation of the computer and a video tape recorder to record data for later analysis when it is possible to readily change various data processing parameters.

2 Hardware to generate standard test and calibration signals to monitor the operation of the computer and associated equipment.

APPENDIX 5

JASMIN MK III RADAR DATA STORE

A5.1 INTRODUCTION

The Jasmin Mk III store is a digital data store specified at RSRE and built by JASMIN Electronics of Leicester. It is designed to hold weather radar data, transmitted along GPO Datel lines. Data is transmitted slowly because of the limited bandwidth of the GPO lines, but needs to be applied to a TV monitor at MHz rates, to synchronise with standard line and frame scan rates.

Data is sent for two display formats: grids of 84 x 84 data squares and grids of 128 x 128 data squares. In both cases data for each displayed square is sent in 3 bit form, to give eight possible colour values. The store is able to hold and display either 4 x 128², 3 bit pictures, or 9 x 84², 3 bit pictures, the mode of operation being selectable by a back-panel switch. The basic facilities provided, are as follows:

- 1 Storage for 9 x 84², or 4 x 128² pictures.
- 2 Eight colour display of 3 bit data.
- 3 The ability to display data at all times, even when data is being transferred into the store.
- 4 All display colours are interchangeable between the eight data values by front panel controls.
- 5 Range grid and crosswire can be displayed simultaneously with data.
- 6 Background map for simultaneous display with data, to be generated within the store by reprogrammable read only memories.
- 7 Selectable seven colour display of grid, crosswire and map.
- 8 Remote control signals to operate audio tape recorder and camera.
- 9 Automatic display of latest picture in store, with manual override to select any of the earlier pictures held in store.
- 10 Variable speed "action replay" of data held in store.
- 11 Free standing 18" colour TV display.

A5.2 DATA INPUTS

The data inputs comply with the CCITT V24 specifications for data interchange inputs. The store has also to meet all GPO requirements of equipment connected to GPO lines.

A5.3 INPUT DATA FORMAT

Data is supplied to the store from GPO Datel line modems, in a serial digital stream, at baud rates of 300, 600 or 1200. The voltage levels of the data waveforms and the source impedance of the modem output comply with the CCITT V24 recommendations. Data is transmitted in eight bit bytes, plus 1 start and 1 stop bit.

A5.4 BIT ORGANISATION OF MODEM BYTES

Data bytes comprise two 3-bit colour words (ie the data required to generate two data squares on the TV display) and a two bit data byte identification code. (See Fig A5A).

Frame bytes consist of a four bit information number, known as the frame number, and a four bit, byte identification code. (See Fig A5B).

Line bytes consist of an eight bit line byte code. (See Fig A5C).

A5.5 DATA TRANSMISSION SEQUENCE

The normal data transmission sequence for an 84 x 84 picture is shown in Fig A5D.

The normal data transmission sequence for a 128 x 128 picture is shown in Fig A5E.

Pictures are always transmitted in a chronological order with ascending, consecutive frame numbers. Thus if a series of nine pictures are transmitted and the frame number of the first is 2, the eighth picture will have frame number 9 and the ninth will have frame number 1.

A5.6 DATA DECODER

Frame bytes are normally used for two functions:

1 Picture frame bytes

These are frame bytes numbered 1-9 and are used to initiate a store condition called frame lock, which enables the store to start receiving a picture. The frame number 1-9, contained within frame bytes, determines to which of the nine possible memory locations the following picture data is to be routed. (When the store is operating in the 128 x 128 mode, frame numbers from 1-4 only are sent, as there is only enough memory capacity for 4 x 128² pictures.) Picture frame bytes are always transmitted in triplicate and the store input decoder only recognises a memory location number (ie frame number from 1-9) and initiates the frame lock state, after determining that two of three transmitted frame bytes are identical.

2 Control frame bytes

These control functions outside the normal data reception procedure. At the time of writing, frame numbers 10 and 11 are being used to remotely control a tape recorder, recording the audio input to the GPO modem.

Line Bytes

Line bytes are used to increment an input data line counter. This counter drives a three digit, seven segment display of the line number of the data being transferred into the store. The store input decoder has a comparison function, similar to the frame byte comparison function. This circuit reads line bytes entering the store and only generates a line sync pulse if two of three bytes are recognised as line bytes.

Other Byte Codes

The store is designed to ignore any byte code different from those described above. This is important, as another device - the Data Logging Unit, is connected to the same data source as the store, but only accepts its own specific byte codes (see Appendix 6).

SEQUENCE OF DATA TRANSFER INTO THE STORE

For this example it is assumed that an 84 x 84 picture having the frame number 1 is being sent.

<u>Input Data</u>	<u>Store response</u>
3 frame byte 10	Any 2 of the 3 frame bytes produce a +ve pulse on the start tape recorder output.
3 frame byte 1	If two of the three frame bytes are decoded frame 1 lockout circuit is set. This ensures that following data is routed to the frame 1 location in memory and that the store output circuit selects frame 1 data for immediate display. The frame lock state is set, to enable the store to accept data.
42 data bytes	Assuming frame lock is set, the first line of data is transferred to the frame 1 memory location during display frame blanking periods and is immediately displayed.
3 line bytes	If two of the three line bytes are decoded, a data line sync pulse is generated. This increments the input line counter on the front panel and clears the frame byte comparison circuits. If the frame lockout circuits are switched off, data line sync also clears the frame 1 lock-out circuit.
42 data bytes	Data is transferred to memory and displayed as for previous line of data.
3 line bytes etc	Line sync is generated subject to the conditions stated previously. Visual line counter is incremented.
84th line of 42 data bytes	84th line of data is transferred to memory and displayed.
84th set of 3 line bytes	Line sync generated subject to conditions stated previously. Final line sync resets frame lock and produces a camera trigger pulse.

frame byte Any 2 of the 3 frame bytes produce a +ve pulse on the stop tape recorder output.

the frame lockout circuit was switched on at the beginning of data transfer, further frame 1 data is locked out, until the frame lockout circuit reset. Resetting is achieved either by pressing the lockout reset button or the decoding of another frame number from the 1-9 picture frame bytes sequence. The same data transfer sequence is used for all pictures.

in the 128 x 128 picture case, data transfer is the same as previously described except that there are 64 data bytes per line of data, 128 lines of data and frame numbers 1-4 only are used.

8 STORE RESPONSE TO MISSING OR EXTRA DATA BYTES

every time a line sync is generated, a check is made on the number of data bytes received since the last line sync. If the number is too great or too small, the accumulated memory address is corrected and a level 5 data cell is displayed at the end of the relevant line of data.

9 DATA OUTPUT FORMAT

the data output from the store is formatted so that each line of data is locked out to the TV display in $\frac{1}{4}$ of the TV line display time. This is to ensure that the complete picture is presented as a grid of true squares on a 3 x 4 aspect ratio TV screen.

10 BACKGROUND DISPLAYS

PROM generated maps

there is a requirement for a fine resolution background map, to be displayed simultaneously with weather data. This display is generated within the store by specially programmed ROMS. The background map is displayed on a 256×256 grid, superimposed upon the 84×84 or 128×128 data grid, with the origin of both the map and data displays at the top left-hand corner of the TV screen.² This means that although the 128^2 data grid will cover the whole of the 256^2 map grid, the 84^2 data grid will only cover 252×252 squares of the map.

the PROMS used are National Semiconductor MM5203Q. These contain 256 8 bit programmable addresses. Eight PROMS are used, each generating an illuminated square at any one programmed square along each line of the 256^2 map grid. In conjunction with the outputs of eight PROMS logically ORed together, there are eight squares with programmable locations along each displayed TV line.

Range Grid

each square of data displayed corresponds to a 5 km square cell in the area covered by the weather radar. Hence an 84^2 display represents an area of 84×420 km and 128^2 represents an area of 640×640 km. A range grid of squares corresponding to 200 km on a 128^2 display is provided.

A5.11 TELEVISION DISPLAY

The displays used so far have been modified 18" Sony colour receivers. The decision to use modified televisions as a TV display was purely on economic grounds. Future stores will be equipped with 20" Digivision colour monitors, to obtain the necessary resolution to produce a good quality 128² picture.

FIG. A5A. DATA BYTES.

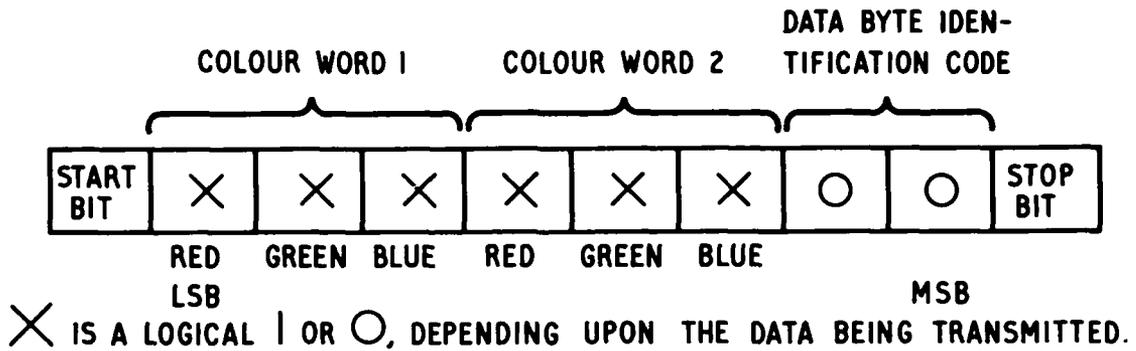


FIG. A5B. FRAME BYTES.

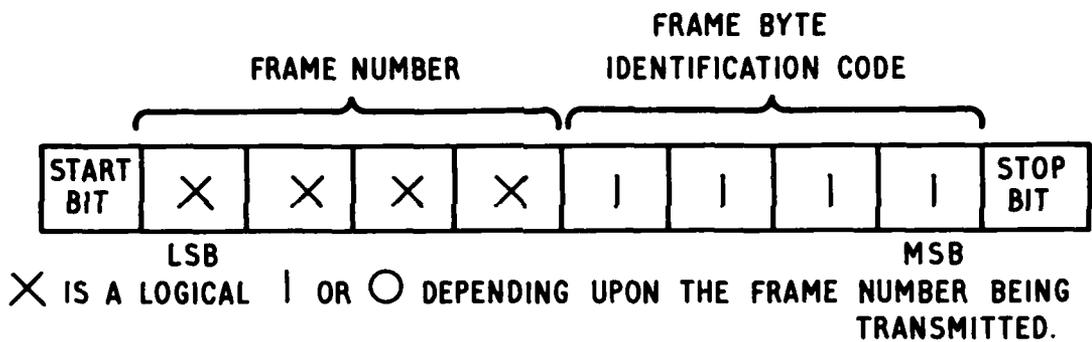


FIG. A5C. LINE BYTES.

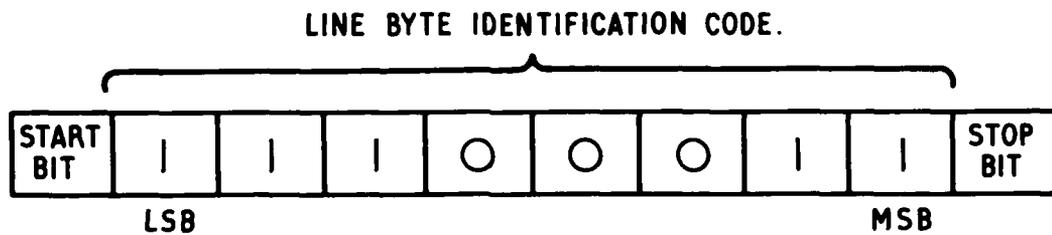


FIG. A5D. NORMAL DATA TRANSMISSION SEQUENCE FOR AN 84 x 84 PICTURE

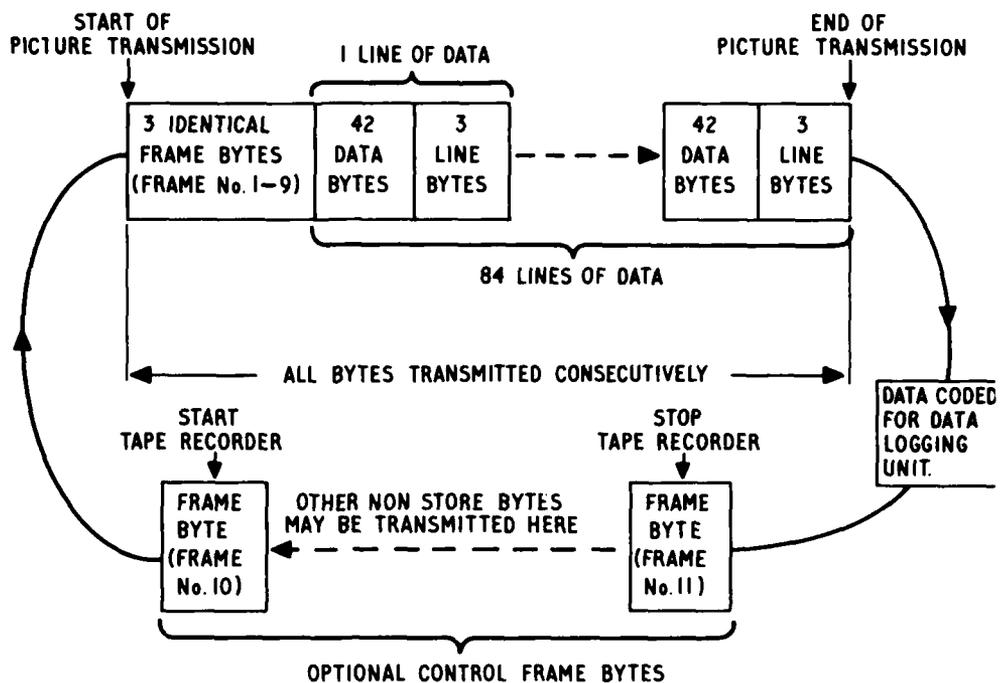
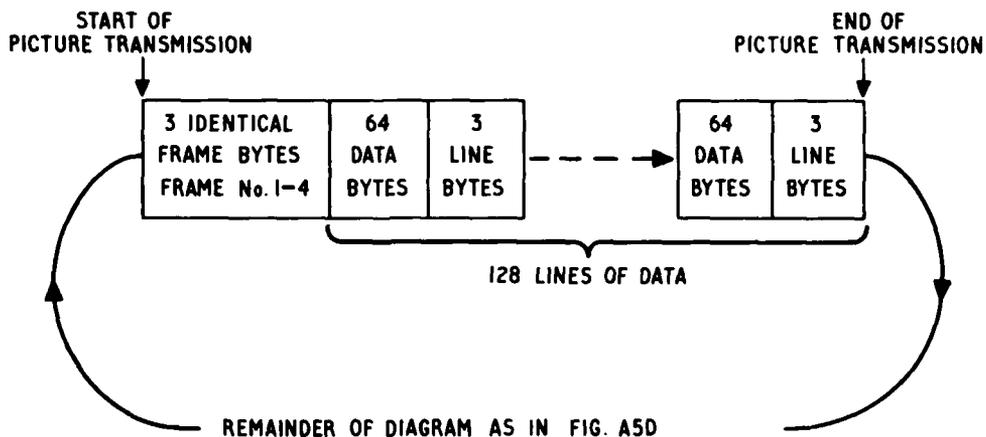


FIG. A5E. NORMAL DATA TRANSMISSION SEQUENCE FOR A 128 x 128 PICTURE:



APPENDIX 6

DATA LOGGING UNIT (DLU)

INTRODUCTION

The display of subcatchment data (ie integrated rainfall totals) at a remote site has been implemented previously during the Dee project (Ref A6.1). The request for this data came from the Severn-Trent Water Authority and could, at that time, be satisfied only by use of the one available corner of the Jasmin store television display. The limited amount of space available severely restricted the amount of data which could be displayed and also forced all users to see the same subcatchment data.

The DLU has been designed to provide a comprehensive facility to display various subcatchment subsets and other specialised data. The subcatchment totals, specified and calculated within the radar-site computer, are transmitted as data appended to the picture data mentioned in Appendix 5. A code is included in each subcatchment subset to allow the user to access the data appropriate to his requirements.

Other facilities include an error-checking system on both picture and subcatchment data based on block check characters and various print mode options.

