Roque de los Muchachos Observatory

William Herschel Telescope

USERS' MANUAL

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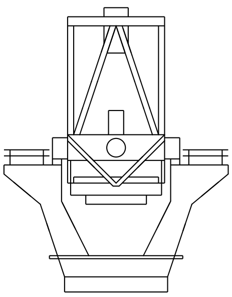

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Contents

I BACKGROUND INFORMATION 1

1 Introduction: scope and documentation 1
- 1.1 Scope of the manual . . . 1
- 1.2 Obtaining copies of this manual . . . 1
- 1.3 Recent information: NEWS and USER_BEWARE . . . 1
- 1.4 Getting help . . . 2
- 1.5 Notation . . . 2

2 The William Herschel Telescope 2
- 2.1 General description . . . 2
- 2.2 Summary of mechanical performance . . . 4
- 2.3 Optics . . . 4
- 2.4 Telescope control . . . 9

3 Planning observations 9
- 3.1 General . . . 9
- 3.2 Positions, finding charts and offsets . . . 9
- 3.3 Catalogues . . . 10
- 3.4 Limits . . . 11
- 3.5 Altazimuth problems . . . 13

4 Getting the best out of the telescope 13
- 4.1 Pointing . . . 13
- 4.2 Acquisition . . . 16
- 4.3 The Television System: integration, filtering and flat fields . . . 18

II GUIDE TO OBSERVING 19

5 Preparation for observing—things to do before dinner 19
- 5.1 Preparing catalogues . . . 19
- 5.2 Starting the telescope control system and TV system . . . 19
- 5.3 Inputting catalogues . . . 19
- 5.4 Checking the building . . . 19

6 Starting up the telescope 19
- 6.1 Safety checks . . . 20
- 6.2 Powering up the telescope . . . 20
- 6.3 Computer-mode control and functional checks . . . 20
- 6.4 Dome, mirror covers and cameras . . . 21
- 6.5 Selecting the focal station . . . 21
- 6.6 Transfer of control to another terminal . . . 22

7 Calibration procedures 22
- 7.1 Focussing . . . 22
  - 7.1.1 FOS–2 . . . 22
  - 7.1.2 Taurus (CCD imaging and Fabry-Perot) . . . 22
  - 7.1.3 Direct CCD imaging at f/11 . . . 23
  - 7.1.4 Manchester Echelle . . . 23

7.2 Pointing calibration . . . 23
7.2.1 All instruments . . . 23
7.2.2 FOS–2 . . . 23
7.2.3 Imaging . . . 24
7.2.4 Instruments with no on-axis field viewing . . . 25

8 Acquiring an object **25**
8.1 Slewing to an object . . . 25
8.2 Using the TV . . . 26
8.3 FOS acquisition . . . 26
8.3.1 FOS—bright objects . . . 26
8.3.2 FOS—objects just visible on the TV . . . 26
8.3.3 FOS—blind offsetting . . . 26
8.4 Acquisition for imaging detectors . . . 27
8.5 Acquisition for instruments without field viewing . . . 27
8.6 Changing the displayed coordinates . . . 27

9 Rotator control **27**

10 Guiding **27**
10.1 General . . . 27
10.2 On-axis guiding—FOS only . . . 28
10.3 Off-axis guiding . . . 28

11 Closing down **28**
11.1 Cameras, mirror cover and dome . . . 28
11.2 Closing down the telescope . . . 29

III REFERENCE SECTIONS **31**

12 Before observing **31**
12.1 Checking the building . . . 31
12.2 Powering up the telescope—full checklist . . . 31
12.3 Safety checks . . . 34
12.4 Opening the dome . . . 34

13 Driving the telescope in engineering mode **35**
13.1 Driving with the rate controls . . . 35
13.2 Parking the telescope . . . 35

14 Starting the computer systems **36**
14.1 Powering up . . . 36
14.1.1 The buffered supply . . . 36
14.1.2 Starting the MicroVAX . . . 37
14.1.3 Starting the TV system . . . 37
14.2 Switching to computer mode . . . 38

15 Computer control of the telescope **38**
15.1 The User Interface—General . . . 38
15.1.1 Line_editing . . . 39
15.1.2 Abbreviation . . . 39
15.1.3 Control-keys . . . 39

15.1.4 Transfer of control . . . 39
15.2 Catalogues . . . 40
15.2.1 Text, binary, user and system catalogues and the edit source . . . 40
15.2.2 The system catalogue . . . 40
15.2.3 Catalogue format . . . 41
15.3 User Interface commands: a classified list . . . 41
15.3.1 General user-interface commands . . . 42
15.3.2 Source data entry . . . 42
15.3.3 Catalogue handling . . . 42
15.3.4 Source change . . . 42
15.3.5 Positional and Aperture offsets . . . 43
15.3.6 Autoguiding . . . 43
15.3.7 Calibration procedures . . . 43
15.3.8 Mechanism control . . . 43
15.3.9 Change of focal station . . . 43
15.3.10 Display functions . . . 43
15.3.11 Logging of test data . . . 44
15.3.12 Meteorological and Earth-rotation data . . . 44
15.4 User Interface commands: an alphabetical glossary . . . 44
15.4.1 ADD . . . 44
15.4.2 ALTITUDE . . . 44
15.4.3 APERTURE . . . 45
15.4.4 AZIMUTH . . . 45
15.4.5 BEAMSWITCH . . . 45
15.4.6 BLIND_OFFSET . . . 45
15.4.7 CALIBRATE . . . 46
15.4.8 CASSEGRAIN . . . 46
15.4.9 CAT_EDIT . . . 46
15.4.10 DEC . . . 47
15.4.11 DEFINE . . . 47
15.4.12 DELETE . . . 47
15.4.13 DIFF_RATES . . . 47
15.4.14 DISPLAY . . . 48
15.4.15 DOME . . . 48
15.4.16 ELEVATION . . . 48
15.4.17 ENGINEERING . . . 48
15.4.18 EPOCH . . . 49
15.4.19 EQUINOX . . . 49
15.4.20 EXIT . . . 49
15.4.21 FLEX . . . 49
15.4.22 FOCUS . . . 49
15.4.23 GET . . . 49
15.4.24 GHRIL . . . 50
15.4.25 GOCAT . . . 50
15.4.26 GOTO . . . 50
15.4.27 GUIDE . . . 51
15.4.28 HANDSET . . . 51
15.4.29 HELP . . . 51
15.4.30 HUMIDITY . . . 52
15.4.31 INPUT . . . 52
15.4.32 LOAD . . . 52
15.4.33 MARK . . . 53

15.4.34 MOON . . . 53
15.4.35 NEXT . . . 53
15.4.36 OFFSET . . . 53
15.4.37 OUTPUT . . . 53
15.4.38 PAGE . . . 54
15.4.39 PARALLAX . . . 54
15.4.40 POINT . . . 54
15.4.41 POLE . . . 55
15.4.42 POSITION . . . 55
15.4.43 PRESSURE . . . 55
15.4.44 PROPER_MOTION . . . 55
15.4.45 RA . . . 55
15.4.46 RADIAL_VEL . . . 56
15.4.47 RECALL . . . 56
15.4.48 REMOTE . . . 56
15.4.49 ROTATOR . . . 56
15.4.50 SAVE . . . 57
15.4.51 SET . . . 57
15.4.52 SHOW . . . 58
15.4.53 SNAPSHOT . . . 58
15.4.54 SOURCE . . . 58
15.4.55 STOP . . . 59
15.4.56 STORE . . . 60
15.4.57 SWITCH . . . 60
15.4.58 TEMPERATURE . . . 60
15.4.59 UES . . . 60
15.4.60 UNWRAP . . . 60
15.4.61 UT1UTC . . . 61
15.4.62 WAVELENGTH . . . 61
15.4.63 ZEROSET . . . 61
15.5 The Handset . . . 62
15.5.1 General . . . 62
15.5.2 ALT_AZ mode . . . 64
15.5.3 RA_DEC mode . . . 64
15.5.4 X_Y mode . . . 64
15.5.5 OFFSET mode . . . 64
15.5.6 APOFF mode . . . 64
15.5.7 FOCUS mode . . . 64
15.5.8 ROTATOR mode . . . 64
15.5.9 Sign conventions . . . 65
15.6 The Display . . . 65
15.6.1 General . . . 65
15.6.2 Source and telescope information . . . 67
15.6.3 Encoder display . . . 68
15.6.4 Limit page . . . 70
15.6.5 Alarms page . . . 72
15.6.6 Overrides and dome page . . . 74

16 The Integrating Television System **75**
16.1 Introduction . . . 75
16.1.1 Cameras . . . 75
16.1.2 Integration, Filtering and Flat-fielding . . . 77
16.1.3 Coordinate system, fields and scales . . . 77
16.1.4 The look-up table . . . 77
16.1.5 Startup and basic control . . . 77
16.1.6 On-line help . . . 80
16.2 Operation of the cameras . . . 80
16.2.1 Powering up . . . 80
16.2.2 Basic operation . . . 80
16.3 Control using the function keys . . . 81
16.3.1 General . . . 81
16.3.2 Keypad functions available in both modes . . . 81
16.3.3 Functions available only in Camera mode . . . 84
16.3.4 Functions available only in LUT mode . . . 85
16.4 Typed commands . . . 85
16.4.1 Utility functions . . . 85
16.4.2 File handling . . . 86
16.4.3 Image arithmetic . . . 87
16.4.4 Setting the camera scales . . . 88
16.4.5 Camera control . . . 88
16.4.6 Image stack manipulation . . . 88
16.4.7 Drawing and clearing graphics . . . 89
16.4.8 Image parameters: distances, statistics and profiles . . . 89
16.4.9 Zooming the display . . . 90
16.4.10 Guiding . . . 90

17 Shutting down the computers **91**

IV APPENDICES **93**

A Test and calibration procedures **93**
A.1 Rotator centre and standard apertures . . . 93
A.2 Pointing tests and their analysis . . . 93
A.2.1 General . . . 93
A.2.2 Preparation . . . 93
A.2.3 Logging the data . . . 95
A.2.4 Analysing the data . . . 95
A.2.5 The model . . . 96
A.2.6 Expected results . . . 98
A.2.7 Altering the initialisation file . . . 98
A.3 Tracking tests . . . 98
A.3.1 Introduction . . . 98
A.3.2 Logging the star position . . . 98
A.3.3 Analysing the data . . . 98
A.3.4 Fitting functional forms to the data . . . 100
A.3.5 Building a look-up table . . . 101
A.4 TV scales . . . 101

B GSEXAM and the initialisation file **103**
B.1 General . . . 103
B.2 Control system versions, logical names and STARTUP . . . 103
B.3 Running GSEXAM . . . 103
B.4 The initialisation file WHT.INI . . . 105
B.5 Routine maintenance of the initialisation file . . . 105
B.6 Apertures . . . 105
B.7 Rotator offset . . . 105
B.8 Encoders . . . 106
B.8.1 General . . . 106
B.8.2 Scaling factors . . . 106
B.8.3 Zero-points . . . 106
B.8.4 Periodic errors . . . 106
B.9 Transducers . . . 107
B.9.1 Radial motion . . . 107
B.9.2 Mirror tilt . . . 107
B.10 Limits . . . 107
B.11 Zeroset data . . . 108
B.12 Focus–temperature relation . . . 108
B.13 Default meteorological data . . . 108
B.14 Pointing coefficients . . . 108
B.15 Default focal station . . . 108
B.16 Earth rotation data . . . 109
B.17 Autoguiding using the television . . . 109

C Fault-finding **111**
C.1 Cannot start the telescope control system . . . 111
C.2 Unable to switch into computer mode . . . 111
C.3 Telescope or rotator will not move in computer mode . . . 111
C.4 Dome does not rotate in computer mode . . . 111
C.5 Focus does not move in computer mode . . . 112
C.6 Failure to open the dome (from gallery) . . . 112
C.7 Sudden switch to engineering mode . . . 112
C.8 Telescope tracking but nothing visible . . . 112
C.9 No light . . . 112
C.10 Bad pointing . . . 113
C.11 Bad tracking . . . 113
C.12 Handset problems . . . 114
C.13 TV system . . . 114

D Listings of system catalogues **115**
D.1 General . . . 115
D.2 Astrometric standards . . . 117
D.3 Spectrophotometric standards . . . 119
D.4 Photometric standards . . . 121
D.5 Photometric sequences . . . 123
D.6 Blank fields . . . 125
D.7 Fields for geometrical calibration . . . 127

List of Figures

1 Schematic view of the William Herschel Telescope . . . 3
2 Optical layout of William Herschel Telescope . . . 5
3 Spot diagrams for William Herschel Telescope foci . . . 6
4 Spot diagrams for William Herschel Telescope Nasmyth focus with derotator . . . 7
5 Vignetting curves for William Herschel Telescope . . . 8
6 Sky accessible to William Herschel Telescope . . . 11
7 William Herschel Telescope Azimuth limits . . . 12
8 Variation of parallactic angle with hour angle . . . 14
9 Variation of atmospheric refraction with wavelength . . . 15
10 Handset mode display . . . 63
11 Part of VT220 keyboard used in handset mode . . . 63
12 Telescope Information Display . . . 66
13 Encoder display screen . . . 69
14 Limit screen . . . 71
15 Alarms screen . . . 73
16 Overrides and dome screen . . . 74
17 Wavelength response of S-20 photocathode for TV . . . 76
18 Transfer function of TV system display (blacker/whiter) . . . 78
19 Transfer function of TV system display (enhance/soften) . . . 79
20 Keypad for TV system in camera mode . . . 82
21 Keypad for TV system in look-up table mode . . . 83
22 Residuals from a pointing test . . . 96

List of Tables

1 *Summary of mirror characteristics for William Herschel Telescope* . . . 4
2 *Optical characteristics of William Herschel Telescope foci* . . . 9
3 *Key bindings relevant to editing command lines* . . . 39
4 *Summary of field size and scale data for integrating TV* . . . 77
5 *Pointing grid for William Herschel Telescope* . . . 94
6 *Pointing model terms for the WHT* . . . 97
7 *Terms for fitting tracking data* . . . 100
8 *Variable names for meteorological data items* . . . 108
9 *Variable names for TPOINT coefficients in the pointing model* . . . 109

Part I
BACKGROUND INFORMATION

1 Introduction: scope and documentation

1.1 Scope of the manual

This manual describes the operation of the William Herschel Telescope and its acquisition and guiding system from the user's point of view. Procedures for planning observations, opening up and closing down, controlling the telescope and dome, locating and tracking objects and using the integrating television system are covered. The appendices cover test and calibration procedures and fault-finding.

The manual is divided into three parts. Part I covers sources of information and help (remainder of Section 1), gives a general description of the telescope (Section 2) and provides the information needed for advance planning of observations (Section 3). It also includes some notes on getting the best out of the telescope (Section 4). These discuss aspects of the telescope control, autoguider and television systems at a conceptual level and, although not strictly necessary for basic operation, should help in optimising pointing, acquisition and detection of faint objects.

Part II (Sections 5 – 11) describes normal observing procedures in summary or checklist form. It is intended for quick reference during the night.

Part III contains reference material. Most users will be concerned only with Sections 15, ??, ?? and 16, which describe the telescope control, acquisition and guiding, autoguider and television systems, respectively. The remaining material describes the full startup and shutdown sequences, and should only be required infrequently (*e.g.* after a major power failure).

The appendices describe: A—test and calibration procedures, B—the GSEXAM diagnostic interface and modification of the initialisation file, C—fault-finding and D—listings of the system catalogues. For safety reasons, some of the operations described in the appendices are restricted to those with access to programmers' accounts on the telescope MicroVAX or to the FORTH system on the microprocessors. These are mostly the test, calibration and diagnostic procedures described in Appendices A and B. Please consult the La Palma software group should you require instruction in their use.

New users should read Section 3 first, followed by Part II, referring to the more detailed explanations in Part III as necessary.

1.2 Obtaining copies of this manual

This manual has been prepared using LaTeX. Copies of the current source for:

- the manual (`USER_MANUAL.TEX`);
- the "User Beware" list (`USER_BEWARE.TEX`);
- the "News" sheet (`USER_NEWS.TEX`).

are held on the La Palma VAX 8300 in directory `[MANUALS.WHT_USER]`, along with their associated rasterized files, `.DVI-CAN`. New copies of the manual may be printed out using:

- `WHT_GLASE [MANUALS.WHT_USER]USER_MANUAL.DVI-CAN` or
- `INT_GLASE [MANUALS.WHT_USER]USER_MANUAL.DVI-CAN`,

(to give output on the laser-printers in the WHT and INT buildings, respectively). Copies are also held on the STARLINK VAX 780 at RGO, in the directory `RGVAD::DISK$USER1:[MANUALS.WHT_USER]`, although they may not be updated as frequently as their equivalents on La Palma.

1.3 Recent information: NEWS and USER_BEWARE

Recent modifications to the operating procedures for the telescope will be included in the "NEWS" sheet and filed with the control-room copy of this manual. Known faults and warnings, especially those affecting safety, are included in the "USER_BEWARE" list, which should also be filed with this manual in the control room.

Any departures from the normal operating procedures for the telescope (because of faults, temporary repairs or testing) should be included in the current "USER_BEWARE LIST", which must *always* be consulted before proceeding further.

1.4 Getting help

The present manual is designed to be the main reference for telescope operation. Additional background information may be found in the *Observers' Guide* (1988 edition). In case of difficulty, consult your Support Astronomer or Duty Technician. More detailed advice may be obtained from the relevant specialists in the software group on La Palma or the Telescope Project Scientist or Telescope Engineer in the UK.

All of the computers whose operation is described in this manual have on-line help systems. Type `HELP` to get started except for the TV system in its normal (keypad) mode, whose help library is accessed by pressing the HELP key. See the reference sections for more details.

1.5 Notation

The following conventions for computerese have been used more-or-less consistently throughout this manual:

- Examples of commands entered at the terminal are in typewriter font: `DEC 12 34 56.78`, as are messages from the computer;
- Angle brackets denote parameter values or character strings: `<angle>`;
- Square brackets denote optional input *e.g.* `[x,y]`; all other parameters are obligatory;
- KEY denotes a function key;
- CTRL–Z means "press the Ctrl (Control) and Z keys simultaneously".

2 The William Herschel Telescope

2.1 General description

The William Herschel Telescope (WHT) has an altazimuth mount with a 4.2-m diameter f/2.5 parabolic primary mirror. At present, the Cassegrain and two Nasmyth focal stations (all f/11) are in use and any one of them may be selected by suitably positioning the Nasmyth flat mirror. Prime and folded Cassegrain foci will be added in due course. A schematic drawing of the telescope is shown in Figure 1.

The altazimuth mount causes the field of view to rotate as the telescope tracks. In order to compensate for this, instruments are either mounted on a turntable or placed behind image derotation optics. The former option is used at the Cassegrain focus, but at Nasmyth, only light instruments may be mounted directly on the turntables and heavy apparatus, which must be kept stationary, is used with image derotators. An image derotator consists of a flat mirror, and a pair of fused silica prisms, each with lens surfaces (see La Palma Technical Note 9). The unit is mounted on one of the Nasmyth turntables and is rotated under computer control at an appropriate rate to keep the final image at a fixed orientation. This allows the instrument to remain stationary, at the cost of a reduced field.

Figure 1: Schematic view of the William Herschel Telescope

2.2 Summary of mechanical performance

- **Telescope software limits:** $-175° <$ Azimuth $< +355°$; $10° <$ Altitude $< 90°$

  An additional effective upper limit to the altitude of the telescope of 89°.8 is imposed by the speed limit for slewing in azimuth—see Section 3.5.

  The telescope aperture is partially obscured at elevations below 12°.

- **Cassegrain turntable software limits:** $-298° <$ mount position angle $< +223°.5$.

  Constraints on slit position angle depend on instrument mounting.

- **Nasmyth turntable limits:** These are instrument-dependent. There are no Nasmyth turntable limits if the instrument is stationary (*i.e.* if derotation optics are used). If instruments are attached directly to the turntables, then limits may be imposed by the twisting of their cables. **Note:** more restrictive limits are likely to be introduced.

- **Speed limits:** Maximum speeds and accelerations for altitude, azimuth and turntables are 1° s^{-1} and 0°.3 s^{-2}, respectively.

- **Switching between focal stations:** Cassegrain to Nasmyth: 4 minutes; Nasmyth to Nasmyth: 1 minute.

- **Tracking and pointing at Cassegrain and Nasmyth:**

Pointing accuracy:	rms residual of a global fit = 1.1–1.4 arcsec (Cassegrain) and 1.5–2.0 arcsec (Nasmyth)
Tracking accuracy:	(unguided) $<$ 0.3 arcsec in 3 minutes; $<$ 1.0 arcsec in 10 minutes (guided) $<$ 0.2 arcsec
Rotator tracking:	$<$ 0.2 arcsec image motion over the whole field
Offsetting accuracy:	$<$ 0.2 arcsec over 10 arcminutes

2.3 Optics

The optical layout of the William Herschel Telescope is shown in Figure 2. The optical data for the principal mirrors and the optical characteristics of the Cassegrain and Nasmyth foci are gathered in Tables 1 and 2. Spot diagrams and vignetting curves for the f/11 foci of the William Herschel Telescope

Table 1: *Summary of mirror characteristics for William Herschel Telescope*

Element	Shape	Asphericity	Working diameter (*mm*)	Focal length (*mm*)	Separation from primary (*mm*)	Material
Primary	Concave paraboloid	−1	4180	10439.6		Cervit
Secondary	Convex hyperboloid	−2.5329	1001	−3115.7	8093	Zerodur
Nasmyth	Flat	0	616×432		1750	Cervit

are given in Figures 3 to 5 and a more detailed optical description is given in La Palma Technical Note 9.

Figure 2: Optical layout of William Herschel Telescope

Figure 3: Spot diagrams for the f/11 Cassegrain and Nasmyth foci of the William Herschel Telescope. (a) Aberrations on a flat focal surface passing though the nominal focus on-axis. (b) Aberrations on a concave surface with radius of curvature 2.2 m. This illustrates the image quality available at the edge of the field for a suitably focussed autoguider. (c) Aberrations on a flat surface which is focussed for a compromise over the field.

Figure 4: Spot diagrams in a single plane for the Nasmyth foci of the William Herschel Telescope when used with the image derotation optics. Images for wavelengths from 330–1000 nm and distances of up to 2.5 arcminutes from the axis are shown.

Figure 5: Vignetting at the f/11 Cassegrain and Nasmyth foci of the William Herschel Telescope. The curves show the percentage transmission as a function of field radius. For accurate photometry, they should be interpreted with caution. The diagram refers to the area outside the constant central obstruction (8.4%) and secondary vane obstruction (0.6%).

Table 2: *Optical characteristics of William Herschel Telescope foci*

Focal station	Prime (without corrector)	Prime[a] (with corrector)	Cassegrain	Nasmyth (without image derotator)	Nasmyth (with image derotator)
Focal length (*mm*)	10440	11753	45738	45738	46419
Focal ratio	f/2.498	f/2.81	f/10.94	f/10.94	f/11.11
Field diameter (*arcmin*)					
(no vignetting)		40	15	7	2.5
(50% vignetting)		60	19	23	5
Scale (*arcsec* mm^{-1})	19.76	17.55	4.51	4.51	4.44
Diameter of central obstruction[b] (*mm*)	1210	1210	1210	1210	1210
Focus/mirror shift[c]			20	20	21

Notes:

[a] Corrected prime focus not yet available: design figures only

[b] Theorectical obscuration (baffles and vanes) is 9.083%

[c] Movement of focus position for unit movement of secondary mirror

2.4 Telescope control

The William Herschel Telescope is controlled by a MicroVAX 2 computer interfaced through CAMAC. The mechanisms currently under computer control are altitude, azimuth and instrument rotator drives, focus and dome rotation. The primary mirror cover, shutters and Nasmyth flat are controlled manually. At present, the telescope control system runs in a stand-alone mode (in the future, control of telescope and instruments will be integrated). The user interface is divided into two mutually exclusive parts: one for typed commands, the other a "handset" for guiding and focussing. Both of these are controlled from the same terminal. In addition, there is a display of telescope parameters, updated once a second. The telescope may be operated from the control room or from the GHRIL enclosure. The control system is described in detail in Section 15.

3 Planning observations

3.1 General

For the purposes of preparation, the observer will need to consider positions, finding charts, catalogue formats, the need for blind offsetting and the restrictions imposed by the altazimuth mount and drive limits (Section 3.5).

3.2 Positions, finding charts and offsets

In order to take advantage of the good pointing of the William Herschel Telescope to speed up acquisition, it is essential that object positions be measured as accurately as possible, preferably to better than 1 arcsecond for slit spectroscopy. In such cases, acquisition to within 3 arcseconds is usually possible and even objects close to the limit of the integrating TV can be identified unambiguously. Obviously, less accurate positions will suffice for imaging observations and for bright objects which are immediately recognisable, but errors comparable with the size of the TV field (1.5 × 1.1 arcminutes) will inevitably cause delays (recall that the finder telescope has not yet been commissioned).

Given accurate positions, it is often possible to do without a finding chart even for slit spectroscopy, but it is vital to ensure that either the target object or a suitable offset star will be visible on the integrating TV system. The approximate limit for a stellar object, under perfect conditions, at new moon and with maximum integration is roughly $m_v = 21.5$, but under many circumstances, this is a gross overestimate. If the object itself is fainter than $m_v = 17$–18 (and especially if it is diffuse), then a suitable offset star brighter than this limit should be found. The recommended procedure for blind offsetting is to slew to the reference star, centre it on a defined position using the handset and then to use the `BLIND_OFFSET` command to move to the target object. This requires the right ascension and declination of both objects, rather than one position and an offset.

A finding chart is obviously essential for very crowded fields or if positions are poorly known. The chart should cover somewhat more than the TV field (say 3–5 arcminutes square) and should reach to the limit of the Palomar or Southern IIIaJ survey. Directions and scale should be clearly marked.

The telescope computer accepts coordinates in three systems: mean pre-IAU76 (FK4; default B1950), mean post-IAU76 (FK5; default J2000) and geocentric apparent of the date and time of observation. Neglect of the distinction between the two mean coordinate systems can lead to errors of up to 1 arcsecond, comparable with the absolute pointing error of the telescope. For most purposes, it is enough to know that published coordinates with equinoxes earlier than 1975 are usually in the pre-IAU76 system (most are B1950) and that modern astrometric measurements use the post-IAU76 system (J2000). Optional parameters are proper motions (any epoch), parallax and radial velocity. For solar-system objects, differential tracking rates in right ascension and declination may be specified. A list of conventions and units is given elsewhere (Section 15.2.3). Very few observers will need to bother with parallax or radial velocity, and most will also be able to ignore proper motions. There are cases, however, where neglect of the proper motions will lead to severe difficulties, the most common trap being set by white dwarfs, which are often used as spectrophotometric standards, and which have large proper motions (see Appendix D.3 for details and list).

In the unlikely event that the target objects have positions in some system not supported by the telescope control software, the COCO package may be used to convert them. This is available on the VAX 8300 and is fully documented in *Starlink User Note 56.* To get started, type `COCO`, followed by `H` (for help).

3.3 Catalogues

The use of the control system's catalogue facilities is recommended for all but the simplest observing programmes. Catalogues of objects may be created through the user interface of the telescope computer or using an editor on the data-reduction VAX 8300. Alternatively, the observer may bring a catalogue on magnetic tape and transfer it to an account on the VAX 8300, whence it can be accessed by the telescope computer. The latter has no tape deck of its own, but can read TK50 cartridges (advance notice is required in this case). Catalogues are text files, which can be transferred using any tape format acceptable to a Starlink VAX. Use of the DCL utility BACKUP is recommended, with DCL COPY as the second choice. Tape densities of 1600 and 6250 bits per inch are supported. Those wishing to transfer files from computers other than VAXes should contact the La Palma computing staff well in advance of their visit.

Catalogues are simply lists of source parameters in free format with spaces separating the fields. Details of the format are given in Section 15.2.3. Extremely large catalogues can be rewritten in binary format to reduce access time, using the `INPUT` and `SAVE` commands as described in Section 15.4. Catalogues of astrometric, photometric and spectrophotometric standard stars are available on the telescope computer. These are described in Section 15.2.2 and full listings are given in Appendix D.

Figure 6: The area of sky accessible to the William Herschel Telescope. Lines of equal zenith distance are given on a plot of declination against hour angle. The limits corresponding to partial obscuration of the telescope by the dome rail (Zenith distance $< 78°$) and the zenith blind spot (Zenith distance $> 0°.21$; see text) are shown.

3.4 Limits

The area of sky accessible to the William Herschel Telescope at any time is determined purely by the horizon limit and the zenith blind spot (see Section 3.5, immediately below) and is shown in Figure 6. The William Herschel Telescope's ability to rotate through more than 360° in Azimuth (the values displayed by the telescope computer are in the range $-175°$ to $+355°$; see Figure 7) sometimes requires a choice to be made between two equivalent Azimuths. This choice is only made on source change and the nearer Azimuth is always selected. The other alternative may allow a longer time on source under the following perverse circumstances. The telescope can run into the positive Azimuth limit whilst tracking, but only for objects with declinations between $70°.7$ and $85°.6$ observed below the Pole (with $6^h <$ hour angle $< 12^h$). This situation is most unlikely to occur in practice, but if it does, the choice of Azimuth can be overridden using the command `UNWRAP AZIMUTH`. The telescope cannot hit the negative Azimuth limit during normal tracking.

