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THE LICK TV AUTOGUIDER

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THE LICK TV AUTOGUIDER

The use of television acquisition and guide equipment for telescope operation is now commonplace. For guiding a telescope, it is customary to observe starlight on the edges of a spectrograph slit, or to guide by comparing a marker on the TV screen with the position of a guide star. The person who must sit for hours making tiny adjustments of the telescope position has a difficult problem in detecting the small errors that must be corrected, to say nothing of the difficulty of staying awake.

McKenna has demonstrated that the electronic signals making up the TV image can be used to automatically guide the telescope, with a significant increase in guiding accuracy. His tests were done using a breadboarded system to prove that auto-guiding from the TV signal was feasible. He also demonstrated that signal level to the spectrograph could be significantly improved when an autoguider replaced an experienced human operator.

This report describes a microprocessor-controlled general purpose auto-guider that should be usable on almost any telescope equipped with a TV camera. The main purpose of the equipment is for guiding a television equipped optical telescope, but in principle the equipment could be used for automating any positioning operation where a TV image is available. The Lick Telescope Controller, "TELCO," accepts signals from the guider and combines these with field rotation and other data to adjust the telescope position.

This report includes a brief description of the theory of operation of the guider, followed by instructions for its use. The remainder of the report will be of concern mostly for those who may wish to maintain the equipment, or to add additional capabilities through augmentation of the software.

QUICK LOOK USER'S GUIDE

Users are advised to read the detailed Operating Instructions before attempting to use the Auto Guider (see Page 6 and Page 7). However, this page may help in remembering how to use the system.

1. Connect RBON from TV controller and ACIA from TELCO.

2. Connect video from TV memory to the Auto Guider, from Auto Guider to Cross Generator, and thence to Monitor. If the Auto Guider performance is turned off, the video will not reach the monitor.

3. Set TELCO digit switch to 13 if a diagnostic display of the Auto Guider performance is desired. (This is not necessary for guiding.)

4. Set Auto Guider Digit Switch to ZERO, Diagnostic Switch to NORMAL, set Function to LOCK, set sensitivity low (CCW), set Averaging Time low (CCW). Set Guide Enable switch to INITIALIZE. Set Auto/Manual switch to Manual.

5. Adjust size, position and separation of Left and Right Guide Reticles to be about 50% bigger than the spectrograph slit if guiding is to be from the slit. Position Left reticle over the left slit and Right reticle over the right slit.

6. Move the Background reticles to a place where no unusual bright or dark patches exist.

7. When a star is at its desired position, center the guide reticle over it and set the switch to Guide Enable. If automatic slit switching is in use, set the Auto/Manual switch to Auto.

8. If the frame sum integration mode is used on the TV camera, it is fine to sum several frames for setting up the star, but for automatic guiding, the frame sum count should be set to 1. Otherwise, the guider is guiding on outdated information.

9. The sensitivity pot can be turned clockwise for more sensitivity, but if turned too far, the telescope may hunt back and forth across the star.

10. The Averaging time is automatically increased to at least two TV integration intervals. If the telescope is tracking well, a longer averaging time may improve the guiding. The AVRG TIME light flashes once for each averaging time completed.

11. Whenever the joystick is used to center the star, the guider starts using the new position so long as the star is still fairly well centered in the reticle. Otherwise, it would be necessary to switch to INITIALIZE and readjust the reticle position.

THEORY OF OPERATION

INTRODUCTION

The autoguider is designed to make use of the electronic signals that make a picture on a video monitor. It adds up and digitizes the signal in small selected areas and, by comparing the integrated signal level under four quadrants of a guide marker or "reticle," it generates error signals that can be used to move the telescope in order to recenter the image.

The equipment is designed to provide small corrections at low rate, perhaps once per second or slower, to a system that is tracking fairly well. Although an error signal could be generated easily for each TV frame, i.e., 30 cycles per second, this is quite unnecessary and indeed undesirable for guiding an astronomical telescope. The noisiness of the TV signal from the guide camera also limits the useable speed of response.

The resolution of the TV system is only 256 lines in the vertical direction, and the camera frequency response gives a similar limit on horizontal resolution. However, by looking for <u>changes</u> in the image position, considerably more precision is possible, provided the image covers several resolution elements. Long-term accuracy depends on the stability of alignment of the TV camera with the telescope image, and also depends on the camera beam deflection circuitry being stable. Tests by McKenna and others indicate that the camera stability is adequate, at least at the 120-inch telescope.