THE HARDWARE

A microprocessor-based system has been chosen because of its inherent flexibility and relative simplicity. The Microprocessor Support Unit (MSU) at RSRE recommended an INTEL 8080A system from their experience of many microprocessors. The input hardware is fully compatible with the Post Office V24 and EIARS232C interface requirements but specific Post Office approval has not been sought for the two prototypes since they are to be operated from a Communication Buffer Unit (Appendix 7). If sole use of a DLU is required, future systems will need Post Office approval. The hardware contains 2 K-bytes of Programmable Read Only Memory (PROM) and 256 bytes of Random Access Memory (RAM). The addition of the interrupt controller (8259) allows greater flexibility in the interrupt handling routines than is available in the basic 8080A.

The printer used as the display is a Mullard 60SR needle matrix impact mechanism which uses non-sensitised paper of a standard width (58 mm). The printer control circuitry has been designed and constructed at RSRE. Figure A6A shows the general hardware configuration. The complete system operates from a mains supply and is sufficiently quiet to be acceptable in an office environment.

THE SOFTWARE

The programming has been implemented in assembly language, using the facilities available at the MSU, and took approximately 4 man-weeks. The three major tasks are controlled by the 8259 interrupt controller to give priorities in the following order.

- 1 Data output to the printer. This takes relatively little of the total time available.

2 Data reception (occupying some 20% of the total time).

3 Force print mode. This is used only if the user has detected an error and demanded a reprint or if, for any reason, the equipment has been off-line during the period of hourly updates.

The remaining time (approximately 75%) is spent waiting for further interrupts.

THE INPUT DATA STREAM

Figure A6B shows how the subcatchment data is added to the picture data at the radar site for reception by the DLU. Fig A6C shows details of a typical subcatchment subset showing the control characters and the 4-bit BCD data characters. The start control characters can take the values octal 341-357, thus allowing 15 different subsets per site. Octal 340 is reserved for an "end of sequence" control character. The hour and day code characters can take values 1-9 only and are used to recognise when the data is changing (normally hourly). This prevents multiple printing and assists the force print option since, if the stored code is cleared, any new data will be printed.

THE PRINTER OUTPUT

Fig A6D shows the format of the printer output. The right hand column is comment only and is not printed.

The DLU has been in operation on the Camborne data since June 1978 and has operated satisfactorily.

Ref A6.1 Dee Weather Radar and Real Time Hydrological Forecasting
Project Report by the Steering Committee
Central Water Planning Unit, Reading Bridge House, Reading.

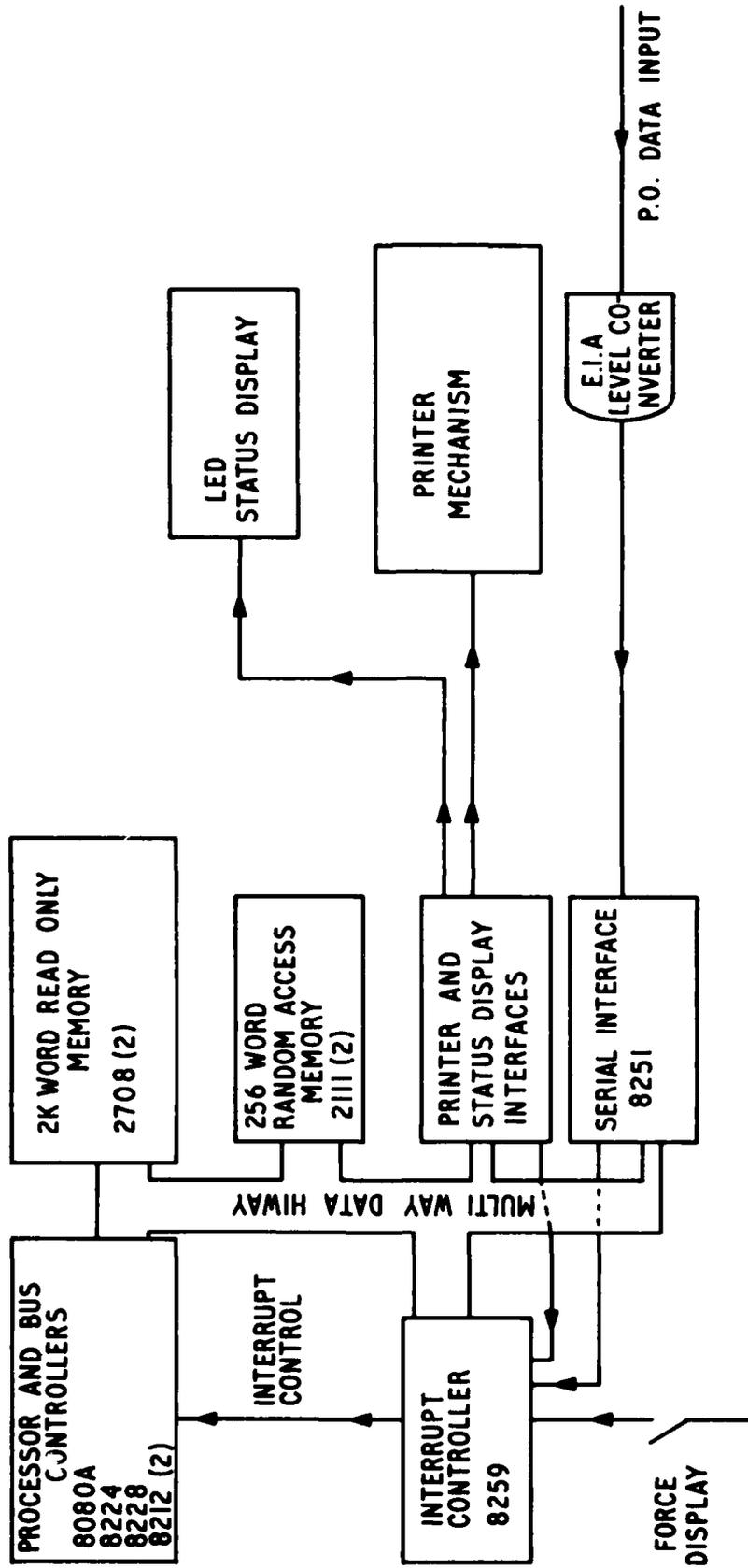


FIG. A6A. DATA LOGGING UNIT GENERAL HARDWARE CONFIGURATION.

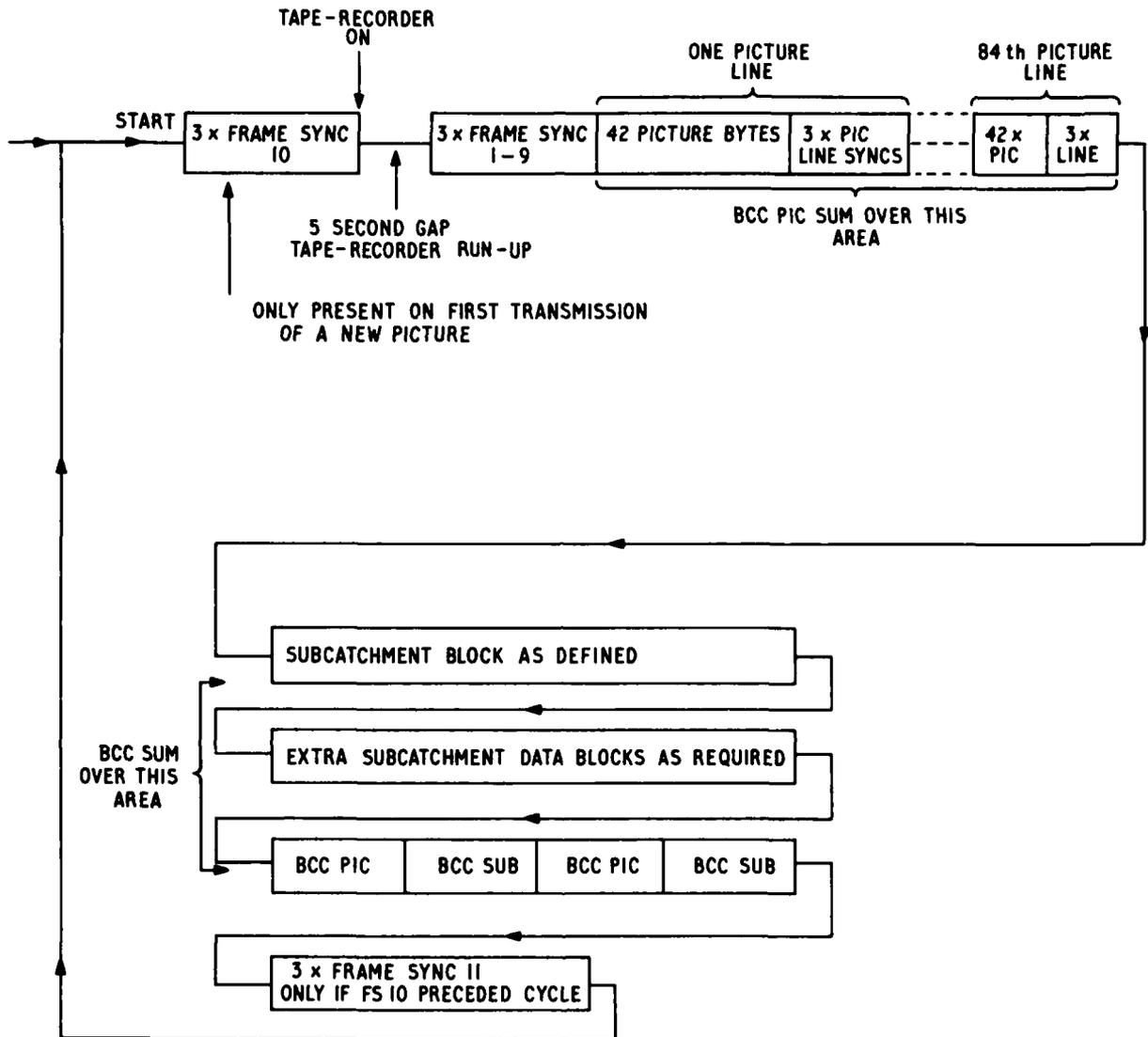


FIG. A6B SUBCATCHMENT DATA DETAILS.

← HIGH BYTE →			← LOW BYTE →			Decimal Reference (Bytes)
	OCTAL 341		OCTAL 341			
'Control' Chars						0
BCD (1-9)	Day Code	Hour Code	Day Code	Hour Code		2
BCD Start	Mins (Units)	Mins (Tens)	Hrs (Units)	Hrs (Tens)		4
Time and date (Hourly Data)	Mth (")	Mth (")	Day (")	Day (")		6
End time and Data (Hourly Data)	Year (")	Year (")	Year (Hunds)	Year (Thous)		8
	Mins (")	Min (")	Hrs (Units)	Hrs (Tens)		10
	Mth (")	Mth (")	Day (")	Day (")		12
	Year (")	Year (")	Year (Hunds)	Year (Thous)		14
	∅	SC1 (Tens)	SC1 (Units)	SC1 (Tenths)		
	"	SC2	SC2	SC2		
	"	SC3	SC3	SC3		
BCD S/C hourly Data						
	"	SC25	SC25	SC25		
Start time and date (Day Data)	Mins (Units)	Mins (Tens)	Hrs (Units)	Hrs (Tens)		66
	Mth (")	Mth (")	Day (")	Day (")		
	Year (")	Year (")	Year (Hunds)	Year (Thous)		
End time and date (Day Data)	Mins (")	Mins (")	Hrs (Units)	Hrs (Tens)		
	Mth (")	Mth (")	Day (")	Day (")		
	Year (")	Year (")	Year (Hunds)	Year (Thous)		
	SC1 (Hunds)	SC1 (Tens)	SC1 (Units)	SC1 (Tenths)		78
	SC2	SC2	SC2	SC2		
	SC3	SC3	SC3	SC3		
BCD S/C Day Data						
	SC25	SC25	SC25	SC25		126
'Control' Chars	OCTAL	34∅	OCTAL	34∅		128

FIG A6C TYPICAL SUBCATCHMENT SUBSET

	DATA PRINTOUT	COMMENT
	SUBCATCHMENT SET NO: X	Subcatchment set no. identities
	0800 18:03:79	Start time and date
	0900 18:03:79	Stop time and date
line no →	1 02.3 04.6 06.9	Data in groups of three
	2 12.4 01.3 05.7	
	↓	↓
	(n lines to last one)	
	N 01.2 02.3 08.4	to the last line
	0900 17:03:79	24 hr data (if applicable)
	0900 18:03:79	on same format as above
	1 52.1 29.2 30.3	hourly data
	2 104.1 09.2 20.9	
	↓	
	(n lines to last one)	
	N 50.2 20.8 99.8	
	ERROR CODE: XXXXXX	Error codes relating to this subcatchment data block (if any errors are present, otherwise it is suppressed).
	SUBCATCHMENT SET NO: Y	Whole block repeated for successive subsets if required.
	← This Data Printed →	

FIG A6D SUBCATCHMENT DATA PRINTOUT FORMAT

APPENDIX 7

COMMUNICATION BUFFER UNITS

Buffer units are required at both the radar site and the remote user site to interface the equipment to the standards required by the Post Office when using their modems.

RADAR SITE BUFFER

The radar picture which is to be sent to the remote users is common to all users. To avoid the need for multiple computer interfaces and their related interrupt control software, a buffer unit has been designed to allow parallel connection of up to 4 users. Further user needs can be catered for by serial connection of the buffer units.

The unit is shown in Fig A7A. It utilises Texas Instruments interface circuits (SN 75150 and SN 75154) which have been designed to comply with the relevant PO interface requirements. A separate barrier circuit (NOLTON Communications DC 614) is incorporated in each output channel.

REMOTE SITE BUFFER

The requirement at the remote site is to operate more than one piece of equipment from the PO modem. Typically, this could be two Jasmin Mk 3 display stores, a Data Logging Unit and a Digital Tape Recorder. The fundamental difference between this unit and the Radar site buffer is that the barrier circuits are on the inputs. (Fig A7B).

Both units have been designed in accordance with the Post Office technical guides, Nos 5 and 26 and have been granted temporary PO approval.