If an attempt is made to slew the telescope to a position below the horizon limit, or if it runs into a limit during normal tracking, then an appropriate message appears on the Information Display and the

Figure 7: Azimuth limits of the William Herschel Telescope. The dotted and full lines show the Azimuth ranges for the two possible cases: WRAP $= -1$ ($-175° <$ Azimuth $< 0°$) and WRAP $= 0$ ($0° <$ Azimuth $< 355°$) .

main drives are stopped.

3.5 Altazimuth problems

Observers who have not previously used an altazimuth telescope may find some aspects of the operation of the William Herschel Telescope to be counter-intuitive. The two main problems are long slews in azimuth and the rotation of the field of view.

The William Herschel Telescope has to move through a large angle in azimuth as it tracks close to the zenith. In fact, the velocity in azimuth exceeds the mechanical speed limit within $0^\circ.21$ of the zenith, so objects in this area (the "zenith blind spot") cannot be observed. Only objects between declinations of $28^\circ\ 30'$ and 29° are affected, but time may also be wasted by alternating between northern ($\delta > 28^\circ\ 45'$, roughly speaking) and southern ($\delta < 28^\circ\ 45'$) objects. The William Herschel Telescope can only move in elevation by 80° between horizon and zenith)—it cannot move through the zenith. Consequently, moving between objects on the meridian but north and south of the zenith takes three minutes (180° in azimuth at $1^\circ\ s^{-1}$). Programmes should be planned so that groups of northern and southern objects are observed together. If the object moves into the zenith blind spot, tracking will fail, but the telescope will rotate as rapidly as possible in Azimuth so as to pick up the object again on the other side of the zenith.

The field of view of an altazimuth telescope rotates as the telescope tracks. At the Cassegrain focus of the William Herschel Telescope, this rotation is compensated by a turntable, driven under computer control and having 520° of travel. The turntable suffers from the same problem as the telescope close to the zenith: the parallactic angle changes rapidly with time (see Figure 8). The mode of operation of the turntable depends on the precise requirements of the observation. The options are:

1. A given position angle on the sky (*e.g.* if a particular slit position angle is required, or if a guide star is only available at one position angle).

2. Compensation for field rotation, but with no constraints on position angle, so that the sky position angle is allowed to alter on source change in order to minimise rotation, but is thereafter held constant.

3. Rotator stopped, so that the field maintains a constant orientation with respect to the vertical.

The last option may be suitable for spectrophotometric observations in which the slit has to be kept close to the vertical to minimise the effects of atmospheric differential refraction, but guiding is only possible by viewing the reflection of the object itself from the slit jaws (off-axis guide stars move). An easier alternative is to set the position angle of the rotator equal to the parallactic angle (or parallactic angle $-$ 180°, whichever is closer) at the beginning of an observation, and to allow it to track thereafter. Figure 9 illustrates the effects of atmospheric refraction as a function of wavelength for various air masses. If the differential refraction over the wavelength range in use exceeds the projected width of the slit, then the rotator should be moved.

Summary of Altazimuth problems:

- Zenith blind spot (telescope will not track within $0^\circ.21$ of the zenith).
- Avoid long slews in Azimuth by grouping objects north and south of declination $28^\circ\ 45'$ together.
- Rotator options: specific sky position angle; floating sky position angle; stopped.

4 Getting the best out of the telescope

4.1 Pointing

Optimum pointing can only be expected if care is taken to determine the potentially variable parameters that affect it. Pointing and tracking tests are carried out by Observatory staff from time to time and are used to determine the coefficients of the mathematical model used to correct for geometrical, flexure and gear errors in the telescope. Accurate measurements of time are also vital, so the time service must be

Figure 8: The variation of parallactic angle with hour angle for objects at different declinations. Note the rapid variation for objects at declinations close to $28^\circ\ 45'$ on the meridian.

Figure 9: The variation of atmospheric refraction with wavelength (normalised at 4500 Angstroms) for a range of air masses.

locked to an external signal and the difference between UT1 (Earth rotation) and UTC (atomic clock) must be made known to the control system. But several effects vary on a timescale short enough to justify altering them from night to night. They are:

- Zero-points of the high-resolution incremental encoders. These are set on startup with reference to absolute encoders of considerably lower resolution, and errors of a few arcseconds are expected.
- Collimation errors. These correspond to slight tilts in the telescope optics and movements of the structure. A collimation error in Elevation is equivalent to an encoder offset, but encoder and collimation errors in Azimuth have different functional forms. The errors expected from a combination of the two effects are:

$$\begin{array}{ll} \Delta E = IE & \text{Elevation} \\ \Delta A = IA + CA/\cos E & \text{Azimuth} \end{array}$$

  where IE and IA are the index errors in Elevation and Azimuth, respectively, and CA is the collimation error in Azimuth.
- The position of the axis of rotation of the instrument rotator on the detector. This is the fundamental reference axis of the telescope, with which the optics should be aligned. Pointing calibration procedures *must* be referred to this axis because it defines the only point on the detector which is invariant under rotation.
- Parameters affecting atmospheric differential refraction. These are wavelength, pressure, temperature and relative humidity, the last having negligible effect. To first order, refraction is given by $R \tan z$, where z is the apparent zenith distance and R is a constant. The default meteorological parameters for La Palma are: pressure, $p = 779$ millibar, temperature, $T = 5°$C and relative humidity, $RH = 0.5$. For a wavelength of $\lambda = 0.45$ microns, these give $R = 45.8$ arcsec. The effects of errors in the parameters are as follows:

$$\begin{array}{lcll} \Delta T & = & 10°C & \Rightarrow \Delta R \simeq 1.7 \text{ arcsec} \\ \Delta p & = & 10 \text{ millibar} & \Rightarrow \Delta R \simeq 0.6 \text{ arcsec} \\ \Delta RH & = & 0.5 & \Rightarrow \Delta R \simeq 0.02 \text{ arcsec} \end{array}$$

  The effect of varying the wavelength is also very significant (see Figure 9). The difference in R between wavelengths of 0.3 and 1.0 microns under typical La Palma conditions is $\simeq 2.8$ arcseconds.

Tools to deal with these problems have been provided within the telescope control system. They are described in detail in the reference sections of this manual and what follows is a brief summary. At the start of a night's observing, and subsequently if required, the commands `TEMPERATURE`, `PRESSURE` and `HUMIDITY` should be used to set the meteorological parameters. The wavelength should be set to match the detector/filter combination in use with the `WAVELENGTH` command. Next, the position of the rotator centre on the detector or on-axis TV camera should be determined. This is the reference position for the next step in the sequence, the `CALIBRATE` procedure, which uses observations of several stars at a variety of Elevations to derive the index and collimation errors. Without these precautions, the pointing performance of the William Herschel Telescope will be degraded significantly.

4.2 Acquisition

Speedy and accurate acquisition, especially of faint objects, requires an understanding of the coordinate systems and types of offset used by the telescope control system. This section outlines the necessary background: details of command syntax are given in Section 15.4.

The origin of coordinates in the focal plane of the telescope is defined by the axis of rotation of the instrument turntable, which is the fundamental reference in the sense that it also defines the direction with which the telescope optics should be aligned. When the telescope pointing is calibrated, this position is used as a reference mark. A new object should appear on the rotator centre (except for small, random errors) and should stay there when the turntable is rotated. In the absence of further software corrections, initial acquisition *must* be at this point, otherwise it will be correct only at one position angle on the sky.

The rotator centre is the origin for a set of (x, y) coordinates fixed in the focal plane. A point in the focal plane is referred to as an **aperture** (by historical association with photometers). The telescope is offset by an appropriate amount so that an object which was at the rotator centre ends up at (x, y). The coordinates are split up as:

$$x = x_{REF} + \Delta x$$

$$y = y_{REF} + \Delta y$$

where (x_{REF}, y_{REF}) is constant and $(\Delta x, \Delta y)$ is altered to move an object around in the focal plane. (x_{REF}, y_{REF}) will be referred to throughout as the **reference position** and $(\Delta x, \Delta y)$ as an **aperture offset**. The reference position is just a new origin of coordinates. A change of origin is often convenient, for example if the rotator centre is not on the detector. One might also want the reference position to be in a particular place, such as the centre of the detector or the middle of a spectrograph slit. The location of the reference position can always be checked: in the absence of offsets, it is the point in the focal plane about which the field appears to rotate when the sky position angle of the rotator is altered. On source change, the new target object should appear at the reference position to within the errors—hence the name.

An aperture offset may then be used to move the object to a different point in the focal plane. The standard procedure for slit spectroscopy (except for very bright objects) is to acquire and centre the target at a point some way off the slit (usually the rotator centre) and then to move it on to the slit using an aperture offset. This avoids the problem of positioning a barely-visible object on the slit. Aperture offsets and changes of reference position do not cause the displayed right ascension and declination of the telescope to change because, conceptually, the *same* object is being observed at a *different* point in the focal plane.

The telescope control system refers to numbered apertures. The reference position is aperture 0 and the offsets are apertures 1–10. The commands affecting the reference position and aperture offsets are as follows:

- `APERTURE` selects a pre-defined aperture offset or returns to the reference position (`APERTURE 0`).
- `BEAMSWITCH` has the same function as `APERTURE` but aperture offsets are input directly as (x, y) coordinates rather than as aperture numbers. `BEAMSWITCH 0 0` returns to the reference position.
- `DEFINE APERTURE` sets up the (x, y) coordinates used by the `APERTURE` command.
- `STORE APERTURE` stores, as a numbered aperture, the aperture offset determined interactively using the handset APOFF function.

Conversely, if the telescope is to be pointed at a *different* object whilst retaining the same reference position, an **offset** is used. This is constant on the sky and so rotates on the detector as the PA changes. The displayed position of the telescope also updates appropriately.

For offsets, it is useful to make the distinction between the cases where the position of the object is known more accurately than that of the telescope and its converse. The first case is appropriate to a blind offset between two objects of accurately known position, one of which is invisible on the TV. The telescope is first set to the visible object. There are inaccuracies in the pointing, so it has to be moved slightly to align the object precisely with the reference position. A local correction to the pointing model is generated and this is used to move the telescope to the exact position of the invisible object, which is then displayed as the telescope coordinates. The pointing correction (which may only be valid over a small area of sky) is removed on source change. The command `BLIND_OFFSET` implements this operation in the telescope control system.

In the second case, the object positions are only known roughly, but the offset between them is accurate. The telescope is set on the first object and the displayed position is the best estimate of its position. The telescope is then offset by the known amount, and the displayed position alters appropriately. This approach is also appropriate, for example, for offset sky measurements with imaging CCD's.

An offset may be specified either as $(\Delta\alpha, \Delta\delta)$ in (seconds, arcseconds), in which case the magnitude varies with declination, or as a tangent-plane offset $(\xi,\ \eta)$ in (arcseconds, arcseconds), with ξ and η parallel to right ascension and declination, respectively, in which case the magnitude is constant on the sky. The commands affecting positional offsets are:

- `POSITION` selects a numbered offset position (`POSITION 0` is a zero offset).
- `OFFSET` has the same function as position, except that input is given directly as $(\Delta\alpha, \Delta\delta)$ or (ξ, η).
- `DEFINE POSITION` sets up the numbered offsets used by the `POSITION` command.
- `STORE POSITION` stores an offset which has been set up interactively with the handset OFFSET function.

4.3 The Television System: integration, filtering and flat fields

The William Herschel Telescope is equipped with microprocessor-controlled intensified television cameras for acquisition and field-viewing. The system is capable of on-target integration and of recursive filtering, both of which increase the signal-to-noise ratio of the images. In direct mode, the camera is read out every 40 milliseconds (standard video rate). On-target integration merely allows charge to build up on the photocathode for some period before it is read out. The integration time is measured in **frames** of 40 milliseconds duration. On-target integration is potentially dangerous because the photocathode may be damaged by excessive build-up of charge, so care is needed. The signal-to-noise ratio (neglecting dark current) is proportional to $N^{1/2}$, where N is the number of frames of integration and the time constant is $40N$ milliseconds.

An alternative method of increasing the signal-to-noise ratio is to use recursive filtering. This has the advantage that it is done in the TV system microprocessor and is therefore non-destructive. The algorithm used is:

$$\Sigma_i = 2^{-S}((2^S - 1)\Sigma_{i-1} + x_i)$$

where x_i is the ith image read out from the camera (after any on-target integration) and Σ_i is the ith smoothed image. The image is effectively smoothed over 2^S frames. The signal-to-noise ratio is proportional to $(2^S - 1)^{1/2}N^{1/2}$ and the time constant is $40(2^S N)$ milliseconds. It is usually better to use moderate on-target integrations with filtering rather than extremely long integrations: the risk of damage to the photocathode is reduced and the images are affected less by transient glitches.

A third technique for improving the quality of the image is flat-fielding. Very deep images, or those obtained in bright conditions, show significant structure in the sky background, especially near the centre of the photocathode. This makes it difficult to see very faint objects. Standard flat fields have been obtained for both cameras, and the FLAT FIELD key or `FF` command may be used to divide the image currently in the TV system memory by the appropriate flat field.

Part II
GUIDE TO OBSERVING

5 Preparation for observing—things to do before dinner

5.1 Preparing catalogues

- Transfer any catalogues you have brought with you on to the VAX 8300 (you will be allocated one of the GUESTnm usernames). Given suitable authorization, you may also transfer catalogues from a remote computer over the PSS link using `MAIL`, `POST` or `TRANSFER`—see the computer manager for more information.
- Edit the catalogues as necessary (see Section 15.2.3 for details of the format).

5.2 Starting the telescope control system and TV system

- Log in to the captive `TCS_LOGIN` account on the telescope computer at the `TXA1:` terminal on the control desk by typing RETURN followed by `TCS_LOGIN` in response to the `Username:` prompt.
- After the initial messages and prompt, enter `START`.
- Wait for the system to start up. It is ready for use when the `USER>` prompt is displayed on `TXA1:` and the Information display above it on the desk begins to update.
- If the TV system is not already running, switch on the VME crate in the CLIP Centre instrument cabinet (green switch in bottom left hand corner). The system boots automatically on power-up.

5.3 Inputting catalogues

- Copy your catalogue(s) to the telescope computer using the `INPUT` command at the user interface. A catalogue called STARS.CAT in the directory [GUEST01.CAT] on the USER1 disk of the VAX 8300 can be copied to the telescope computer using `IN LPVA::DISK$USER1:[GUEST01.CAT]STARS`.
- Use `CAT_EDIT` for any remaining editing of text-file catalogues on the telescope computer.
- For small numbers of objects, input data using `SOURCE` and associated commands (`PROPER`, `EPOCH`, `PARALLAX` and `RV`) and `ADD` to the catalogue.
- Make a local backup of the catalogue using `OUTPUT`. The command `OUT FILE STARS` creates a file called STARS.CAT on the telescope computer which can be recalled using `INPUT STARS`.
- If you have very large catalogues (>100 objects, or so), make binary copies using `SAVE`, but input all positions needed during the night first because you cannot append to a binary catalogue. `LOAD` reads in a binary catalogue.
- Produce a listing of the catalogue on the line printer with `OUTPUT PRINTER` (if no printout appears, check that the printer is switched to the telescope computer).

5.4 Checking the building

- Close all of the blinds so that the building appears dark from the outside.
- Check unnecessary sources of heat and light.

6 Starting up the telescope

Power up the telescope before dinner and run through the list of functional checks. Unless a responsible person remains in the building, the telescope should be left with the bearing and gear-box oil turned off and the dome control should be switched OFF at the gallery. The power amplifiers may be left on.

6.1 Safety checks

- Check the commissioning log-book for possible problems and safety hazards.
- Check for people and obstructions around the telescope and dome.
- Turn off all dome lights (buttons on Engineering desk).
- Check that all heat-lock doors into the dome are shut.

6.2 Powering up the telescope

Engineering desk

- On the "SERVICES" panel:
  - Ensure "MODE" key set to "ENG";
  - Press "BEARING OIL PUMP" ON (button from red ⇒ green);
  - Press "G/B OIL" ON (button from red ⇒ green);
- Wait for *all* lamps on the alarms panel to go out. At this point, the green "COMP RESET" light should come on, indicating that it is possible to switch to computer control.

Marconi power cabinet and Nasmyth cabinet

- Check that the power amplifiers appropriate to the focal station(s) to be used are switched on:
  - Altitude;
  - Azimuth;
  - Cassegrain turntable ("CTT");
  - Cassegrain cable wrap ("CW");
  - Focus drive ("FD");
  - Nasmyth turntable(s).

Dome gallery

- "DOME CONTROL" keyswitch set to "REMOTE".

6.3 Computer-mode control and functional checks

- Turn the COMP/ENG key on the engineering desk to COMP and press the COMP RESET button to select computer mode.
- Check that the drive amplifiers have all powered up.
- Check that the shutters and primary mirror cover are under engineering control (yellow manual override lamps on Engineering desk lit) but the dome and focus are not.
- At this point **no** red lights should be lit on the engineering desk.
- Check telescope, rotator, focus and dome by moving each mechanism independently, *e.g.*:
  - `ALT 45`
  - `AZ 120`
  - `ROT/MOUNT 20`
  - `FOCUS 82.0`
  - `DOME 120`

  Use the information display to make sure that each mechanism is driving correctly.
- Check the tracking by tracking a suitable position, *e.g.* `GOTO TEST 12 00 00 45 00 00 A` followed by `ROT 0`. Look at the tracking errors in Elevation (ΔE) and Azimuth (ΔA). Neither ΔE nor $\Delta A \cos E$ should be larger than 0.1 arcseconds for a significant fraction of the time. Similarly, the rotator tracking error should be a few arcseconds. Check that the dome and telescope Azimuths are approximately the same.

- Check encoder consistency using the second page of the Information Display. The absolute and (gear) incremental encoders for the main drives and all of the rotators should read the same values to within about 10 arcseconds when the telescope is moving slowly (at higher speeds, the values appear to differ because the display locations are not updated simultaneously).
- Repeat the rotator checks for all of the focal stations to be used during the night.
- Open and close the primary mirror cover using the buttons on the engineering desk. *Now leave it shut until you have opened the dome.*
- If you plan to use a Nasmyth focus, move the telescope to the zenith (`ALT 90`) and check the motion of the Nasmyth flat. *Put it back in the stowed (Cassegrain) position unless you are about to start observing, or it will get dusty.*
- If **any** of these checks fail, contact the Duty Technician. Appendix C may help in locating the fault.
- If you are about to start observing immediately, carry on to the next section. Otherwise, type `STOP` at the user interface to stop the main mechanisms, wait for a few seconds and then type `ENG` to return to engineering mode. Then turn off the bearing and gearbox oil at the engineering desk and return the "DOME CONTROL" keyswitch on the gallery control panel to the "OFF" position. The telescope is now safe to leave.

6.4 Dome, mirror covers and cameras

- Check that the primary cover is closed.
- Check that the dome lights are turned off.
- Check the weather (wind speed < 80 km h^{-1} for at least 85% of the time, with gusts < 90 km h^{-1}; humidity $< 90\%$, not obviously wet or very dusty).
- Keyswitches on the control panel on the dome balcony: "DOME CONTROL" set to "REMOTE", "TOP SHUTTER" and "BOTTOM SHUTTER" to "LOCAL".
- Open shutters: bottom first (micro-drive lower until the "main overtravel" light goes out, then main drive lower until the power cuts out), then top (micro-drive raise until the "main overtravel" light goes out, the main drive raise until the power cuts out).
- Turn on the vent fans using the buttons on the engineering desk.
- Open the mirror cover by pressing the "primary open" button on the engineering desk.

6.5 Selecting the focal station

The Cassegrain focus is the default in hardware and software: the Nasmyth flat should be left in its stowed position and the computer system initialises with the appropriate software configuration. In order to change focal station, proceed as follows:

- Make sure that the telescope is near the zenith (use `ALT 90` if not).
- Move the Nasmyth flat using the buttons on the engineering desk. The three useful configurations are:
  - Nasmyth stowed (*alias* Cassegrain);
  - Nasmyth 1 (*alias* cable-wrap or GHRIL);
  - Nasmyth 2 (*alias* drive-side, FLEX or UES).
- Select the correct parameters in software using one of the commands:
  - `CASSEGRAIN`;
  - `GHRIL` (instrument mounted directly on rotator);
  - `GHRIL/DEROTATOR` (derotation optics mounted);
  - `FLEX` (instrument mounted directly on rotator).

6.6 Transfer of control to another terminal

The telescope can be controlled from secondary terminals, currently located in the GHRIL room, on the FLEX Nasmyth platform and in the Engineering desk, instead of the primary terminal on the control desk.

- Select one of these at the switch box on top of the telescope MicroVAX cabinet.
- Type `REMOTE COMMAND` at the user interface. This transfers control to the secondary terminal.
- To restore control to the primary terminal, type `REMOTE OFF` at the user interface or CTRL–Z on the primary terminal.

7 Calibration procedures

These procedures should be carried out in twilight, before the start of observing. With care, they can be done at sunset or even before, so as to avoid waste of observing time.

7.1 Focussing

7.1.1 FOS–2

- Select a bright star at some suitable position (*e.g.* approximately one hour off the meridian with $35° < \delta < 50°$) from the pointing grid listed in Appendix D and drive the telescope to it with `GOCAT <source_name>`. It should appear close to the centre of the on-axis camera field.
- Select $\boxed{\text{DIRECT}}$ on the TV system and slowly increase the camera gain until the star becomes visible.
- Press $\boxed{\text{HANDSET}}$ to select the handset mode of the user interface and use X_Y mode to move the star to a position just above the centre of the slit.
- Select handset $\boxed{\text{FOCUS}}$ with increments of 0.1 millimetres and use the ⇒ and ⇐ keys to increment and decrement the focus to give minimum image size. The current focus position is shown on the Information Display. The focus drive is a bit sticky, so wait for the reading to stop changing before observing the image.
- In good conditions *only*, use 0.03 millimetres focus increments.
- Check the focus on the FOS slit by moving the star on to the slit, exposing and measuring the spatial width of the spectrum with the command `20 X-LINE` on the CCD VME system. Drive the telescope focus by ±0.1 millimetres and repeat. The coarse (0.8 arcsec/pixel) spatial scale of FOS makes this test relatively insensitive, however.

7.1.2 Taurus (CCD imaging and Fabry-Perot)

- Focus Taurus using the pinhole mask (see Taurus documentation for details).
- Select a brightish star (with due regard to CCD saturation or IPCS safety).
- Use the `FOCUS` command to set up an approximate focus (typically 88.3 millimetres).
- Move the star to the off-axis camera with `APERTURE 1` or `BEAMSWITCH 0 -602`.
- Select $\boxed{\text{HANDSET}}$ and $\boxed{\text{FOCUS}}$ with increments of 0.1 millimetres and use the ⇒ and ⇐ keys to increment and decrement the focus to give the best image (note that the images are not round at this field radius—see Figure 3). The current focus position is shown on the Information display. The focus drive is a bit sticky, so wait for the reading to stop changing before observing the image.
- Move the star back on-axis using `APERTURE 0` or `BEAMSWITCH 0 0`.
- Expose the CCD or IPCS.
- Measure the image size:

- For the CCD, type `CURS` on the VME system and use the arrow keys to position the cursor so that the image is in the middle of the lower centre of the box. Exit from cursor mode (CTRL–C) and type `20 Y-LINE`. A profile will be displayed, followed by a FWHM. To clear the profile page, switch back to the CCD display or get the profile page back type `P-CL`, `LP` or `NP`, respectively.
- For the IPCS, observe the image directly.

- Change CFOC by 50 units at a time and determine the value for minimum image size. Set CFOC to this value. Both the CCD and guide camera should now be in focus.

7.1.3 Direct CCD imaging at f/11

This differs from Taurus imaging because the CCD camera cannot be focussed independently. The telescope focus should be determined accurately for the CCD, which is nominally parfocal with the off-axis camera. If the latter is noticeably out of focus, then its position should be adjusted by hand.

- Select a brightish star (not so bright as to saturate the CCD in 1 second).
- Use the `FOCUS` command to set up an approximate focus.
- Expose the CCD and measure the image size on the VME system by typing `CURS` and using the arrow keys to position the cursor so that the image is in the middle of the lower centre of the box. Exit from cursor mode (CTRL–C) and type `20 Y-LINE`. A profile will be displayed, followed by a FWHM. To clear the profile page, switch back to the CCD display or get the profile page back type `P-CL`, `LP` or `NP`, respectively.
- Select HANDSET and use the cursor keys to increment the focus in steps of 0.1 millimetres. Repeat the CCD exposures (remembering to wait until the focus has settled) and find the focus for minimum image size.
- Check the focus on the off-axis guide camera by selecting `APERTURE 1` to move the star on to it. The CCD and TV should be parfocal: if they are not, a mechanical adjustment is needed.

7.1.4 Manchester Echelle

The assumption is made that the spectrograph and off-axis camera are parfocal.

- Select a brightish star.
- Use the `FOCUS` command to set up an approximate focus.
- Move the star to the off-axis camera with `APERTURE 1` or `BEAMSWITCH 0 -602`.
- Select HANDSET and FOCUS with increments of 0.1 millimetres and use the ⇒ and ⇐ keys to increment and decrement the focus to give the best image (note that the images are not round at this field radius—see Figure 3). The current focus position is shown on the Information display. The focus drive is a bit sticky, so wait for the reading to stop changing before observing the image.

7.2 Pointing calibration

7.2.1 All instruments

Enter the effective wavelength, outside air temperature and pressure to be used in the refraction correction using the commands `WAVELENGTH`, `TEMPERATURE` and `PRESSURE`. Units are micron, °C and millibar. Temperature and pressure may be read from the Vaisala probe and the control-room barograph, respectively (CAMC has really accurate values).

7.2.2 FOS–2

- Check the reference position. For FOS-2, the convention is that the rotator centre is used. Its TV coordinates will be noted in the log book.
  - Move a cursor to this position and use the MARK key to draw a red box around it.

  - Slew the telescope to one of the pointing calibration stars (generally done already to focus the telescope). It should appear very close to the mark.
  - Move the star exactly on to the mark using the handset and then increment the rotator sky position angle by 180°. The star should remain on the mark to within the telescope tracking accuracy.
  - Check this by returning the sky position angle to its initial value.
  - If the star moves in a semi-circle then the rotator centre coordinates are incorrect: estimate a better value by taking the mean of the star coordinates at the two rotator position angles.
  - Clear the old mark using the CL MARKS key, mark the new position and repeat the check.
- Execute the procedure to measure collimation and index errors.
  - Type `CALIBRATE` at the user interface.
  - The telescope will slew to a star and handset mode will be selected. The star should appear within approximately 5 arcseconds of the rotator centre. You can re-adjust the focus provided that you do not leave handset mode in the process.
  - Use the handset to align the star with the mark, then press the HANDSET key. This logs the position and slews to the next object.
  - After 7 of these stars, the program asks whether the stars were all correctly centred. Answer `Y` unless you want to abort the procedure.
  - The coefficients and their errors are listed (after a short delay). The rms errors should be in the range 0.5–1.0 arcsec for IE, 1.0–2.0 arcsec for CA and 1.0–3.0 arcsec for IA. If so, answer `Y` when asked whether you want to use these values.
  - Repeat the last `GOCAT` to check that the pointing has been improved.
  - To abort `CALIBRATE` at any stage, type CTRL–Z.
  - To recall the last `CALIBRATE`, type `CALIBRATE/LAST`; to revert to the default coefficients, type `CALIBRATE/DEFAULT`.
- Check the aperture offset from the rotator centre to the centre of the FOS slit.
  - Find the slit, which can usually be seen using sky brightness and full TV gain. Beware of increasing the gain with a bright star in the field. If necessary move the star off the TV and mark the outline of the slit on the screen (`D-BOX` command).
  - Move a star to the reference position and type `APERTURE 2`. The star should move on to the slit.
  - If it does not, return to the reference position (`APERTURE 0`), select the handset APOFF function, move the star to the right place using the cursor keys and use the `STORE APERTURE 2` command. This overwrites the values used by `APERTURE 2` (use another aperture number if you prefer).
  - The object can be more precisely aligned if required by taking FOS exposures (beware of differential refraction between TV and FOS wavebands at low elevations).

7.2.3 Imaging

This section refers to imaging through Taurus (used as a focal reducer with the f/2 or f/4 cameras and a CCD or in Fabry-Perot mode with the IPCS) or directly, at f/11. For many purposes, the default pointing solution will be adequate, but for precise object identification the reference position, index and collimation errors should be checked.

- Slew to a star (the one used for focussing will do).
- Take an exposure and measure the star's position on the detector.
- Establish the relation between handset X_Y and detector coordinates by moving the star around and repeating the exposure.
- Change the sky position angle of the rotator by 180° and repeat the exposure.
- The mean of the positions for position angle 0° and 180° is the best estimate of the rotator centre.

- Move the star to this position and repeat as a check.
- Execute the procedure to determine index and collimation errors.
  - Type CALIBRATE to start the pointing calibration procedure.
  - The telescope will slew to the first star and handset mode will be selected.
  - Take an exposure and measure the position of the star.
  - Work out the x, y displacement needed to move the star to the rotator centre and move it there using the handset (in X_Y mode).
  - Repeat the exposure to check the centering and then press the HANDSET key to enter the data and slew to the next star.
  - After 7 of these stars, the program asks whether the stars were all correctly centred. Answer Y unless you want to abort the procedure.
  - The coefficients and their errors are listed (after a short delay). The rms errors should be in the range 0.5–1.0 arcsec for IE, 1.0–2.0 arcsec for CA and 1.0–3.0 arcsec for IA. If so, answer Y when asked whether you want to use these values.
  - Repeat the last GOCAT and exposure to check that the pointing has been improved.
  - To abort CALIBRATE at any stage, type CTRL–Z.
  - To recall the last CALIBRATE, type CALIBRATE/LAST; to revert to the default coefficients, type CALIBRATE/DEFAULT.