The signal that would normally go to the TV monitor is daisy-chained through the guider first. The guider adds dark reticle markers to the picture, and measures the signal amplitude under the reticle. Guide and background reticles are provided, as well as two reticles that can be used to measure seeing. The guide reticle consists of 4 individual quadrants, while the seeing reticle only has 2 of the 4 quadrants displayed. The size, position, and quadrant separation of the reticles can be adjusted by the joystick. The reticle intensity can be adjusted without changing the sensitivity of the guider.

Guiding signals are generated by comparing the signal levels in the 4 quadrants of a reticle after the corresponding background reticle is subtracted. If the background signal is bigger than the guide signal, no guiding occurs. The results from successive frames are averaged to produce a low-noise guide signal. The averaging time between guide signals is controlled by a potentiometer, while a second potentiometer sets a divisor which essentially determines the sensitivity, i.e., the size, of the guide signal for a given error signal. The potentiometer and the joystick settings are digitized in an 8 bit ADC and used by the microprocessor. (Note that TELCO uses the background signal for a baseline, but does not subtract it from the guide reticle.)

Two sets of reticles are stored that can be positioned to correspond with the left and right spectrograph slit positions. Sizes and quadrant separations are maintained identical for both left and right reticles, so that an adjustment of, say, the left-side guide reticle size will also adjust the size of the right-side guide reticle. Background size and separation are also kept the same as the guide size and separation.

The reticles are generated by opening electronic gates at preset times during the video frame. The vertical position is controlled by the microprocessor which sets a delay at the end of the video vertical blanking, and then counts lines to determine vertical size and separation. The horizontal positions are set by delay times loaded into digitial counters that count down an 8MHz oscillator for each line of the picture.

On each frame, the signals under four quadrants of the reticle are integrated in four sample and hold analog amplifiers. At the end of each frame, the four analog signals are digitized and the result added to appropriate registers by the microprocessor. Different reticles are generated on successive frames, with the digitized results being added to corresponding registers, so that an averaged background can be subtracted from an averaged guide signal, with the differences between the four quadrants being used to generate an error signal to the telescope controller.

Guide information is computed by the guider and pulses "UP DOWN LEFT RIGHT" are generated, whose length in time is proportional to the error. However, field rotation at the coudé and at the Cassegrain requires a trigonometric computation before the signals can be used to guide the telescope. This calculation could be done in the guider but has instead been done by the telescope controller "TELCO," which has the arithmetic hardware to deal with it, and also knows the correct rotation angle. Raw data consisting of sums of reticle readings for an averaging time, plus the frame count, switch positions, etc., are fed to TELCO on the ACIA serial link. In early experiments, the PET computer was used as an intermediary, programmed in BASIC and carrying out the field rotation calculations. Because BASIC is very slow, the use of the PET added several seconds of delay to the control loop. It also made it awkward to use the PET for other necessary tasks. For these reasons the rotation, gain and diagnostic displays were written in assembly language and placed in the TELCO.

OPERATING INSTRUCTIONS - TV AUTOGUIDER

The Autoguider can only operate when it is receiving a video signal. Guide signals are only generated after the RBON signal goes high. (It goes high if the RBON co-ax link is disconnected, or whenever a TV frame is read from the camera.)

Connect the video signal from the TV memory to the Autoguider "Video IN" and from the Autoguider "Video OUT" to the TV monitor (via the cross generator).

Connect the RBON signal from the TV memory to the Autoguider "RBON" connector.

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1. Turn on power to the Guider. Set menu switch to 0. Set Digit switch to zero. Set Guide Enable switch to INITIALIZE.

   The LED display first will run through all possible combinations to prove that the lamps work. If a hardware error is detected, the address of the offending component will be flashed continuously. Otherwise, dark reticle marks should appear on the TV monitor; if not, check error lights for NO TV SYNC. The intensity of the marks can be adjusted without affecting the guide sensitivity.

2. Select left or right reticles by setting the auto/manual switch to manual and the left/right switch appropriately. Use the joystick to adjust the position of guide and background reticles for both left and right slits. Adjust size and separation appropriately for the guide object selected. Set the average time pot to low (CCW) limit. Set sensitivity pot low (CCW).