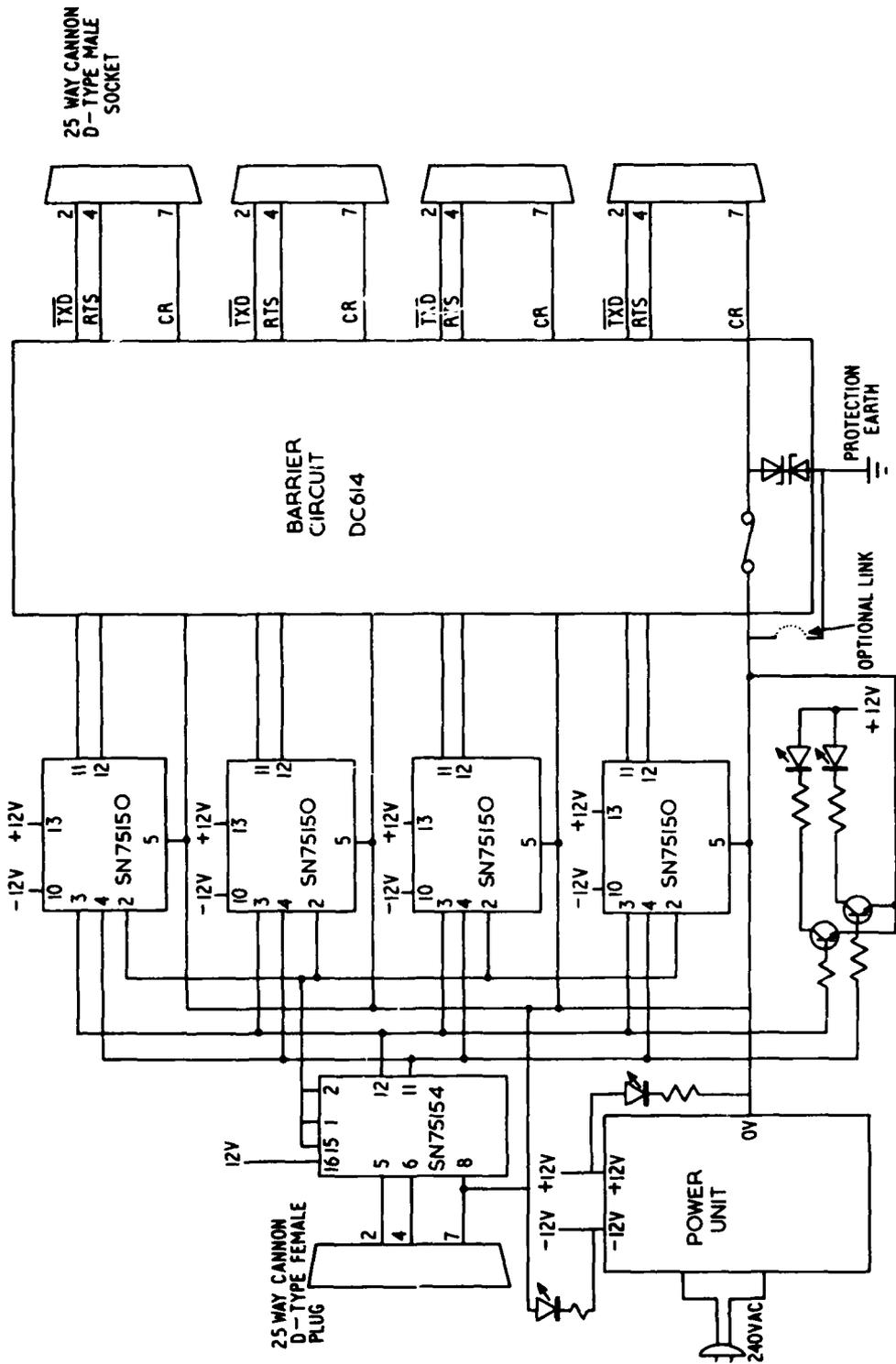


FIG. A7A
A FOUR CHANNEL MODEM BUFFER

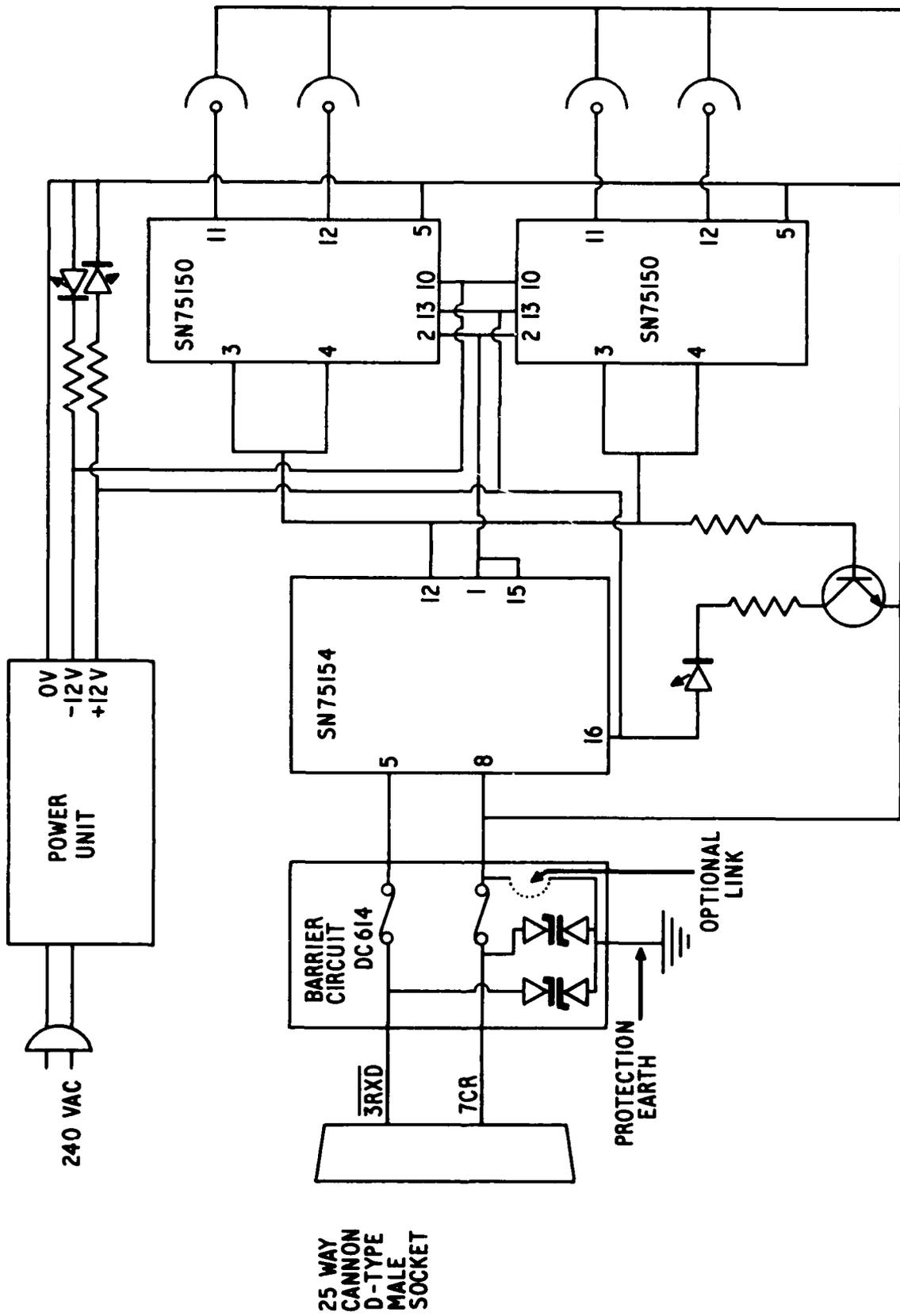


FIG. A7B. A FOUR CHANNEL DATA DISTRIBUTOR.

APPENDIX 8

OVERALL SOFTWARE DESCRIPTION

This appendix details the individual tasks of each of the 18 modules which make up the Camborne software program. Each module has a generic name (SETUP, TASKMASTER, etc) and will be referred to as such. Since various tasks can be taking place interactively, it is difficult to itemise the software in any other than the order in which the modules appear in the load map.

The software description and the accompanying flow diagrams in this Appendix are in broad outline only. The full listings contain greater than 100 pages of documented assembly code and can be made available on request.

Appendix 9 is a detailed description of the radar processing software.

Fig A8A gives an overall view of the tasks involved. This software is the result of approximately 5 man-years of effort involving 3 different programmers.

Many of the tasks have been operational for more than 4 years and were entirely the work of Mr B D Davy (RSRE). These include the ingenious polar-cartesian transformation routine described in Appendix 9.

The various modules which make up the complete program are itemised below with details of some of the less obvious routines.

A8.1 SETUP

Entered at switch-on time only. This is a baseload program which initialises all list areas, flags, interfaces, interrupt routines, etc. This module also contains the data allocation area for the majority of the lists and flags required in the program. The derivation and positioning of the TV numerics are contained in SETUP. Each numeric (1-9) is held in a 2-word look-up table (DIGITS). The 16 bits of the first word plus the lowest 4 bits of the second word are used as a 5 by 4 bit mask to describe the numeric (Fig A8B). Each line is treated as a 4 bit number (1st line is least significant). The position of the numeric is described in the tables DIGLINE and DIGCOLUMN and the total number of numerics used on the TV picture is held in DPLACES. The colour of the masked number and its background are held in a 2 byte array, DCOLOUR.

The rainfall rate values corresponding to a change in colour on the 3 bit TV display are held in their 8 bit "float" notation (A8.3n) in the list PLEVEL. The corresponding colours are held in the list PCODE. PCODE's colours assume that red takes the value 1, green 2 and blue 4. This gives the 8 colours and their corresponding values as:

COLOUR	VALUE
0	Black
1	Red
2	Green
3	Yellow
4	Blue
5	Purple
6	Cyan
7	White

se colours can be changed on the Jasmin Mk 3 display control panel to ch the user's requirements.

rainfall rates which fall below a preset value, NOISE, are cleared.

JP also contains the Time-Of-Day (TOD) list. This includes time, date, gram name and many other parameters associated with a particular task is used as the header for all magnetic tape files. Time and date are ated at 1 minute intervals by CLOCK (A8.9).

4 lists L0CLUT, L1CLUT, L2CLUT and L3CLUT are the storage areas for clutter maps for each of the 4 beam elevations. The length of these ts is dependant on the site and elevation and is normally trimmed to roximately 10% greater than the required initial map size. This is to ow adequate storage area when new clutter maps are requested which may be ghtly different due to seasonal variations, etc.

2 TASKMASTER (Fig A8.C)

ered initially from SETUP (A8.1) at baseload level. This is the control iple of the program which initiates the required radar task via CSI (A8.5). trol always returns to this module, either to perform a further task or await further instructions.

various tasks are separated into 2 types, one single-beam and the other tinuous PPI.

h single beam task is one data collection revolution of the aerial at an ator-defined elevation. (Beam 0, 1, 2 or 3) as follows:

a CLUTASK - Clutter map collection task (A8.8). If the data area reserved for the cluttered cells is exceeded, TASKMASTER reports to the teletype a CLFAIL error report (A8.4, A8.14).

b CLUPIC - Clutter picture generation on local TV display for on-site clutter analysis (A8.10, A8.11). If an illegal cell size has been inserted, this is reported as in a above.

c PPI - Rainfall intensity and distribution data collection task (A8.10, A8.11).

the end of both CLUPIC and PPI, it is the responsibility of TASKMASTER to:

Organise the update of the alpha-numeric legend in the TV picture display (A8.6).

Increment the TV Frame Sequence Number (Modulo 9999).

Output the TV picture, via the modem interrupt routine (A8.6), to on-site and remote users.

Check the occurrence of timing and data overflow errors in the software.

(Typically due to fast or erratic aerial rotation rate.)

Record these errors to teletype and/or magnetic tape.

Store data on magnetic tape.

The continuous PPI task is described in the main text (4 (2)). TASKMASTER monitors this task at the end of each beam, performing the tasks mentioned above except that the Frame Sequence Number update and TV picture output take place only at 15-minute intervals.

Other functions relating to the continuous PPI task only are to:

Initialise the transmission of 5 km 8-bit data to the network centre (A8.15).

Set up the magnetic tape recording mode for the next beam - different data sets are recorded for each elevation.

Set up elevation for the next beam.

Check that the task has not exceeded the allocated time available. The 4 beams are repeated 3 times in a 15-minute interval. If this sequence is incomplete, the software forces sequence termination and a subsequent restart on Beam 0.

A8.3 SUBROUTINES

This module contains various routines which are required by the program in general. These are:

- a ATOBIN - Decimal, octal or binary ASCII string conversion to binary.
- b CONVERT - Binary to ASCII string conversion.
- c SAVE and UNSAVE - Register protection routines.
- d DMASTOP - RSAU and Azimuth interrupt switch-off.
- e REVCHECK - Converts angles $>360^{\circ}$ to their $0-360^{\circ}$ equivalent.
- f CLEARANCE - General list clearance.
- g NEGSET - As above, but forces -1's into all values in list, (used in the Polar-Cartesian transformation).
- h SINCOMP and COSCOMP - Calculates the X and Y incremental co-ordinates of a polar angle.
- j DELAY - Allows time delays from 1-60 secs.
- k GETAZ - Measures the Azimuth 12-bit binary value. (LSB = 0.1°)
- l MOVECHECK - Checks aerial rotation. If the aerial has stopped, error is reported to the teletype.
- m LOOPSET - General list handling routine to set processing limits.

- n FLOAT - Converts 12-bit binary values to their 8-bit "float" notation equivalent. The low 6 bits contain the positive integers and the top 2 bits, the exponent. Exponent values are 2^0 , 2^2 , 2^4 and 2^6 giving a total range with an LSB of $1/64$ mm/hr of $1/64 \rightarrow 63$ mm/hr.
- o RMT and - Read and write bootstrap to load or dump a program
WMT to and from magtape. The load function has been superceded by the mini-monitor (Appendix 10) but the dump is useful in the event of a malfunction when the contents of the computer core can be saved for later analysis.

A8.4 TELETYPE

General purpose module to control input (keyboard) and output (punch) to teletype in interrupt mode. The teletype is not absolutely essential to the site operation but is a useful aid, especially in the early development stage, for program control and diagnostic routines. Input commands, via the keyboard, are interpreted by CSI (A8.5). The usual DEC features are allowed (ie delete, delete line, comment, if preceded by semi-colon). The input and output buffers (one of each) are limited to 64 bytes and any attempt to exceed this number without a terminating character (carriage return or Control U) is forcibly terminated (and error-reported) by the software.

When an input command is terminated, a flag is set to be serviced by the SCHEDULER (A8.18). This allows entry to CSI (A8.5).

A8.5 CSI (COMMAND STRING INTERPRETER)

Entered, at 1 second intervals, if the keyboard flag has been set. Interprets all keyboard input messages and reports errors in Command via TELETYPE (A8.4). (In the absence of a teletype, commands could be inserted via the computer switch register.)

If the input command is legal, CSI sets up the conditions for the required task and prints "OK". These tasks are listed below:

- | | | | |
|---|---------------------|----------------|---|
| a | TI 1200 | Time (NOON) | Enters the Time of Day (TOD) list. Normally used only at switch-on time. |
| b | DA 251278 | Date (XMAS) | Similar to a above. |
| c | LI xxxxxx | Lights | Outputs the contents of Octal address xxxxxx to a set of 16 lights at 1 second intervals. Useful diagnostic aid. LI 0 is a special case to switch off the lights interrupt. |
| d | PA xxxxxx | Print Address | Allows teletype print of any even octal address. |
| e | CA xxxxxx
xxxxxx | Change Address | Similar to d above but changes the octal address to contain the second value. Both "old" and "new" values are printed. |

The following input commands control the data collection operation of the system:

The single beam task commands are:

f	BM x	PPI task on beam x	x can take values 0, 1, 2 or 3 only. (A8.13c). Any other value is error-reported.
g	CL x	Clutter map collection	Rules as in f above. If the task exceeds the preset data area, "CLFAIL" is printed.
h	CP x y	Clutter picture, beam x, cell size y (metres)	Software checks ensure that the cell size can be processed.

For each of these tasks (f, g and h), the "OK" report, signifying correct input parameters, is followed by a message describing the task. ("PPI" for f and h, "CLUTASK" for g). At the end of the task, the subroutine FAULT, in TASKMASTER (A8.2), reports any timing errors or data overflow. Termination of the task is indicated by the report "WAITING".

The 4-beam continuous PPI task commands are:

j	RU	Run Continuous task	The "OK" report is issued immediately. The task cannot start, however, until the next "GO" command from the CLOCK module (A8.9). These occur at 15-minute intervals, locked to the time (preset by the "TI" Command). At this time, a report "4 BEAM TASK RUNNING" is printed.
k	ST	Stop Continuous task	Again, "OK" is printed immediately. The task is not terminated until the end of the current beam. At this time the 2 reports, "4 BEAM TASK TERMINATED" and "WAITING" are printed.

A8.6 MODEM

A synchronous 600 baud modem interrupt routine initialised in SETUP (A8.1). Outputs TV picture and subcatchment data, control and check characters (Frame sync, line sync, tape-recorder control, subcatchment subset control, block check characters etc) to local and remote users. The module also contains the sub-routine RECORD, called by TASKMASTER (A8.2) to update the alpha-numeric and legends in the 4 corners of the TV display.

A8.7 POWERLAW

Entered from PPI (A8.10, A8.11) at baseload level. Contains a 1024 word look-up table to convert radar values to equivalent rainfall rates. The assumed relationship between amplitude (a), the output of the RSAU and rainfall, R is

$$a^2 = KR^{1.6} \text{ where } K \text{ is a constant normally assumed to take the value } 200.$$

The output of POWERLAW is the solution to the equation

$$R = \frac{1.6 \sqrt{a}^2}{8} = \frac{a^{1.25}}{8} \text{ where the } 8 \text{ is a convenient scaling factor.}$$

The overall calibration of rainfall is a function of this solution, various other scaling factors, the value of the work SENSITIVITY plus a correction for the $1/r^2$ dependance of the signal return beyond the maximum range of the PIN diode (RCORRECTION) (A8.13).

A8.8 CLUTASK

Entered from TASKMASTER (A8.2) when CSI (A8.5) has detected a "CL x" command. Collects a polar map of cluttered cells in a similar manner to the normal PPI task (A8.10, A8.11). A cluttered cell is a cell whose amplitude exceeds a threshold, CLUTTER, preset in SETUP (A8.1). This value is normally set to the same as the value NOISE in SETUP. The task should be performed only in the absence of precipitation and anomolous propagation. Clutter maps should be collected for each of the 4 beams and storage of these maps for insertion in future programs is effected by use of the Mini Monitor (Appendix 10). Further details of this program are contained in Appendix 9.