7.2.4 Instruments with no on-axis field viewing

This section covers instruments such as the Manchester Echelle which have neither a TV camera nor an imaging detector on-axis. In this case, objects must be acquired and centred first on the off-axis camera.

- Slew to one of the pointing calibration stars
- Type APERTURE 1 to move it to the off-axis camera.
- Determine the exact position on the camera corresponding to this aperture offset:
  - Find the position of the star in TV coordinates.
  - Increment the rotator sky position angle by 180° and measure the position again. Take the mean.
  - Move the star to the mean position and repeat the test as a check.
  - MARK the centre of rotation and make a note of the coordinates.
- Move back to the reference position using APERTURE 0.
- Now locate the main detector:
  - Select HANDSET and APOFF mode.
  - Move the star around until it is centred on the slit, fibre or other desired location.
  - Type STORE APERTURE 2 to record the aperture offset.
- Note: it should be possible to perform a CALIBRATE using the off-axis camera, but a bug in the control system prevents this at present.

8 Acquiring an object

8.1 Slewing to an object

Note: make sure that the TV cameras are in **direct** mode with their gain controls in the clicked-off position before starting a slew. Go to a new object using one of the following commands:

- GOCAT slews to a object in the user catalogue, specified by name, *e.g.* GOCAT NGC4151.
- GOTO slews to an object specified directly by name, right ascension , declination, Equinox, *e.g.* GOTO NGC8888 12 34 56.78 -22 22 22 J2000.

- `NEXT` slews to the edit source, whose parameters are entered using `SOURCE`, `PM`, `EPOCH`, `PARALLAX` and `RV`.
- For solar-system objects, use the command `DIFF_RATES` to input a non-sidereal tracking correction.

The use of catalogues and `GOCAT` is recommended. Check that the object is accessible. If it is not, the Information Display will show "S/W LIM" and the telescope will stop.

8.2 Using the TV

Refer to Section 4.3 for background information. For best results:

- Keep the cameras in **direct** mode with their gains at zero during a slew.
- When the telescope is in position, turn the gain up **slowly**— the camera has a time constant of about 3 seconds.
- If you cannot see enough in direct mode, turn up the on-target integration step by step (each step is a factor of 2 *i.e.* $N = 2, 4, 8, \ldots$ frames).
- Use AVERAGE with the smoothing parameter, $S = 2$ or 3. SUM is not recommended.
- Remember that frames take 2^S readouts to build up to full intensity in average mode—be patient.
- If you cannot see enough on a deep integration ($N > 100$, $S > 2$, say), then try flat-fielding the image with FLAT FIELD key.

8.3 FOS acquisition

8.3.1 FOS—bright objects

A "bright" object in this context is one which can be seen easily on the TV even when it is on the slit. In this case, it makes sense to reset the reference position to be on the slit, rather than at the rotator centre, and to acquire directly on to the slit.

- Slew to a star and centre it precisely on the rotator centre using the handset in X_Y mode.
- Switch to APOFF mode and move the star to the new reference position on the centre of the slit.
- Type `STORE APERTURE 0` to enter the required offset. Subsequent source changes should bring the objects close to the slit centre.

Use the handset in X_Y mode to make final small corrections to centre objects precisely on the slit.

8.3.2 FOS—objects just visible on the TV

If an object is difficult to see on the TV, it is much easier to centre it precisely on the rotator centre and then to use an `APERTURE` command to move it on to the slit. Adjust the TV gain, integration and smoothing so that the object is easily visible and use handset X_Y to centre the object on the mark at the rotator centre, then type `APERTURE 2` to move it to the slit. Final, very small, corrections can be put in while the FOS integration is in progress, using heavy TV integration if necessary.

8.3.3 FOS—blind offsetting

Very faint objects are best found by offsetting from a nearby star of accurately-known position. A reference star should have $V < 17$, so as to be visible on the TV with minimal integration. The relative positions of target and reference *must* be known to better than 0.5 arcseconds.

- Slew to the reference star and move it precisely to the rotator centre using the handset in X_Y mode.
- Use the command `BLIND_OFFSET` to slew to the faint target, *e.g.* `BLIND 3C294`. This keeps the pointing offsets determined on the reference star.
- Type `APERTURE 2` to move the target on to the slit.

A succession of `BLIND` commands uses the same pointing offsets; `GOCAT` *etc.* reset them.

8.4 Acquisition for imaging detectors

It should be unnecessary to do any more than to slew to the object and take a test exposure. To examine the field on the off-axis TV camera, type `APERTURE 1`; to return it to the detector, type `APERTURE 0`.

8.5 Acquisition for instruments without field viewing

In the absence of field viewing using a TV or other imaging detector, it is necessary to locate the object of interest on the off-axis camera, centre it, and then move it to the main instrument. This assumes that the steps described in Section 7.2.4 have all been taken.

- Slew to the object.
- Type `APERTURE 1` to move the field to the off-axis camera.
- Use the handset to centre the object of interest on the previously-determined reference point.
- Move the object on to the spectrograph slit (or fibre, or whatever) with `APERTURE 2`.

8.6 Changing the displayed coordinates

On slewing to an object, the control system displays coordinates of the telescope's tracking position in the system used for data input. This can be changed to other coordinate systems with the command `DISPLAY.`

- `DISPLAY HA_DEC`—topocentric hour angle and declination.
- `DISPLAY A` —geocentric apparent coordinates.
- `DISPLAY INPUT` —resets to the default system used for data entry
- `DISPLAY J2000` —J2000 mean place (post-IAU76 system).
- `DISPLAY B1950` —B1950 mean place (pre-IAU76 system).

9 Rotator control

The instrument rotator may be operated in various ways, depending on the relative importance of autoguiding, keeping the slit vertical to avoid light loss from a slit due to differential refraction or loss of time due to unnecessary rotator movement.

- Tracking a specified sky position angle (default). Essential for observations requiring a particular slit orientation or choice of guide star. The `ROTATOR` command is used to specify the position angle.
- Stopped, usually with the spectrograph slit vertical. Use `ROT/MOUNT 91.2` to set the FOS slit vertical, followed by `SET ROT NOTRACK` to turn off rotator tracking.
- Tracking with the slit approximately vertical. This allows guiding without losing too much light from a spectrograph slit due to differential refraction. Set the sky position angle equal to the parallactic angle (or 180° different from it) at the start of the observation.
- Minimising movement. Adjust the demand sky position angle so that the mount angle does not change, *e.g.* by typing `STOP ROT`, followed by `SET ROT TRACK` to re-enable rotator tracking

10 Guiding

10.1 General

Autoguiding is usually worthwhile for exposures longer than 500 seconds. There are two possible methods in the interim system. The first is to use an object in the field of the slit-viewing camera (FOS only). The field is so small that this is not always possible. The second is to use an off-axis guide star. The off-axis TV camera is fixed in the focal plane, so the rotator must be moved in order to search for guide stars. Note that this system will change completely with the introduction of the new Cassegrain Acquisition and Guiding Box during 1989.

10.2 On-axis guiding—FOS only

- Centre the object of interest on the slit.
- Search for a stellar object in the field (note that not all of the TV field is in focus if a narrow dekker is used), taking care not to use too much on-target integration, especially if the target object is bright.
- Place the TV cursor close to the guide star.
- Press the GUIDE or I-GUIDE key on the TV system keypad for direct and sum/average modes, respectively. The latter will not work with less than 12 frames of integration: if necessary, integrate for longer and turn down the camera gain. The cursor should now follow the star image.
- Type `GUIDE ON` at the user interface. This causes the telescope to respond to guiding errors from the TV.
- Check that the information display shows a GUIDING message and note the pixel coordinates for future reference.
- To make minor centering adjustments with the guiding loop locked, type `GUIDE ON x y`, where x and y are the desired TV pixel coordinates of the guide star. For example, if guiding starts with the cursor at (250, 150) and the target is 2 pixels below the slit, type `GUIDE ON 250 148`.

10.3 Off-axis guiding

- Centre the object of interest on the slit.
- Select the OFF-AXIS camera, initially in direct mode.
- Look for a guide star, increasing the integration if necessary (*e.g.* at high galactic latitude).
- If no star is visible, move the rotator by selecting HANDSET and ROTATOR and incrementing with the cursor keys.
- When a star appears, place the TV cursor close to it.
- For FOS, it is worthwhile reverting to the on-axis camera and checking the centering of the target object, especially if the rotator has been moved a long way.
- Press the GUIDE or I-GUIDE key on the TV system keypad for direct and sum/average modes, respectively. The latter will not work with less than 12 frames of integration: if necessary, integrate for longer and turn down the camera gain. The cursor should now follow the star image.
- Type `GUIDE ON` at the user interface. This causes the telescope to respond to guiding errors from the TV.
- Check that the information display shows a GUIDING message and note the pixel coordinates for future reference.
- The FOS slit can now only be viewed in direct mode on the mini-monitor (not normally useful).

11 Closing down

11.1 Cameras, mirror cover and dome

This procedure is to be used at the end of the night and to close for bad weather.

- Close the primary mirror cover (button on the engineering desk).
- Select DIRECT on the TV system.
- Turn camera gain controls to their clicked-off positions.
- Turn cameras OFF (red buttons).
- Switch OFF the dome "VENT FANS".
- Close the dome:

- ◦ Ensure the bottom shutter is lower than the group of switch trips on the right hand side of the slit.
- ◦ Drive the top shutter using "MAIN DRIVE LOWER" until the power cuts out close to the park position. The "MAIN DRIVE OVERTRAVEL" lamp will come on shortly before the power cuts out; this is quite normal.
- ◦ If the power cuts out immediately due to a torque trip, press "TORQUE TRIP RESET", continue for a bit in "MICRO DRIVE LOWER" and switch to "MAIN DRIVE LOWER" again. It may be necessary to move the top shutter over its point of balance in micro drive.
- ◦ Complete the travel using "MICRO DRIVE LOWER", again until the power cuts out.
- ◦ Now raise the bottom shutter with "MAIN DRIVE RAISE" until the power cuts out (again, the "MAIN DRIVE OVERTRAVEL" lamp will come on).
- ◦ Finally raise it with "MICRO DRIVE RAISE" until the power cuts out.
- ◦ Leave the shutter and dome drives "OFF". The key should stay in the dome control panel.

11.2 Closing down the telescope

This procedure is to be used when leaving the telescope at the end of an observing session, having completed the actions in the previous section.

- Park the telescope by typing `ALT 90` at the user interface (be sure to wait until the telescope has finished moving—indicated by "STOPPED" messages on the information display—before proceeding further). The telescope may also be parked by driving manually to the zenith using the controls on the engineering rack after switching to engineering mode. The telescope may be left at any azimuth.
- Put the telescope into engineering mode by typing `ENG` at the user interface.
- Type `EXIT` to stop the control system. The TV system is normally left running.
- At the engineering rack:
  - ◦ Press "G/B OIL" OFF (button green ⇒ red);
  - ◦ Press "BEARING OIL PUMP" OFF (button green ⇒ red);

Part III
REFERENCE SECTIONS

12 Before observing

12.1 Checking the building

Checklist:

- LIGHTS—make sure that the building is dark when viewed from outside and that no light shines into the dome:
  - Draw the blinds on *all* outside windows and at the end of the control room;
  - Check that all unnecessary lighting within the building, and especially in the dome, is extinguished (not forgetting the air-conditioning plant and its inner room);
  - Check that the dark slides on the doors into the dome are closed and that no corridor lights can shine into the dome.
- HEAT—eliminate any unnecessary heat sources that might affect the dome:
  - Check that all heat lock doors are firmly shut.
  - Check that the large door to the aluminising area is fully shut.

12.2 Powering up the telescope—full checklist

Under most circumstances, it should be unnecessary to do more than is given in Section 6. The following is a comprehensive list of the operations needed to power up the telescope after a complete shutdown. It will also help to find out whether a switch has been left off by accident. Most of the switches and indicators are in the engineering desk next to the window or in cabinets close to the right-hand wall as you face the telescope. Starting at the end closest to the window, these are:

<u>Cabinet identities</u>

0. Engineering desk;
1. Contactor cabinet (main power switches);
2. Interconnection cabinet (no switches or indicators—ignore);
3. CLIP cabinet (CAMAC and 24V and 110V supplies);
4. Nasmyth cabinet (CAMAC and Nasmyth turntable servo electronics);
5. Marconi servo cabinet (Marconi CAMAC Crate and servo electronics);
6. Marconi power cabinet (amplifiers);
7. CAMAC system crate (also has Time Service and DECservers).

Notes:

- Where there is a statement "Check x ON" you should expect to find x set in the "ON" state, and you should *not* switch it off at the end of the night.
- All the steps to be taken in powering down are stated explicitly in the section on "Shutting down".
- The labels of all switches, buttons, keys *etc.* which are referred to in the checklists appear between double quotation marks, *e.g.* "VENT FANS" on the engineering desk.

Checklist:

a) Contactor cabinet (1)—working from top to bottom

- Check that the 415V supply is available (green lamp);
- Check that the voltage is within tolerance on all 3 phases (390–430V);
- All contact breakers in this cabinet should already be set correctly but check row by row to make sure:

  ROW 1

  - Check "TELESCOPE POWER" ON;
  - Check "HYDRAULIC SUPPORT" ON;
  - Check "DOME POWER" ON.

  ROW 2

  - Check "GEAR BOX PUMP" ON;
  - Check "GEAR OIL ALARM" ON (also powers secondary collimation "SEC.COLM");

  ROW 3

  - Check "MIRROR COVER" ON;
  - Check "COUNTERWEIGHTS" ON;
  - Check "MIRROR SUPPORT" ON;
  - Check "CLIP CENT. PSUs" ON (these circuits are permanently energized independently of the "TELESCOPE POWER" switch in ROW 1. This switch should *always* be left on to ensure a correct up power sequence and prevent spurious klaxon alarms).

  ROW 4

  - Check "SERVO 3-PHASE" ON;
  - Check "SERVO 1-PHASE" ON;
  - Check "DESK & ENG. FAC." ON;
  - Check "CAMAC BAY 5" ON;
  - Check "CAMAC, P.POINTS, FANS" ON;
  - Check "MOUNT LIGHTS" OFF;
  - Check "MOUNT SKTS" as indicated locally;
  - Check "DOME LIGHTS" ON;
  - Check "DOME ENCODER" ON;

  ROW 5

  - Check "INSTRUMENT SUPPLIES" ON;
  - Check "CLIP CENTRE" ON.

b) CLIP cabinet (3)

- Check that the CAMAC crate is powered up (green lamp in switch);
- Check that "24V DC" supply is ON (green lamp);
- Check that 110V "SYNCHRO SUPPLY" is ON (amber lamp).

c) Nasmyth cabinet (4)

- Check that the CAMAC crate is powered up (green lamp in switch);
- Check that "MAINS" circuit breaker is ON (amber lamp);
- Check that "LOCAL POWER" keyswitch is ON;
- Check that "EMERGENCY SUPPLIES" amber lamp is lit;
- Check "POWER UNIT" ON;

- Check "CAMAC" ON;
- Check "FANS" ON;
- Check that red, green and yellow lamps on "POWER SUPPLY UNIT" are ON.

d) Marconi servo cabinet (5)

- Check "240V AVAIL" (amber lamp) ON;
- Check "240V ON" (green lamp) OFF;
- Check "EM SUPPLY AVAIL" (red lamp) ON;
- Check that the CAMAC crate is powered up (green lamp in switch);
- Check that the white switches on the 5V and 24V supplies are ON (N.B. there will be NO power to the 5V supply at this stage).

e) Marconi power cabinet (6)

- Check "415V ON" and "240V ON" (amber lamps) ON;

f) CAMAC system crate (7)—at the bottom of the rack

- Check that the CAMAC crate is powered up (orange lamp in switch);
- Initialize CAMAC:
  - Clear and Zero the system crate by moving the switch on the "PROGRAMMED DATAWAY CONTROLLER" successively to "C" and "Z";
  - Initialize the branch controller (yellow front) by switching from "ON-LINE" to "OFF", flicking the "BRANCH INITIALISE" switch down and letting it spring up again, and then switching back to "ON-LINE".

g) Engineering desk (0)

- On the "SERVICES" panel:
  - Check "POWER" key ON;
  - Ensure "MODE" key set to "ENG";
  - Press "TELESCOPE" power ON (button from red ⇒ green);
  - Press "DOME" power ON (button from red ⇒ green);
  - Press "BEARING OIL PUMP" ON (button from red ⇒ green);
  - Press "G/B OIL" ON (button from red ⇒ green);
  - Press "N_2 SUPPORT" ON (button from red ⇒ green);
- Wait for *all* lamps on the alarms panel to go out. At this point, the green "COMP RESET" light should come on, indicating that it is possible to switch to computer control.

h) Marconi servo cabinet (5)

- Check "240V ON" (green lamp) ON;
- Check "5V SUPPLY" and "24V SUPPLY" (meters on the two bottom racks) are reading the correct values;
- Check "PA ON" (green lamps—PA = power amplifier) OFF, except for the Cassegrain cable wrap, which should be ON;
- Check "SERVO ON" (amber lamps) ON for all drives.

i) Marconi power cabinet (6)

- Switch ON the power amplifiers appropriate to the focal station(s) in use:
  - Altitude;
  - Azimuth;

- ∘ Cassegrain turntable ("CTT");
- ∘ Cassegrain cable wrap ("CW");
- ∘ Focus drive ("FD").

j) Nasmyth cabinet (4)

- Switch ON the power amplifiers appropriate to the focal station(s) in use:
  - ∘ UES/FLEX Nasmyth turntable;
  - ∘ GHRIL Nasmyth turntable.

12.3 Safety checks

Checklist:

- People around the telescope;
- Crane cables;
- Electric cables;
- Telescope in Access Park position;
- Telescope out of balance;
- Anything (especially ladders) propped up against the telescope;
- Mirror trolley (if on the bridge) positioned so that it does not obstruct the telescope;
- Double doors on GHRIL.

> Before driving either the telescope or the dome, it is IMPERATIVE to check for safety hazards and to look in the commissioning log-book to make sure that the system is in a safe state.

12.4 Opening the dome

Checklist:

- Check that the primary mirror is covered;
- Ensure that *all* lights in the dome are off using the buttons marked "MAIN DOME", "T/S FLOOD", "DRUM" and "DRUM RED" (top right-hand corner of the engineering desk);
- Go to the control panel on the dome balcony and check that the keyswitches are set: "DOME CONTROL" to "REMOTE" and "TOP SHUTTER" and "BOTTOM SHUTTER" to "LOCAL" (the key should be left in the panel);
- Open the dome:
  - ∘ Start with the bottom shutter (right hand side of panel). Drive it down with the "MICRO DRIVE LOWER" button until the "MAIN DRIVE RAISE OVERTRAVEL" (amber) lamp goes out;
  - ∘ Use "MAIN DRIVE LOWER" to lower it until the power cuts out;
  - ∘ *DO NOT attempt to go any further in "MICRO DRIVE LOWER".*
  - ∘ Next raise the top shutter (left hand side of panel). Drive it up using "MICRO DRIVE RAISE" until the "MAIN DRIVE LOWER OVERTRAVEL" (amber) lamp goes out;
  - ∘ Use "MAIN DRIVE RAISE" to drive the shutter right over the top and keep the button pressed until the power cuts out;
  - ∘ At this stage no amber lamp should be lit;
  - ∘ It is important that both shutters are opened to the full extent allowed in main drive in order to avoid obstructing the telescope aperture.
- On the Engineering rack switch ON the dome "VENT FANS" (groups 1–6).

13 Driving the telescope in engineering mode

Most users will only wish to drive the telescope under computer control. This section is relevant for engineering applications and in case of computer failure.

13.1 Driving with the rate controls

Proceed as follows:

- Set speed potentiometers to ZERO (fully anticlockwise);
- Press the '+' or '−' button as required and *slowly* increase the speed (0 to maximum in about 5 seconds). For the maximum permissible speed use about $\frac{3}{4}$ of the full travel;
- When slowing or stopping DO NOT suddenly release the drive buttons whilst driving at speed: this causes the telescope to decelerate too quickly and may damage the gears;
- To stop, gradually decrease the speed to zero using the potentiometer and only then release the drive button.

> The William Herschel Telescope is significantly easier to damage than either the Isaac Newton or Jacobus Kapteyn telescopes because the velocity is not ramped up automatically when it is driven in engineering mode. Consequently, *the drive buttons must NEVER be pushed without first checking that the rate demand is zero.*

13.2 Parking the telescope

In engineering mode the telescope may be parked in one of 3 positions by pressing the appropriate button on the engineering rack or on the control panel at the access park position on the gallery:

- Zenith Park (Azimuth ∼300°, altitude 90°);
- Access Park 1 (Azimuth ∼300°, altitude 19°);
- Access Park 2 (Azimuth ∼300°, altitude 7°);

> If the telescope is at Access Park 3 ("AP3" indicator on engineering rack) DO NOT attempt to drive the telescope from the control room, only from the gallery; it should be driven to Access Park 2 before using the manual controls on the engineering rack. In particular NEVER go to computer control with the telescope at AP3.

To drive the telescope from the panel at the access park position on the gallery proceed as follows:

Procedure:

- Turn the "MODE" keyswitch to "LOCAL";
- To park the telescope at the zenith or at the first two access park positions press the "ZP", "AP1" or "AP2" buttons respectively;

- The telescope will then move to the requested position under engineering mode control and can only be interrupted in cases of urgent need by use of the "EMERGENCY STOP" button (DO NOT use unless absolutely necessary);
- To move to the final park position "Access park 3":
  - Start with the telescope at AP2;
  - Unbolt and open the sliding gates to their full extent;
  - Unbolt and lower the hinged section of floor;
  - Press the "AP3" button.
- NEVER attempt to start a move away from AP3 from anywhere but the gallery control panel. To do so:
  - Press, and hold in, the "AP2" button until the telescope stops;
  - Raise and bolt the hinged section of the floor;
  - Close and bolt sliding gates;
- The telescope may now be parked in AP1 or the zenith by pressing the appropriate button;
- Return the "MODE" keyswitch to "REMOTE" before leaving the gallery.

14 Starting the computer systems

14.1 Powering up

14.1.1 The buffered supply

Follow this section only when the buffered supply has failed. For safety reasons, only duty officers and members of the technical staff are allowed to enter the Buffer-set room. **Under no circumstances should you go in there: contact the Duty Technician or Duty Officer.**

In an emergency or if the power fails and the buffer set does not turn itself off (most obvious indication is that the terminals stay on for some time and start to flicker, disk drive lights will flash, printer and laser printer will behave strangely when the room lights go out), a highly dangerous condition can arise in which the power to the computers has very low voltage and frequency. If this happens, IMMEDIATELY isolate the supply using the buffer set EMERGENCY STOP button (actually labelled "TOTAL SHUTDOWN") on the "BUFFER SET ALARM BOARD" in the control room. To reset the emergency stop button, get a key from the Duty Technician.

The MicroVAX which controls the William Herschel Telescope is run off the buffered supply. If the buffered supply is interrupted because of a mains failure:

Safety procedure:

- To ensure that the telescope and TV computers are in a safe state:
  - Switch OFF all "MAIN SWITCH" of the buffer set supply (on the wall behind the MicroVAX);
  - turn the MicroVAX processor off;
  - switch off the VME crate power for the TV system.

- *Wait for the Duty Officer to say that it is safe to do so* and call the Duty Technician or software staff to restart the buffer set.

They will have to restart the buffer set in the Electrical Distribution Room on the ground floor.

14.1.2 Starting the MicroVAX

The MicroVAX is located immediately to the right of the CAMAC system crate (which is is the bottom of cabinet 7): its system console is on the table next to the VAX 3600 and VAX 8300 system consoles.

If starting with the computers running, but protected, skip this procedure and go to "Warm start procedure":

Cold start procedure: (from complete power down or power failure)

- Ensure that the computer and disks are in a safe state (see "Safety Procedure" at the beginning of the previous section);
- Switch the "MAIN SWITCH" on the wall behind the MicroVAX ON;
- DO NOT touch the individual circuit breakers under the transparent cover unless one of them has tripped out and needs to be reset;
- Switch the "MAIN SWITCH" on the wall to the left of the door nearest to the telescope ON (this controls power to the terminals in the control desk);
- Check the disc "Write protect" buttons are OFF (on panel behind door on face of processor cabinet facing the wall—red light means protected);
- Switch the processor ON (switch at top of cabinet on the wall side of the processor cabinet—'1' is ON); the MicroVAX boots automatically on power up.

14.1.3 Starting the TV system

The VME system which runs the intensified TV cameras lives in the CLIP Centre instrument cabinet furthest from the control desk. It consists of a VME crate, three Westinghouse camera control units (two normally in use) and a disk drive. The microprocessor boots automatically on power-up.

Starting procedure:

- At the instrument cabinet:
  - Switch the VME crate power ON (green switch in bottom LH corner);
  - Switch both controllers for the TV cameras ON;
- At the control desk:
  - Check that the gain controls for the TV cameras are turned down (fully anticlockwise and clicked off);
  - Check that the gain controls for the monitors are turned down (fully anticlockwise);
  - Switch the camera(s) ON (black push button);
  - Check that the scan orientation switches ("H" and "V") on the monitors are at the positions indicated by the Dymo "x"s.

> Before starting the control system software it is ESSENTIAL to check that the CAMAC crate is powered up and initialized (see Section 12.2 (f)), and that the "TELESCOPE" power button on the engineering rack has been pressed (12.2 (g)). Failure to do so will cause the MicroVAX to crash!

The control system is run from the captive account TCS_LOGIN which does not require a password and allows the user to perform only one of three functions:

`START` the control system running;

`STOP` it running;

`SHUTDOWN` the MicroVAX operating system (but only after stopping the control system).

Any MicroVAX terminal may be used for logging in, including one connected via the DECserver. It is most convenient to use the normal operating terminal, TXA1:.

Starting procedure:

- Hit RETURN to get the `Username:` prompt;
- Enter `TCS_LOGIN`;
- After the initial messages and prompt enter `START`.

The START procedure first loads the CAMAC driver, if it is not already present, and then initializes the global sections. Messages emanating from the debugger are normal and should be ignored. When the process is complete, a message about TCS_CHECK will be output and the account is logged out again. Shortly afterwards, terminals TXA1: (User Interface) and TXA7: (Display) will become active, and the display on TXA7: will start to update. This indicates that the control system is running.

14.2 Switching to computer mode

This is only possible if the green "COMP RESET" button on the engineering rack is lit. If it is not (check the bulb!), then some lack of power or alarm condition is indicated. Proceed no further until the fault is cleared.

> The control system should always be started with the telescope in engineering mode (which is indicated by the position of the "MODE" keyswitch and the yellow indicator lamp on the engineering rack). The first action of the control system software is to ensure that engineering mode is selected. Only make the switch to computer mode when the telescope is ready for normal operation.

Procedure:

- Check the "COMP RESET" lamp on the engineering rack;
- If it is green, turn the "MODE" keyswitch to "COMP";
- Press "COMP RESET".

The indicator next to "COMP RESET" should now show "COMP" and, shortly afterwards, the drive amplifiers should power up (see the meters on the engineering rack).

15 Computer control of the telescope

15.1 The User Interface—General

The telescope is controlled from a single VT220 terminal. The user interface is divided into two mutually exclusive parts: one for typed commands, the other a "handset" for guiding and focussing. On startup the interface is ready to receive typed commands as indicated by the prompt: `USER>`. The command structure employed by the user interface is based on DCL, the DEC command language, so experienced VAX users will notice some familiar features. In particular, typing `HELP` and following the prompts gives information about the available commands via a standard VMS help library. To switch to the handset mode, press the HANDSET key on the user keyboard or enter the `HANDSET` command in response to the prompt `USER>`. To return to the prompt, simply press the HANDSET key again. The control software may be safely closed down using the command `EXIT`.

15.1.1 Line_editing

Just as in DCL the following keys may be used to edit command lines:

Table 3: *Key bindings relevant to editing command lines*

Key names and equivalents					Action from single key stroke
CTRL–A			=	F14	toggle between INSERT/OVERSTRIKE entry for single line (default reset to overstrike for each new line)
CTRL–B	=	⇑			search Back through 50 line command buffer
		⇓			search down through 50 line command buffer
CTRL–D	=	⇐			move cursor 1 character to left
CTRL–F	=	⇒			move cursor 1 character to right
CTRL–E					move cursor to end of line
CTRL–H	=	BACKSPACE	=	F12	move cursor to start of line
		DELETE			delete character to left of cursor and close up
CTRL–J	=	LINEFEED	=	F13	delete word to left of cursor
CTRL–U					delete from beginning of line to cursor
CTRL–Z					return to USER> prompt

15.1.2 Abbreviation

All commands, qualifiers and keywords may be abbreviated to the minimum, unambiguous string (four characters or less). Cases of ambiguity will be flagged as errors by the command interpreter and the user should re-enter the command with more characters in the offending string.

15.1.3 Control-keys

Typing CTRL and Z simultaneously on the control room terminal ALWAYS returns control to that terminal and also returns to the `USER>` prompt, thus allowing exit from commands such as `CALIBRATE`. CTRL–Y and CTRL–C are disabled, to avoid accidentally crashing the user interface.

15.1.4 Transfer of control

The telescope is normally controlled from the VT220 terminal TXA1: on the control desk. The `REMOTE` command can be used to transfer control to another terminal. There are three possible locations, selected using the switch box on top of the MicroVAX processor cabinet: the GHRIL laboratory, the FLEX Nasmyth platform and the Engineering desk. The video output from the Information display is permanently available at these locations. A second switch box (on the control desk) routes the output from various terminals to a screen-dump printer and should normally be ignored.