3. Adjust sensitivity and averaging time to obtain a satisfactory guide signal, when guiding starts.

4. When ready to guide, set the guide enable switch UP to instruct TELCO to accept guide signals. Set TELCO "display select" switch to 13 to get a diagnostic display.

5. The left or right guide reticle can be selected manually, or will be set by TELCO if the auto left/right switch is set to AUTO.

   See Page for a more detailed set of instructions.

6. If the guider is moved to a different TV camera, the video baseline may require adjustment. (This is best done by an electronics tech, using an oscilloscope.) The clearest indication that the baseline needs adjustment would be if the Background values shown by the TELCO display are above 60, or at zero. Misadjustment of the baseline can lead to failure to guide on faint objects, or saturation of the analog-to-digital comverters for bright sky.

To do the adjustment, turn TV camera on, set guide enable switch to ENABLE, then turn on the TV guider power. (This inhibits the automatic baseline adjust, which would make manual adjustments difficult.)

After the INITIALIZE Led starts to blink, examine the signal at card A3 pin M. First, adjust the rear on-board potentiometers (R1-EL919) so that the sync pulses have an amplitude of about 150 mVolts. Then adjust the front on-board potentiometer (R2) until the videl level (with no light to the TV camera) is about 150 mVolts.

The guide enable switch now can be set to INITIALIZE. This is all on the microprocessor to adjust the baseline. Some small changes of the baseline level at pin M, card A3 may be observed as the noisy video signal is tested by the microprocessor. The baseline may also automatically adjust when the reticle size is changed.

SEEING DISPLAY

A rudimentary test for seeing has been included. This measures the distance from the center of the star to a half-intensity point. To use it, place the left hand side of the seeing reticle on the center of a star. The right side of the reticle will move until the signal it sees is half as bright as the center. (The seeing-background reticle must be in an area of uniform sky.) This measurement is limited to situations where the star image is big enough to cover several lines on the TV. The spacing measured is shown on the "seeing" LED in hexadecimal numbers.

The seeing background signal is subtracted from the "seeing" signals, and a badly chosen position for the seeing background reticle will affect the result. A code "FF" is flashed if ever the seeing background is larger than the seeing signal.

The seeing display LEDs are also used for diagnostic information. When the baseline is being automatically adjusted, code nB will flash, where n--(0--7) is the baseline setting.

DIAGNOSTIC INDICATIONS

Front panel LED displays allow the user or maintenance technician to detect most operating problems. Note that the Menu Switch should normally be in position 0. If it is set to the diagnostic mode, the error indicator lamps are used for data display rather than error display. The error display register can be erased by pressing the ERROR RESET button.

LED display meaning:

ACIA ERROR	An error was detected in the link to the PET microcomputer.
NO TV SYNC	No video signal is being detected. Check that video cables are connected, and that camera is turned on.
INITIALIZE	Set guide enable switch down, and adjust the reticles for left and right slits. Press "ZERO JOYSTICK."
GAIN/4	The video signal is so large that the internal gain has been reduced to accommodate it.
RBON LOW	The RBON signal is connected but is always at ground level. The guider will work with RBON disconnected, but does not know if camera is integrating or not, so that it may produce more than one guide command for a single frame of data.
BG ABOVE SIG	Background reticle is on a brighter area than the guide reticle. Guiding continues but adjustment for varying camera sensitivity is not done.
SIG TOO BIG	The video signal is so bright it saturates the ADC. If signal cannot be reduced, guider amplifier will have to be changed for lower gain. There is a baseline adjustment on the video input card, that should be used with caution. (It must be adjusted with the aid of an oscilloscope.)
AVRG TIME	Flashes once each time a set of frames is sent to TELCO. Period is controlled by the average TIME potentiometer.

Codes flashed on the SEEING display may be of interest: "nB" - Baseline level set to n. (n=0--7)

DIAGNOSTIC PROCEDURES

Microprocessor systems have many critical states stored in memory registers that are inaccessible to an oscilloscope probe. To avoid the need for complex test equipment or a development system for routine diagnotic tests, a self-checking program was included in the autoguider. This allows the content of any memory location, including input/output ports, to be displayed continuously. Such a display is particularly valuable when evaluating the effect of software modification, but is also important if the equipment should behave in any unexpected way.

An additional test program allows a check that all the front panel switches are correctly wired and operating properly.