A8.9 CLOCK

Entered, via SCHEDULER (A8.18) at 1 second intervals. The module performs the following tasks:

- a Updates time to the time-of-day (TOD) list.
- b Updates date to the time-of-day (TOD) list.
- c outputs "GO" commands to the continuous 4-beam task on the quarter-hour
- d Outputs time to the teletype on the hour.
- e Outputs time and date at midnight.
- f Initiates subcatchment data averaging hourly and daily.
- g Initiates magtape rewind at 12-hour intervals. (Preset to 0900 and 2100 GMT in "MAP" (A8.13).) (See also Appendix 11 for data packing techniques.)

A8.10, A8.11 - PPI (This module is split into 2 routines simply to reduce the physical size of each to ease editing and assembly)

A detailed description is contained in Appendix 9 but a summary is included here:

Entered from TASKMASTER (A8.2) at baseload level. Can be single-beam PPI or Clutter picture or continuous 4-beam task depending on the parameters derived from CSI (A8.5). The tasks are:

- a Set up range processing limits.

- b Clear all input polar data lists.
- c Preset all polar-cartesian data lists to -1.
- d Calculate the next quadrant angle.
- e Initiate digital video data transfers from the RSAU at the angle calculated in d above to continue for 1 aerial revolution.

The following tasks are run under interrupt control, initiated by a 0.1° change in azimuth, and synchronised to the next radar transmitter pulse.

- f Transfer RSAU data to input list, LIST1, by direct memory access.
- g Sum successive input data transfers in separate list, LIST2, and keep count of number of entries in SCANS.
- h At 1° intervals (SCANS = 10), average LIST2 data. (Divide LIST2 by SCANS, answer in LIST3).

Meanwhile, at baseload level:

- k Adjust LIST3 values for clutter by interpolating in range across cluttered cells.
- l Adjust LIST3 values for occultation effects.
- m Average LIST3 data from 750 metre 0.1° polar cells to 1.5 km 1° polar bins.
- n Convert the LIST3 values to their rainfall rate equivalent.
- o Apply polar-cartesian transformation on LIST3 data. (From 1.5 km, 1° polar bins to 2 and 5 km grids). Note that clutter picture is a special case. One grid only is used - dimensions are preset by the CP x y call.

A8.12 MAGTAPE

Direct memory access transfer, initiated by TASKMASTER (A8.2) at the end of the task for each beam.

This routine is responsible for the storage of the following data sets:

- a 2 km grid (50 x 50 bytes). 8-bit "float" notation data. Lowest elevation only.
- b 5 km grid (84 x 84 bytes). 8-bit "float" notation data.
- c Subcatchment data (1500 bytes) (A8.16).
- d Time of day (TOD) list (128 bytes).

The routine also looks after general housekeeping tasks such as magtape availability (ON-LINE, WRITE-ENABLE etc), rewind and the generation, via "SITEMESSAGE" (A8.14), of magtape status reports to the teletype.

A8.13 MAP

This module contains information which is site-dependant. These are:

- a Magtape change times (Preset to 0900 and 2100 GMT). (See also Appendix 11)
- b Subcatchment daily total printout time (Preset to 0900 GMT).
- c Elevation angle table. (Defines the elevation angle of each of the 4 beams.)
- d SENSITIVITY or system calibration factor. This value is directly related to the programming of the read-only memory in the RSAU, the look-up table in POWERLAW (A8.7) and various scaling factors within the software. The read-only memory is programmed to give an output equivalent to 4 mm/hr at the midpoint value of the 8-bit output of the A-D convertor. Each bit on the A-D convertor equates to 0.25 dB (ie 256 x 0.25 dB = 64 dB, the dynamic range of the logarithmic receiver for an output of 0 to 2 volts). The resultant overall dynamic range is -32 dB to +31.75 dB (-20 to +19.84 dB rainfall rate equivalent). The software is therefore capable of measuring rainfall rates from 0.04 mm/hr to 384 mm/hr. (But note that the 8-bit FLOAT notation (A8.3n) limits the maximum to 63 mm/hr.)
- e $1/r^2$ correction beyond range of swept-gain hardware (>50 km).
- f Program name (6 ASCII characters). This is stored on the magtape in the TOD list.
- g Radar site offset wrt nearest SW 10 km Ordnance Survey Grid crossing. This is to simplify the compositing software at the network centre.

A8.14 SITEMESSAGE

Entered, at baseload, by a call from various modules. Contains 2 types of output to the teletype in interrupt mode.

- a A library of standard messages (eg "WAITING").
- b A set of site reports that are capable of synthesising the output message from the data contained in its input message (eg to indicate software processing errors).

A8.15 DATATRANSMIT

Entered, at baseload level, from TASKMASTER (A8.2) at 15 minute intervals. This module is responsible for initialisation and transmission of the 5 km 8-bit data required at network centre.

The following protocol is observed:

- a The transmission is interrupt controlled.
- b The data is sent as 14 blocks, each of 6 lines of 84 characters. Each block is preceded by start, block number and block check characters, and terminated by an end character. The time of day list is sent preceded by a start character and terminated by a final block character. Control characters are sent 3 times to improve data confidence.

c The complete set of 14 blocks and time of day list plus control characters is transmitted twice to allow corrective procedures in the event of errors at network centre.

A8.16 SUBCATCHMENT

Entered, from TASKMASTER (A8.2), at baseload level after each surface beam of the continuous 4-beam task. Selects data (by masks) for each of the sub-catchments either from the 2 km grid for ranges up to 50 km or the 5 km grid (Ranges beyond 50 km). A description of this mask process is shown in Fig A8D.

Sums this data into 2 separate lists, one for hourly and one for daily averaging.

Converts list data to BCD format for hourly and daily output. The lists also include time, date, subset number and modulo 9 counters to identify both hourly and daily data.

The output data is transmitted, after the TV picture, by MODEM (A8.6).

A8.17 PRINT

Entered, for diagnostic purposes only, from SUBCATCHMENT (A8.16) if the flag TTYSC is set (normally cleared at initialisation time). Routine prints sub-catchment data to teletype.

A8.18 SCHEDULER

Entered, initially from SETUP (A8.1), to plant software trap vectors and to enable the 1 second clock interrupts. Thereafter, entered on interrupt. The tasks are:

- a Force entry to CLOCK program.
- b Service keyboard commands if flag is set.
- c Service PA, CA and LI outputs if the various flags have been set by CSI (A8.5).

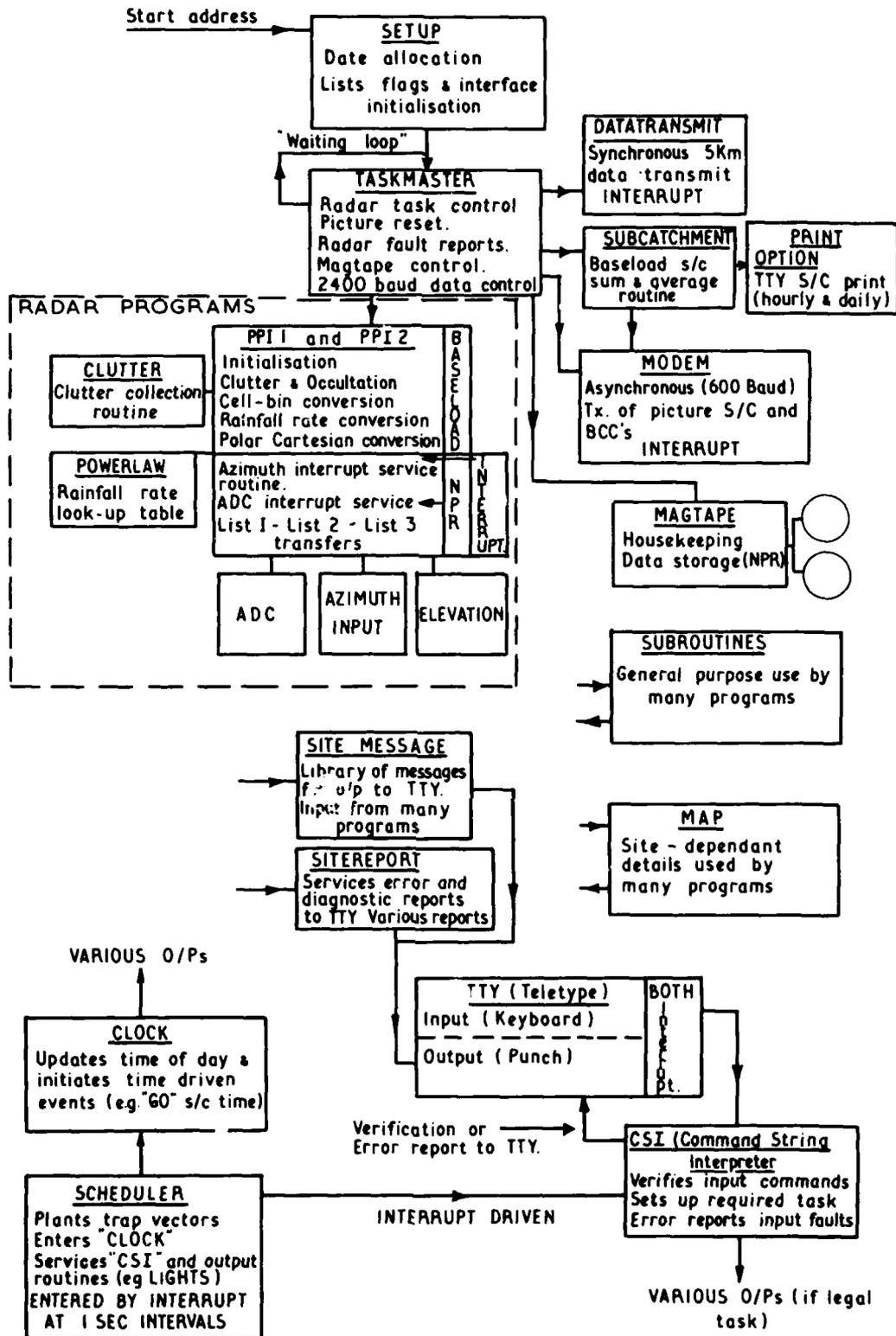


FIG. ABA.

OVERALL SOFTWARE FLOW DIAGRAM

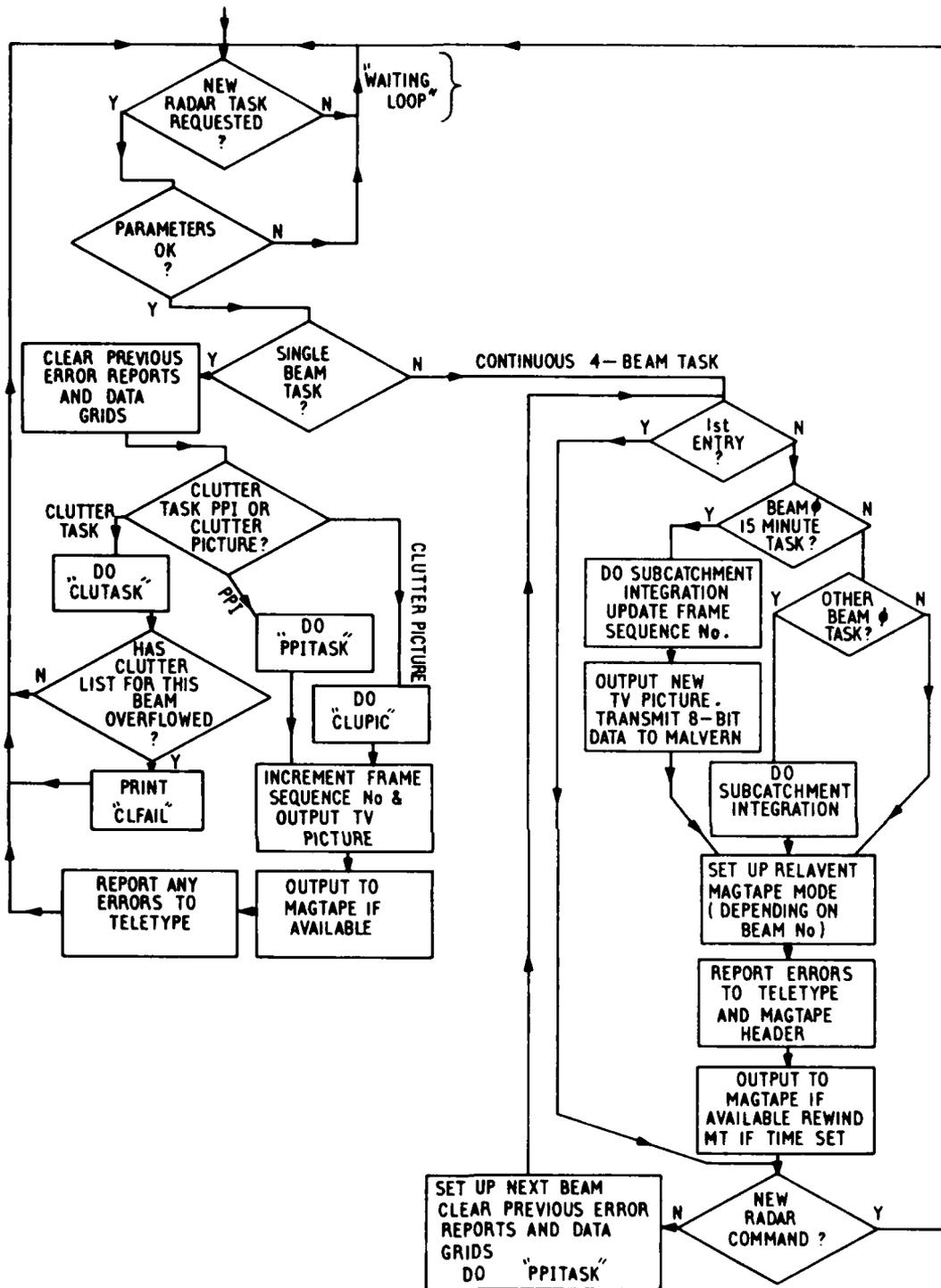
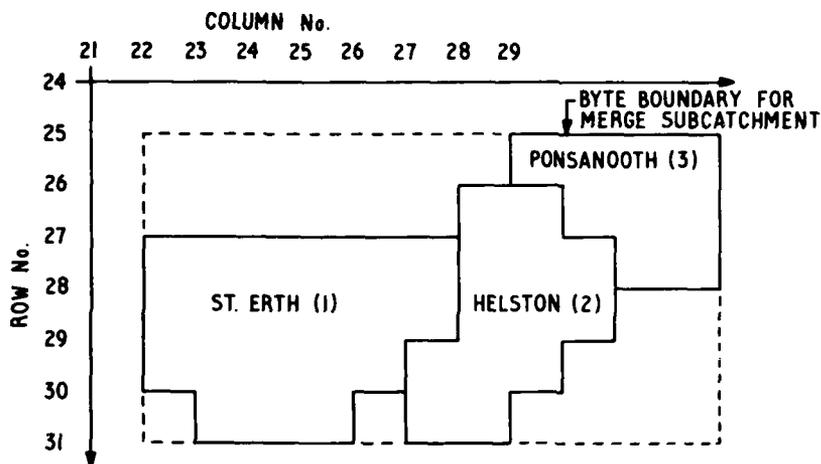


FIG. ABC
TASKMASTER



	1	2	3	4	5
SUBCATCHMENT	ROW No.	COLUMN No.	No. OF BYTES	No. OF ROWS	DATA MASK
ST. ERTH (1)	27	22	1	4	77,77,37,16
HELSTON (2)	26	27	1	5	6,16,16,7,3
PONSANOOTH (3)	25	29	1	3	17,16,14
MERGE OF (1) (2) AND (3)	25	22	2	6	200,7,300,7,377,7, 377,1,377,ϕ,156,ϕ

SUBCATCHMENT DATA IS DERIVED FROM EITHER THE 2KM GRID (RANGE < 50KM) OR THE 5KM GRID [RANGE 50 → 200KM].

THE LIST CONTAINS

1. ROW No. OF RELAVENT GRID
2. COLUMN " " " "
3. No. OF BYTES (8BITS) TO COVER THE S/C IN THE X DIRECTION.
4. No. OF ROWS TO COVER THE S/C IN THE Y DIRECTION.
5. DATA MASK. (SEE BELOW)

} THESE ARE DECIMAL VALUES DERIVED BY ENCLOSING THE SUBCATCHMENT BY A SQUARE.

THE DATA MASK.