15.2 Catalogues

15.2.1 Text, binary, user and system catalogues and the edit source

This section explains the various forms in which source data are held on the telescope computer and the methods used to convert between them.

- **Text catalogues** are simple, free-format files of object positions which may be prepared using a standard text editor. It is usually most convenient to create them on the VAX 8300 or to transfer them to that machine *via* magnetic tape or over an electronic link with `MAIL`, `POST` or `TRANSFER`. The format is described in the next section.
- **Binary catalogues** are created on the telescope computer from text catalogues or data input through the user interface. They may be read in more rapidly than text catalogues and are therefore preferred for very large source lists, but are otherwise less convenient.
- The **edit source** is specified by name, right ascension, declination, equinox, proper motions, parallax and radial velocity, as in a catalogue entry, but using the commands `SOURCE`, `RA`, `DEC`, `EQUINOX`, `PM`, `EPOCH`, `PARALLAX` and `RV` to input the data. The contents of the edit-source data area may be added to the user catalogue (see below) or the telescope may be slewed directly to the object using the command `NEXT`.
- The **user catalogue** is the data area on the telescope computer which contains the current source list. It is formed as follows:
  - `ADD` appends the contents of the edit-source data area (see above);
  - `INPUT` appends a text-file catalogue;
  - `MARK` appends the current tracking position of the telescope;
  - `LOAD` overwrites the current contents with a new binary catalogue.

  Data may be transferred from the user catalogue to the edit-source data area using `GET`, but the usual procedure is to slew to a named object directly using `GOCAT`. If a named object is not found in the user catalogue, then the system catalogue is searched (see below). The user catalogue may be saved on disc using the command `OUTPUT FILE` and `SAVE`, which produce text and binary files, respectively.
- The **system catalogue** contains positions for commonly-used standard objects and fields (see Section 15.2.2 immediately below and Appendix D). It is accessed automatically.

15.2.2 The system catalogue

The system catalogue currently available at the William Herschel Telescope contains the following subsets:

- **FK5GRID:** a grid of bright stars with accurately known positions selected from the FK5 astrometric catalogue and used for pointing calibration (*e.g.* in the `CALIBRATE` procedure). The positions are accurate to better than 0.1 arcseconds in both coordinates.
- **SPECPHOT:** a catalogue of spectrophotometric standards, with accurately known positions and proper motions.
- **UBVRI:** a catalogue of photometric standards, selected from "UBVRI photometric standards around the celestial equator", A. U. Landolt, 1983, *Astron. J.,* **88**, 439. The photometry is by Landolt.
- **SEQUENCES:** a set of photometric sequences suitable for CCD photometry.
- **BLANK:** a set of fields with unusually few stars. These are useful for CCD flat fields.
- **GEOM:** fields to be used for checks of detector geometry. They have several stars with accurately-measured positions in an area of a few arcmin^2.

15.2.3 Catalogue format

For all but the simplest programmes, a catalogue of object positions should be prepared and checked in advance. A catalogue is simply a text file of positional information in free format with spaces as separators. All data for an entry should be on one line of the file. Anything following an asterisk or exclamation mark is treated as a comment and is ignored. Do not use tab, control or other peculiar characters. The parameters must be in the order: Name, Right Ascension, Declination, Equinox, proper motion in right ascension, proper motion in declination, Epoch, Parallax, Radial velocity. The first four parameters are mandatory and the remainder are optional with sensible defaults. The formats and units of the necessary parameters are as follows:

- **Name**—up to 20 characters. Embedded spaces are allowed, but if they are used, then the name must be enclosed in double quotes (*e.g.* `"NGC 7027"`).
- **Right ascension**—hours, minutes, seconds, separated by spaces.
- **Declination**—degrees, minutes, seconds, separated by spaces.
- **Equinox**—for *mean* positions, a leading letter indicates the coordinate system:
  `B` implies mean pre-IAU76 or FK4
  `J` implies mean post-IAU76 or FK5

  The letter is followed immediately by a number indicating the epoch of the mean equator and equinox of that system (*e.g.* `B1950.0` or `J1987.5`).
  For *apparent* positions this field should contain the word `APPARENT` (abbreviable to `A`)—no epoch is required.

The formats, units and defaults of the optional parameters are as follows:

- **Proper motions**—in right ascension (seconds of time per year) and declination (arcseconds per year). Default to zero if not specified.
- **Epoch of position**—(year). This should not be confused with the equinox. The epoch of observation is used in conjunction with the proper motions to correct for the space motion of the object. If the epoch is not specified, then it is assumed to be the same as the equinox.
- **Parallax**—(arcseconds). Generally negligible. Defaults to zero if not specified.
- **Radial velocity**—(km s^{-1}, positive for a receding object). Generally unimportant. Defaults to zero if not specified.

Although not part of a catalogue entry, differential tracking rates may also be specified, using the command `DIFF_RATES`. These are in seconds of time per second for right ascension and arcseconds per second for declination. Examples of catalogue files are:

- The simplest possible catalogue contains only name, right ascension, declination and equinox:

```
3C567    12 34 56.78  -01 23 45.6  B1950
NGC123   00 12 46.6    05 34 56    J1987.5
COMET    12 12 12.12  +12 12 12.1  A
```

- A more complicated entry might include proper motions:

```
SP1  00 31 22.2  -12 24 21  B1950.0  0.011 -0.17
```

- The ultimate in complexity has parallaxes and radial velocities too:

```
S01-07  00 50  7.596  -10 38 39.54  J2000  -0.01531 -0.2287 2000  .059    8
S01-22  01 06  7.724  -23 59 33.07  J2000  -0.00225 -0.0409 2000  .000    0
```

Catalogues may be transferred to the telescope computer using the `INPUT` command at the User Interface.

15.3 User Interface commands: a classified list

This section contains a summary of the commands available at the User Interface, classified into functional groups. Details of individual commands are given in the alphabetical list of Section 15.4.

15.3.1 General user-interface commands

- `ENGINEERING` Select engineering mode.
- `EXIT` Select engineering mode and close down the control system.
- `HANDSET` Select handset mode.
- `HELP` Get help on a command.
- `RECALL` Recall a previous command.
- `REMOTE` Transfer control to a remote terminal.
- `SWITCH` Transfer control to the System Computer.

15.3.2 Source data entry

- `DEC` Enter Declination of edit source.
- `DIFF_RATES` Enter non-sidereal tracking rates for current source.
- `EPOCH` Enter epoch of position for edit source.
- `EQUINOX` Enter equinox for edit source.
- `PARALLAX` Enter parallax of edit source.
- `PM` Synonym for `PROPER_MOTION` (*q.v.*).
- `PROPER_MOTION` Enter proper motions of edit source.
- `RA` Enter Right Ascension of edit source.
- `RADIAL_VEL` Enter radial velocity of edit source.
- `RV` Synonym for `RADIAL_VEL` (*q.v.*).
- `SOURCE` Enter Name, Right Ascension, Declination and Equinox for edit source.

15.3.3 Catalogue handling

- `ADD` Add the contents of the edit source data block to the catalogue as a named entry.
- `CAT_EDIT` Edit a text-file catalogue from the user interface.
- `DELETE` Delete a catalogue entry.
- `GET` Get a named catalogue entry and put it in the edit source block.
- `INPUT` Append a text catalogue to the current user catalogue.
- `LOAD` Replace the current user catalogue with a new binary catalogue.
- `MARK` Store the current telescope position as a named catalogue entry.
- `OUTPUT FILE` Save the current catalogue as a text file.
- `OUTPUT PRINTER` Save the current catalogue as a text file.
- `OUTPUT TERMINAL` Save the current catalogue as a text file.
- `SAVE` Save the current user catalogue as a binary file.

15.3.4 Source change

- `BLIND_OFFSET` New source (named catalogue entry), but with local corrections to the pointing model.
- `GOCAT` New source (from catalogue; specified by name only).
- `GOTO` New source (direct input of name, right ascension, declination and equinox).
- `NEXT` New source (using data in edit source block).

15.3.5 Positional and Aperture offsets

- `APERTURE` Execute a preset (numbered) aperture offset.
- `BEAMSWITCH` Execute an aperture offset with direct input of x and y.
- `DEFINE` Input data for numbered aperture or positional offsets.
- `OFFSET` Execute a positional offset with direct input of $\Delta\alpha$ and $\Delta\delta$.
- `POSITION` Execute a preset (numbered) positional offset.
- `STORE` Store aperture or positional offsets set up using the handset.

15.3.6 Autoguiding

- `GUIDE` Turn autoguiding on or off.

15.3.7 Calibration procedures

- `CALIBRATE` Determine encoder zero-points and collimation errors.

15.3.8 Mechanism control

- `ALTITUDE` Move the telescope to a given Altitude and stop it.
- `AZIMUTH` Move the telescope to a given Azimuth and stop it.
- `DOME` Move the dome to a given Azimuth and stop it.
- `ELEVATION` Synonym for `ALTITUDE` (*q.v.*).
- `FOCUS` Move the focus to a specified position.
- `ROTATOR` Move the rotator to a given sky position angle (tracking) or mount position angle (stopped).
- `SET DOME` Turn dome tracking on or off.
- `SET ROTATOR` Turn rotator tracking on or off.
- `SET WRAP` Override Azimuth zone indication.
- `STOP` Stop a mechanism or combination of mechanisms.
- `UNWRAP` Rotate in Azimuth or mount position angle by 360°.
- `ZEROSET` Determine incremental encoder zero-points.

15.3.9 Change of focal station

Note that "Select" in this context means "set up software and drive the correct rotator": the Nasmyth flat is not moved.

- `CASSEGRAIN` Select Cassegrain focus.
- `GHRIL` Select GHRIL (alias Cable-wrap side) Nasmyth focus.
- `FLEX` Select the FLEX (alias Drive-side or UES) Nasmyth focus.
- `UES` Synonym for `FLEX` (*q.v.*).

15.3.10 Display functions

- `DISPLAY` Change the coordinate system of the displayed telescope position.
- `MOON` Give the current right ascension and declination of the Moon.
- `PAGE` Switch to the next Information Display page.
- `SHOW` List the edit source block.
- `SNAPSHOT` Record the current Information Display page.

15.3.11 Logging of test data

- `POINT` Write encoder coordinates to a data file.
- `SET LOG` Turn on or off the logging of TV guiding errors.
- `SET ENCLOG` Turn on or off the logging of encoder readings.

15.3.12 Meteorological and Earth-rotation data

- `HUMIDITY` Input relative humidity used in refraction calculation.
- `POLE` Input values of polar motion.
- `PRESSURE` Input barometric pressure used in refraction calculation.
- `TEMPERATURE` Input temperature used in refraction calculation.
- `UT1UTC` Input UT1 − UTC.
- `WAVELENGTH` Input wavelength used in refraction calculation.

15.4 User Interface commands: an alphabetical glossary

The following section gives a brief summary of the operation of each command together with examples and defaults.

Notation:

- Examples of commands entered at the terminal are in typewriter font: `DEC 12 34 56.78`;
- Angle brackets denote parameter values or character strings: `<angle>`;
- Square brackets denote optional input: `[x,y]`; all other parameters are obligatory;
- Parameter and qualifier descriptions are introduced by the name of the parameter or qualifier in bold type: **/SKY**.

15.4.1 ADD

Writes the current contents of the edit source data area as a new entry in the user catalogue.

Format: `ADD`
Defaults: None

15.4.2 ALTITUDE

Moves to the specified altitude and stop.

Format: `ALTITUDE <angle>`
Units: degrees
Example: `ALTITUDE 85.72`
Defaults: None
Comments: To park the telescope at the zenith without moving it in azimuth, type `ALTITUDE 90`. This is much faster than the hardware ZENITH PARK function and is all that is required in most circumstances. Tracking in azimuth and for the rotator are also disabled by this command.

15.4.3 APERTURE

Offsets the telescope so that an object moves by a vector fixed in the focal plane.

Format :	APERTURE <aperture-number>
Example :	APERTURE 2
Defaults:	None. The reference position usually coincides with the rotator centre, (0,0). Two apertures are set up in the initialisation file (but can be overridden): APERTURE 1 is the off-axis guide camera and APERTURE 2 is the centre of the FOS slit.
Number:	The aperture number is in the range 0–10. The corresponding (x, y) displacement must have been set up previously in the initialisation file, or by using the DEFINE or STORE commands. Aperture 0 is the reference position (see below).
Philosophy:	As described in Section 4.2, an (x, y) shift in the focal plane is divided into two parts: the reference position, which is unaltered on source change and an aperture offset which is reset to zero on source change. The APERTURE command provides a means of switching between the reference position and previously-defined aperture offsets.

15.4.4 AZIMUTH

Move to the specified azimuth and stop.

Format:	AZIMUTH <angle>
Units:	degrees
Example:	AZIMUTH 275.34
Defaults:	None
Comments:	Tracking in altitude and for the rotator are also disabled by this command.

15.4.5 BEAMSWITCH

Moves an image by an amount specified in the focal plane.

Format:	BEAMSWITCH <offset_x> <offset_y>
Units:	arcseconds
Example:	BEAMSWITCH 20.2 -100
Defaults:	None. On source change (*e.g.* GOTO), offsets are reset to zero.
Comments:	To view a field on the off-axis TV, move the telescope using BEAMSWITCH 0 -602; To guide, return the field to the detector with BEAM 0 0.

15.4.6 BLIND_OFFSET

Offsets between a reference object which is centred on the acquisition TV and a faint target object.

Format:	BLIND_OFFSET <source_name>
Example:	BLIND 0512+22E
Defaults:	None
Comments:	This is the standard method for locating very faint objects, which are difficult or impossible to see on the acquisition TV. Accurate positions for a brightish star and the faint target object must be entered in the catalogue. Slew to the bright star using GOCAT and centre it on the reference position with the handset keys. Then type BLIND <source_name> for the faint object. This offsets the telescope so that the faint object is accurately aligned with the rotator centre. It can then be moved around the detector (*e.g.* on to a spectrograph slit) using BEAMSWITCH or APERTURE commands. BLIND_OFFSET performs a local correction to the pointing model, assuming that the position of the reference object is accurate. Subsequent executions of BLIND_OFFSET all use this correction, so several faint objects can be observed using the same reference star. The NEXT, GOTO and GOCAT commands revert to the default global pointing solution.

15.4.7 CALIBRATE

Updates pointing coefficients at the start of an observing session.

Format: `CALIBRATE`

Comments: The `CALIBRATE` command initiates an automatic sequence which does a restricted pointing measurement on 7 stars from the pointing grid in order to update the values for the encoder zero-points in Azimuth and Elevation and the collimation error in Azimuth. Stars are selected to be close to the meridian and either North or South of the zenith, depending on the initial Azimuth. A range of elevations must be covered. The telescope is driven to the first star and the handset mode is selected. When the telescope is tracking, the star should be moved on to the reference position using the handset keys. Once you are satisfied, press the HANDSET key. This logs the position and drives to the next star. Repeat these operations until all 7 positions have been logged. You will then be asked whether all of the stars were centred correctly. If you do not answer `Y` to this question, then the procedure will be aborted. The derived and previous values will be displayed, together with their r.m.s. errors, and you will be asked whether the solution is reasonable. The errors should be in the range 0.5–1.0 arcsec for IE, 1.0–2.0 arcsec for CA and 1.0–3.0 arcsec for IA. If the errors are much larger than these values, then the solution should be rejected. Unless there has been a major change of configuration, the coefficients should not alter by more than a few arcseconds from night to night. Gross differences may indicate a problem. CTRL–Z may be used to abort the procedure at any time, but all of the measurements will be lost.

Qualifier: **/LAST**

Function: Recalls the last pointing solution. This may be useful if the running of the control program has been interrupted, but does not ensure very accurate pointing because the encoder zero-points may have changed.

Qualifier: **/DEFAULT**

Function: Reverts to the default pointing solution in the initialisation file. A suitable course of action if the `CALIBRATE` command fails (*e.g.* gives very large rms errors).

15.4.8 CASSEGRAIN

Selects the Cassegrain focal station.

Format : `CASSEGRAIN`

Comments: Applies Cassegrain pointing model, enables Cassegrain rotator and disables all other rotators. Note that the Nasmyth flat *cannot* be stowed under computer control, so the button on the Engineering desk must be used for this purpose.

15.4.9 CAT_EDIT

Edits a text-file catalogue from the user-interface terminal

Format : `CAT_EDIT <catalogue_name>`

Example : `CAT_EDIT CATACLYSMICS`

Parameter: **Catalogue_name**

Function: Names the input catalogue.

Format: `[[[<node>::]<device>:]<directory>]<file>[.<extension>]`

Defaults: Node: `LPVB`,
Directory: `USER_CAT` and
Extension: `.CAT`.

Comments: The editor is basic EVE and is documented in the VAX/VMS *Guide to Text Processing*, Chapter 3.

15.4.10 DEC

Enters a declination in the edit source data area

Format: DEC <dec_degrees> <dec_minutes> <dec_seconds>
Example: DEC -12 34 56.78
Defaults: Value of declination: None
Sign of declination: '+'
Checks: The DEC is rejected if the any of the components lies outside the following ranges:

Dec_degrees	0–89 inclusive
Dec_minutes	0–59 inclusive
Dec_seconds	0.0–59.99... inclusive

15.4.11 DEFINE

Sets up apertures and positional offsets for repeated use.

Format : DEFINE APERTURE <aperture_number> <x_offset> <y_offset>
DEFINE POSITION[/ARC] <position_number> <RA_offset> <DEC_offset>
DEFINE POSITION/TIME <position_number> <RA_offset> <DEC_offset>
Units : <aperture_number> is an integer in the range 0–10, 0 being the reference position (the default on source change).
<position_number> is an integer in the range 1–10. Position 0 is a zero offset and may not be redefined.
<x_offset>, <y_offset> and <DEC_offset> are in arcseconds.
<RA_offset> is in seconds of time (/TIME qualifier) or arcseconds (/ARC qualifier).
Examples: DEFINE APERTURE 3 1.5 20.3
DEF POS 3 -3.0 12.0
DEF POS/TIME 1 -0.33 -11
Defaults: /ARC is the default qualifier for DEFINE POSITION; otherwise none.

APERTURE DEFINE APERTURE sets up an aperture offset which can be applied using the APERTURE command.

POSITION DEFINE POSITION sets up a positional offset which can be added to the telescope demand position using the POSITION command.

15.4.12 DELETE

Removes the entry for the named source from the user catalogue.

Format: DELETE <source_name>
Example: DELETE HD123456
Defaults: None

Parameter: **Source_name**
Function: Names the source to be deleted.
Format: String of up to 20 characters; extra characters are lost. To include spaces the whole string should be enclosed within double quotes.
Examples: NGC_4151
"Supernova in LMC"
Default: None

15.4.13 DIFF_RATES

Enters values of differential tracking rates in right ascension and declination.

Format: DIFF_RATES <diff_rate_in_RA> <diff_rate_in_Dec>
Units: seconds/second and arcseconds/second respectively
Example: DIFF_RATES 9.7 -0.3

Default:	None. Unspecified differential rates are assumed to be zero.
Comments:	The differential (non-sidereal) tracking rates are added to the edit source data block. They must be actioned using the `NEXT` command. Note that differential rates are not included in a catalogue entry.

15.4.14 DISPLAY

Changes the coordinate system for the Information Display

Format:	`DISPLAY <coordinate_system>`
Example:	`DISPLAY J2000`
Default:	None
Parameters:	The allowed coordinate systems are:

`INPUT`	α and δ in the system used to input the source position (this is the default on startup);
`APPARENT`	α and δ in Geocentric apparent coordinates;
`J2000`	α and δ in J2000 Mean coordinates;
`B1950`	α and δ in B1950 Mean coordinates;
`HA_DEC`	Topocentric hour angle and declination.

Comment: The systems are described in more detail in Section 15.6. For technical reasons, there are restrictions on the permitted combinations of input and display coordinates, as follows:

`INPUT`	always allowed;
`APPARENT`	always allowed;
`J2000`	not allowed for input in apparent coordinates;
`B1950`	not allowed for input in apparent or FK5 (J) coordinates;
`HA_DEC`	always allowed.

15.4.15 DOME

Causes the dome to move to the specified azimuth and stop.

Format :	`DOME <angle>`
Units :	degrees
Example :	`DOME 275.34`
Defaults:	None

15.4.16 ELEVATION

Synonym for `ALTITUDE` (*q.v.*)

15.4.17 ENGINEERING

Puts the telescope into engineering mode.

Format :	`ENGINEERING`
Comment :	The command should be used: as part of the normal shutdown procedure at the end of the night, to return to engineering mode at any time or in an emergency to remove power from the drives and put on the brakes. It is equivalent to turning the COMP/ENG key on the engineering desk to the ENG position. To return to computer mode, turn the key to the COMP position and press the COMP/ENG button next to it on the desk.

15.4.18 EPOCH

Enters a value for the epoch of the position into the edit source data block.

Format:	`EPOCH <date>`
Units:	years
Example:	`EPOCH 1967.35`
Default:	None.
Comments:	The epoch is used in conjunction with the proper motions to compute the position of date.

15.4.19 EQUINOX

Enters a value for the equinox of the position into the edit source data block.

Format:	`EQUINOX <equinox>`
Units:	years
Examples:	`EQUINOX B1950`
Default:	None.

15.4.20 EXIT

Initiates an orderly shutdown of the telescope control system.

Format:	`EXIT`

15.4.21 FLEX

Selects the UES/FLEX/Nasmyth drive side focal station.

Format :	`FLEX`
Qualifiers :	`/DEROTATOR` moves gives a stationary image if the derotation optics are mounted. Otherwise it is assumed that the instrument is mounted directly on the turntable.
Comments :	Applies UES/FLEX pointing model, enables UES/FLEX rotator and disables all other rotators. Note that the Nasmyth flat must be controlled from the Engineering desk.

15.4.22 FOCUS

Drives the focus to a specified setting and stops it.

Format:	`FOCUS <setting>`
Units:	millimetres, in the range 34.5–129.0 millimetres.
Example:	`FOCUS 50.5`
Defaults:	None
Notes:	The focus drive is somewhat sticky, and may take a few seconds to settle to within 0.01 millimetres of the requested value.

15.4.23 GET

Retrieves data for the named source from the user catalogue and places them in the edit source data block.

Format:	`GET <source_name>`
Example:	`GET HD123456`
Defaults:	None
Parameter:	**Source_name**
Function:	Names the source to be retrieved.
Format:	String of up to 20 characters; extra characters are lost. To include spaces the whole string should be enclosed within double quotes.

Examples: `NGC_4151`
`"Supernova in LMC"`
Default: None

15.4.24 GHRIL

Selects the Ghril/Nasmyth cable-wrap side focal station.
Format : `GHRIL`
Qualifiers : `/DEROTATOR` is for use when the derotation optics are mounted. It drives the rotator so as to give a stationary image. Otherwise, it is assumed that the instrument is mounted directly on the turntable.
Example : `GHRIL`
Comments : Applies GHRIL pointing model, enables GHRIL rotator and disables all other rotators. Does not move the Nasmyth flat, which is not under computer control.

15.4.25 GOCAT

Causes the telescope to move to a new source in the catalogue and track it.
Format: GOCAT <source_name>
Defaults: None.

15.4.26 GOTO

Causes the telescope to move to a new source and track it.
Format: GOTO <source_name> <right_ascension> <declination> <equinox>
Example: `GOTO HD123456 12 34 56.78 76 54 32.10 J2000`
Defaults: None.

Parameter: **Source_name**
Function: Names the source
Format: String of up to 20 characters; extra characters are lost. To include spaces the whole string should be enclosed within double quotes.
Examples: `NGC_4151`
`"Supernova in LMC"`
Default: None

Parameter: **Right_Ascension**
Function: Specifies Right Ascension of the new source in three fields separated by spaces.
Format: <ra_hours> <ra_minutes> <ra_seconds>
Example: `12 34 56.78`
Defaults: None
Checks: The right ascension is rejected if the any of the components lies outside the following ranges:

RA_hours	0–23 inclusive
RA_minutes	0–59 inclusive
RA_seconds	0.0–59.99... inclusive

Parameter: **Declination**
Function: Specifies Declination of the new source in three fields separated by spaces. The Dec_degrees field may be signed.
Format: <dec_degrees> <dec_minutes> <dec_seconds>
Example: `-11 22 33.44`
Defaults: Value of declination: None
Sign of declination: '+'

Checks:	The DEC is rejected if the any of the components lies outside the following ranges:	
	Dec_degrees	0–89 inclusive
	Dec_minutes	0–59 inclusive
	Dec_seconds	0.0–59.99... inclusive

Parameter: **Equinox**
Function: Specifies Equinox of the source coordinates. A valid equinox must have two components: a leading letter indicating the system of the coordinates; and a number indicating the epoch of the mean equator and equinox of that system.
Format: `<equinox>`
Examples: `B1950`
`J2000`
`APPARENT` (for which no number is required)
Default: None.
Checks: Only B, J or A are acceptable as leading letters.
The year must lie in the range 1800.0 to 2100.0.

15.4.27 GUIDE

Turns autoguiding on or off.
Format: `GUIDE <state> [x y]`
Examples: `GUIDE ON`
`GUI ON 12 34`
Default: `<state>`: None

Parameter: **ON**
Function: Specifies that the telescope should be guided in response to guiding errors from the TV microprocessor.
Format: `GUIDE ON [x y]`
Units: TV screen coordinates (as read from the TV display).
Defaults: the default guiding position is the current position of the TV cursor.
Comment: To change the guiding position during autoguiding, merely enter "`GUIDE ON`" with a new position; there is no need to type "`GUIDE OFF`" in between.

Parameter: **OFF**
Function: Specifies that autoguiding is to be switched off, *i.e.* ignore any guiding errors from the TV microprocessor.
Format: `GUIDE OFF`

15.4.28 HANDSET

Places the user interface in handset mode.
Format: `HANDSET`
Comments: In handset mode, the keypad may be used to guide the telescope, set up offsets or apertures, change the focus or move the rotator. See Section 15.5 for a more detailed description.
Key: This command is bound to the $\boxed{\text{DO}}$ key on a standard VT220 keyboard.
To exit from the handset mode press the $\boxed{\text{DO}}$ key and control will return to the `USER>` prompt.

15.4.29 HELP

Provides information about the commands available via the user interface.
Format: `HELP [topic [subtopic]...]`
Example: `HELP GOTO EQUINOX`

Default: Lists all available commands
Notes: Invoking the HELP command initiates an interactive dialogue with the user interface HELP library, a normal VMS HELP library. In response to a Topic? or subtopic prompt you may:

- Type the name of the command/topic for which you need help;
- Type a question mark (?) to redisplay recently requested text;
- Press the RETURN key one or more times to exit from HELP;
- Press CTRL–Z once to exit from HELP;
- Abbreviate any topic name, but note that ambiguous abbreviations result in *all* matches being displayed.

15.4.30 HUMIDITY

Enters the value of the relative humidity used in the calculation of refraction.
Format: `HUMIDITY <relative humidity>`
Units: Fractional humidity in the range 0–1
Example: `HUMID 0.5`
Default: None. The value assumed on startup is 0.5.

15.4.31 INPUT

Reads in a text format source catalogue.
Format: `INPUT <catalogue_name>`
Example: `IN USER_CAT:SPECPHOT.CAT` or
`IN SPECPHOT`
to input the standard list of spectrophotometric standards, or
`IN LPVA::DISK$USER1:[GUEST02.CAT]TARGETS`
to input a file called TARGETS.CAT in the [.CAT] subdirectory of the GUEST02 account on the VAX 8300.

Parameter: **Catalogue_name**
Function: Names the input catalogue.
Format: `[[[<node>::]<device>:]<directory>]<file>[.<extension>]`
Defaults: Node: `LPVB`,
Directory: `USER_CAT` and
Extension: `.CAT`.

15.4.32 LOAD

Reads in a binary version of a saved catalogue.
Format: `LOAD <catalogue_name>`
Example: `LOAD USER_CAT:SPECPHOT.SAV` or
`LOAD SPECPHOT`
to read in the list of spectrophotometric standards.
Notes: The binary file is copied into memory as the current user catalogue. Existing entries are lost. Although the command can be used to copy a file from the VAX 8300 (see below), it is expected that the normal mode of use will be to copy a text file into the user catalogue with `INPUT` (*q.v.*), to dump a binary copy to the default catalogue area on the telescope computer with `SAVE <filename>` and then to `LOAD` this copy on subsequent nights. Binary copies should only be made of very large catalogues (> 50 objects).

Deletion: The command `LOAD DELETE_CAT` can be used to erase the entire user catalogue.

Parameter: **Catalogue_name**

Function:	Names the input catalogue.
Format:	`[[[<node>::]<device>:]<directory>]<file>[.<extension>]`
Examples:	see main entry
Default:	Node: `LPVB`, Directory: `USER_CAT`, Extension: `.SAV`.

15.4.33 MARK

Stores the current position of the telescope as a named catalogue entry.

Format :	`MARK <source_name>`
Example :	`MARK SUPERNOVA`
Defaults:	None
Comments:	This command stores the current position to allow return to an object at a later date. The position is stored in the current input coordinate system.

15.4.34 MOON

Displays the current right ascension and declination of the moon.

Format : `MOON`

15.4.35 NEXT

Sends the telescope to track the source whose data are in the edit source block

Format: `NEXT`

15.4.36 OFFSET

Offsets the telescope by given amounts in right ascension and declination.