1,2,3 AND 4 ABOVE GIVE THE SQUARE WITHIN WHICH THE RELAVENT SUBCATCHMENT CELLS ARE CONTAINED. THE DATA MASK SETS A BINARY 1 VALUE IN EACH CELL WHICH IS IN THE S/C AND ϕ ELSEWHERE. THE SQUARE IS BYTE ORIENTED WITH THE LSB AT THE LEFT.

NOTE THAT DATA MASK VALUES ARE OCTAL [77 = 11111100 (LSB AT LEFT)].

THE EXAMPLE SHOWS 3 SUBCATCHMENTS IN USE AT CAMBORNE PLUS A MERGE OF ALL 3 TO SHOW HOW THE SOFTWARE MANAGES S/C DATA EXTENDING OVER MORE THAN 1 BYTE IN THE X DIRECTION.

FIG. A8D. DERIVATION OF SUBCATCHMENT DATA CELLS.

APPENDIX 9

DETAILED DESCRIPTION OF RADAR PROCESSING SOFTWARE

A9.1 PPITASK

Figures A9A and A9B give an overall description of the radar task and a detailed view of the implementation of the radar control program PPITASK.

Data processing is partly at baseload level and partly interrupt-driven. Referring to Fig A9A, the task begins with an initialisation routine at baseload level. This includes:

- a Aerial elevation positioning.
- b Check of aerial rotation.
- c Initialisation of flags and lists.
- d Radar Signal Averaging unit input interface initialisation to enable video interrupts.
- e Azimuth interrupt initialisation for 0.1° interrupts.
- f Calculation of the start and end angle of next quadrant.
- g Setting of clutter map pointers depending on the start quadrant.
- h Set-up of maximum polar range for the PPI task (210 km) or CLUPIC (Clutter picture) task (Dependant on input command - see Appendix 8).

The baseload program then spins in a loop, with azimuth interrupts at 0.1° intervals, where it waits for the present input angle (INTAZ) to equal the calculated start angle (L3AZ and GRIDAZ). At this time, a flag DMAGO is set to enable the interrupt-driven input data processing to begin as follows:

The next radar transmitter pulse enables the transfer of digitised video data from the Radar Signal Averaging Unit (RSAU) to the computer. A master clock operates at a frequency of 8 MHz which corresponds to a maximum overall range delay error of less than 20 metres. This clock is divided by 10 to provide the RSAU digitisation rate. The digitised values are averaged within this unit and transferred to the computer at a 0.2 MHz rate by Direct Memory Access.

In normal error-free conditions, the output data from the RSAU (290 range cells, each of 750 m at 0.1° azimuth intervals) are entered into LIST1 and further added into the initially zeroed LIST2. A count of each entry from LIST1 to LIST2 is held in SCANS.

When the input azimuth angle (INTAZ), which is updated at 1° intervals, is different from L3AZ, the LIST2 values are averaged into LIST3 (LIST3 = LIST2 ÷ SCANS). This gives an average value for each of the 290, 750 m, 1° range segments. L3AZ is now updated to pick up the new value of INTAZ ready for the next 1° integration processing.

At baseload level, the 1° angle change is detected ($L3AZ \neq GRIDAZ$) and the baseload processing begins. For the PPI task, this involves Clutter cancellation (Fig A9D), occultation correction, further averaging from 750 m polar cells to 1.5 km polar bins and conversion from amplitude to range normalised rainfall rate. The CLUPIC task does not enter these routines but displays instead a TV picture of the clutter amplitudes with a cartesian cell size determined by the input request.

The modified LIST3 values, now containing rainfall rate data to a 12-bit accuracy, are then converted from polar values to their cartesian equivalents (Figs A9E1 and 2 and A9.3 below).

The baseload program then checks to see if this is the last angle for this aerial revolution ($L3AZ = LASTANGLE$). If not, the program spins awaiting the next 1° change in azimuth and updates GRIDAZ to the new value of L3AZ. (The interrupt-driven 0.1° changes in azimuth occur concurrently.)

At the end of the aerial revolution ($L3AZ = LASTANGLE$), a routine is entered to disable the interrupt routines for both the azimuth and the RSAU and to return control to the overall baseload control program TASKMASTER.

Two flags, P2DONE and P6DONE, allow graceful degradation of data processing in the event that the processor cannot keep up with the real time task. This situation can occur if the aerial rotation rate, and hence the azimuth interrupt interval, is erratic. If, when it is time to add the LIST1 values into LIST2, P2DONE indicates that LIST2 to LIST3 transfers are incomplete, the processor simply leaves LIST1 to be over-written by the next input transfer. The system will catch up at the end of the current 1° integration bracket, when SCANS will be one less than it would normally have been. If, when it is time to transfer data from LIST2 to LIST3, P6DONE indicates that baseload processing of LIST3 data is still in progress, the LIST2 data is not transferred. The effect is that the end of the 1° bracket is rotated (by 0.1°) so that SCANS is one greater than it would normally be. Normal timing will be resumed at the end of the next 1° bracket, when SCANS will be one less than normal.

A count of the incidence of these errors is recorded on teletype and magnetic tape at the end of each aerial revolution.

A9.2 CLUTASK (Clutter map gathering task)

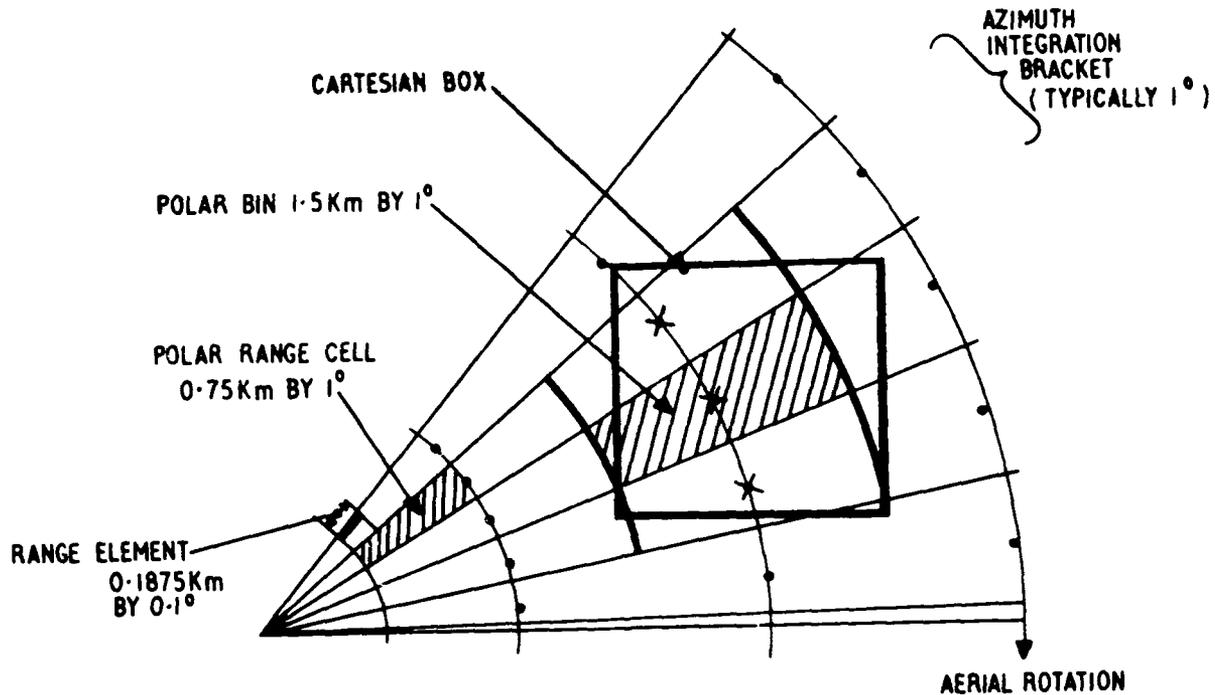
This is similar in operation to PPITASK except that the LIST3 amplitude values are compared with a pre-defined clutter threshold (CLEVEL). If this is exceeded, the polar cell is designated as cluttered. A simplified block diagram is shown in Fig A9C.

Fig A9D refers to the software necessary to use a previously gathered clutter map in the main PPITASK program. The clutter map is stored as the start and finish range cell numbers of the cluttered polar cells.

A9.3 POLAR TO CARTESIAN CO-ORDINATE TRANSFORMATION

The number of integrated polar bins which are handled in one aerial revolution is typically $>50,000$ (ie 145 range bins, each of 1.5 km, at 1° intervals). Each cell should retain the 12 bit rainfall rate accuracy inherent in the input hardware. To store this amount of data would demand an array which is twice as large as the total capacity of the present computer core.

The method used is a real-time transformation and integration from polar bins into cartesian grids of 2 km and 5 km squares, (GRID2 and GRID5), based on the National Grid. This uses a limited number of cartesian BOXES for any one azimuth, each one of which can accept a number of data entries from the appropriate polar bins for that particular azimuth as the following diagram illustrates.



. - denotes the centre of a typical polar bin

x - denotes the centre of a typical polar bin which is to transfer its data to the cartesian box shown

The LIST3 data is integrated into the appropriate cartesian box. This method removes the requirement for very large data areas but does place a strict limit on the length and efficiency of the software in the conversion routine. In order to preserve accuracy, the conversion to the 8-bit "float" notation (Appendix 8.3) is applied after it is known that no more polar bin entries are expected in the cartesian box on this aerial revolution.

DETAILED DESCRIPTION

Each value of the input data list, LIST3, has its own corresponding location in the lists SUM2, SUM5, COUNT2, COUNT5, BOX2, BOX5 relevant to the arrays GRID2 and GRID5. The algorithm performs sequentially for the two grids (for convenience, the generic names SUM, COUNT, BOX and GRID will be used).

- BOX is a list of cartesian box numbers, corresponding to each polar bin, derived by program P5 (see below), from a knowledge of the current input azimuth angles.
- SUM is a list of summations of LIST3 rainfall rate data relevant to its corresponding box number in the BOX list.
- COUNT is a list of the number of entries of LIST3 data to the SUM list. An average value of the rainfall rate data collected in a given BOX can thus be derived from the corresponding SUM and COUNT lists when the data is passed into the GRID.
- GRID is a two-dimensional array of boxes, numbered in TV raster scan order from the top left hand corner (Fig A9E3). The box number is the index that is used to access the box in the GRID.

Each polar value in LIST3 is a 12-bit rainfall rate which constitutes one input to the cartesian box masked by the polar co-ordinates (measured from the radar position) derived from L3AZ and the LIST3 polar bin position in the list. L3AZ contains the end angle of the 1° azimuth integration bracket - thus the polar angle used is $L3AZ - 0.5^\circ$.

Only a small number of cartesian boxes will be masked by corresponding polar bins along one azimuth and hence only these boxes need be in an "open" condition (ie capable of accepting inputs). These successive inputs of data to each box are summed in the SUM list for those boxes which are open and the number of inputs to each open box is contained in the COUNT list. An average value can be derived when a box is eventually "closed" to further inputs (ie the knowledge of the current aerial position dictates that no further inputs to a box are possible).

Hence, at any one time, only a small number of boxes will be open and boxes which have been opened and then closed, and an average value transferred to the GRID, will stay closed for the duration of the current aerial revolution. Thus a considerable saving in core storage can be achieved by keeping BOX, SUM and COUNT list values only for open boxes.

The primary functions of the four major programs required to implement this software are described below.

P5 This program reviews the BOX list when LIST3 data is available (ie when the data corresponding to a polar bin has been converted to a corrected 12-bit rainfall rate value). It is responsible for calculating the box number relevant to the LIST3 polar bin centre and placing this value in the BOX list. It is also responsible for calling program P6 if P5 finds that a new box number, NEWBOX, differs from the value already planted in the BOX list from previous entries, OLDBOX.

P6 This program is ultimately responsible for passing the data from closed boxes into the GRID. To this end, it uses the services of several sets of buffers and list searches to ensure that boxes are not closed prematurely.

If a box number NEWBOX is calculated that differs from the box number, OLDBOX calculated in the BOX list then the OLDBOX data values (ie BOX number, and corresponding SUM and COUNT value in appropriate lists)

must be displaced and the data stored in order to make room in the BOX list for the NEWBOX data values. This is achieved as follows: A check is made of the BOX list to see if the OLDBOX data values that are about to be displaced by NEWBOX data values can be added to another entry in the box list with the same box number. This search is confined to either side of the present OLDBOX position and if successful the appropriate data values are added to those already present. This displacement of OLDBOX, and its corresponding data values (SUM, COUNT), will release a space in the BOX list for the NEWBOX number and zero the SUM and COUNT values. This is done with the use of a set of intermediate buffers (ISUM and ICOUNT) that are always cleared to zero on entry to P6 and so when used in this case will transfer zero to the appropriate SUM and COUNT values.

If a search of the BOX list is unsuccessful in locating a place for the displacement of OLDBOX then it is tentatively assumed that this box is about to 'close' (due to the geometry of the system). A double buffer system of FBOX and TBOX boxes is used to actually achieve permanent closure of the box whilst ensuring that any possible further entries are not prohibited from entry. The OLDBOX data values are put into the first buffers (FBOX, FSUM and FCOUNT) to allow the BOX, SUM and COUNT lists to be updated to NEWBOX with SUM and COUNT zeroed via the I buffers as above.

ISUM and ICOUNT are used if a later entry to P6 finds the F buffer FBOX contains the same value as NEWBOX. In this case, ISUM and ICOUNT pick up the FSUM and FCOUNT values for transfer back to the SUM and COUNT lists corresponding to NEWBOX.

If the FBOX number is not equal to NEWBOX, the F Buffers are transferred to the Transfer buffers. (TBOX, TSUM and TCOUNT). In either case, since the F Buffer data has been released, the F buffers are available for the next P6 entry. A similar data handling occurs for the T Buffers with the exception that if TBOX does not equal NEWBOX, then the box is assumed to have closed and the program GRIDTRAN transfers the averaged data (SUM : COUNT) to the GRID.

(P7 is concerned with a previous software task and is not used now.)

- P8 When P5 (and P6) have reorganised the relative numbers in the BOX list, P8 is responsible for summing the LIST3 data into the SUM list and incrementing the COUNT list.
- P9 When the last azimuth data has entered the BOX, SUM and COUNT lists, P9 is responsible for closing all boxes since no more entries are expected. It uses the facilities of P6 to empty these boxes and also empties the F and T buffer data into the GRID.

The simplified flow diagrams are illustrated in Figs A9E1 and 2).

A simplified form of the algorithm is described below with the aid of Fig A9E3. Three sets of LIST3 inputs are shown for adjacent azimuth integration brackets. (The list length has been reduced to 10 range elements, (ie polar bins), for simplicity.) The dots mark the centres of the polar bins which are contributing rainfall rate values signified by the associated numbers. The cartesian box numbers are also marked. Initially all BOXES are empty, including both the

FBOX and TBOX. (Signified in the software by the presence of -1 in the BOX.) This simplified example does not need the services of the Intermediate buffers, ISUM and ICOUNT, except to transfer zero values to the SUM and COUNT lists since NEWBOX is never equal to either FBOX or TBOX.

Column 1 in Fig A9E3 shows the condition of the BOX, SUM and COUNT lists after the first operation of P5 and P8. (P6 is not called to deal with this first entry since all previous box numbers (OLDBOX) were -1.)

Column 2 in Fig A9E3 shows the lists after the second operation of P5 in anticipation of the second LIST3 input via P8. Each polar bin is considered in turn and the effect on the list values for other bins and the F and T buffers are shown below.

POLAR BIN NO	CALCULATION AND OPERATIONAL DESCRIPTION	F BUFFERS			T BUFFERS		
		FBOX	FSUM	FCOUNT	TBOX	TSUM	TCOUNT
1	P5 calculates NEWBOX = OLDBOX. P6 is not called and SUM and COUNT values are unchanged	-1	∅	∅	-1	∅	∅
2		"	"	"	"	"	"
3		"	"	"	"	"	"
4		"	"	"	"	"	"
5	NEWBOX = 36. OLDBOX = 25. Since both F and T boxes are empty, P6 immediately searches for another bin with OLDBOX = 25. BIN 6 is found and BIN5's SUM and COUNT values are added to BIN 6 leaving BIN 6 as BOX = 25, SUM = 2, COUNT = 2 (henceforth referred to as 25, 2, 2). BIN 5 becomes 36, ∅, ∅.	"	"	"	"	"	"
6	NEWBOX = 26. OLDBOX = 25. Similar to bin 5 above. Bin 7 becomes 25, 3, 3 and bin 6, 26, ∅, ∅.	"	"	"	"	"	"

POLAR BIN NO	CALCULATION AND OPERATIONAL DESCRIPTION	F BUFFERS			T BUFFERS		
		FBOX	FSUM	FCOUNT	TBOX	TSUM	TCOUNT
7	NEWBOX = 26. OLDBOX = 25. P6's search of the BOX list now finds no other OLDBOX value of 25. OLDBOX is .'. moved to the FBOX with it's associated SUM and COUNT. Bin 7 becomes 26, 0, 0.	25	3	3	"	"	"
8	NEWBOX = 16. OLDBOX = 15. P6 first deals with the full FBOX. Since this is not equal to NEWBOX, the F Buffers are moved to the T Buffers. OLDBOX is not found in BOX list and is placed in FBOX. Bin 8 becomes 16, 0, 0.	15	0	1	25	3	3
9	NEWBOX = 17. OLDBOX = 16. P6 first deals with T Buffers which, not being equal to NEWBOX, are put to the grid using the services of program GRIDTRAN. FBOX is also unequal to NEWBOX and thus the F Buffers are moved to the T Buffers. P6's search finds Bin 8 value = OLDBOX and adds present value of Bin 9 to old value of Bin 8. Bin 8 .'. becomes 16, 2, 1 and Bin 9, 17, 0, 0. The FBOX remains empty.	-1	0	0	15	0	1
10	NEWBOX = 17. OLDBOX = 6. T Buffers to GRID. OLDBOX value to F Buffers. Bin 10 becomes 17, 0, 0. T Box remains empty.	6	4	1	-1	0	0

Note that BOX numbers 25 and 15 have now closed. Column 3 in Fig A9E3 shows the result of the action of P8 for the second set of LIST3 samples. These values have simply been added into the SUM and COUNT lists relevant to the BOX list calculated above.

Column 4. The effect of P5 setting up the BOX list for the third input of LIST3 data is as shown below.

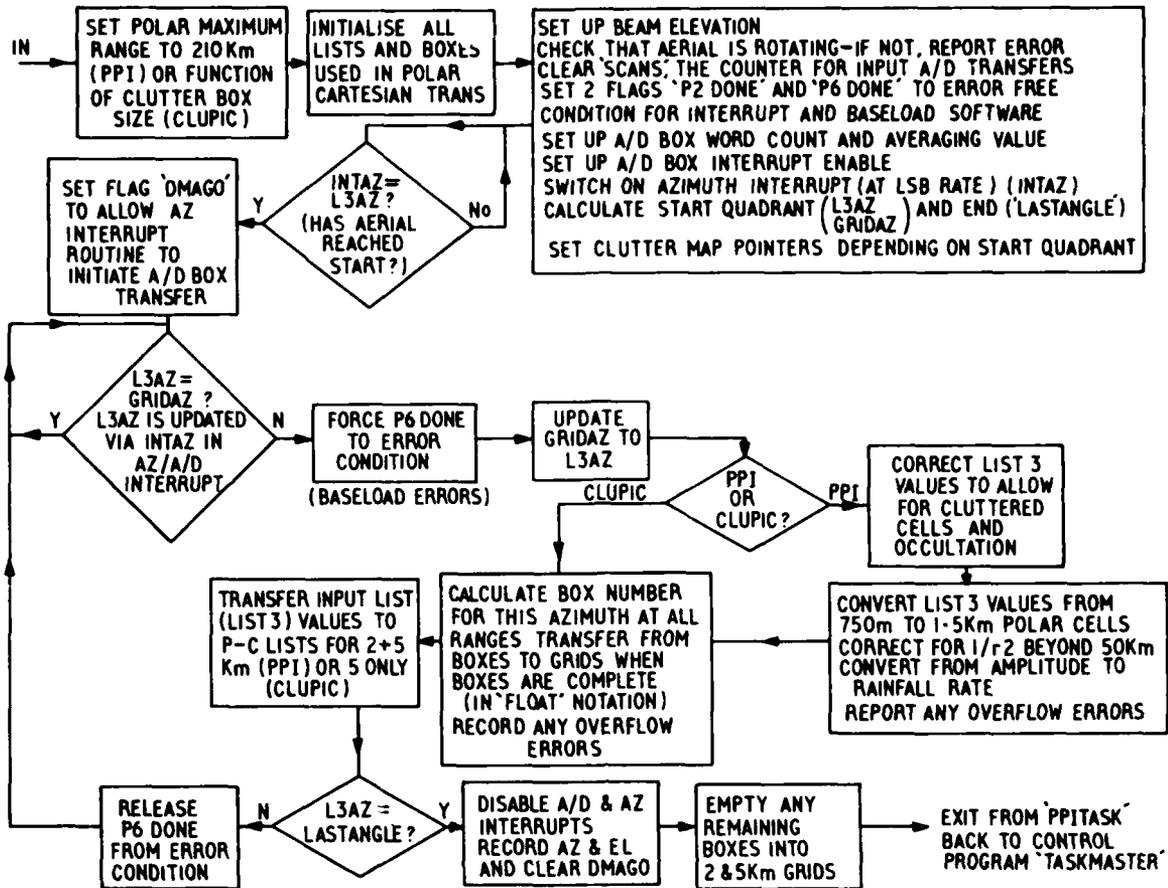
POLAR BIN NO	CALCULATION AND OPERATIONAL DESCRIPTION	F BUFFERS			T BUFFERS		
		FBOX	FSUM	FCOUNT	TBOX	TSUM	TCOUNT
1	NEWBOX = OLDBOX	6	4	1	-1	0	0
2	.∴ no call to P6						
3	NEWBOX = 45. OLDBOX = 35. F Buffers to T Buffers. OLDBOX values added to BIN 4 which becomes 35, 22, 4. Bin 3 becomes 45, ∅, ∅. F Box now empty.	-1	∅	∅	6	4	1
4	NEWBOX = 36. OLDBOX = 35. T Buffers to GRID. OLDBOX values to F Buffers. Bin 4 becomes 36, ∅, ∅. T Box is now empty.	35	22	4	-1	0	0
5	NEWBOX = OLDBOX .∴ no call to P6.	"	"	"	"	"	"
6	NEWBOX = 37. OLDBOX = 26. F Buffers to T Buffers. Bin 6's values added to Bin 7 which becomes 37, ∅, ∅. F Box now empty.	-1	∅	∅	35	22	4
7	NEWBOX = 27. OLDBOX = 26. T Buffers to GRID. OLDBOX value to F Buffers. Bin 7 becomes 27, ∅, ∅. T Box now empty.	26	1	2	-1	∅	∅
8	NEWBOX = 27. OLDBOX = 16. F Buffers to T Buffers. OLDBOX values to F Buffers. Bin 8 becomes 27, ∅, ∅.	16	4	2	26	1	2
9	NEWBOX = 28. OLDBOX = 17 T Buffers to GRID. F Buffers to T Buffers. Bin 9's values added to Bin 10 which becomes 17, 4, 2. Bin 9 becomes 28, ∅, ∅. F Box now empty.	-1	∅	∅	16	4	2
10	NEWBOX = 28. OLDBOX = 17 T Buffers to GRID. OLDBOX values to F Buffers. Bin 10 becomes 28, ∅, ∅. T Box now empty.	17	4	2	-1	∅	∅

Note that boxes 6, 35, 26 and 16 have now closed.

Column 5. The new LIST3 values are added in from the third set of LIST3 data.

The program continues until the end azimuth is reached (LASTANGLE) when P9 organises the BOX list and the F and T Buffers by closing all remaining boxes and transferring their data to the GRID.

(ENTERED FROM TASKMASTER AT BASELOAD LEVEL. PERFORMS 1 REVOLUTION FOR EACH ENTRY.
 A FLAG INDICATES, AT ENTRY, WHETHER TASK IS PPI OR CLUPIC)



INTERRUPT-DRIVEN PROGRAMS (INITIATED BY PPITASK)

(ENTERED BY LEVEL 5 INTERRUPT WHEN LSB AZIMUTH CHANGES)



(ENTERED BY LEVEL 5 INTERRUPT WHEN A/D BOX HAS COMPLETED TRANSFER TO LIST 1)

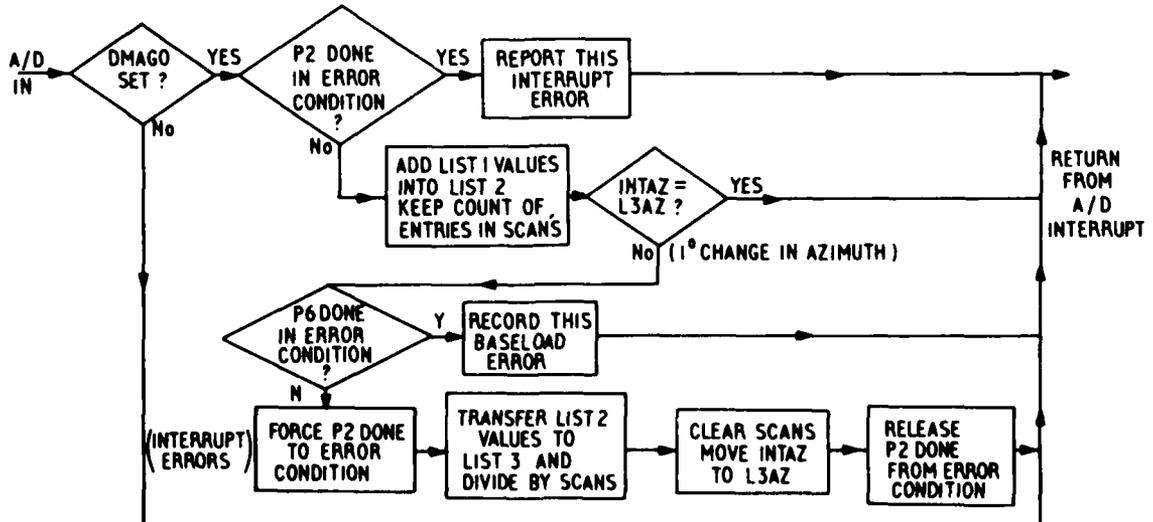
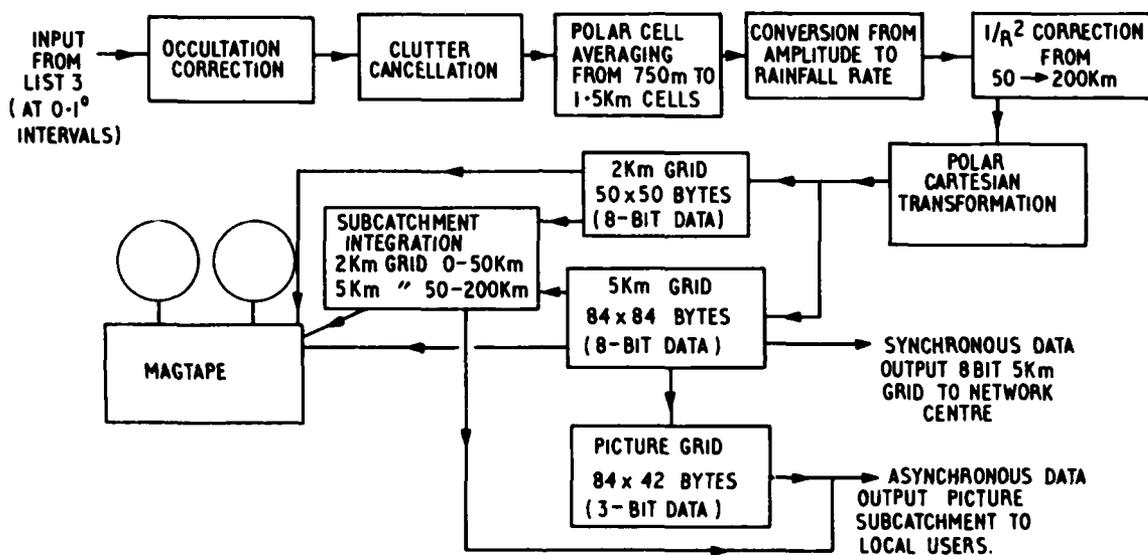
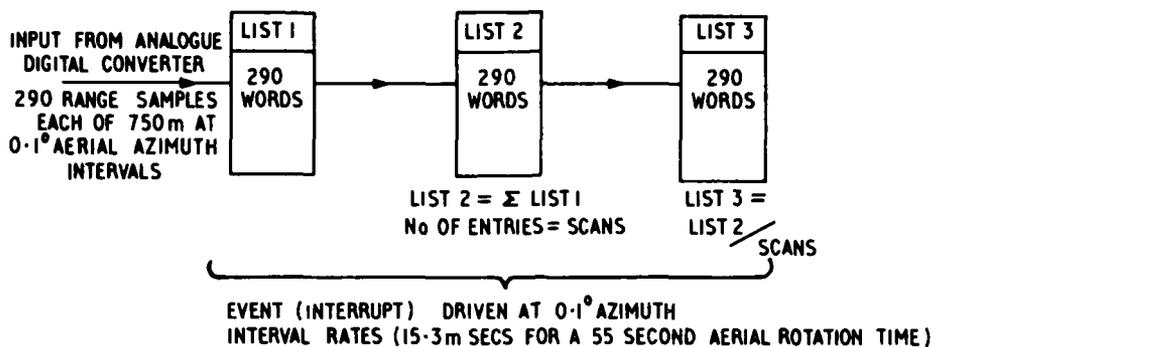


FIG.A9A
 PPITASK



NOTE:

IT IS ESSENTIAL THAT THE POLAR-CARTESIAN TRANSFORMATION SOFTWARE IS COMPLETED DURING THE 10 AZIMUTH INTERRUPTS WHICH FORM THE INPUT DATA. I.E. MAX TIME FOR PROCESSING FROM LIST 3 THROUGH TO THE GRIDS IS 153mSEC FOR 55 SECOND AERIAL ROTATION TIME