Qualifier:	**/ARC** (default)
Function:	Offsets the telescope by given amounts parallel to right ascension and declination in the tangent plane. Positive offsets imply that the right ascension and declination of the telescope both increase. The magnitude of the offset is independent of position.
Format:	`OFFSET[/ARC] <offset_RA> <offset_Dec>`
Units:	arcseconds
Example:	`OFFSET 12.6 -18.8`
Default:	None
Qualifier:	**/TIME**
Function:	Offsets the telescope by given amounts in right ascension and declination. The magnitude of the offset depends on declination. $\Delta\alpha$ and $\Delta\delta$ are assumed to be in the input coordinate system.
Format:	`OFFSET/TIME <offset_RA> <offset_Dec>`
Units:	right ascension in seconds of time, declination in arcseconds.
Example:	`OFFSET/TIME 0.32 -13.4`

15.4.37 OUTPUT

Stores or prints a text-file catalogue.

Format:	`OUTPUT <device-keyword> [[[<node>::"<username password>"] <device>:]<directory>] <file>[.<extension>]`
Units:	Not applicable.
Qualifier:	**/MOUNT**
Function:	Specifies that the parameter gives a mount position

Device:	**/FILE**
Function:	Sends the output to a named file. See Defaults.
Device:	**/TERMINAL**
Function:	Sends the output to the user input terminal.
Device:	**/PRINTER**
Function:	Sends the output to the WHT line printer.

Examples:	`OUTPUT FILE LASTNIGHT`
	`OUTPUT FILE LPVA::"GUEST01 GDHUDG"DISK$USER1:[GUEST01.CATS]LASTNIGHT`
	`OUTPUT PRINTER`
	`OUTPUT TERMINAL`

Defaults:	The defaults for the catalogue name are: Node: `LPVB` (telescope computer), Directory/device: `USER_CAT`, (*alias* `U1:[WHT.TCS.USER.CAT]`), Extension: `.CAT`.
Comments:	The catalogue may be saved in the default catalogue area on the telescope computer, whence it may be recovered on a subsequent night. It will, however, be deleted when you leave the site. Files which are to be backed up should be transferred to your account on the VAX 8300. The syntax for this is somewhat cumbersome: the username and password must be specified, otherwise the file will be owned by DECNET and will therefore be unreadable by the user. The password is needed in order to avoid overwriting of other users' files. To print the catalogue on the line printer in the control room, type `OUTPUT PRINTER` and to list it at the user interface terminal, type `OUTPUT TERMINAL`. Do not under any circumstances type `OUTPUT TXA7:` as this hangs up the Information Display.

15.4.38 PAGE

Displays the next page in the cycle of information and status displays.

Format:	`PAGE`
Default:	The information display appears on startup.
Screens:	The various displays in the cycle are, in order: 1. Information display (appears on startup) 2. Encoder readings 3. Limit indicators 4. Alarm indicators 5. Overrides, trip indicators and interlocks
Notes:	See Section 15.6 for more details.

15.4.39 PARALLAX

Enters a parallax into the edit source data area

Format:	`PARALLAX <parallax_arcsecs>`
Example:	`PARALLAX 0.023`
Default:	None. Unspecified parallaxes are assumed to be zero.
Checks:	The parallax is rejected if it lies outside the range 0.0 to 10.0 arcseconds

15.4.40 POINT

Logs the telescope encoder coordinates.

Format :	`POINT` `POINT/NEW`
Comments:	The data are logged to a pointing data file in a format suitable for input to the TPOINT analysis package. `POINT/NEW` always creates a new pointing file. `POINT` uses the latest file created that night or creates a new one if none has been created that night. The function key $\boxed{\text{F20}}$ is equivalent to the `POINT` command.

15.4.41 POLE

Inputs values of polar motion.

Format: POLE <x_position> <y_position>

Units: arcseconds

Example: POLE 0.10 -2.10

Defaults: None. This command overrides the initial values for polar motion, which are derived from an interpolation formula supplied by the Earth Rotation Prediction Service. It makes a very small difference to the pointing of the telescope and is too esoteric for normal use.

15.4.42 POSITION

Offsets the telescope by a previously-stored vector.

Format : POSITION <Position_number>

Example : POSITION 2

Defaults: None. POSITION 0 (zero offset) is automatically selected on startup or change of source.

Number The position number is an integer in the range 0-10. The offset values for a given position number must have been set up using the DEFINE or STORE commands. POSITION 0 corresponds to a zero offset and returns the telescope to the reference position.

15.4.43 PRESSURE

Enters the value of the barometric pressure used in the calculation of refraction.

Format: PRESSURE <pressure>

Units: millibars

Example: PRESSURE 779.5

Defaults: None. The pressure assumed on startup is 779 millibar.

Comments: The refraction correction is proportional to the pressure. An error of 5 millibar is just about noticeable (it corresponds to a pointing deviation of 1 arcsecond at a zenith distance of 75°).

15.4.44 PROPER_MOTION

Enters proper motions into the edit source data area.

Format: PROPER_MOTION <pm_in_ra> <pm_in_dec>

Units: seconds/year and arcseconds/year, respectively

Example: PROPER_MOTION -1.54 0.675

Defaults: Unspecified proper motions are assumed to be 0.

Synonym: PM

15.4.45 RA

Enters a right ascension in the edit source data area.

Format: RA <ra_hours> <ra_minutes> <ra_seconds>

Example: RA 12 34 56.789

Defaults: None

Checks: The right ascension is rejected if the any of the components lies outside the following ranges:

RA_hours	0–23 inclusive
RA_minutes	0–59 inclusive
RA_seconds	0.0–59.99... inclusive

15.4.46 RADIAL_VEL

Enters a radial velocity in the edit source data area.

Format:	`RADIAL_VEL <radial_velocity>`
Units:	km/sec; positive velocity implies a receding source.
Example:	`RADIAL_VEL -98`
Default:	Unspecified radial velocities are assumed to be 0.
Synonym:	`RV`

15.4.47 RECALL

Recalls a previous command.

Format:	`RECALL <command_name>`
Examples:	`RECALL GOCAT` `REC SET ROT`
Default:	Last command
Comments:	`RECALL` is used to recover the last occurrence of a typed command within a 50-line buffer, just as in DCL.

15.4.48 REMOTE

Controls the operational state of remote terminals.

Format :	`REMOTE <remote_state>`
Example :	`REMOTE COMMAND`
Keyword :	**COMMAND**
Function :	Allows command input from a remote terminal. This would usually be in the GHRIL room, but could be configured elsewhere if required. Also copies the control-room user-interface display to the remote terminal if this has not already been done with the `REMOTE DISPLAY` command.
Keyword :	**DISPLAY**
Function :	Enables the remote terminal so that a copy of the control room display appears on it. Also disallows command input and returns control to the default terminal in the control room.
Keyword :	**OFF**
Function :	Disables remote terminal entirely, returns command input to the control room terminal and clears the remote display.

15.4.49 ROTATOR

Moves the rotator to the specified mount or sky position angle.

Qualifier:	**/SKY**
Function:	The parameter gives a position angle on the sky (measured anticlockwise from North which is 0°).
Format:	`ROTATOR <position_angle>` `ROTATOR/SKY <position_angle>`
Units:	degrees
Example:	`ROTATOR 275.34`
Defaults:	None
Comments:	`/SKY` is the default qualifier. If rotator tracking is enabled (as is the case on startup), then the rotator will follow this position angle as the telescope moves.
Qualifier:	**/MOUNT**

Function: Specifies that the parameter gives a mount position angle, *i.e.* measured with respect to a fiducial mark fixed to the mirror cell.
Format: ROTATOR/MOUNT <position_angle>
Units: degrees
Example: ROTATOR/MOUNT 28.0
Defaults: None
Comments: ROTATOR/MOUNT stops the turntable at the requested position angle (it makes no sense to track a mount P.A.).

15.4.50 SAVE

Saves a binary version of the current user catalogue in the named file.
Format: SAVE [[[<node>::"<username password>"] <device>:]<directory>] <file>[.<extension>]
Example: SAVE LASTNIGHT to save a file in the default catalogue area with the filename LASTNIGHT.SAV.
SAVE LPVA::"GUEST01 GDHUDG"DISK$USER1:[GUEST01.CATS]LASTNIGHT
to copy a file to the VAX 8300. The file will be in the [.CATS] subdirectory of the GUEST01 account on the USER1 disk and will be called LASTNIGHT.SAV.
Defaults: Node: LPVB (telescope computer)
Device/directory: USER_CAT,
Extension .SAV.

15.4.51 SET

Sets the states of various mechanisms and facilities.
Format: SET <keyword> <parameter>
Defaults: None

Keyword: **DOME**
Function En/disable tracking of telescope by the dome
Format: SET DOME TRACK
SET DOME NOTRACK

Keyword: **ENCLOG**
Function: Turns logging of encoder readings on or off.
Format: SET ENCLOG ON
SET ENCLOG OFF

Keyword: **LOGGING**
Function: Turns logging of TV position errors on or off.
Format: SET LOGGING ON
SET LOGGING OFF
Comments: If SET LOGGING ON is specified when logging is already enabled, a reset is performed whereby the current logging data file is closed and a new one opened.

Keyword: **ROTATOR**
Function: En/disable movement of the rotator to compensate for field rotation.
Format: SET ROTATOR TRACK
SET ROTATOR NOTRACK
Notes: The effect of SET ROTATOR TRACK is to cause the instrument rotator to start tracking at its current sky position angle. It is therefore useful if there is no constraint on the detector position angle, as it causes the rotator to slew by the minimum amount.

Keyword: **WRAP**

Function: Override the Azimuth wrap value (*i.e.* the multiple of 360° which must be added to the raw encoder reading to give the correct Azimuth.
Format: SET WRAP <wrap_value>
Example: SET WRAP -1
Units: Units are multiples of one revolution. The allowed values are '0' and '−1'.
Notes: The absolute encoder in Azimuth has a travel of exactly 360°, after which it repeats. The telescope has a total travel of 530° in Azimuth, and the ambiguity must therefore be resolved on startup by reading the position of a zone switch. The command SET WRAP should only be necessary when the zone switch fails, in which case the Azimuth reading will be incorrect by 360° and the telescope will sometimes slew into a hardware limit. In this case, SET WRAP may be used to enter the correct value.

15.4.52 SHOW

Displays data on the topic indicated by the keyword.
Format: SHOW <keyword> [<parameter>]
Defaults: SHOW EDIT

Keyword: **DEFAULTS**
Function: Displays the default parameters for the edit-source data area.

Keyword: **EDIT**
Function: Displays the parameters of the edit source.

15.4.53 SNAPSHOT

Dumps a copy of the Information Display screen to a file or physical device.
Format: SNAPSHOT <filename>
Examples: SNAPSHOT ARCHIVE
SNAPSHOT LP:
SNAP NGC1234.DAT
Defaults: Directory: LOG_DIR on the telescope computer,
Extension: .LOG.
Comments: This command may be used to record information relevant to an observation or to provide evidence of problems. Most users will find it easiest to print the screen directly using SNAPSHOT LP:. In case of a problem with the telescope, please record all of the Information Display screens on disk (*e.g.* using SNAPSHOT ERROR).

15.4.54 SOURCE

Enters new source data into the edit source data area.
Format: SOURCE <source_name> <right_ascension> <declination> <equinox>
Example: SOURCE HD123456 12 34 56.789 11 22 33.44 B1900
Notes: SOURCE copies the user default values for all source values into the edit source entry and then takes the command line or prompted input for source name, right ascension, declination and equinox.
Defaults: Name Right Ascension, Declination, Equinox: None
All other source values: User defaults

Parameter: **Source_name**
Function: Names the source
Format: String of up to 20 characters; extra characters are lost. To include spaces the whole string should be enclosed within double quotes.
Examples: NGC_4151
"Supernova in LMC

Default:	None
Parameter:	**Right_Ascension**
Function:	Specifies Right Ascension of the new source in three fields separated by spaces.
Format:	`<ra_hours> <ra_minutes> <ra_seconds>`
Example:	`12 34 56.78`
Defaults:	None
Checks:	The right ascension is rejected if the any of the components lies outside the following ranges: *RA_hours* 0–23 inclusive *RA_minutes* 0–59 inclusive *RA_seconds* 0.0–59.99... inclusive
Parameter:	**Declination**
Function:	Specifies Declination of the new source in three fields separated by spaces. The Dec_degrees field may be signed.
Format:	`<dec_degrees> <dec_minutes> <dec_seconds>`
Example:	`-11 22 33.44`
Defaults:	Value of declination: None Sign of declination: '+'
Checks:	The declination is rejected if the any of the components lies outside the following ranges: *Dec_degrees* 0–89 inclusive *Dec_minutes* 0–59 inclusive *Dec_seconds* 0.0–59.99... inclusive
Parameter:	**Equinox**
Function:	Specifies Equinox of the source coordinates. A valid equinox must have two components: a leading letter indicating the system of the coordinates; and a number indicating the epoch of the mean equator and equinox of that system.
Format:	`<equinox>`

Examples:	`B1950`
	`J2000`
	`APPARENT` (for which no number is required)

Default:	None.
Checks:	Only B, J or A are acceptable as leading letters. The year must lie in the range 1800.0 to 2100.0.

15.4.55 STOP

Stops the named mechanism

Format:	`STOP <mechanism>`
Example:	`STOP DOME`
Default:	`STOP TELESCOPE_DOME`
Keyword:	**ALL**
Function:	Stops all mechanisms
Keyword:	**ALTITUDE**
Keyword:	**AZIMUTH**
Keyword:	**DOME**
Keyword:	**FOCUS**
Keyword:	**ROTATOR**
Keyword:	**TELESCOPE_DOME**
Function:	Stops altitude, azimuth, rotator and dome.

15.4.56 STORE

Stores aperture and positional offsets.

Format :	`STORE APERTURE <aperture_number>` `STORE POSITION <position_number>`
Example :	`STORE APERTURE 3`
Defaults:	None
Notes:	The command may be used to store positional or aperture offsets which have been found using the APOFF or OFFSET handset modes or input using the `BEAMSWITCH` or `OFFSET` commands. They may then be recalled for future use with the `APERTURE` or `POSITION` commands.
Keyword:	**APERTURE**
Function:	`STORE APERTURE` sets up a beamswitch position which can be applied to the telescope using the `APERTURE` command. <aperture_number> is an integer in the range 0–10. Aperture 0 is the reference position and is not reset on source change (see Section 4.2).
Keyword:	**POSITION**
Function:	`STORE POSITION` sets up a positional offset which can be added to the telescope reference position using the `POSITION` command.

15.4.57 SWITCH

Transfers control from the user interface to the D-task running on the system computer.

Format:	`SWITCH`

15.4.58 TEMPERATURE

Enters the value of the outside air temperature used in the calculation of refraction.

Format:	`TEMPERATURE <temperature>`
Units:	degrees C
Example:	`TEMPERATURE 7.5`
Defaults:	None. A temperature of 5° C is assumed on startup.
Notes:	An error of 10°C gives a pointing error of 1.7 arcseconds at an elevation of 45°.

15.4.59 UES

Selects the UES/FLEX focal station (synonym for `FLEX`).

Format :	`UES`
Qualifiers :	/DEROTATOR gives a stationary image when the derotation optics are mounted.
Comments :	Applies UES/FLEX pointing model, enables UES/FLEX rotator and disables all other rotators. Note that the Nasmyth flat cannot be moved under computer control.

15.4.60 UNWRAP

Rotates the named mechanism through 360°.

Format:	`UNWRAP <mechanism>`
Example:	`UNWRAP AZIMUTH`
Default:	None
Notes:	Unwrapping is only allowed when the mechanism is on the ambiguous portion of its travel. Rotation is in whichever direction a complete turn is possible.
Timing:	To unwrap either the azimuth or the rotator takes about 6 minutes.
Parameter:	**AZIMUTH**
Notes:	The telescope may rotate through 530° in azimuth (geographically from −175° through zero (North) to +355°). Thus in the range of azimuth −5° to 185° there is only one

possible orientation for the telescope; elsewhere the telescope may be in either of two positions in the azimuth travel, exactly 360° apart.

Parameter: **ROTATOR**

Notes: The Cassegrain turntable may rotate through 520° in mount angle (*i.e.* the angle measured with respect to a fiducial mark on the mirror cell. The travel is from −300° through zero to +230°.

15.4.61 UT1UTC

Enters the value of UT1-UTC used in the control system pointing calculations.

Format : `UT1UTC <correction>`

Units : seconds

Example : `UT1UTC -0.0222`

Defaults: None. This command overrides the startup value of UT1 − UTC, which is determined from an interpolation formula supplied by the Earth Rotation Prediction Service.

15.4.62 WAVELENGTH

Enters the value of the wavelength of light used in the calculation of refraction.

Format: `WAVELENGTH <wavelength>`

Units: micron

Example: `WAVELENGTH 0.55`

Defaults: None. The startup value is 0.4 μm.

15.4.63 ZEROSET

Sets the zero-points of incremental encoders by a variety of methods.

Format: `ZEROSET <mechanism> <method> [<position>]` or
`ZEROSET <mechanism> <method> [<auto_manual>]`

Examples: `ZEROSET ALTITUDE ABSOLUTE`
`ZERO AZIMUTH TARGET`
`ZERO AZ ZENITH`
`ZERO ROT TO 60 00 00`

Mechanism: The possible mechanisms are:
`ALTITUDE`
`AZIMUTH`
`ROTATOR`
`MAIN` (meaning Altitude and Azimuth; this is the default)
`ALL` (Altitude + Azimuth + Cassegrain rotator)

Method: Several different methods are provided to set the zero-points of the incremental encoders, in order to reduce the dependence on individual bits of electronics. These are:

Keyword: **ABSOLUTE** The incremental encoders are set to read the same as the absolute encoders for the same mechanisms. This is done automatically on startup, to provide an initial estimate. It is prone to failure because the bulbs in the absolute encoders are not especially reliable.

Keyword: **TARGET** This is the default method and is, in principle, capable of the highest accuracy. A mechanical target is used to provide a fixed reference point. The mechanism is driven slowly through a standard position and the encoder is reset when the target is detected electronically. Provided that the encoder is approximately correct on startup, this can be done automatically using `ZEROSET <mechanism> TARGET AUTO`, but in case of problems, the mechanism can be driven through the zeroset position in engineering mode, in which case the command is `ZEROSET <mechanism> TARGET MANUAL`.

`ZENITH` is used to set the zero-points in Altitude and/or Azimuth assuming that the telescope is at its hardware zenith park position. This is a useful backup option because the telescope can be moved to a reproducible position independently of the encoders.

Keyword: **AP1** As for `ZENITH` but using the hardware Access Park 1 position.

Keyword: **AP1** As for `AP1` but using the hardware Access Park 2 position.

Keyword: **TO** Allows the current position of the mechanism to be input. This would normally be the derived from the Engineering-desk synchros (in Altitude and Azimuth) or from the scale on the Cassegrain rotator and is corrected for known zero-point errors. This method provides a starting point for the `TARGET` procedure and a backup in case of failure of both the absolute encoder and the target electronics.

Format: `<degrees> <minutes> <seconds>`

15.5 The Handset

15.5.1 General

The handset provides an interactive way of incrementing the position of the telescope in various coordinate systems, setting apertures and offsets and altering the focus and rotator position angle. The handset is selected by pressing the HANDSET key or typing `HANDSET` at the user interface. There are seven **modes**, selected by labelled function keys:

- **ALT_AZ** Changes the demand position in Altitude and Azimuth.
- **RA_DEC** Changes the demand position in right ascension and declination.
- **X_Y** Changes the demand position in directions fixed in the focal plane.
- **OFFSET** Used with the `STORE POSITION` command to set up offsets.
- **APOFF** Used with the `STORE APERTURE` command to set up apertures.
- **FOCUS** Changes the focus.
- **ROTATOR** Changes the sky position angle of the instrument rotator.

The functions divide naturally into three groups:

- ALT_AZ, RA_DEC and X_Y increment the demand position and differ only in the directions of the increments. The increments displayed are therefore the accumulated values from all three modes in the coordinate system of the current mode. The tracking position on the Information Display also changes.
- OFFSET and APOFF are used in conjunction with the `STORE` command to set up positional and aperture offsets interactively. The tracking coordinates do not change.
- FOCUS and ROTATOR move individual mechanisms.

Units are arcseconds for the positional modes, millimetres for FOCUS and degrees for ROTATOR.

Pre-defined and user-selectable increments may be used and the arrow keys are used to input the steps. These auto-repeat when held down, so a continuous motion may be generated by selecting a small increment and holding down the appropriate key. The > and < keys select the next larger and next smaller increments, respectively. >> requests the input of an increment value. Enter the value, in the appropriate units, and then hit the RETURN key. Just hit RETURN to escape from increment selection if you press >> by accident. The handset display (a variant of that shown in Figure 10) is drawn at the top of the user-interface screen. It shows the available increment values, the accumulated increments and the modes. Currently-selected values are in reverse video. Only the keys labelled in Figure 11 remain active. The HANDSET key is used to return to the `USER>` prompt. The default on first selecting the handset is the X_Y mode with an increment of 3 arcseconds. Thereafter, the accumulated increments in each mode and the currently-selected mode and increment value are remembered on exit to `USER>` level and restored when the handset is next used. They are reset on source change (`GOTO`, `GOCAT`, `NEXT` or `BLIND_OFFSET`).

Figure 10: An example of the handset-mode display. This version applies to change of the reference position in x, y coordinates and is the default on startup.

Figure 11: The portion of the VT220 user-interface keyboard used in handset mode. Only those keys with labelled functions are active.

15.5.2 ALT_AZ mode

The image is moved horizontally or vertically on the sky. Increments are defined in the tangent plane, so their magnitudes do not depend on Elevation. This mode is used to establish the vertical direction (*e.g.* when worrying about differential refraction) or to ascertain whether a failure in telescope tracking or pointing is predominantly in Azimuth or Elevation.

15.5.3 RA_DEC mode

The image is moved in the East-West or North-South direction. Increments are defined in the tangent plane, so their magnitudes do not depend on declination. Image movement on the TV and detector will depend on the chosen sky position angle. At a sky position angle of 0°, the movements in X_Y and RA_DEC are identical. RA_DEC mode is most useful for wandering around finding charts and establishing orientations on the instrument. It can also be used for rough offsetting from a reference source although this can be done more easily and accurately with other methods such as the `BLIND_OFFSET` command.

15.5.4 X_Y mode

This is the most commonly used of all the modes. It moves the telescope in a sensible way corresponding to the normal sense of X, Y coordinates on the acquisition TV screen (independent of rotator orientation and with equal steps in X and Y) and is the normal method for final alignment of an object on to an instrument aperture such as a spectrograph slit. It cannot, however, be assumed that the same XY increments can be used for more than one observation of the same field. The reason is that the handset is being used to compensate both for pointing errors (which tend to be functions of Azimuth and Elevation and therefore rotate with respect to the focal plane when the *mount* position angle changes) and for errors in the position of the object (which are fixed on the sky and therefore rotate when the *sky* position angle changes).

15.5.5 OFFSET mode

Used in conjunction with the `STORE POSITION` command to set up positional offsets which may be recalled with `POSITION`. To define an offset, move an object to the start position using one of X_Y, RA_DEC or ALT_AZ. Then switch to OFFSET mode, move the object to the end position, exit from the handset and store the offset with `STORE POSITION <position_number>`, where position_number is in the range 1–10. `POSITION <position_number>` recalls the offset, which is defined in the tangent plane.

15.5.6 APOFF mode

This mode changes the aperture offset interactively. It is intended to be used to shift an object to an instrument aperture away from the reference position. The aperture coordinates may be recorded for future use with the command `STORE APERTURE`. The image moves in X and Y on the TV and/or detector. To set up a new aperture, move an object to the reference position using X_Y, RA_DEC or ALT_AZ mode, switch to APOFF, move it to the new aperture (spectrograph slit or whatever), exit from the handset and type `STORE APERTURE <aperture_number>`, where aperture_number is in the range 0–10. `STORE APERTURE 0` redefines the reference position.

15.5.7 FOCUS mode

Always allow time for the focus to settle after an increment, as the drive is a bit sticky. It should eventually stop within 0.01 millimetres of the requested position.

15.5.8 ROTATOR mode

This increments the *sky* position angle of the rotator and therefore only works when the rotator is tracking.

15.5.9 Sign conventions

The first five of the handset modes cause an image to move in the focal plane. The sense of motion for the keys has been set so that the *image* moves in the obvious way. The displayed cumulative totals for each mode refer to the motion of the *telescope*. This, coupled with the variety of handednesses of astronomical coordinate systems, requires the sign conventions summarised below:

- **ALT_AZ** mode.
  - $\Leftarrow$ Image moves left on the sky; −Azimuth displayed
  - $\Rightarrow$ Image moves right on the sky; +Azimuth displayed
  - $\Uparrow$ Image moves up on the sky; −Altitude displayed
  - $\Downarrow$ Image moves down on the sky; +Altitude displayed
- **RA_DEC** mode.
  - $\Leftarrow$ Image moves East; −Right Ascension displayed
  - $\Rightarrow$ Image moves West; +Right Ascension displayed
  - $\Uparrow$ Image moves North; +Declination displayed
  - $\Downarrow$ Image moves South; −Declination displayed
- **X_Y** mode. The sign convention has been used to be consistent with that used for apertures (`BEAMSWITCH` and `DEFINE APERTURE` commands).
  - $\Leftarrow$ Image moves left on TV; $-x$ displayed
  - $\Rightarrow$ Image moves right on TV; $+x$ displayed
  - $\Uparrow$ Image moves up on TV; $-y$ displayed
  - $\Downarrow$ Image moves down on TV; $+y$ displayed
- **OFFSET** mode. As **X_Y**
- **APOFF** mode. As **X_Y**
- **FOCUS** mode.
  - $\Leftarrow$ −Focus;
  - $\Rightarrow$ +Focus.
- **ROTATOR** mode.
  - $\Leftarrow$ −Sky position angle;
  - $\Rightarrow$ +Sky position angle.

15.6 The Display

15.6.1 General

The Display has five screens, arranged as follows:

- Source and telescope information (appears on startup);
- Encoder readings;
- Limit indicators;
- Alarm indicators;
- Overrides, trip indicators and interlocks.

The first screen is intended for normal operation, the rest for fault-finding. The user-interface command `PAGE` (*q.v.*) is used to cycle around them. The following sub-sections describe the contents of the pages in more detail.

Figure 12: The Telescope Information Display. This is the first of the display screens and is the default on startup.

15.6.2 Source and telescope information

The layout of this, the default screen, is shown in Figure 12. Its contents are as follows:

- Time
  - ∘ Date
  - ∘ UT—Universal time (UTC) from the time service.
  - ∘ ST—Local apparent sidereal time.
  - ∘ MJD—Modified Julian Date (*i.e.* Julian Date − 2400000.5), in days.
- Input data for the current source.
  - ∘ Name
  - ∘ Right Ascension
  - ∘ Declination
  - ∘ Equinox—Mean pre-IAU76 (B), post-IAU76 (J) or Apparent
  - ∘ Differential tracking rates (blank if not specified)
  - ∘ Proper motions and epoch (blank if not specified)
  - ∘ Parallax and radial velocity (blank if not specified)
- Apertures and offsets
  - ∘ Reference position—offset from the rotator centre in x and y
  - ∘ Aperture offset currently enabled (blank if zero)
  - ∘ Positional offset currently enabled (blank if zero)
- Telescope state. The possible messages are:
  - ∘ STOPPED;
  - ∘ MOVING
  - ∘ TRACKING (the telescope is within 1 arcsecond of its demanded position);
  - ∘ GUIDING (autoguiding on signals provided by the TV system at the displayed cursor position);
  - ∘ S/W LIM (the demanded position is inaccessible: this will occur when the telescope tracks into a software limit or, on source change, when the new object is below the horizon)

  These messages exclude the instrument rotator which is treated separately below.
- Telescope position.
  - ∘ right ascension or hour angle and declination (displayed only when the telescope is tracking).
  - ∘ Equinox (usual conventions)
  - ∘ Topocentric Azimuth, A, and Elevation, E
  - ∘ Position errors in Azimuth and Elevation. Note that the pointing error in Azimuth *on the sky* is $\Delta A \cos E$.
  - ∘ Limit information. "Rise" and "set" refer to the telescope software limits. During tracking, the time remaining until the earliest of the zenith blind spot, horizon limit, Azimuth + limit or rotator limit is displayed, if relevant. Objects having ($\delta > 85^\circ.6$ can be followed indefinitely without encountering a limit, and the message 'SOURCE NEVER SETS' is displayed in this case. See Section 3.4 for a fuller discussion. If the target is currently invisible but will be above the limits later, then its rise time is given. Finally, the message 'SOURCE NEVER RISES' is displayed for objects too far South ever to be observed with the William Herschel Telescope.

  Note that the coordinate system may be changed using the `DISPLAY` command. The available options are:
  - ∘ `INPUT` (default)—the coordinate system used to input the source data. Any space motions have been removed, so the position refers to the *current* epoch. If proper motions, parallax or radial velocity are specified, then the position will differ from the input position even in the absence of offsets.
  - ∘ `B1950`—available for pre-IAU76 mean input coordinates only. Current epoch.