FIG. A9B
SUMMARY OF PPI TASK FROM RADAR I/P TO USER O/P

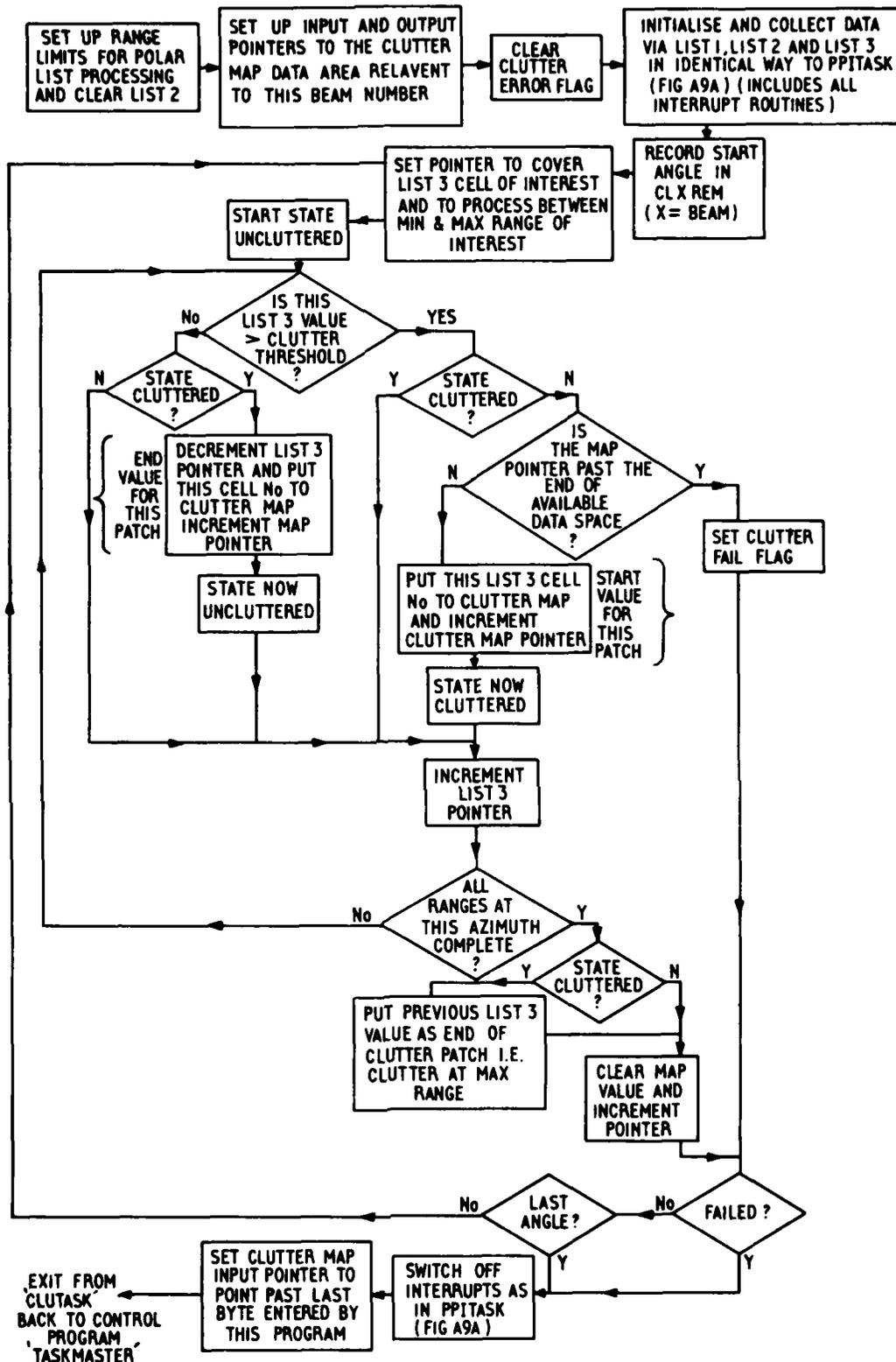
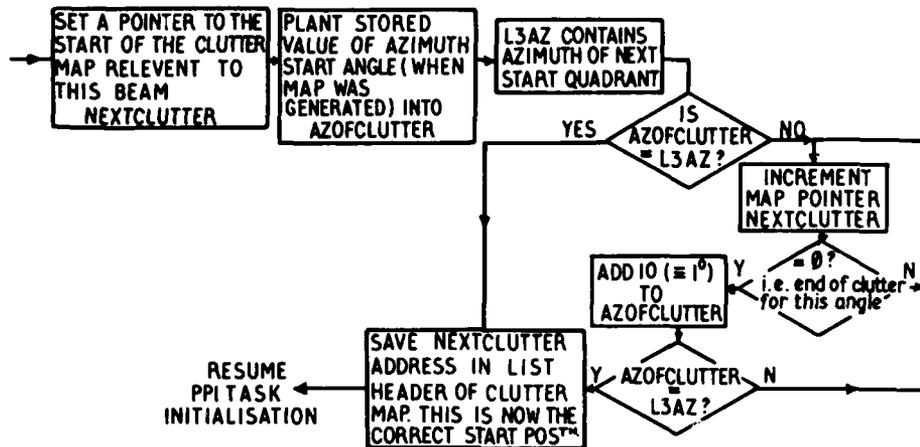
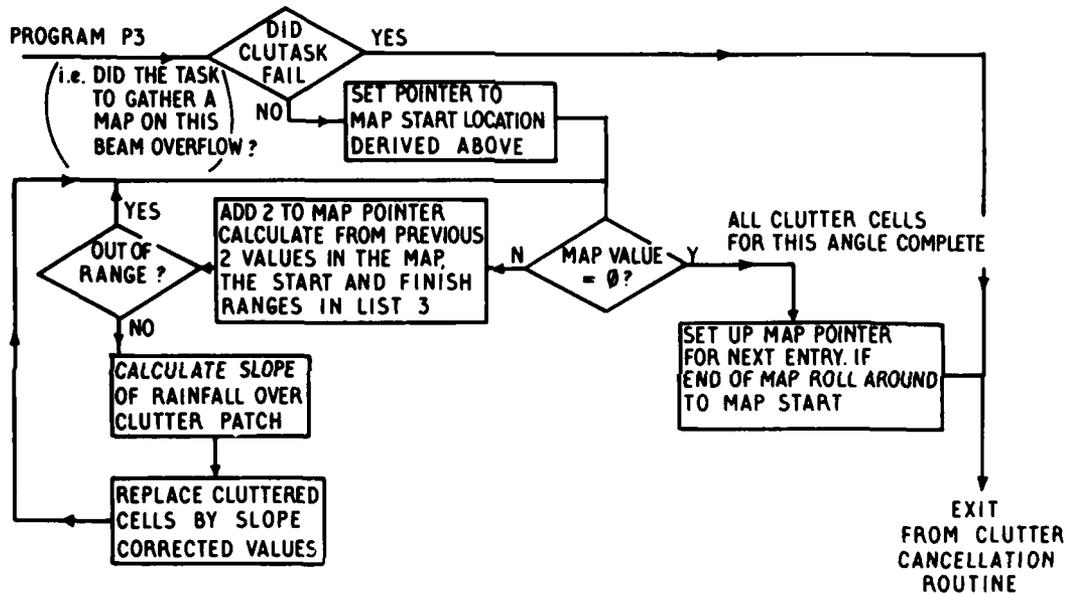


FIG. A9C
CLUTASK (CLUTTER MAP GENERATION)

A. WITHIN INITIALISATION ROUTINE



B. CLUTTER CANCELLATION MAIN ROUTINE (ENTERED AT EACH 1° CHANGE IN AZIMUTH IN P3)



C SECTION FROM PRINTOUT OF TYPICAL CLUTTER MAP

AZIMUTH (DEG)	RANGE CELL No. IN LIST 3 (1 RANGE CELL = 750m)
241	5 8 10 12 20 20 26 26 31 31 58 64 86 86 0
242	5 8 11 11 20 21 25 26 31 43 57 59 61 64 84 86 0
243	5 8 11 12 18 21 25 28 31 33 35 43 58 59 62 64 84 86 0
244	6 7 11 12 18 20 24 29 32 32 34 39 41 43 58 59 84 86 0

[A ZERO INDICATES THAT NO FURTHER CLUTTER IS TO BE FOUND WITHIN THIS AZIMUTH BRACKET]

FIG. A9D.

CLUTTER CANCELLATION (WITHIN PPI TASK - (FIG. A9A))

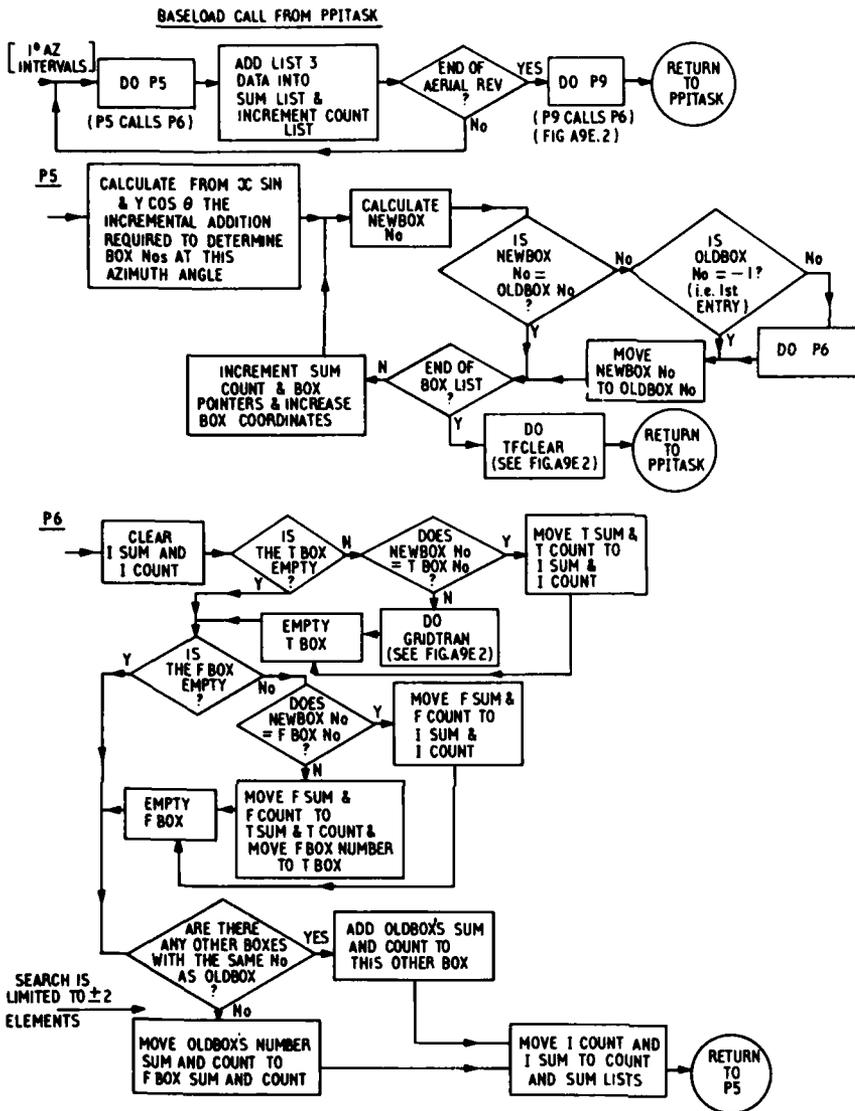


FIG. A9E.1
POLAR-CARTESIAN TRANSFORMATION SIMPLIFIED BLOCK DIAGRAM

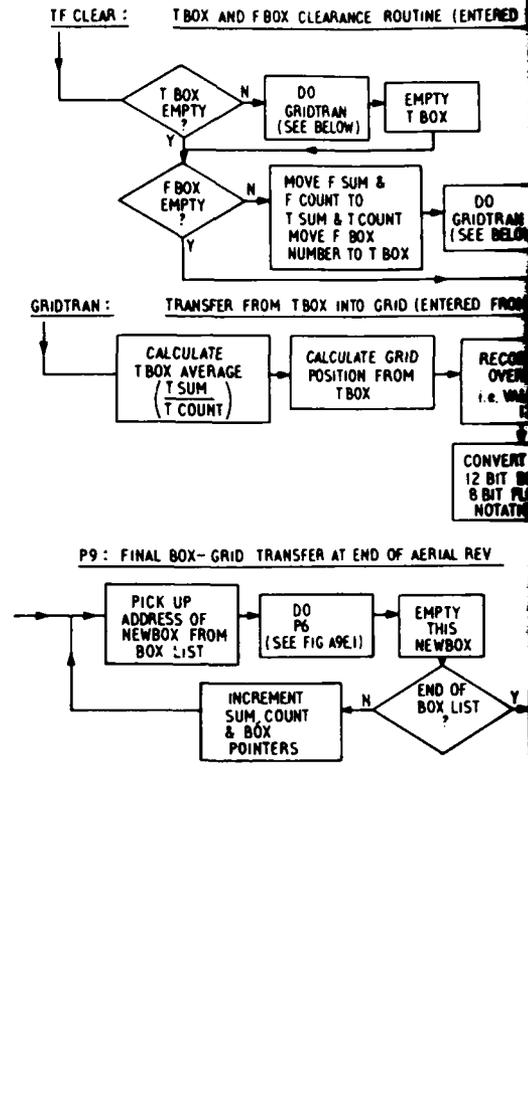
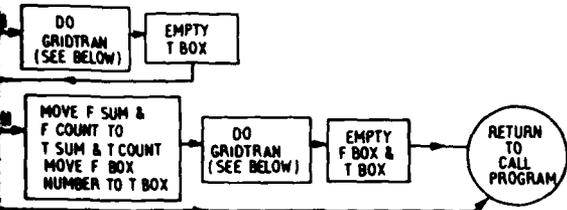
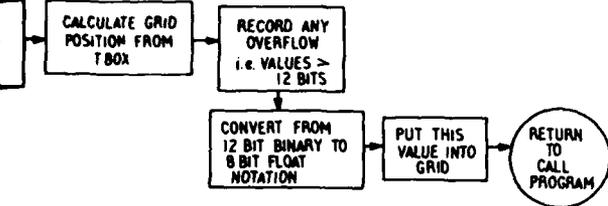


FIG. A9E.2
POLAR-CARTESIAN TRANSFORMATION SIMPLIFIED BLOCK DIAGRAM

F BOX CLEARANCE ROUTINE (ENTERED FROM P5 AND P9)



FROM T BOX INTO GRID (ENTERED FROM P6 AND TFCLEAR)



TRANSFER AT END OF AERIAL REV

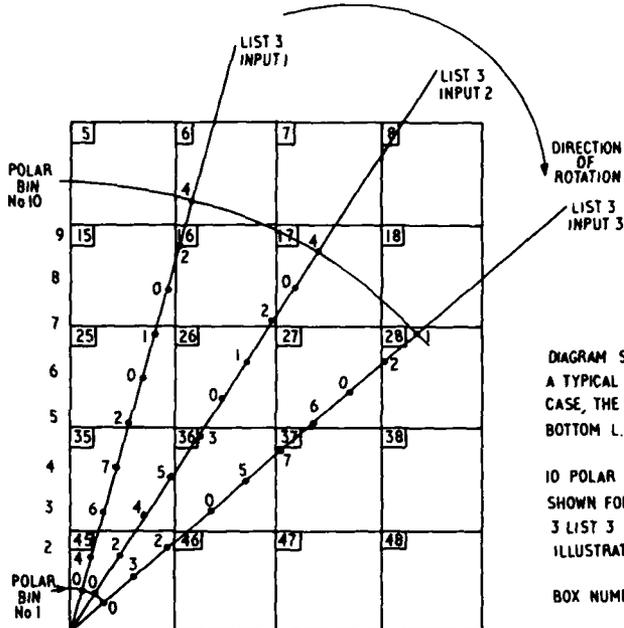
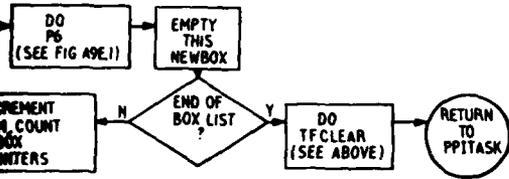


DIAGRAM SHOWS A SECTION OF A TYPICAL CARTESIAN GRID. IN THIS CASE, THE RADAR IS SITUATED AT BOTTOM L.H. CORNER OF BOX 45.

10 POLAR BIN VALUES ARE SHOWN FOR EACH LIST 3 INPUT. 3 LIST 3 INPUTS ONLY ARE ILLUSTRATED

BOX NUMBERS ARE SHOWN THUS: 8

LIST 3 POLAR BIN NUMBER	COLUMN 1			COLUMN 2			COLUMN 3			COLUMN 4			COLUMN 5		
	BOX	SUM	COUNT												
1	45	0	1	45	0	1	45	0	2	45	0	2	45	0	3
2	45	4	1	45	4	1	45	6	2	45	6	2	45	9	3
3	35	6	1	35	6	1	35	10	2	45	0	0	45	2	1
4	35	7	1	35	7	1	35	12	2	36	0	0	36	0	1
5	25	2	1	36	0	0	36	3	1	36	3	1	36	8	2
6	25	0	1	26	0	0	26	0	1	37	0	0	37	7	1
7	25	1	1	26	0	0	26	1	1	27	0	0	27	6	1
8	15	0	1	16	2	1	16	4	2	27	0	0	27	0	1
9	16	2	1	17	0	0	17	0	1	28	0	0	28	2	1
10	6	4	1	17	0	0	17	4	1	28	0	0	28	1	1

AFTER P5 AND P8 FOR LIST 3 INPUT 1 AFTER P5, READY FOR INPUT 2 AFTER P8 (INPUT 2) AFTER P5, READY FOR INPUT 3 AFTER P8 (INPUT 3)

FIG. A9E.2

CARTESIAN TRANSFORMATION (CONT.)

FIG. A9E.3

POLAR-CARTESIAN CONVERSION ALGORITHM

APPENDIX 10

THE MINI-MONITOR

PREAMBLE

The work described in this Appendix by Flt Lt D F K Singleton of the RAF Radio Introduction Unit stationed at RSRE is concerned with the loading and operation of radar site computers. These machines do not contain a DEC operating system and previous machine loading has been effected either by remote down-line transmission via the synchronous link or a simple magnetic tape transfer of the core area. By a fortunate coincidence of events, Flt Lt Singleton's requirement for knowledge of the operation of the PDP-11 machine and our need for a more sophisticated load and test procedure have been merged to produce this work.