  - J2000—available for any mean input coordinates. Current epoch.
  - APPARENT—geocentric apparent coordinates of the current date. Always available.
  - HA_TOPO—topocentric hour angle and declination. Always available.
- Turntable information.
  - The message 'STOPPED', 'MOVING', 'TRACKING' or 'S/W LIM' is displayed, with the same meanings as for the telescope, except that the software limit can only be encountered during tracking, never on source change.
  - The Focal Station currently selected. This means that the software has been configured for that focal station and that the appropriate turntable will be driven. It does *not* refer to the position of the Nasmyth flat. The options are CASSEGRAIN (default), GHRIL and FLEX, the latter two also indicating DEROTATION when the turntable is to be driven at a rate appropriate for the derotation optics rather than a directly-mounted instrument.
  - Demand sky position angle (as input using ROTATOR/SKY and modified subsequently using the handset. Blank if the rotator is not tracking (*e.g.* for a ROTATOR/MOUNT command).
  - Mount position angle.
  - Mount error, that is the error in mount position angle (only displayed when the rotator is tracking). Note that an error of 1 arcsecond corresponds to a displacement on the sky of 0.003 arcseconds at a typical maximum field radius of 10 arcminutes.
  - Parallactic angle.
- Miscellaneous:
  - Focus;
  - Dome Azimuth;
  - Air mass (relative to the zenith);
  - Alarm warning. This indicates that one of the other screens shows an alarm.

15.6.3 Encoder display

The second page displays the encoder readings for Altitude, Azimuth and all of the instrument rotators. The layout is shown in Figure 13. In case of pointing difficulties, it is particularly useful to compare the absolute and (gear-driven) incremental encoders on the same axis (see Appendix C). The values displayed are as follows:

- Azimuth (units are degrees:minutes:seconds)
  - Absolute (AZ ABS);
  - Incremental gear (AZ GEAR);
  - Incremental roller (AZ ROLL)—not yet functional.
- Elevation (units are degrees:minutes:seconds)
  - Absolute (EL ABS);
  - Incremental gear (EL GEAR);
  - Incremental roller (EL ROLL)—not yet functional.
- Cassegrain rotator (units are degrees:minutes:seconds)
  - Absolute (CA ABS);
  - Incremental gear (CA INCR).
- Nasmyth (FLEX/UES/Drive side—units are degrees:minutes:seconds)
  - Absolute (ND ABS);
  - Incremental gear (ND INCR).
- Nasmyth (GHRIL/cable-wrap side—units are degrees:minutes:seconds)
  - Absolute (NC ABS);
  - Incremental gear (NC INCR).

Figure 13: Encoder display screen

- Dome (Units are degrees:minutes);
- Shutter—not yet functional;
- Lower windshield—not yet functional;
- Mirror cover position in arbitrary units from 0 (closed) to 100 (full open).

In addition, the values of a number of hardware status bits are displayed:

- Focal station in use (displays SELECTED)
  - Cassegrain (status bit not working);
  - Prime (status bit not working);
  - Nasmyth drive side (FLEX/UES);
  - Nasmyth cable-wrap side (GHRIL);
  - Folded Cassegrain (not yet in use).
- Primary mirror cover.
  - CLOSED/NOT CLOSED reads CLOSED when the cover is *fully* shut; NOT CLOSED otherwise.
  - OPEN/NOT OPEN reads OPEN when the cover is *fully* open; NOT OPEN otherwise.
- Nasmyth flat. STOWED is the appropriate position for Cassegrain and Prime foci; NOT STOWED for Nasmyth and folded Cassegrain. The flat should always be STOWED when not in use.
- Secondary mirror cover. Always OFF.
- Azimuth zone. This gives the position of the switch that is read on startup to resolve the ambiguity in the Azimuth absolute encoder. RED $\Rightarrow -180° <$ Azimuth $< +120°$ and YELLOW $\Rightarrow +120° <$ Azimuth $< +360°$, approximately.
- Zenith park ties. These are inserted to stop the telescope moving when it is out of balance at the zenith (*e.g.* when the mirror cell has been removed) and force engineering mode. Normal state OUT.
- Revolving floor latch. This stops the telescope moving in Azimuth when it is at the correct position for the mirror to be removed (*i.e.* with the fixed and moving parts of the mirror trolley rails lined up). Normal state CLEAR.
- AP 3 access barrier. This stops the telescope being driven in Azimuth when the barrier is removed to give access to the top-end ring. Normal state OPEN.

15.6.4 Limit page

This page displays the state of the hardware limits and pre-limits for Altitude, Azimuth, rotator and focus drives, together with emergency stop, power and engineering/computer mode indicators. The layout is shown in Figure 14.

- Emergency stop. This shows the state of the red emergency stop buttons. None of the drives will function unless *all* the buttons are out, in which case the display shows RELEASED.
- Telescope power. Should be ON.
- Computer reset button. This is the button on the engineering desk which is pressed to switch from engineering to computer mode. It is ENABLED (lamp on) when switchover is allowed.
- Mode selected. COMPUTER or ENGINEER (duplicated on the top-level display).
- Azimuth limits. These are *hardware* limits and should not be encountered in normal (computer-controlled) operation. The pre-limits are hit first, and cause the system to revert to engineering mode. The telescope can only be driven out of a main limit by hand. The display should show CLEAR for all limits and pre-limits in normal operation. The nominal hardware limit positions are:
  - LIMIT+ 362°;
  - PRE-LIMIT+ 360°;

Figure 14: Limit screen

  - PRE-LIMIT− −180°;
  - LIMIT− −182°.
- Altitude limits. As for Azimuth, except that the final limit refers to the Access Park 3 position, which can only be reached under engineering-mode control from the balcony. The nominal positions are:
  - LIMIT+ 97°;
  - PRE-LIMIT+ 95°;
  - PRE-LIMIT− 6°.5;
  - LIMIT− 6°.0;
  - FINAL LIMIT− 0°.75.
- Prime focus turntable limits. Not yet in use.
- Cassegrain turntable limits (status bits not working at the moment). There are no pre-limits. If a limit is hit, the drive is turned off and the system switches to engineering mode. The turntable must be driven out of the limit using the + and − buttons on its base. The Cassegrain cable-wrap is driven independently (using a simple hardware servo) and therefore has its own limits (activated if it is more than 1°.75 out of phase with the turntable. If it hits one, then the *turntable* must be driven under engineering control until the cable-wrap limit is cleared.
- Nasmyth turntable limits. Not yet implemented—the Nasmyth turntables are allowed to rotate continuously.
- Focus limits. Hitting a limit stops the focus drive, but does not cause a switch to engineering mode.

15.6.5 Alarms page

This page contains alarm indicators for serious faults, principally in the hydraulic support system, mirror support and power supply. All except the control room temperature, Nasmyth gate and dome emergency stop alarms have counterparts on the alarm panel of the engineering desk (red light + audible alarm). The layout is shown in Figure 15.

- Hydraulic and lubrication system
  - Oil pad alarm. Indicates high or low pressure at one of the hydraulic support pads. Check the engineering desk to ascertain which pad(s) are involved. Warning only—does not cause switch to engineering mode. Normal state CLEAR.
  - Gearbox oil alarm. Indicates incorrect oil pressure in the gear-boxes. Warning only. Normal state CLEAR.
  - Oil pump alarm. Normal state CLEAR. (Currently broken so always indicates TRIPPED).
  - Altitude and Azimuth oil filter alarms. Normal state CLEAR.
  - Oil temperature. Should read NORMAL.
  - Oil pressure. Should read NORMAL.
- Power
  - Mains alarm. Normal state CLEAR.
  - Power amplifier. Normal state WORKING.
- Primary mirror support
  - Nitrogen pressure. Normal state NORMAL. A failure here generally means that the nitrogen supply has run out.
  - Load cell alarm. Indicates that the forces on the radial or axial load cells which control the position of the mirror are excessive. Normal state CLEAR.
  - Mirror height. Normal state NORMAL.
- Weather alarms (none connected yet)
  - Wind speed. Normal state CLEAR.

Figure 15: Alarms screen

  - Ice. Normal state CLEAR.
  - Rain. Normal state CLEAR.
  - Dust. Normal state CLEAR.
- Control room temperature alarm. This is used to detect a failure of the air-conditioning system and to turn off the power supply to the computers if the control room overheats. Normal state CLEAR.
- Nasmyth gate alarm. This is triggered if one of the Nasmyth access gates on the balcony is open, but there is no Nasmyth platform next to it. It causes a switch to engineering mode. Normal state NOT OPEN.
- Dome emergency stop. Normal state CLEAR.

15.6.6 Overrides and dome page

This page contains the engineering override indicators for individual mechanisms and the status bits concerning dome and shutters. The layout is shown in Figure 16.

Figure 16: Overrides and dome screen

- Engineering overrides. These cause computer control for individual mechanisms to be disabled and are controlled by latching buttons on the engineering desk. Overrides are on when the buttons are latched down. The yellow lamps will be lit when the mechanisms concerned are under engineering control, either because the system as a whole is in engineering mode or as a result of overrides. Mechanisms which may be overridden and their states in normal (computer-controlled) operation are:
  - Dome (normally COMPUTER);
  - Focus (normally COMPUTER; note that the focus drive does not work under override);
  - Shutters (normally ENGINEER);
  - Mirror cover (normally ENGINEER);

  Note: at present there are problems with the allocations and latching of the status bits.
- Control locations. These show the state of the remote/local/off keyswitches on the gallery control panel.
  - Dome (normally REMOTE);
  - Shutter (normally LOCAL);
  - Windshield (normally LOCAL).
- Power. Normally ON.
  - Dome;
  - Shutter;
  - Windshield.
- Overtravel alarms. Micro or main? Normally CLEAR.
  - Shutter;
  - Windshield.
- Torque trip alarms. Shut down the drive until reset on the gallery control panel. Normally CLEAR.
  - Shutter;
  - Windshield.
- Windshield parked indicator. What does PARKED mean—full down or closed position?
- Shutter and windshield OPEN/CLOSED.
- Platform pin. If in, this disables dome rotation. Normally OUT.
- Dome interlock. I have no idea what this does. Normally DISABLED.

16 The Integrating Television System

16.1 Introduction

16.1.1 Cameras

The integrating television system at the Cassegrain focus of the William Herschel Telescope has two Westinghouse ISEC cameras: one on-axis for slit-viewing (used with FOS-2) and a second for off-axis guiding (permanently available). The off-axis TV views a portion of the focal plane of the telescope offset by about 600 arcseconds from the reference axis. The target object will normally be on-axis, but it may be moved into the field of the off-axis camera using the command `APERTURE 1` and returned to the detector with `APERTURE 0`. The cameras have S-20 photocathodes and are at present unfiltered. Their wavelength response is shown in Figure 17. The cameras are blue-sensitive, so the effects of atmospheric differential refraction are very noticeable at low elevations, the images being extended along the vertical direction (see Figure 9).

Figure 17: Wavelength response of the S-20 photocathode used in the Westinghouse ISEC Television Cameras.

16.1.2 Integration, Filtering and Flat-fielding

As was described in more detail in Section 4.3, the TV system is capable of on-target integration (where charge builds up on the photocathode for N 40 millisecond frame times) and recursive filtering over 2^S integrated images in digital memory. The resulting signal-to-noise ratio is proportional to $N^{1/2}(2^S-1)^{1/2}$. Moderate integrations with filtering are preferred to extremely long integrations: the risk of damage to the photocathode is reduced and the images are less affected by transients. Flat-fielding of deep images (to remove the effects of photocathode sensitivity variations) is also recommended.

16.1.3 Coordinate system, fields and scales

The coordinate system (pixel numbers) has its origin, (1,1), in the top right-hand corner: x increases to the right; y increases downwards. The image is 512 pixels square. The nominal scales are as follows:

Table 4: *Summary of field size and scale data for integrating TV*

Coordinate	Number of pixels	Field (*mm*)	Field (*arcsec*)	Pixel size (*arcsec*)
x	512	20.0	90.2	0.176
y	512	15.0	67.7	0.132

The scale for each camera should be measured after every adjustment and stored on the TV system's disk using the `SET-XSCALE` and `SET-YSCALE` commands. Some residual distortion of the camera field is inevitable, even after careful set-up, so accurate relative astrometry should not be attempted.

16.1.4 The look-up table

The TV system allows display of images in monochrome or colour. Figures 18 and 19 illustrate the control of the monochrome transfer function. The output grey levels are derived from the input signal using a linear transfer function of positive slope between thresholds L and H. There are 256 possible grey levels. The functions BLACKER and WHITER control the thresholds. On startup, $L = 0$ and $H = 255$. BLACKER increases both threshold values in steps of 8, subject to the conditions that $H \leq 255$ and $L \geq 0$, whereas WHITER decreases L and H in steps of 8, subject to the same conditions. The slope of the transfer function is unchanged. ENHANCE reduces H by 16, subject to $H - L \geq 32$, leaving the lower threshold, L, unaltered. Finally, SOFTEN increases H by 16, up to a limit of 255. The values of L and H are not displayed and the number of steps available for BLACKER / WHITER and ENHANCE / SOFTEN are interdependent, so manipulation of the transfer function is sometimes tricky.

For the colour LUT, there is a "colour spiral pattern" of dubious artistic merit and the ENHANCE and SOFTEN functions determine how many times this pattern is wrapped around in the LUT. BLACKER and WHITER in spite of their names, control which colours are mapped to the minimum and maximum intensities.

16.1.5 Startup and basic control

The TV system loads automatically on power-up or operation of the reset switch on the front panel of the TV VME system. If the system hangs up, it may be restarted by pressing the reset button. Commands are entered through the VT 220 terminal labelled "TV SYSTEM" and images are displayed on the colour monitor below this terminal.

Figure 18: The transfer function of the TV system display for black-and-white images, showing the effects of the $\boxed{\text{BLACKER}}$ $\boxed{\text{WHITER}}$ keys.

Figure 19: The transfer function of the TV system display for black-and-white images, showing the effects of the ENHANCE and SOFTEN keys.

Basic control is via the function keys in **keypad** mode (the normal typewriter keyboard is locked out). These operate in one of three sub-modes: **camera control**, **look-up table** or **help**, as described in detail below. Keypad mode is the default on startup.

Alternatively, the system may be used in **keyboard** mode, where the typewriter keys are active but only some of the function keys, those along the top row of the VT220, remain available (press SHIFT with the key). The keypad functions do not work correctly: pressing a key on the keypad in keyboard mode will cause odd characters to be written on the screen. A range of additional functions is available *via* typed keywords in keyboard mode. These include the storage and retrieval of images on disc and basic image processing. Commands *must* be entered in upper case. The current task may be aborted by typing CTRL–C on the TV terminal but note that this leaves the terminal in keyboard mode.

16.1.6 On-line help

On-line help may be obtained by pressing the HELP key in keypad mode, or SHIFT + HELP in keyboard mode, and following the instructions.

Keypad mode Pressing the HELP key brings up a screen with instructions on how to obtain more detailed help. Use of the PREV SCREEN and NEXT SCREEN keys on the editing keypad gives access to two further screens containing keypad diagrams indicating the functions of allowable keys. At any stage pressing one of the keypad keys gives detailed help on that key. The terminal remains in help mode until the space bar is pressed.

Keyboard mode The full list of typed HELP commands is:

- HELP for the startup screen of general information;
- CAMERA for help on camera control operations;
- CURSOR for help on cursor control;
- LUT for instructions on changing the look-up table;
- TRACK for details of autoguiding; and
- WHAT-FUN for a complete list of additional functions available from the keyboard.

16.2 Operation of the cameras

16.2.1 Powering up

Before turning on the TV cameras, ensure that all dome lights (including torches) are turned off and that the dome appears to be dark. Be particularly careful of any lights in the immediate vicinity of the cameras. The main lights in the dome are interlocked with the camera power supply, but this is not true, for example, of lamps plugged into a wall socket. Turn the camera gain controls to their clicked-off (full anticlockwise) positions. Then press the "ON" buttons for the cameras in use and wait until the yellow reset lights go off.

> The high-gain intensified television cameras used in this system are very easily damaged by over-illumination, especially during long integrations.

16.2.2 Basic operation

When the telescope is pointing at the correct field, make sure that the camera is in **direct** mode (*i.e.* not integrating—see below), turn the camera gain up **slowly** (there is a time lag of about 3 seconds between altering the gain and the full effect's being seen) and observe the picture on the mini-monitor. Always view a field in direct mode first, never in sum or average and always turn the camera gain controls to "OFF" before moving the telescope (you may accidentally point at a bright star or even the Moon!).

In order to get the best picture, select the direct mode and the appropriate camera—ON-AXIS for slit viewing or OFF-AXIS for guide star selection. This will bring up the image on the main monitor. Then adjust the gain and the (colour or monochrome) look-up table (LUT). Note that the black-and-white LUT has a greater range of adjustment. It should give better discrimination between object and sky than does the colour LUT and is to be preferred in most cases. If further gain is required, select AVERAGE and gradually increase the number of frames of on-target integration and the smoothing factor with >SUM and >SMOOTH respectively. An on-target integration allows charge to build up on the TV photocathode. This can lead to dangerous over-illumination (just as in direct mode), so never do a long integration with a bright star in the field.

16.3 Control using the function keys

16.3.1 General

The function keys used by the TV system are illustrated in Figures 20 and 21. Some of the functions (especially those relevant to camera safety) are available in both modes. The corresponding keys are labelled appropriately. The remaining functions are associated with the buttons labelled '1'–'6' on the keypad. Their functions are always displayed at the top of the monitor screen and the LUT-CAMERA key at the bottom left of the keypad is used to toggle between modes.

The KEYBOARD key is used to switch from keypad to keyboard mode. The reverse operation requires SHIFT and KEYPAD to be pressed simultaneously. On startup, the system is set to keypad mode.

16.3.2 Keypad functions available in both modes

For locations of the various keys, see Figures 20 or 21.

FREEZE — This freezes the image currently on the TV screen. It also terminates any on-target integration and switches all TV beams back on and is therefore very useful in an emergency.

> If in doubt, hit FREEZE or type `FREEZE` and turn the gain control to its clicked-off position.

DIRECT — Digitizes, stores and displays the signal from the currently-selected TV camera. The effective integration time is 40 milliseconds.

SUM — This turns off the TV read beam for N frames and then reads out the resulting on-target integration in a single frame time. N is set using the >SUM and <SUM functions in camera mode. N is an even number in the range $2 \leq N \leq 512$. The signal- to-noise ratio is proportional to $N^{1/2}$ and the time constant is $40N$ milliseconds.

AVERAGE — The on-target integrations (see SUM above) are filtered recursively, giving a higher signal-to-noise ratio at the expense of a longer effective time constant. AVERAGE should normally be used in preference to SUM except for quick looks with short integrations *e.g.* acquisition of an object just below the limit for direct mode). The algorithm (see Section 4.3) effectively smooths over 2^S integrations, where S is an integer in the range $0 \leq S \leq 7$. SUM is equivalent to $S = 0$ (no smoothing). The signal-to-noise ratio is proportional to $N^{1/2}(2^S - 1)^{1/2}$ and the time constant is $40(2^S N)$ milliseconds

ON-AXIS — Selects the Cassegrain on-axis (slit viewing) camera if the latter is fitted (FOS-2 is the most usual application).

Figure 20: Keypad for TV system in camera mode

Figure 21: Keypad for TV system in look-up table mode

OFF-AXIS — Selects the Cassegrain off-axis (guiding) camera, which is always fitted.

FINDER — This will eventually select the TV camera mounted on the guide-star finder which does not, however, exist at present.

KEYBOARD — Switches to keyboard mode.

PROFILE — Draws an intensity profile in the x or y direction, between the current cursor position and the last mark. Profiles in arbitrary position angles are not allowed.

LUT-CAMERA — Toggles between LUT and camera modes. The mode currently selected is displayed on the monitor.

MARK — Leaves a red marker at the current cursor position. Marks can be erased using the CL MARKS key, which clears all markers (see below).

X-HAIR — Toggles on or off a cross-hair centred on (256, 256).

$\Leftarrow\Rightarrow\Downarrow\Uparrow$ — These move the cursor in obvious directions (by one pixel on the screen for a single press; auto-repeat causes a continuous of the cursor if the key is held down). The cursor position is displayed at the bottom right-hand corner of the screen.

FLAT FIELD — Flat-fields a TV image. The image currently in the TV system memory is multiplied by NORM (default = 1000) and divided by a standard flat field for the appropriate camera. Note that this makes no allowance for the effects of different filters, but since local variations in the photocathode efficiency cause most of the problems, this may not matter. Identical to the `FF` function in keyboard mode.

SEEING — Determines the FWHM of an image at the current cursor position in x and y. The units are arcseconds. Identical to the `SEEING` function in keyboard mode. Does not work for integrated images with no smoothing: use AVERAGE with SMOOTH $\neq 0$.

CL OVERLAY — Clears the overlay plane used most recently. The image must be frozen. There are 4 graphics overlay planes: marks are in plane 1, cursors in plane 4 and profiles in 2 or 3. Any function affecting an overlay resets the current overlay plane, which is cleared by the CL OVERLAY function. Thus, if you draw an intensity profile and then move the cursor, the cursor, not the profile will be erased.

CL MARKS — Clears the red marks. The image must be frozen. Duplicates the `CL-MARKS` command.

CL ALL — Clears all of the overlay planes. The image must be frozen. Duplicates the `CL-ALL` command.

16.3.3 Functions available only in Camera mode

These function keys control the integration and smoothing parameters and turn on autoguiding.

>SUM — The number of frames of on-target integration, N, is increased by 2 every time this key is pressed. The number of frames is displayed in the bottom left-hand corner of the screen. The default value is $N = 2$ and the range is $2 \leq N \leq 512$.

<SUM — As >SUM but the number of frames is decreased by 2.

>SMOOTH — The smoothing parameter, S, used by AVERAGE is increased by 1 each time this key is pressed. It is displayed next to the frame count. Smoothing is over 2^S frames. $S = 0$ corresponds to no smoothing and is equivalent to summation. This is the default on startup. S is restricted to the range 0–7.

<SMOOTH — As >SMOOTH but the smoothing parameter is decreased by 1.

GUIDE — turns on image following. Place the cursor on or at least within about 20 pixels of the object to be followed and press the GUIDE key. The cursor will then lock on to the object and follow its motion, provided that this is not too quick. Guiding errors are also sent to the telescope computer, but not acted upon until a `GUIDE ON` command is issued. The errors may also be logged using the `SET LOG ON` command. The camera must be in direct mode for this command to work (*cf.* I-GUIDE below).

I-GUIDE — The equivalent of GUIDE for an integrated image. First set up suitable integration parameters (*at least* 12 frames of integration and a smoothing factor of 1 or more; 50 frames with a smoothing factor of 2 works very well). Place a cursor in the vicinity of the object and press the I-GUIDE key. The cursor position is sent to the telescope computer after every readout ($40N$ milliseconds, where N is the number of frames).

16.3.4 Functions available only in LUT mode

These functions all affect the display look-up table.

ENHANCE — This enhances the current LUT (either greyscale or colour) by steepening the transfer function.

SOFTEN — This has the opposite effect to ENHANCE *i.e.* the slope of the transfer function is decreased and the contrast reduced.

BLACKER — This is used in conjunction with enhance/soften for greyscale LUT's to change the threshold: the overall picture is made darker. A colour LUT is rolled.

WHITER — As BLACKER but the picture is made lighter.

MONO — Loads the default greyscale look-up table, which is a linear ramp of unit gain.

COLOUR — Loads the default colour look-up table.

16.4 Typed commands

Remember that TV commands must be typed in UPPER CASE and that no abbreviations are allowed. The typed commands for the TV system are divided here into 9 groups: utility, image arithmetic, file handling, camera control, camera scale factors, guiding, image stack handling, drawing and clearing graphics and profile fitting.

16.4.1 Utility functions

These include commands to be used in case of disaster, to print out help text and to switch to keypad mode.

`KEYS` selects the keypad when in keyboard mode.
Format: `KEYS` or
Press the SHIFT and DO keys simultaneously.

`HELP` prints the top-level help screen.
Format: `HELP`

`CAMERA` prints the camera-control help screen.
Format: `CAMERA`

`CURSOR` prints the cursor-control help screen.
Format: `CURSOR`

`LUT` prints the look-up table help screen.

Format: `LUT`

`WHAT-FUN` prints the help screen for typed keywords.
Format: `WHAT-FUN`

`TRACK` prints the autoguiding help screen.
Format: `TRACK`

`KEYPAD` prints the keypad layout.
Format: `KEYPAD`

`REBOOT` reboots the TV system.
Format: `REBOOT`

`OVERLAY` restores the display to its proper state if exiting from GUIDE or I-GUIDE causes the overlays to disappear.
Format: `OVERLAY`

`MEND-HELP` rebuilds the help screens.
Format: `MEND-HELP`
Notes: TV system errors sometimes cause the help screens to be corrupted. The `MEND-HELP` command restores them.

16.4.2 File handling

Up to 40 images may be stored on the TV system's disc. They have reserved names (TV01 – TV40), but can also have associated identifiers. They can be overwritten but not deleted. The following commands are concerned with transfer of files between disc and memory, display and housekeeping.

`?IMAGES` lists the files stored on disc.
Format: `?IMAGES`

`DISP` gets the specified TV scratch file (TV01 – TV40) from the disc, loads it into the TV memory and displays it.
Format: `DISP [<filename>]`
Default: If no filename is specified, then the top of the image stack is displayed.
Examples: `DISP TV01`
`DISP`

`GET-F` gets the specified TV scratch file (TV01 – TV40) from the disc, loads it into the TV memory and displays it.
Format: `GET-F <filename>`
Example: `GET-F TV40`

`GET-FILE` gets the specified TV scratch file (TV01 – TV40) from the disc and places it on the image stack without displaying it.
Format: `GET-FILE <filename>`
Example: `GET-FILE TV40`

`PUT-F` stores the TV image in the specified TV scratch file, overwriting any previous image.
Format: `PUT-F <filename>`
Example: `PUT-F TV40`

`PUT-FN` stores the TV image in the specified TV scratch file, overwriting any previous image and prompts for an identifier to be associated with the image.
Format: `PUT-FN <filename>`
Example: `PUT-FN TV40`

`RENAME` changes the identifier of the specified file, prompting for a new one.

Format: `RENAME <filename>`
Example: `RENAME TV40`

`WHATS` prints the identifier of the specified file.
Format: `WHATS <filename>`
Example: `WHATS TV40`

16.4.3 Image arithmetic

The following commands perform simple arithmetic operations on one or two TV images. The most important is `FF`, which divides an image by a standard flat field to remove sensitivity variations in the photocathode.

`FF` Flat-fields a TV image. Identical to the FLAT FIELD key.
Format: `FF`

`TVFF` multiplies the TV image by NORM (default = 1000) and divides by the top of the image stack. The image on top of the stack is lost and the rest of the stack is moved up by one. This command may also be used for flat-fielding a TV image if, for example, a non-standard flat field has been obtained and placed on the stack.
Format: `TVFF`

`TV+C` adds a constant value to the TV image.
Format: `<constant> TV+C`
Example: `200 TV+C`

`TV-C` subtracts a constant value from the TV image.
Format: `<constant> TV-C`
Example: `200 TV-C`

`TV*C` multiplies the TV image by a constant.
Format: `<constant> TV*C`
Example: `2 TV*C`

`TV*/C` multiplies the TV image by one constant and divides by another.
Format: `<multiplier> <divisor> TV*/C` (or possibly the other way round).
Example: `2.3 15.1 TV*/C`

`TV+` adds the image on top of the stack to the currently displayed image. The image on top of the stack is lost and the rest of the stack is moved up by one.
Format: `TV+`

`TV-` subtracts the image on top of the stack from the currently displayed image. The image on top of the stack is lost and the rest of the stack is moved up by one.
Format: `TV-`

`-TV` subtracts the TV image from the top of the image stack. The image on top of the stack is lost and the rest of the stack is moved up by one.
Format: `-TV`

`TV*` multiplies the TV image by the top of the image stack. The image on top of the stack is lost and the rest of the stack is moved up by one.
Format: `TV*`

`TV-SMOOTH` does a block smooth on the TV image.
Format: `<x-size> <y-size> TV-SMOOTH`
Example: `2 3 TV-SMOOTH`
Comments: `<x-size>` and `<y-size>` are the dimensions of the smoothing box, in pixels.

FILL	Smooths pairs of lines to remove the flicker which occurs for on-target integration with no smoothing.
Format:	FILL
Notes:	This command freezes the image and then does `1 2 TV-SMOOTH` (see above).

16.4.4 Setting the camera scales

Scales must be redetermined every time a camera is changed or set up. Values are stored on disc for both cameras and are not, therefore, lost on reboot. The ratio between x and y pixel sizes should be 4/3, otherwise the displayed images will not have the same scales in x and y.

SET-XSCALE	sets the TV x scaling factor.
Format:	<x-scale-factor> SET-XSCALE
Example:	80 SET-XSCALE
Comments:	The scale is set such that the distance between the cursor and the last marker is x arcseconds.
SET-YSCALE	sets the TV y scaling factor.
Format:	<y-scale-factor> SET-YSCALE
Example:	55 SET-YSCALE
SCALE?	prints out the camera scales in arcseconds/pixel.
Format:	SCALE?

16.4.5 Camera control

The commands in this section both duplicate function keys. They are provided for safety reasons, in order to disable integration when the terminal is in keyboard mode and the function keys are not available.

FREEZE	freezes the image currently being digitized (equivalent to the FREEZE key in keypad mode).
Format:	FREEZE
BEAM-ON	turns all camera readout beams back on (equivalent to the DIRECT key in keypad mode).
Format:	BEAM-ON
Notes:	This causes the charge on the TV photocathodes to be read out in the normal frame time, rather than accumulating as it does during on-target integration. The images are not digitised or displayed. The command should be used to disable integration in an emergency (over-illumination, generally).

16.4.6 Image stack manipulation

The TV system maintains an *image stack* analogous to the stack on a reverse Polish calculator. The following operations list or manipulate the image stack.

.IS	lists the contents of the image stack.
Format:	.IS
E-STK	removes all images from the image stack.
Format:	E-STK
IM-DROP	removes the top item from the image stack.
Format:	IM-DROP
IM-SWAP	swaps the top two items on the image stack.
Format:	IM-SWAP

`IM-DUP` duplicates the top item on the image stack.
Format: `IM-DUP`

`TV>STK` transfers the TV image to the top of the image stack.
Format: `TV>STK`

`STK>TV` copies the image on top of the image stack to the TV. The image stack is not altered.
Format: `STK>TV`

16.4.7 Drawing and clearing graphics

These commands affect the graphics overlay planes used for drawing marks (red), profiles, lines and boxes (green) and cursors (violet).

`CL-OL` clears the overlay plane used most recently (duplicates the CL OVERLAY key).
Format: `CL-OL`
Note: The image must be frozen.

`CL-ALL` clears all of the overlay planes (duplicates the CL ALL key).
Format: `CL-ALL`
Note: The image must be frozen.

`CL-MARKS` clears the red markers (duplicates the CL MARKS key).
Format: `CL-MARKS`
Note: The image must be frozen.

`D-BOX` draws a box centred on the current cursor position.
Format: `<x-size> <y-size> D-BOX`
Example: `4 20 D-BOX`
Units: pixels

`D-LINE` draws a line between the cursor and the last marker.
Format: `D-LINE`

`D-CIRCLE` draws a circle centred on the current cursor position.
Format: `<radius> D-CIRCLE`
Example: `100 D-CIRCLE`
Units: pixels

16.4.8 Image parameters: distances, statistics and profiles

The commands in this section are used to derive image statistics and to measure distances and image sizes.

`?N` does statistics of the TV image in a box centred on the current cursor.
Format: `<x-size> <y-size> ?N`
Example: `10 20 ?N`
Units: pixels

`?DIST` calculates the distance between the last marker and the current cursor.
Format: `?DIST`
Units: arcseconds

`TV-XLINE` measures the position and FWHM of the brightest object on a line extending positively in x (downwards on the screen) from the cursor position.
Format: `<x-distance> TV-XLINE`
Example: `100 TV-XLINE`

Notes: The length of the search line is <`x-distance`> pixels from the cursor position.

`TV-YLINE` measures the position and FWHM of the brightest object on a line extending positively in y (rightwards on the screen) from the cursor position.
Format: `<y-distance> TV-YLINE`
Example: `100 TV-YLINE`
Notes: The length of the search line is <`y-distance`> pixels from the cursor position.

`X-SEE` determines the FWHM in x of the image on which the cursor has been placed.
Format: `X-SEE`
Units: arcseconds

`Y-SEE` determines the FWHM in y of the image on which the cursor has been placed.
Format: `Y-SEE`
Units: arcseconds
Warning: This will not work properly on an integrated image which has not been smoothed. Use $\boxed{\text{AVERAGE}}$ with SMOOTH > 0, as $\boxed{\text{SUM}}$ gives silly results.

`SEEING` determines the FWHM in x and y of the image on which the cursor has been placed. Duplicate of the $\boxed{\text{SEEING}}$ key.
Format: `SEEING`
Units: arcseconds
Warning: This will not work properly in y on an integrated image which has not been smoothed. Use $\boxed{\text{AVERAGE}}$ with SMOOTH > 0, as $\boxed{\text{SUM}}$ gives silly results.

16.4.9 Zooming the display

Note that zooming an image stops digitisation.

`UNZOOM` unzooms the image
Format: `UNZOOM`

`2ZOOM` zooms the image by a factor of 2, centred on the current cursor position.
Format: `2ZOOM`

`4ZOOM` zooms the image by a factor of 4, centred on the current cursor position.
Format: `4ZOOM`

16.4.10 Guiding

The TV system's autoguiding commands cause the cursor to follow an image. The position of the cursor is then sent regularly to the telescope computer. The guiding loop must also be closed on the telescope computer. The commands `GUIDE` and `I-GUIDE` are the exact equivalents of the keypad functions of the same name.

`GUIDE` turns on image following.
Format: `GUIDE`
Notes: Place the cursor on, or at least within about 20 pixels of, the object to be followed and type `GUIDE`. The cursor will then lock on to the object and follow its motion, provided that this is not too quick. Guiding errors are also sent to the telescope computer, but not acted upon until a `GUIDE ON` command is issued to the telescope computer. The errors may also be logged using the `SET LOG ON` command. The camera must be in direct mode for this command to work (cf. `I-GUIDE`, below). The star position is determined every 60 ms, but only sent to the telescope computer every 0.48 seconds.

`I-GUIDE` The equivalent of `GUIDE` for an integrated image.

Format: I-GUIDE
Notes: First set up suitable integration parameters (*at least* 12 frames of integration and a smoothing factor of 1 or more; 50 frames with a smoothing factor of 2 works very well). Place a cursor in the vicinity of the object and type I-GUIDE. The cursor position is sent to the telescope computer after every readout ($40N$ milliseconds, where N is the number of frames) provided that $N \geq 12$ (update interval >0.48 seconds). I-GUIDE will not operate if the number of frames is below this limit.

Q terminates image following. Several repetitions may be needed, as the system is unresponsive during guiding, so try holding the key down for a few seconds to make use of the auto-repeat function of the terminal. If this fails, use CTRL–C abort the guiding task, but beware of the fact that the terminal will be left in keyboard mode.
Format: Q

LOG-ACQ Simultaneous tracking of stars on two cameras.
Format: LOG-ACQ
Notes: This is a test procedure used to check the tracking of the instrument rotator and most users should ignore it. Ensure that there are stars in the fields of both the on- and off-axis cameras. Their positions, in TV coordinates, need to be < 200 pixels apart. Both cameras will operate in direct mode, so ensure that the stars are bright enough. Position a cursor in the approximate vicinity of the star on the currently-selected camera and type LOG-ACQ. Guide errors from both cameras will be logged at 1 Hz by the VME system, but only those from the off-axis camera will be sent to the telescope computer. These can be guided on if required. The run must be terminated by CTRL–C. See Appendix A for some notes on data analysis. This command may mess up the image stack, in which case type E-STK to clear it.

17 Shutting down the computers

Only follow this section if there is a good reason to close down the MicroVAX and the TV system, such as:

- Notice of a power break from the electrical section;
- Reported faults in the air-conditioning. If the air-conditioning is likely to fail when the building is unmanned for more than about an hour or two, the control room may overheat, causing a power trip;
- Reported computer faults.

Power down the TV system by turning off the green switch on the front panel of the VME system. Also turn off the camera controllers in the same cabinet.
If the MicroVAX has to be shut down then proceed as follows:

Shutdown procedure:

- Log in to account TCS_LOGIN;
- Enter SHUTDOWN in response to the prompt.

VMS is then shutdown in an orderly fashion. When the shutdown is complete the message
SYSTEM SHUTDOWN COMPLETE - USE CONSOLE TO HALT SYSTEM
appears on the MicroVAX system console indicating that all the software procedures have been completed. Now close down the hardware:

- Switch the processor OFF.

If circumstances are such that the MicroVAX has to be closed down, then the same should be done for the VAX 8300 if that is running. Use the procedure detailed in the listing on top of the VAX 8300 processor cabinet.

Part IV
APPENDICES

A Test and calibration procedures

A.1 Rotator centre and standard apertures

Techniques for finding the rotator centre on an on-axis detector and of establishing standard apertures for various instrumental configurations have been covered in Section 7. The following quantities should be determined and logged regularly:

- The position of the rotator centre on the (FOS) on-axis camera.
- The aperture offset required to move an object from the rotator centre to the off-axis camera (this should be stored in the initialisation file to be accessed by `APERTURE 1` (see Appendix B).
- The position on the off-axis camera corresponding to this aperture (*i.e.* the apparent centre of rotation).
- The aperture offset from the rotator centre to the centre of the FOS slit (accessed by `APERTURE 2` and stored as in Appendix B).

A.2 Pointing tests and their analysis

A.2.1 General

The purpose of a *pointing test* is to observe a grid of stars covering the whole of the area accessible to the William Herschel Telescope, to measure the pointing errors and to fit a global model describing the geometrical misalignments and flexure of the telescope. This model is then applied by the control system to correct these errors. The steps in the procedure are:

- Select stars of accurately-known position from the pointing grid in the system catalogue (full list in Appendix D.2; see also Table 5 on page 94). There should be about 100 up at any one time.
- Slew to each star (in a sequence that minimises the slew time), centre it at a defined point in the focal plane and log the Altitude and Azimuth encoder readings.
- Analyse the resulting data file using the TPOINT analysis package with the standard model for the William Herschel Telescope.
- Enter the model coefficients in the initialisation file WHT.INI and compile it.

A.2.2 Preparation

The pointing grid consists of a set of stars selected from the FK5 astrometric catalogue (see Appendix D for a full listing). They all have accurate positions and proper motions. There is a basic grid covering the whole sky plus extra stars within 2° of the zenith to improve the accuracy of the model for an Altazimuth mount. The extra stars are called ZENnn. The grid star names begin with either 'S' or 'N' indicating whether they are north or south of the zenith at the William Herschel Telescope in the year 2000. The grid stars were selected at intervals of approximately 1^h in right ascension and 15° in declination, with alternate hour zones offset in declination. Each even right ascension zone has two stars selected with declinations close to 30°, one North and the other South of the zenith. A schematic representation of the distribution of grid stars on the sky is given in Table 5.

It is useful to take a copy of Table 5 to mark the stars which have been measured. Decide roughly which stars to observe using the grid and Figure 6 for the current sidereal time. Individual stars may be observed more than once, provided that their Azimuths and/or Elevations change significantly during the test, since the position of a star is much more accurate than the pointing of the telescope. This applies particularly to stars passing close to the zenith, whose Azimuths change rapidly with time.

Table 5: *Pointing grid for William Herschel Telescope*

	N01		N03		N05		N07		N09		N11		N13		N15		N17		N19		N21		N23
	+82		+82		+82		+82		+82		+82		+82		+82		+82		+82		+82		+82
N00		N02		N04		N06		N08		N10		N12		N14		N16		N18		N20		N22	
+75		+75		+75		+75		+75		+75		+75		+75		+75		+75		+75		+75	
	N01		N03		N05		N07		N09		N11		N13		N15		N17		N19		N21		N23
	+67		+67		+67		+67		+67		+67		+67		+67		+67		+67		+67		+67
N00		N02		N04		N06		N08		N10		N12		N14		N16		N18		N20		N22	
+60		+60		+60		+60		+60		+60		+60		+60		+60		+60		+60		+60	
	N01		N03		N05		N07		N09		N11		N13		N15		N17		N19		N21		N23
	+52		+52		+52		+52		+52		+52		+52		+52		+52		+52		+52		+52
N00		N02		N04		N06		N08		N10		N12		N14		N16		N18		N20		N22	
+45		+45		+45		+45		+45		+45		+45		+45		+45		+45		+45		+45	
	N01		N03		N05		N07		N09		N11		N13		N15		N17		N19		N21		N23
	+37		+37		+37		+37		+37		+37		+37		+37		+37		+37		+37		+37
N00		N02		N04		N06		N08		N10		N12		N14		N16		N18		N20		N22	
+30		+30		+30		+30		+30		+30		+30		+30		+30		+30		+30		+30	
S00		S02		S04		S06		S08		S10		S12		S14		S16		S18		S20		S22	
+30		+30		+30		+30		+30		+30		+30		+30		+30		+30		+30		+30	
	S01		S03		S05		S07		S09		S11		S13		S15		S17		S19		S21		S23
	+22		+22		+22		+22		+22		+22		+22		+22		+22		+22		+22		+22
S00		S02		S04		S06		S08		S10		S12		S14		S16		S18		S20		S22	
+15		+15		+15		+15		+15		+15		+15		+15		+15		+15		+15		+15	
	S01		S03		S05		S07		S09		S11		S13		S15		S17		S19		S21		S23
	+07		+07		+07		+07		+07		+07		+07		+07		+07		+07		+07		+07
S00		S02		S04		S06		S08		S10		S12		S14		S16		S18		S20		S22	
+00		+00		+00		+00		+00		+00		+00		+00		+00		+00		+00		+00	
	S01		S03		S05		S07		S09		S11		S13		S15		S17		S19		S21		S23
	−07		−07		−07		−07		−07		−07		−07		−07		−07		−07		−07		−07
S00		S02		S04		S06		S08		S10		S12		S14		S16		S18		S20		S22	
−15		−15		−15		−15		−15		−15		−15		−15		−15		−15		−15		−15	
	S01		S03		S05		S07		S09		S11		S13		S15		S17		S19		S21		S23
	−22		−22		−22		−22		−22		−22		−22		−22		−22		−22		−22		−22
S00		S02		S04		S06		S08		S10		S12		S14		S16		S18		S20		S22	
−30		−30		−30		−30		−30		−30		−30		−30		−30		−30		−30		−30	
	S01		S03		S05		S07		S09		S11		S13		S15		S17		S19		S21		S23
	−37		−37		−37		−37		−37		−37		−37		−37		−37		−37		−37		−37
S00		S02		S04		S06		S08		S10		S12		S14		S16		S18		S20		S22	
−45		−45		−45		−45		−45		−45		−45		−45		−45		−45		−45		−45	
	S01		S03		S05		S07		S09		S11		S13		S15		S17		S19		S21		S23
	−52		−52		−52		−52		−52		−52		−52		−52		−52		−52		−52		−52

It is assumed that the test will be done using an on-axis television camera. First establish the rotator centre as accurately as possible and mark it on the TV screen. Then turn off the rotator tracking using the commands `STOP ROTATOR` and `SET ROTATOR NOTRACK`. This ensures that an error in the rotator centre position enters only as a change in the collimation terms and does not affect the *rms* error of the test or any of the other terms.

A.2.3 Logging the data

Proceed as follows:

- Enter the data necessary for the calculation of refraction, *i.e.* barometric pressure, outside air temperature, relative humidity and observing wavelength. These are used by the analysis software. It does not matter too much if they are slightly wrong, as the data file can be edited later.
- Slew to the first star, align it as accurately as possible with the rotator centre using the handset, and then type `POINT/NEW`. This opens a new data file, writes a header and logs the name, encoder coordinates and sidereal time.
- Slew to the next star (chosen to avoid a large rotation in Azimuth) and repeat the process, but this time using the `POINT` command, which is also tied to the F20 key on the VT220 keyboard.
- Continue until about 100 stars have been observed, well distributed in Azimuth and Elevation. Concentrate on the zenith and avoid observing many stars at very high declination, which are all in the same area of sky.

A.2.4 Analysing the data

The data files are stored in the directory with logical name TPOINT$:[000000.WHT] on the telescope MicroVAX (for the development or released system, as appropriate). Three files are produced per test, one for each of the absolute, gear incremental and roller incremental encoding systems. The relevant one is that for the gear incremental encoder, which is called GEAR_<date>.DAT, where <date> is the date of observation in the format 'yymmdd' (*e.g.* GEAR_890323.DAT). If more than one pointing test is done on the same day, then several versions of this file will be produced. The file is in the format required by the TPOINT analysis package written by P.T. Wallace. An example of the first few lines of a file is:

```
WHT Cassegrain 1989 01 27
28 45 37.7 1989 01 27  5 779.0 2344.0 0.50 0.40 0.0065
*   N10+45                  10 16 37.833   + 42 57 51.63    11 24 29.200
*   N10+30                  10 00 30.873   + 31 59 14.48    11 26 11.830
*   N10+60                  09 50 31.762   + 59 04 45.42    11 28 35.422
```

The first line is a comment field containing the focal station and date. The second line has the latitude (degrees, minutes, seconds), the date (year, month, day), temperature (°C), pressure (millibar), height (m), humidity (0–1), wavelength (μm) and temperature lapse rate (Km^{-1}). Each data line contains an asterisk, the name of the star, its right ascension and declination (as derived from the *raw* encoder readings) and the sidereal time.

The TPOINT package is fully described in *Starlink User Note 100* and has an on-line help system, so this section concentrates on aspects specific to the William Herschel Telescope.

- Set the default directory to TPOINT$:[000000.WHT].
- Start the TPOINT program by typing `TPOINT` and ignore any messages about being unable to find STARS.DAT.
- Type `INSTARS TPDIR:FK5GRID` to read in the star catalogue, `INDAT GEAR_yymmdd` to do the same for the data and `INPRO PROCS` to set up the procedure library.
- Now run the least-squares fit to the standard model with `CALL WHT`. This does the fit twice, in each case printing out the coefficient values, their errors and the *rms* of the fit. It ends by listing the residuals for each star.

Figure 22: Residuals from a pointing test at Cassegrain focus of the William Herschel Telescope. The overall *rms* error is 1.14 arcseconds.

- If a term in the model is consistent with zero to within $<1.5\sigma$, say, then it should be omitted from the model using the commands `LOSE` <`term`> and `FIT` to repeat the fit.
- To plot the residuals, type `PLTON 2600` (laser printer) or `PLTON 825` (if you are working at a Pericom terminal), followed by `CALL A9`. This produces a summary plot like that shown in Figure 22.
- Finally, type `END` to terminate the session, `PRINT LOG.LIS` to list the log file for the session and `WHT_GLASE CANON.DAT` to plot the residuals on the laser printer in the William Herschel Telescope control room.

A.2.5 The model

The terms which may be used in the standard William Herschel Telescope model are selected from the list in Table 6 (it is unlikely that all the harmonics will be used at once).

The physical meanings of the geometrical terms IE, IA, CA, AX and AY are well-defined. The left-right and Elevation harmonics are likely to be due mostly to deformation of the Azimuth track. The Azimuth second harmonics are an effect of the displacement transducer which corrects for gear errors in Azimuth. This runs on the roller encoder track, which is itself elliptical, and therefore introduces a spurious signal.

Table 6: *Pointing model terms for the WHT*

Term	Description
IA	Index error in Azimuth
IE	Index error in Elevation
CA	Collimation error in Azimuth
$NPAE$	Non-perpendicularity of Azimuth and Elevation axes
AX	E–W tilt of Azimuth axis
AY	N–S tilt of Azimuth axis
TF	$\cos E$ (Hooke's law) tube flexure
TX	$\cot E$ tube flexure
$HSCA1$	$\cos A$ term left-right on the sky
$HSSA1$	$\sin A$ term left-right on the sky
$HSCA2$	$\cos 2A$ term left-right on the sky
$HSSA2$	$\sin 2A$ term left-right on the sky
$HSCA3$	$\cos 3A$ term left-right on the sky
$HSSA3$	$\sin 3A$ term left-right on the sky
$HZCA1$	$\cos A$ term in Elevation
$HZSA1$	$\sin A$ term in Elevation
$HZCA2$	$\cos 2A$ term in Elevation
$HZSA2$	$\sin 2A$ term in Elevation
$HZCA3$	$\cos 3A$ term in Elevation
$HZSA3$	$\sin 3A$ term in Elevation
$HACA2$	$\cos 2A$ term in Azimuth
$HASA2$	$\sin 2A$ term in Azimuth

A.2.6 Expected results

The *rms* error expected from a full pointing test is in the range 1.1–1.4 arcseconds at Cassegrain and 1.5–2.0 arcseconds at Nasmyth. If significantly worse results are obtained, then check the file LOG.LIS for stars with large residuals. If the entire problem is caused by one or two miscentered stars, then comment them out of the file by placing an '!' before the relevant line(s). The residuals should be distributed randomly.

A.2.7 Altering the initialisation file

The results of a pointing test must be edited into the initialisation file WHT.INI. The format of the file is described in Appendix B, as is the translation between variable names used in TPOINT and by the telescope control system. The values must be converted to radians. Make sure that they apply to the correct focal station. Once the file has been edited, start up the control system using the `STARTUP` command with the `SLOW` option to compile the file into a binary image. This can be done either for the released or development systems—just set up the appropriate logical names using the commands `USE_RELEASE` or `USE_DEV`, as described in Appendix B.2.

A.3 Tracking tests

A.3.1 Introduction

Tracking tests use the television system to measure the position of a star at regular intervals and to transmit it to the telescope computer, where it may be logged and analysed. It is also possible to save the data on the television system's own disk, but this no advantages except for rotator tests. The system has a minimum update interval of 60 milliseconds.

A.3.2 Logging the star position

- Tests should always be done with the rotator tracking turned on.
- Find a reasonably bright star travelling at an appropriate speed, make sure that it is in focus and position it well away from the edges of the TV screen.
- Set up the necessary gain and integration parameters according to the application. Fast logging (to look at servo errors and vibrations) is normally done at maximum rate in direct mode. A suitable combination of parameters for measuring gear errors is 50 frames (2 seconds) of on-target integration with SMOOTH = 2. The effective time constant is 8 seconds.
- How do you change the update rate?
- Position the cursor close to the star and press GUIDE (direct) or I-GUIDE (integrating) to start generating positions.
- Start logging on the telescope computer by typing `SET LOG ON`. The x and y coordinates of the cursor will be transferred to the telescope computer and logged
- To terminate the test, type `SET LOG OFF`.

A.3.3 Analysing the data

Tracking data are written to the directory with logical name TPOINT$:[000000.TV_LOG] (which translates to [WHT.UTILITY.TPOINT.TV_LOG] for the development system or for the released version of the system [WHT.RELEASE.UTILITY.TPOINT.TV_LOG]. The files are called TV_LOG_<date>.DAT, where <date> is specified in the standard 'yymmdd' format (*e.g.* TV_LOG_890203.DAT). To plot the data, proceed as follows:

- Type `PLOT` to start the plotting program.
- Enter the name of the data file (with disk and directory specified explicitly if you have not `SET DEFAULT` to the appropriate directory). .DAT is the default extension.

- Select a plot from the list of options. These are:
  1. Azimuth error against azimuth;
  2. Altitude error against altitude;
  3. Azimuth error against altitude;
  4. Altitude error against azimuth;
  5. X error against azimuth;
  6. X error against altitude;
  7. Y error against azimuth;
  8. Y error against altitude ;
  9. Azimuth error on sky (*i.e.* $\Delta A \cos E$) against azimuth;
  10. Azimuth error on sky against altitude;
  11. X error against rotator position angle;
  12. Y error against rotator position angle;
  13. Radial motion against azimuth. This is the reading of the displacement transducer which measures the movement of the telescope structure along the line joining the two azimuth drive motors. This motion is seen by the gear encoder as an azimuth error and the readings are scaled to give ΔA.
  14. Axial load cell 1, scaled to give component of primary tilt, against elevation.
  15. Axial load cell 2, scaled to give component of primary tilt, against elevation.
  16. Axial load cell 3, scaled to give component of primary tilt, against elevation.
  17. Mirror cell transducer 1, scaled to give component of primary tilt, against elevation
  18. Mirror cell transducer 2, scaled to give component of primary tilt, against elevation
  19. Mirror cell transducer 3, scaled to give component of primary tilt, against elevation
  20. Mirror cell transducer 4, scaled to give component of primary tilt, against elevation
  21. Primary tilt in Azimuth as deduced from transducers against Azimuth.
  22. Primary tilt in Elevation as deduced from transducers against Elevation.
  23. Primary tilt in Azimuth as deduced from load cells against Azimuth.
  24. Primary tilt in Elevation as deduced from load cells against Elevation.
- You will then be given the range of the plot (x-axis in degrees and y-axis in arcseconds) and asked whether you wish to change it. If you do, all of the plot limits must be entered. They are read with an F7.2 format descriptor, so decimal points *must* be included.
- The program also asks for the GKS workstation number of the plotting device (generally 825 for a Pericom terminal, 2600 for a Canon laser-printer and 1200 for the Printronix line-printer).
- The plot will be generated automatically on a Pericom screen (although you will have to select graphics mode explicitly to keep it on the screen at the end of the program). The plot files produced for laser or line printers must be sent to the correct device using `WHT_LASE CANON.DAT` or `PRINT/NOFEED PRINTRONIX.BIT`, respectively).

The plots of ΔE against E and $\Delta A \cos E$ against A measure the tracking performance of the telescope. The known errors which have been diagnosed and corrected using tracking tests are:

- The Azimuth error caused by horizontal translation of the telescope structure, which couples into the gear encoder. This has the drive-gear tooth period of $0^\circ.40$. It is corrected by subtracting the scaled reading of the displacement transducer. The effectiveness of the correction may be judged by comparing the plots of ΔA and transducer reading against A. Note that the transducer also picks up spurious effects such as the ellipticity of the roller encoder track (on which it runs) and imperfections in the surface. The former effect is compensated by terms in the pointing model (see Appendix A.2), but the procedure is not entirely satisfactory.

- An Azimuth error of period $1^\circ.09$ (the rotation period of the second gear in the encoder gearbox) with an amplitude of 0.8 arcseconds and the form of a saw-tooth. These have been modelled by fitting a saw-tooth function to the Azimuth residuals (after subtracting the displacement term).
- The effects of errors in the mirror support system, which cause tilts of the primary mirror. These are small ($<$ 0.3 arcseconds, usually) and can be determined from the displacement transducers which measure the position of the primary or (less reliably) from the axial load cells. The derived tilts in Azimuth and Elevation may be compared with $\Delta A \cos E$ and ΔE, which are the corresponding errors on the sky. Note that the primary tilts must be multiplied by two to give image motion.

A.3.4 Fitting functional forms to the data

A variety of functions may be fitted to the tracking data. This has so far been done for periodic errors in Altitude and Azimuth. To start the analysis program, type `FIT`. This initially behaves exactly like `PLOT`. Select option 1 (ΔA against A) or option 2 (ΔE against E) and produce a plot as before. You will then be prompted for the following information.

- `Terms file>` This is the name of a file containing the values of coefficients which must remain constant during the fit.
- `Number of maximum term for fit>` The terms are numbered, the most useful being those in Table 7. Enter the term in your proposed model with the highest number.

Table 7: *Terms for fitting tracking data*

No.	Description
1	Constant
2	Straight line
3	First harmonic sine term
4	First harmonic cosine term
9	Roller encoder rotation period ($8^\circ.77$) sine term
10	Roller encoder rotation period ($8^\circ.77$) cosine term
11	First encoder gear rotation ($8^\circ.84$) sine term
12	First encoder gear rotation ($8^\circ.84$) cosine term
15	Drive gear tooth period ($0^\circ.40$) sine term
16	Drive gear tooth period ($0^\circ.40$) cosine term
19	Second incremental encoder gear rotation ($1^\circ.09$) sine term
20	Second incremental encoder gear rotation ($1^\circ.09$) cosine term
23	Second incremental encoder gear rotation ($1^\circ.09$) saw-tooth term
24	Drive gear period ($0^\circ.40$) saw-tooth term

- `Number of adjustable terms>` These are the terms allowed to float in the fit. Use commas to separate the numbers.
- `Numbers of fixed terms>` These are held constant during the fit.
- `Give 1.09 deg phase>` This applies to the $1^\circ.09$ saw-tooth term only. It is necessary because only the amplitude of a saw-tooth can be determined by a least-squares fit. Start with an approximation (derived, for example, by fitting sine and cosine functions of the same period) and refine it by trial and error.
- `Give 0.4 deg phase>` As above, but for the drive tooth period.
- The program will then do a least-squares fit to the data, producing a list of coefficients, a value of χ^2 and plots of the raw data, fitted function and residuals. These may be printed out as described for `PLOT`.

A.3.5 Building a look-up table

The residuals from `FIT` may be used to generate, or add to a look- up table of tracking errors (the program offers this option after completing the fits and plots). This option is currently used in Altitude, but not in Azimuth.

A.4 TV scales

Scales should be redetermined whenever a camera is changed or adjusted. To do this, position a star at the left-hand edge of the TV monitor, MARK its position, and move it across to the right-hand side using the handset in X_Y mode. Note the distance moved, x, in arcseconds. Position the TV cursor on the star, switch the TV system terminal to keyboard mode and enter the command `x SET-XSCALE`. Repeat the operation for the y-coordinate with the `SET-YSCALE` command. The scales will be listed on the TV terminal and stored on the system's disk, so that they will not be lost on power-down. Scales are, of course, stored separately for the on- and off-axis cameras. The nominal sizes for the pixels are 0.176 arcseconds in x and 0.132 arcseconds in y. Any serious deviations from an aspect ratio of 4:3 indicates an incorrect set-up and should be reported.

B GSEXAM and the initialisation file

B.1 General

This section describes the diagnostic interface GSEXAM, which may be used to read and write system variables while the telescope control system is running. System variables are stored in an initialisation file, which may be read by GSEXAM on startup. The format of this file is described and variables which are likely to be changed regularly are listed. Some knowledge of the TCS and its directory structure is assumed. In particular, the logical names for the appropriate version of the control system must be set up (see below; Appendix B.2).

Misuse of the programs and files described in this section could cause severe damage to the telescope. For this reason, access is restricted to those with programmers' accounts on the MicroVAX.

B.2 Control system versions, logical names and STARTUP

There are two versions of the telescope control system: development and released, run from the captive accounts `TCS_DEV` and `TCS_LOGIN`, respectively. Either can be started from a personal account, given sufficient privilege. Modification of the initialisation file *must* be done from such an account. The logical names needed for the two systems are set up in the GROUP logical name table, which will be set up on login. Type `USE_RELEASE` or `USE_DEV` to select the appropriate set of definitions.

To start the system, type `STARTUP` from '`$`' prompt level. You will be asked to select `FAST` or `SLOW` initialise. The SLOW option generates a new shareable image containing the global sections used by the control system and the initialisation file WHT.INI is used to provide initial values for global variables. The FAST option merely installs the shareable image created during the last SLOW startup, which must therefore be done after any change to WHT.INI.

B.3 Running GSEXAM

GSEXAM can be run from one of the captive accounts `TCS_LOGIN` or `TCS_DEV` by answering `GSEXAM` to the initial question and giving the correct password. You must log in to the appropriate account for the running system (`TCS_LOGIN` for released and `TCS_DEV` for development). Alternatively, log in to a private account on the telescope MicroVAX, select the appropriate set of definitions (`USE_RELEASE` or `USE_DEV`) and type `GSEXAM`. Typing RETURN then selects screen mode. Typed commands will be echoed at the bottom of the screen and output from the program will appear in the upper window.