MAGNETIC TAPE MONITOR FOR PDP-11 COMPUTERS

INTRODUCTION

10.1 The Magnetic Tape Monitor, henceforth called the Mini Monitor, is designed to provide the following facilities:-

- a It loads PDP-11 programs from magnetic tape, provided the programs are in DOS.LDA format on the tape.
- b It allows locations in the loaded program to be inspected and modified as necessary.
- c It causes the loaded program to be entered either at the location specified in the program load description, or at another location specified by a command to the Mini Monitor.
- d It monitors the hardware, by planting a trap in location 4 of PDP-11 store, to detect software faults such as illegal instructions and odd address errors. This facility is provided while the loaded program is running, provided that the loaded program does not:-

- (1) Over-write the Mini Monitor.
- (2) Set its own traps in location 4.

10.2 This description of the Mini Monitor assumes some knowledge of PDP-11 software terms. For further details of these terms, the reader should refer to PDP-11 handbooks.

USING THE MINI MONITOR

10.3 The Mini Monitor is first bootstrapped into core from magnetic tape, using the appropriate magnetic tape bootstrapping procedures for the particular hardware configuration. The Mini Monitor is entered automatically on completion of the bootstrapping process and announces itself as follows:-

TOR MK1

The asterisk is an invitation to type a command, and the following may be entered:-

E DDDDDD

Where each D is an octal digit. This causes a program which has already been loaded by a G command to be entered at location DDDDDD. It is not necessary to type leading zeros; thus if the program is to be entered at address 2460, E 2460 would be the appropriate command.

G FILENAME

Where FILENAME is replaced by the name of the file to be loaded from magnetic tape. This causes the specified file to be loaded into core. A full file name must be given; if it is required to load a file called, say, PROG.LDA, then it is not sufficient to type G PROG, which will give the error message: FILE NOT FOUND. During the load process, the Monitor will print:

O PROGRAM PARAMETERS X Y Z

Where X, Y and Z are octal numbers with the following meanings:

- The address of the first byte of the program.
- The length of the program in bytes.
- The preset transfer (ie start) address for the program.

Normally, on completion of the load, the message: LOAD COMPLETE is given and a further invitation to type is printed.

M DDDDDD

Where the Ds represent an octal number as described under paragraph 4a. This allows locations in core to be inspected and modified, provided that a program has been loaded. For further details of this command, see the section on using the modify command.

R FILENAME

This command combines the G and the S commands, causing the specified file to be loaded and entered in one operation.

S

This command causes a loaded program to be entered at its preset starting address.

USING THE MODIFY COMMAND

10.5 As indicated in paragraph 10.3c, the modify command is typed:

M DDDDDD

Where the Ds represent an octal number of one to 6 digits. If no program is loaded, the modify routine will give the error message NO PROGRAM and return to the Monitor. Otherwise, the following is printed:

DDDDDD/ZZZZZZ *

Where the Ds are the previously entered address to be inspected and the Zs are the contents of that location as an octal number. The asterisk is an invitation to type. The user may respond either with an octal number, which is to be the new contents of the opened location, or with a carriage return, indicating that no change is required. On completion, the modify routine returns control to the Monitor. Modification or inspection of further words requires further use of the command M.

ERROR MESSAGES

10.6 Aborts

Certain error messages will be followed by the word ABORT. This indicates that a serious error has occurred and that the Mini Monitor has re-initialised itself. It is unlikely that the integrity of the Monitor will have been compromised by the abort, but in the event of further difficulties, the user should re-boot the Mini Monitor into core.

10.7 Error Messages

The following error messages could be printed:-

a INPUT ERROR

This message will be printed if an unrecognised command letter is given, or no file name is given after an R or G command. The Monitor requests further input after giving the error message.

b TRAP TO 4 DDDDDD ABORT

This message will be printed if an error occurs causes a hardware trap through address 4. The Ds represent an octal number which was the value of the program counter when the trap occurred. A typical error causing this trap is accessing an odd address with a word instruction. For further details of faults which can cause a trap through address 4, the reader should refer to the appropriate PDP-11 processor handbook. The Monitor re-initialises itself and then gives an invitation to type.

c NO PROGRAM

This message will be printed if an E, M or S command is given before a program has been loaded. Note that any abort error causes the Monitor to reinitialise itself and cancel the loaded program.

d ADDRESS ERROR ABORT

This message will be printed if the Monitor finds that the program to be loaded will over-write the Monitor during the load process. The Monitor re-initialises itself.

e RAD50 ERROR DDDDDD ABORT

This message will be printed if the Monitor finds a character that is not a valid RAD50 character (A to Z, 0 to 9, \$ and . (dot)) in the name of a file input to the Monitor as part of an R or G command. The octal number DDDDDD is the octal value of the illegal character. The Monitor re-initialises itself.

f FILE NOT FOUND

This message will be printed if the file specified in an R or G command is not found on the magnetic tape. The Monitor re-initialises itself after giving the message.

g FILE HEADER WRONG ABORT

This message will be printed if a file header read from magnetic tape does not have the correct length (14 bytes long). The Monitor then re-initialises itself.

h EOF READ EARLY ABORT

This message will be printed if an end of file mark is read unexpectedly from magnetic tape. The Monitor re-initialises itself.

i SKIP ERROR ABORT

This message will be printed if the Monitor detects more than 10 null bytes between formatted binary records while reading a file into core. The Monitor re-initialises itself after printing the message.

j BUFFER TOO SMALL DDDDDD ABORT

This message will be printed if a formatted binary record to be read is too big for the Monitor's formatted binary buffer (40 bytes long). The octal number DDDDDD is the length of the record read. The Monitor then re-initialises itself.

k CHECKSUM ERROR ABORT

This message will be printed if the Monitor detects a checksum error in a formatted binary record. The Monitor then re-initialises itself.

l MT ERROR DDDDDD ABORT

This message will be printed if a magnetic tape error is detected at any time. The octal number DDDDDD printed is the contents of the magnetic tape status register. The Monitor then re-initialises itself.

SOFTWARE DESCRIPTION

10.8 The following paragraphs describe the software modules making up the Mini Monitor and highlight particular features of the individual modules. Briefly, the modules do the following:-

a MINMON

MINMON is the main Monitor module. It also carries out Monitor initialisation and contains the ABORT routine.

b LOADER

LOADER is the module which loads files from magnetic tape into core.

c CVTUTL

CVTUTL provides 2 utility routines: OCTRD and ASCRAD. OCTRD converts ASCII numeric characters to an octal number, and ASCRAD converts 3 ASCII characters to their RAD50 equivalent.

d FBUTIL

FBUTIL provides 2 utility routines for formatted binary input. FB OPEN opens a file on magnetic tape and FB READ reads formatted binary records and puts them in the formatted binary buffer.

e MTUTIL

MTUTIL provides a number of basic magnetic tape handling routines:-

1 MTRDBK

MTRDBK reads a block of data from magnetic tape into core.

2 MTSPCE

MTSPCE spaces forward one block on magnetic tape, without reading.

3 MTRWND

MTRWND rewinds the magnetic tape.

f KBUTIL

KBUTIL provides a number of basic keyboard (TTY) handling routines:-

1 CRLF

CRLF outputs a carriage return and a line feed character.

2 OCTPRT

OCTPRT prints an octal number.

3 PRINT

PRINT prints a message.

4 PNCH

PNCH prints a character.

5 READ

READ reads a line of input.

g ENDPRO

ENDPRO declares the label ENDPRO, which module LOADER uses to find the address of the last location in the monitor.

10.9 MINMON

The program listing for MINMON is self-explanatory. The following point is, however, relevant. During initialisation and re-initialisation, the address of label TRAP is planted in location 4, so that any faults causing a hardware trap through location 4 cause a jump to the label TRAP.

10.10 LOADER

On entry to LOADER, the name of the file to be loaded is present in KBBUF in ASCII character form. LOADER first transfers this character string to the buffer FNAME, packing out the name of the file with spaces to form a 6 letter name with a 3 letter extension. It then converts the file name to RAD50 format and opens the file. The first formatted binary record read from the file contains details of the program to be loaded as follows:-

BYTE POSITIONS IN RECORD (0 is first byte)	MEANING
4, 5	Address of start of code.
6, 7	Length of program in bytes.
8, 9	Transfer address.
14, 15, 16, 17	Name of program (6 characters in RAD50 format)

LOADER then checks that the monitor will not be over-written by the target program to be loaded and proceeds to load the program. The first word of each formatted binary record of program in load format contains the address at which transfer of the rest of the record is to start. Finally, on completion of the load process, the magnetic tape is rewound.

10.11 CVTUTL

CVTUTL contains 2 utility routines:-

a OCTRD

OCTRD converts an ASCII character string to an octal value. The routine

exits either when it has converted 6 characters or when it finds a character that is not ASCII 0 to 7.

b ASCRAD

The listing is self-explanatory.

10.12 FBUTIL

FBUTIL contains the formatted binary buffer and 2 utility routines:-

a FBBUF

FBBUF is the formatted binary buffer into which formatted binary records are placed by FBREAD. Location FBBUF-2 is always set to the number of bytes in the buffer.

b FBOPEN

FBOPEN is the routine which, given a file name, searches the magnetic tape for a file with that name and having found it, sets up for subsequent formatted binary reading of the file. After rewinding the tape, it examines each file header in turn to see if the name is that of the desired file. The file header on a magnetic tape is a 14 byte block. The first 3 words of the header hold the file name in RAD50 format.

c FBREAD

FBREAD takes blocks of data containing a number of records from the magnetic tape, extracts the individual formatted binary records, and places them in FBBUF. Each call on FBREAD gets the next record for the caller. Each formatted binary record is surrounded by certain 'overheads' in a block of data on magnetic tape. These overheads are as follows:-

1 Two words preceding the record. The first contains a start of record marker, 1, and the second contains a count of the number of bytes in the record plus 4 (to allow for the 4 header bytes). It was found that the longest record length was 40 bytes, therefore the length of FBBUF was set at 40 bytes.

2 One byte following the record, containing a checksum for the record. The sum of all the bytes making up the record plus the 4 bytes in the header plus the checksum is zero, modulo 256.

Additionally, the formatted binary records may be separated by a number of null filler words, principally where a record overlaps 2 blocks of data. FBREAD places an arbitrary limit of 10 on the number of filler words; this limit is unlikely to be exceeded as the number of filler words, when they occur, is normally only one or 2.

10.13 MTUTIL

MTUTIL contains the magnetic tape buffer and 3 utility routines. It should be noted that all the routines have 2 possible exit points; to the first instruction after the call if an end of file mark was read; and to the second instruction after the call if the operation was satisfactory and no end of file mark was read.

a BUFFER

BUFFER is the magnetic tape buffer into which blocks of data are read from magnetic tape. Location BUFFER-2 is set to contain a count of the number of bytes that have been read in to the buffer.

b MTRDBK

MTRDBK reads the next block of data on magnetic tape into BUFFER. The listing is self-explanatory.

c MTSPCE

MTSPCE moves the magnetic tape forward one block without reading. The listing is self-explanatory.

d MTRWND

MTRWND rewinds the magnetic tape. The listing is self-explanatory.

10.14 KBUTIL

KBUTIL contains a number of routines for teletype interfacing plus a 20 byte buffer for keyboard input.

a KBBUF

KBBUF is a 20 byte (ie 20 character) buffer for keyboard input. Characters read by the READ routine are stored in KBBUF for subsequent use. KBBUF-2 is always set to the count of the number of characters in KBBUF.

b PNCH

PNCH outputs a single character to the teletype. During program development, it was found that a RESET instruction, issued shortly after a call of PNCH, could cause the character to be lost before the teletype had actually printed the character. For this reason, PNCH does not exit until the teletype output status byte goes negative, indicating that the teletype is ready to receive another character.

c PRINT

PRINT outputs a message to the teletype. The message must follow the calling instruction and should, ideally, be declared using the macro MSG. The first byte of the message contains a count of the number of characters to be printed, and the subsequent bytes contain the ASCII characters to be printed. Control is returned to the caller at the first instruction after the message.

d CRLF

CRLF outputs a carriage return and a line feed character to the teletype.

e OCTPRT

OCTPRT takes a number, converts it to 6 octal digits and prints it.

f READ

READ reads a line of input from the teletype and places the line of text in KBBUF, setting KBBUF-2 to the number of characters read. The only legal terminator for a line is a carriage return. This is not placed in KBBUF or included in the count of characters read in KBBUF-2. All characters with ASCII values from 40 octal (space) to 140 octal (@) are considered legal characters. The input of any other character will cause a ? to be typed, indicating an illegal character. Input restarts again from the start of the line, that is, all input in the current line is thrown away. Input of more than 19 characters in a line is illegal and causes a ? to be printed, and the data input so far to be thrown away. On exit from READ, the byte following the last character input is set to ASCII space to ensure that OCTRD in module CVTUTL sees a correct terminator.

10.15 ENDPRO

ENDPRO contains no code. Its sole purpose is to declare the label ENDPRO, to allow module LOADER to find the address of the last location of the Monitor.

CREATING THE MONITOR

10.16 The following series of instructions should be followed to create a copy of MINMON on a magnetic tape, starting with the assembly language copies of the Monitor. This sequence of instructions assumes that the DOS system program PIP, MACRO, LINK and CILUS are resident on the system disc, and that copies of the 7 modules making up the Monitor are also resident on the system disc.

a ASSEMBLY

```
RU MACRO
MINMON. OBJ, LP: < MINMON
LOADER. OBJ, LP: < LOADER
CVTUTL. OBJ, LP: < CVTUTL
FBUTIL. OBJ, LP: < FBUTIL
MTUTIL. OBJ, LP: < MTUTIL
KBUTIL. OBJ, LP: < KBUTIL
ENDPRO. OBJ, LP: < ENDPRO
```

b LINKING

```
RU LINK
MINMON. LDA, LP: < MINMON, LOADER, CVTUTL, FBUTIL
MTUTIL, KBUTIL, ENDPRO/B:600/E
```

c PREPARING CORE IMAGE

```
RU CILUS
,LP: DC:MINMON.LCL < DC: MINMON. LDA/BU/E
DT: MINMON. CIL/HO/MT < DC: MINMON. LCL/LO
```

d TRANSFER TO MAGNETIC TAPE

RU PIP

MT:/ZE

MT:<DT: MINMON. CIL

PIP is then used to transfer the programs to be loaded by MINMON, to the magnetic tape in the normal way.

APPENDIX 11

MAGNETIC TAPE DATA PACKING TECHNIQUES

P R Larke Met O RRL, Malvern

This appendix describes the techniques which are used to reduce the amount of magnetic tape storage at the radar site. The radar picture data and the 8-bit data sent to the Network composite site occur only at 15 minute intervals, but the radar task also includes eleven other aerial revolutions, each gathering precipitation data, to provide extra information for later off-line analysis.

The objectives of data packing are to achieve a reduction in the number of magnetic tapes and hence an increase in the time between tape changes.

The data sets which are stored on tape are:

The 5 km cartesian grid [84 x 84 cells encompassing the maximum radial range of 210 km]

The 2 km cartesian grid [50 x 50 cells with a radial range limit of 50 km, produced only on the lowest aerial elevation]

The subcatchment data list [1500 bytes changing at hourly intervals]

Standard 600 ft, 9 track, 800 bpi tape, containing data archived in the above fashion, requires a tape change at approximately 14 hour intervals. Accordingly, a regular tape change at 12 hour intervals (0900 and 2100) has operated for these unpacked data.

Three separate techniques have been used to achieve a 24 hour tape change:

1 The precipitation data at longer ranges are of less importance on aerial revolutions at the higher elevations since the beam at these ranges is generally above the rainfall. A reduction in the range of the 3rd highest elevation to $\frac{2}{3}$ maximum range and in the 4th highest elevation to $\frac{1}{2}$ maximum range has reduced the data content by approximately 20%.

2 An obvious saving, which can be made with no penalty to the data, is to remove those data which occupy the 4 corners of the cartesian grids and are out of the specified ranges. This also corresponds to a reduction of approximately 20%.

3 The reductions mentioned above are not sufficient to achieve a 24 hour tape change and a further modification has been incorporated. This involves packing all data which contains a predetermined number of cells containing zero rainfall into a special format. The data produced from 1 and 2 above is scanned to find sequences of 10 or more consecutive zeroes. When found, a header containing a data sequence of zero probability is followed by a number to indicate how many zeroes were in the original data stream. The header is a 6 or 7 byte sequence of values which can never occur in the FLOAT notation (ie octal 111, 303, 111, 303 - etc) ending at an even address, and is followed by a word containing the number of consecutive zeroes detected.

These 3 modifications ensure that for all but extremely rare occurrences, a 24 hour magtape change time can be achieved. Offline processing techniques have been developed by Met O RRL to reconstitute the data stream in its original form before the modifications by 2 and 3 above.

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