The program is based on the VAX debugger and its commands are fully documented in the debugger manual. It can be used to set and read any *global variable* in the telescope control system. A full list of these is too extensive to give here (and in any case will change from time to time). Listings of the global-section INCLUDE files should be consulted for a definitive list. Note that PARAMETERs must be specified explicitly when using GSEXAM interactively. Thus although array indices are given in the control-system code and the initialisation file WHT.INI, they must be given explicitly to GSEXAM (*e.g.* ENC_AD_VAL(ENC_K_AL_ABS), the Altitude absolute encoder reading, must be rendered as ENC_AD_VAL(9)). The most useful of GSEXAM's commands are:

- `EXAMINE` Prints out the current value of a variable.
- `EXAMINE/HEX` Prints out the current value of an integer in hexadecimal. Useful for raw data from CAMAC.
- `EVALUATE` works out the value of an arithmetic expression.
- `SHOW SYMBOL` Useful if you cannot remember the name of a variable, as it takes wild cards.

- `DEPOSIT` changes the value of a variable.
- `EXIT` Exit from GSEXAM.

GSEXAM is used primarily to check for hardware failures and to reconfigure the system interactively in the event of a problem. The most important applications are as follows:

- Checking the time service. The variable `SYR_GR_UT` contains raw data read from the time service. It is a structured record with fields:
  - .DATE.DIY day-in-year, starting at January 0.
  - .DATE.NYR last two digits of the year.
  - .TIME.SEC seconds.
  - .TIME.MIN minutes.
  - .TIME.HRS hours.
  - .MSEC milliseconds.
- Raw encoder readings. These are in a record array `SYR_AR_ENC_RAW`. The array index is the encoder number, as follows:
  1. Altitude absolute;
  2. Azimuth absolute;
  3. Cassegrain rotator absolute;
  4. Prime rotator absolute;
  5. GHRIL/cable wrap Nasmyth rotator absolute;
  6. UES/FLEX/drive Nasmyth rotator absolute;
  7. Altitude gear incremental;
  8. Altitude roller incremental;
  9. Azimuth gear incremental;
  10. Azimuth roller incremental;
  11. Cassegrain rotator incremental;
  12. Prime rotator incremental;
  13. GHRIL/cable wrap Nasmyth rotator incremental;
  14. UES/FLEX/drive Nasmyth rotator incremental;
  15. Focus;
  16. Dome;
  17. Shutter;
  18. Windshield.

  Use `EXAMINE/HEX` to look at the .VALUE field, *e.g.* `EXA/HEX SYR_AR_ENC_RAW(9).VALUE`, except for the Altitude and Azimuth absolute encoders, where the coarse and fine parts should be looked at separately with `EXA/HEX SYR_AR_ENC_RAW(1).COARSE` and `.FINE`. These commands should be sufficient to locate broken encoders or to track down stuck bits.
- Temperature sensors. SYR_GR_T_SENSOR.UP_TRUSS_C and _D contain the raw data from the sensors on the GHRIL and UES-side Serrurier trusses, respectively.
- Mirror load cells. SYR_GR_MISC_ADC.AX_LOAD_1, _2 and _3.
- Transducers. These are in the array SYR_AL_TRANS. Those currently in use are:
  - 1–4 Primary mirror displacement transducers.
  - 5 Mercer gauge measuring horizontal displacement of the telescope structure.

- Enabling and disabling encoder corrections. In the event of a failure in the displacement transducer system, it will be necessary to change the variables governing tracking corrections, as follows:
  - The correction to the Azimuth gear encoder for the effects of horizontal translation of the telescope is controlled by ENC_GD_AZ_MULT. This should be set to '−1' to enable the correction or '0' to disable it.
  - The record array ENC_AR_MODEL contains the coefficients for saw-tooth, cosine and look-up table corrections. At present, a saw-tooth correction is used for the 1°.09 Azimuth error. If the sensor correction described above is disabled, then an alternative 0°.40 saw-tooth correction may be introduced. The coefficients required are ENC_AR_MODEL(9).SAW_AMP(1), .SAW_PHASE(1,1), .SAW_PHASE(1,2) and .SAW_PERIOD(1). The last of these should be set to 7.01248361D-3 radians; the values for the others are redetermined periodically and should be listed (with the amplitude commented out) in WHT.INI.
  - A correction is made for the residual tilt of the primary mirror in its cell, using a set of displacement transducers. To disable this, set ENC_GD_TILTSCALE(1) and (2) to zero; to restore it, set both equal to '2'.

B.4 The initialisation file WHT.INI

The file WHT.INI contains initial values for all of the global variables used by the TCS. It is read by GSEXAM during a slow `STARTUP`, and used to create a new version of the image which is installed during a normal (FAST) start. The global sections are defined by a set of INCLUDE files _xxxGSD.INC in the directory with logical name TCS_DEF. All non-zero global variables must be initialised in WHT.INI (logical variables default to .TRUE.). For the purposes of routine maintenance, only a subset of variables are relevant, the most important being pointing coefficients, encoder model parameters, mechanical limits, time and Earth rotation data.

B.5 Routine maintenance of the initialisation file

The following sections list the variables which may have to be altered during normal operation, as a result of instrument changes or secular variations of pointing or Earth-rotation parameters. Other modifications to the file may be required as a result of software or major hardware changes: listings of WHT.INI and the global-section INCLUDE files should be consulted in these cases, which normally require specialist attention.

B.6 Apertures

Default values should be set up for some of the apertures. Those referred to in this manual are apertures 0 (reference position), 1 and 2. Others may be added as necessary. The current allocations are:

- Aperture 0 is the rotator centre, (0,0).
- Aperture 1 is the centre of the off-axis TV camera, roughly (0,−602) arcseconds.
- Aperture 2 is the centre of the FOS slit, roughly (0,8) arcseconds.

The following variables should be set up, where n is the aperture number:

- APE_AR_OFFSET(n).NAME (8-character name);
- APE_AR_OFFSET(n).X (double precision radians);
- APE_AR_OFFSET(n).Y (double precision radians).

B.7 Rotator offset

It is convenient to redefine the zero-point of sky position angle so that position angle 0° is along some natural direction (*e.g.* a spectrograph slit or detector axis). The offset is *subtracted* from the demanded sky position angle before conversion to mount coordinates. The offset is called DIS_GD_SLIT_OFF and is in radians (it should be indexed on focal station—the present value refers to the FOS slit).

B.8 Encoders

B.8.1 General

Each encoder or analogue-to-digital converter has an associated parameter, given in the file TCS_DEF: _ENCDEF.INC. Most of the encoder constants are stored as arrays indexed on these parameters. Any encoder currently in use must have the corresponding element of the LOGICAL array ENC_GB_IN_USE set to .TRUE.

B.8.2 Scaling factors

Encoder scaling factors are stored in the array ENC_AD_FACTOR (double precision, indexed on encoder number), except for the coarse absolute encoders on the main axes. It is unlikely that any of the scaling factors for the gear encoders will have to be changed, as they are determined by simple ratios.

B.8.3 Zero-points

If an encoder is removed from the telescope or remeshed, then it likely that its zero-point will change. The following constants may have to be modified in the initialisation file:

- Absolute encoder ranging constants (integer array ENC_AL_RANGER, indexed on encoder number). These are used to set the zero-points of the 8- and 13-bit absolute encoders and are integers in the range 0–255 and 0–8191, respectively. For Altitude and Azimuth, they refer to the *coarse* (8–bit) parts of the absolute encoders and must be adjusted together with the fine encoder zero-points (see below). For the rotators (13–bit), they are merely used to make sure that the encoders do not go through zero in the relevant range of travel. Separate variables are used to set the exact zero-points.
- Fine absolute encoder zero-points ENC_GD_FINE_ZP (double-precision array (radians) indexed on encoder number). These apply to Altitude and Azimuth (only these axes have dual coarse+fine encoders). Note that these variables should be adjusted so that the pointing coefficients POI_GD_AZZ and POI_GD_EZ are both close to zero.
- Zero-points ENC_AD_ZEROPT (double-precision array, indexed on encoder number). Units are rad (Altitude, Azimuth, rotators, dome, shutters), millimetres (focus) and K (temperatures).

B.8.4 Periodic errors

The following periodicities are expected in the encoder errors for the main axes:

- Roller:
  - Track eccentricity: 360° (altitude and azimuth);
  - Roller eccentricity: 2^{20} bits (31588.67 arcseconds in altitude and 31581.12 arcseconds in azimuth)
- Absolute and gear-driven incremental encoders (altitude and azimuth):
  - Main gear eccentricity: 360°.
  - First gear rotation (896:22): 1 revolution = 31821.4 arcseconds = 8°.839378.
  - First gear tooth: 1 tooth = 1446.4 arcseconds = 0°.4018.
- Gear-driven incremental encoders only (altitude and azimuth):
  - Second gear rotation (170:21): 1 revolution = 3930.88 arcseconds = 1°.0919.
  - Second gear tooth: 1 tooth = 187.18 arcseconds.

Corrections for periodic errors are implemented using the structured record ENC_AR_MODEL. This has room for two saw-tooth functions (phase dependent on the direction of motion), four cosines and a look-up table. The elements are:

- SAW_AMP: amplitudes of the saw-tooth functions;

- SAW_PHASE: phases of the saw-tooth functions (the second element; of the array differentiates between motion with increasing and decreasing encoder reading);
- SAW_PERIOD: periods of the saw-tooth functions;
- COS_AMP: cosine amplitude;
- COS_PHASE: cosine phase;
- COS_PERIOD: cosine period;
- LU_MULT: multiplier to be applied to the look-up table for the encoder.

The corrections may be disabled by setting the amplitudes or multiplier to zero. The units are radians.

B.9 Transducers

This section covers the displacement transducers used to measure the tilt of the primary mirror and motions of the telescope structure.

B.9.1 Radial motion

This refers to the horizontal motion of the entire telescope structure along the line joining the two Azimuth motors, which produces an Azimuth error with the drive tooth period. The relevant variables are:

- Conversion factor from transducer readings to Azimuth errors, ENC_GD_D_TO_AZ (rad/ADU).
- Multiplier for the correction (where '0' ⇒ no correction), ENC_GD_AZ_MULT.

B.9.2 Mirror tilt

There are two ways of deriving the tilt of the primary mirror: from displacement measurements or from the axial load cells. The following variables contain the scaling factors:

- Axial load-cell scales ENC_GD_AXL_SCALE (array, indexed on load cell number, rad/ADU).
- Displacement transducer scales ENC_GD_LVDTSCALE (array, indexed on transducer number, rad/ADU).
- Multipliers for the correction ENC_GD_TILTSCALE(n) ($n = 1$ for Altitude, 2 for Azimuth). 0 ⇒ no correction, 2 ⇒ correction turned on.
- Select between transducers and load cells to derive corrections (.TRUE. ⇒ transducers; .FALSE. ⇒ load cells).

B.10 Limits

It may occasionally be necessary to modify the mechanism limits, for example to reach an object at an elevation below the normal software limit or as a result of a temporary failure. Each mechanism may have the following limits specified (n is the mechanism number, coded as in TCS_DEF:_MECDEF.INC).

- MEC_AR_DAT(n).LIMIT.POS_PLUS (positive position limit);
- MEC_AR_DAT(n).LIMIT.POS_MINUS (negative position limit);
- MEC_AR_DAT(n).LIMIT.ACCEL (acceleration limit);
- MEC_AR_DAT(n).LIMIT.VEL (velocity limit).

Not all of the limits are needed for every mechanism, and some are used only for validation of user input. The necessary limits are as follows:

- Altitude, Azimuth, rotators: all limits are used; the units are rad, rad s^{-1} and rad s^{-2}.
- Focus: position and velocity limits used; the units are millimetres and mm s^{-1}.
- Dome: there are no position limits as such, but the values are used to validate the input from the `DOME` command. There is no acceleration limit and the velocity limit is in output units.
- Shutter, windshield and mirror cover: constant-speed drives with position limits only.

B.11 Zeroset data

This section refers to the hardware zeroset targets, which are currently in place for Altitude, Azimuth and Cassegrain rotator. The variables must be changed if the targets are moved. They are (n is the mechanism number):

- MEC_AR_DAT(n).ZERO.TARGET: target position (rad);
- MEC_AR_DAT(n).ZERO.WINDOW: search window (rad);
- MEC_AR_DAT(n).ZERO.SPEED: search speed (rad s^{-1}).

B.12 Focus–temperature relation

The variable MEC_GF_TEMP2FOC controls the correction of focus position for expansion of the telescope tube. It is the gradient of the relation in mm K^{-1}.

B.13 Default meteorological data

The quantities used in calculating refraction, and their units are:

- Pressure (millibar);
- Outside air temperature (K);
- Relative humidity (0–1);
- Effective wavelength (μm);
- Temperature lapse rate (Km^{-1}).

The variable names for the values assumed on startup (which may be overridden) and the limits used to validate user input are given in Table 8. Seasonal changes should be entered in the initialisation file.

Table 8: *Variable names for meteorological data items*

Quantity	Default	Minimum	Maximum
Pressure	MET_GD_PRESS	MET_GD_MIN_PRESS	MET_GD_MAX_PRESS
Temperature	MET_GD_TEMP_OUT	MET_GD_MIN_TEMP	MET_GD_MAX_TEMP
Humidity	MET_GD_HUMID	MET_GD_MIN_HUMID	MET_GD_MAX_HUMID
Wavelength	MET_GD_WAVEL	MET_GD_MIN_WAVEL	MET_GD_MAX_WAVEL
Lapse rate	MET_GD_TLR		

B.14 Pointing coefficients

The pointing coefficients depend on focal station and are therefore held in arrays indexed by mechanism number. They are all in double-precision radians (the TPOINT analysis package produces results in arcseconds). The coefficients used in the standard William Herschel Telescope model, with the translations between variable names, are shown in Table 9. The format for the harmonic terms is as given in Appendix A, which should be consulted for further details.

B.15 Default focal station

The default focal station is determined by the integer TEL_GL_FOC_STN. This is set equal to the appropriate mechanism number.

Table 9: *Variable names for TPOINT coefficients in the pointing model*

Variable name	TPOINT	Function
POI_GD_AZZ	IA	Azimuth zero-point
POI_GD_EZ	IE	Elevation zero-point
POI_GD_CH	CA	Azimuth collimation error
POI_GD_AX	AX	E–W component of Azimuth axis tilt
POI_GD_AY	AY	N–S component of Azimuth axis tilt
POI_GD_PNP	$NPAE$	Non-perpendicularity of axes
POI_GD_TF	TF	$\cos E$ tube flexure
POI_GD_TX	TX	$\cot E$ tube flexure
POI_GD_Hxcyn	$Hxcyn$	Harmonic terms
POI_GD_NRX	NRX	Nasmyth collimation term in x
POI_GD_NRY	NRY	Nasmyth collimation term in y

B.16 Earth rotation data

The variables which must be adjusted from time to time are as follows:

- The difference between Terrestrial Dynamical Time and UTC, TIM_GD_DELT (days).
- The coefficients of the interpolation formula used to calculate UT1 − UTC and the polar motion correction. These are obtained from the *Bulletin of the Earth Rotation Prediction Service* (ERPS), which is regularly faxed to La Palma. The coefficients are called K(1) – K(14) in the bulletin and TIM_GD_ERPS(1) – TIM_GD_ERPS(14) in the file. The units are identical. The values should be updated at least every month (estimates for the errors of extrapolation are given in the bulletin).
- The date and time of the next leap second, TIM_GD_LEAP_DAY, expressed as a modified Julian date. The time service can be armed to add or subtract a leap second at the correct moment, and this variable is used to warn the control system. The values of TIM_GD_DELT and TIM_GD_ERPS must be adjusted appropriately on the first occasion that the control system is stopped after the leap second. Details are given in the time-service circulars.

B.17 Autoguiding using the television

The following variables may need to be changed from time to time:

- TV scales (TV_GR_PIXEL_SIZE.X and .Y, in radians). These should, in principle, be altered whenever the camera scales are redetermined. In practice, only major changes (*e.g.* involving different optics) are important.
- Loop gains (TV_GR_LOOP_GAIN.XI and .ETA).
- Maximum difference between the demand guiding position and current cursor position in x and y (TV_GL_GUIDE_RAD, integer pixels). No attempt will be made to lock the guiding loop if the difference in either coordinate exceeds this value.
- Maximum guiding offsets (TV_GR_MAX_OFFSET.X and .Y; REAL pixels). These set a threshold to the offset demand in order to prevent the telescope moving so fast that the TV system loses the guide star.

C Fault-finding

C.1 Cannot start the telescope control system

- No response from terminal:
  - Terminal in Hold Screen. Check the Hold Screen lamp on the top row of the keyboard, which should be OFF. If it is not, press the HOLD SCREEN key to release the scrolling.
  - Terminal powered off. Is the lamp lit on the front of the monitor? If not, check the power switch on the back (should be set to "1"), the power lead and the relevant circuit-breakers.
  - Telescope MicroVAX turned off or crashed (try logging in from the system console; check lamps on back panel and power switch on cabinet).
- MicroVAX crashes when control system is started. CAMAC turned off or not initialised. Check that the CAMAC crates are powered up (orange lamp in switch). There are four crates: system (bay 7), Marconi (bay 5) Nasmyth (bay 4) and CLIP (bay 3). If a crate was turned off, then initialize CAMAC:
  - Clear and Zero the system crate by moving the switch on the "PROGRAMMED DATAWAY CONTROLLER" successively to "C" and "Z";
  - Initialize the branch controller (yellow front) by switching from "ON-LINE" to "OFF", flicking the "BRANCH INITIALISE" switch down and letting it spring up again, and then switching back to "ON-LINE".

C.2 Unable to switch into computer mode

All of these errors except the Nasmyth gate alarm are signalled by one or more red lights on the engineering desk.

- Hydraulic support system not turned on or failed.
- Telescope, rotator or cable-wrap drive in a hardware limit or pre-limit. The offending mechanism must be driven out of the limit in engineering mode or (for main axis final limits) by hand (Section 13).
- Mirror support system not turned on or failed (check nitrogen supply).
- Telescope power off.
- Zenith park ties in.
- Nasmyth gate open adjacent to one of the platforms.

C.3 Telescope or rotator will not move in computer mode

- Object below software limit or other illegal position (check information display and user interface). Affects Altitude, Azimuth and rotator drives.
- Computer mode disabled. Affects everything (Information Display will show "ENG MODE" on top-level screen).
- Power amplifiers never turned on or tripped.

C.4 Dome does not rotate in computer mode

- Manual override on.
- "DOME CONTROL" keyswitch on gallery set to "OFF" or "LOCAL" instead of "REMOTE".
- Dome power turned off at Engineering desk.

C.5 Focus does not move in computer mode

- Manual override on.
- Focus drive (FD) power amplifier turned off or tripped.
- Demanded focus position outside software limits (the user interface will complain).

C.6 Failure to open the dome (from gallery)

- Dome power off.
- Shutter or windshield "OFF" or "REMOTE" instead of "LOCAL".
- Shutter or windshield in computer mode (engineering override should be on).
- Torque trip (reset).
- Main drive overtravel (use micro drive to clear).

C.7 Sudden switch to engineering mode

- Nasmyth gate encountered.
- Cassegrain cable-wrap failure (or power-amplifier turned off). Signalled by a cable-wrap pre-limit alarm on the engineering desk. The Cassegrain turntable can drive for a short distance with the cable-wrap disabled.
- Telescope has run into the Azimuth pre-limit or limit because the zone switch has failed. Check by comparing the displayed Azimuth with the known values for the limits (approximately $-180°$ and $360°$, for the positive and negative limits, respectively). Zone- switch failure will cause the Azimuth to be $360°$ out. Override temporarily using the `SET WRAP` command.
- Encoder failure (see Appendix C.10).
- Sudden failure as in Appendix C.2.

C.8 Telescope tracking but nothing visible

- Check whether any light is reaching the TV cameras or other detectors. Increase TV gain and integrate if necessary.
- TV camera or controller not turned on.
- TV camera not reset correctly.
- TV system not turned on, wrong camera selected or silly look-up table (check the camera mini-monitors).
- If trying to observe a bright star, move it on to an alternative detector (*e.g.* the off-axis guide camera, using `APERTURE 1`).
- Is the telescope grossly out of focus?
- Check for cloud.
- Decide on the basis of these tests whether the light path is blocked or the telescope pointing has failed.

C.9 No light

- Primary cover closed.
- Nasmyth flat in the wrong place (incorrect focal station selected or flat stuck). If it is stuck, move the telescope to the zenith and repeat the move. May get some light in this case, depending on conditions.
- Dome closed or windshield not fully lowered.

- Dome not tracking (*e.g.* on manual override). Compare dome and telescope Azimuths on Information Display and/or go and look.
- Comparison system left in FOS (light should be visible through the off-axis camera).

C.10 Bad pointing

- Check for errors in position first and slew to one of the pointing standards to confirm that there is a problem.
- Silly reference position as a result of an incorrect use of `DEFINE APERTURE 0` or `STORE APERTURE 0`.
- Silly results from `CALIBRATE`. Was the rms reasonable? Did you centre all of the stars properly? If not, use `CALIBRATE/DEFAULT` to restore the default coefficients and check again.
- Wrong reference position used for `CALIBRATE`.
- Encoders broken. Go to page 2 of the Information Display using the `PAGE` command. Check that the ABSOLUTE and GEAR INCREMENTAL encoders are consistent in Altitude and Azimuth.
  - If the absolute encoder is updating, but the incremental encoder is not, put the system into engineering mode immediately by typing `ENGINEERING` or pressing the COMP/ENG button on the engineering desk. The system cannot function without an incremental encoder and the telescope may run into a limit.
  - If the incremental encoder is updating, but the absolute is not, or is changing sporadically, then the zero-point for the axis in question is likely to be wrong. This can be repaired using the `ZEROSET` command. Use `ZEROSET <mechanism> TO <position>` using a value from the synchro or switch to engineering mode, type `ZEROSET <mechanism> TARGET MANUAL` and drive past the target point to trigger a hardware zeroset.
  - A frequent fault is a blown bulb on an absolute encoder. These have two independent sections, "coarse" and "fine". To determine which has failed, use the GSEXAM interface to `EXAMINE/HEX SYR_AR_ENC_RAW(`*n*`).COARSE` and `EXAMINE/HEX SYR_AR_ENC_RAW(`*n*`).FINE` (each several times when the telescope is moving), where $n = 1$ for Altitude and 2 for Azimuth. A blown bulb causes one of the COARSE or FINE variables to stop updating.

C.11 Bad tracking

- Telescope tracking with an offset in Azimuth (large, but fairly constant position error). Check whether the telescope is close to the zenith blind spot and is travelling at very high speed. No cure, other than to wait for the object to transit.
- Oscillations in Azimuth at 0.5–2 Hz with an amplitude of about 0.1–0.2 arcseconds on the sky. Azimuth servo problem. Under investigation, but please log particularly severe occurrences.
- 1 Hz oscillation in Right Ascension (check carefully to distinguish this from Azimuth). Time service synchronization problem.
- Motion in Azimuth with a period of $0^\circ.4$. Residual gear error. May indicate a problem with sensor electronics.
- Apparent oscillation of an integrated image on the TV, by one line in the y direction, alternate frames being displaced '+' and '−'. This is an artefact of the TV readout. Guiding errors sent to the telescope computer are corrected appropriately. Ignore.
- Brief glitch of 5–10 arcseconds in Azimuth. Known problem which is under investigation. Please log.
- Drifts. Possible causes:
  - Telescope has stopped. Software limit or switch to engineering mode (see above).
  - Zenith blind spot.
  - Large error in encoder zero-points. Check pointing, which should also be way off.

C.12 Handset problems

- Directions of motion reversed in X_Y mode. Check positions of TV scan switches against dymo labels.

C.13 TV system

- Camera will not turn on: controller turned off.
- Camera apparently turns on when the black button is pressed but no images appear: check that yellow reset light. If it remains on after 10 seconds, check that the gain control is in its clicked-off position—the camera will not reset otherwise.
- No response from keyboard. Terminal in keypad mode (keypad should function correctly) or hold screen (lamp will be lit) or system not running.
- System does not understand typed commands and responds with ?'s. Commands must be typed in upper case. Also, beware that the cursor is positioned at the end of a line after an error message, so you must either backspace to the beginning of a line or hit RETURN twice to clear the junk.
- Image visible on mini-monitor but not on TV system display. Check that the correct camera is selected and that the look-up table is sensible.
- Garbage is printed out in response to any of the help commands. Type `MEND-HELP` to restore the help screens, which have been overwritten.
- Overlays disappear on exit from GUIDE or I-GUIDE modes. Type `OVERLAY` to restore them.

D Listings of system catalogues

D.1 General

The system catalogue contains positions for astrometric, photometric and spectrophotometric standard stars visible from La Palma, together with centre positions for fields suitable for photometric or geometric calibration of imaging detectors and for flat-fielding. It is searched automatically if no object of a given name is found in the user catalogue. The following sections give brief descriptions of the contents of the catalogue. Tables of positions, magnitudes and other useful information are given at the end of the manual.

D.2 Astrometric standards

The system catalogue contains a grid of stars selected from the FK5 catalogue for use in determining telescope pointing (in full tests and the `CALIBRATE` routine). They all have very accurate positions and proper motions. There is a basic grid for the whole sky together with extra stars within 2 degrees of the zenith to improve calculations for an Altazimuth telescope. The extra stars are called ZENnn. The grid star names begin with either 'S' or 'N' indicating whether they pass North or South of the zenith at La Palma in the year 2000. The grid stars were selected at approximately 1 hour intervals in right ascension and 15 degrees in declination, with alternate hour zones offset in declination. Each right ascension zone with a star near $+30°$ has two stars selected, one North and the other South of the zenith. The names have the format N$\alpha\alpha$+$\delta\delta$ or S$\alpha\alpha \pm \delta\delta$, where $\alpha\alpha$ is the Right Ascension (hours) and $\pm\delta\delta$ is the declination (degrees), *e.g.* N01+37, S20-45.

Table 5 is a schematic of the grid layout, for use in selecting stars for pointing tests. This appendix gives a detailed listing of the positional data for those stars, with the following column layout:

1. Name. This indicates the position on the grid.
2. Right Ascension
3. Declination
4. Proper Motions in Right Ascension and Declination.
5. Parallax
6. Radial Velocity
7. Approximate visual magnitude
8. Spectral type

All positions refer to equinox and epoch J2000.

D.3 Spectrophotometric standards

This section of the catalogue contains spectrophotometric standard stars from a variety of sources. The columns of the table are:

1. Common name. This is *not* the name understood by the control system, which is given under '`WHT_Name`' (see below). This is done because of the wide variety of naming conventions and for these stars, some of which are impossible to generate at a keyboard.
2. Eggen-Greenstein (EG) number. Beware of aliases, some of which are given in the notes.
3. Right Ascension
4. Declination
5. Proper motions
6. Monochromatic magnitude at 5556 Å, m_{5556}.
7. Spectral type
8. WHT name, *i.e.* the name by which the star is known to the control system.
9. Notes and references.

The positions are referred to Equinox and Epoch B1950. It is unlikely that any of the unknown (blank) proper motions are large.

References

Oke, J.B., 1974. *Astrophys. J. Suppl. Ser.*, **27**, 21.
Stone, R.P.S., 1977. *Astrophys. J.*, **218**, 767.
Filipenko, A.V. & Greenstein, J.L., 1984. *Publ. astr. Soc. Pac.*, **96**, 530.

D.4 Photometric standards

These are the equatorial standards observed by A. U. Landolt, 1983, *Astron. J.,* **88**, 439. The U, B and V magnitudes are on the Johnson system, whereas R and I are on the Kron Cousins system. The column layout of the table is:

1 Common name. Again, this is *not* the name used by the control system.
2 Right Ascension
3 Declination
4 Proper motions
5–14 Magnitudes and colours
15 WHT name, as known to the control system.
All positions are referred to Equinox and Epoch B1950.

D.5 Photometric sequences

The catalogue contains a number of photometric sequences for CCD observations. The coordinates refer to the frame centre.

References

Christian, C. A., Adams, M., Barnes, J. V., Butcher, H., Hayes, D. S., Mould, J. R. & Siegel, M., 1985. *Publ. astron. Soc. Pacif.*, **97**, 363.
Schild, R. E., 1983. *Publ. astron Soc. Pacif.*, **95**, 1021.
Stobie, R. S., Sagar, R. & Gilmore, G., 1985. *Astron. Astrophys. Suppl. Ser.*, **60**, 503.

The columns are:

1. Name (as known to the control system).
2. Right Ascension
3. Declination
4. V magnitude of brightest star in sequence
5. V magnitude of faintest star in sequence
6. Bands for which photometry is available.

All positions are referred to Equinox B1950.

D.6 Blank fields

These are fields with a paucity of bright stars. They are useful for flat fields, especially if the sky is dark.

References

Christian, C.A., *et al.*, 1985. *P.A.S.P.*, **97**, 363.
Users' Manual for the CCD Camera on the 0.9m telescope, KPNO.

Table format:

1. Name
2. Right Ascension
3. Declination

All positions are referred to Equinox B1950.

D.7 Fields for geometrical calibration

These are intended for geometrical calibration of detectors such as TV cameras, which suffer from distortion, and guide probes.

Table format:

1. Name, in the form Field.star_number
2. Right Ascension
3. Declination

All positions are referred to Equinox B1950.