In addition, an initial test program will check that all EPROMs are in place, that checksums stored agree with those measured, and that RAM memory and port chips work properly.

Initial Tests

When power is first applied, the program starts by testing all the hardware it can. The 8 vertical LED lamps and the 2 byte "SEEING" LED are made to count through all possible combinations, to prove they are working. Next, the RAM memories in pages 0 and 1 on the microprocessor card are tested. Then checksums in all the EPROM are tested, as well as checking that each EPROM is plugged in at its proper address. Then the RAM memory in the port cards is tested, and finally the ability to set and read the port registers is checked.

If no errors are found, the TV guide program starts. If an error is found, the lamps will be clocked through codes 00, 11, 22, 33 -- FF, and the memory address at which an error was found will be displayed, most significant byte in the SEEING LEDs, lower byte in the 8 indicator LEDS where the top lamp displays "80" and the bottom lamp displays "1". The SEEING LED will blink the complement of the error address every second or so. An EPROM in the wrong address will result in all "1s" in the 8 display LEDs.

If you wish to try and continue in spite of an error, push the "ERROR RESET" button for a second or so.

TV GUIDER DIAGNOSTICS

Front panel LED display allows potentiometers, joystick, switches, and contents of memory to be tested.

a) Using Digit switch and the Menu switch, the joystick potentiometers and other switches can be displayed on the 8 light Error Display.

Switch Tested	'Menu' Switch Setting	Digit Switch Setting	Readout Lamps (OFF for true)
Menu, Move	X	13	
Joystick X	0	15	Binary Codes: ADC output 2^0–2^7
Joystick Y	1	15	
Averaging Time Pot	0	14	
Sensitivity Pot	1	14	
Zero Joystick	2	14	"ACIA Error"
Auto Center	2	14	"No TV Sync"
Change	2	14	"Initialize"
Man/Auto	2	14	"Gain 14"
Guide Enable	2	14	"RBON Low"
Left/Right	2	14	"BG Above Signal"
Error Reset	2	14	"Signal Too Big"
Function	2	15	"AVRG Time"

b) Display of Memory Contents

If the Menu Switch is set to 3, ('Diagnostics'), then a memory address will be displayed in the Seeing Display LEDs and the data in that byte will be displayed in the eight error display lights. The upper or lower byte of the address will be displayed depending on whether the left/right switch is set to left or right, respectively.

The 4 hexadecimal digits of the address are shifted left each time the "Change" switch is pressed, with the new lowest precision digit being copied from the Digit switch. The address is incremented each time the "Auto Center" switch is pressed and decremented each time the "Zero Joystick" is pressed.

This feature allows the contents of specific registers to be checked during actual operation. It is much easier to use than the description would indicate.

TV GUIDER TO TELCO COMMUNICATION

The TV Guider loads an "output buffer" which is read by TELCO, and the TELCO loads an "input buffer" that can tell the TV Guider what to do.

OUTPUT BUFFER Byte #		Meaning	INPUT BUFFER Byte #		Meaning
0		New Input Buffer	0		
1		"FF" = Data Ready	1		Data Taken = 11 ; INIT = 67
2		Signed Horizontal guide	2		Side Select: 0 = right, 80 = left
3		Signed Vertical guide	3		
4		Sensitivity Pot.	4		
5		Averaging Time Pot.	5		
6		Seeing Measurement	6		
7		Guide Enable Switch, etc. Guide = 10 : Man = 20 LEFT = 40 DIGIT = 0--F BAD BASELINE = 80	7		Change Positions if = $(99)_{16}$ = $(153)_{10}$
8,9	8,9	Horizontal Position : 1	8		Horizontal Position Guide : 1
10	A,B	Vertical Position	10	A	Vertical Position Guide
12	C,D	Horizontal Position : 2	12	C	Horizontal Position BG : 2
14	E,F	Vertical Position	14	E	Vertical Position Guide
16	10	Horizontal Position : 3	16	10	Horizontal Position Seeing: 3
18	12	Vertical Position	18	12	Vertical Position Seeing
20	14	Horizontal Position : 4	20	14	Horizontal Position Seeing BG : 4
22	16	Vertical Position	22	16	Vertical Position Seeing
24	18	Guide Frame Count			
26	1A	BG Frame Count			
28	1C	Seeing Frame Count			
30	1E	Seeing BG Frame Count			

20-27 Guide
28-2F Guide BG
30-37 Seeing
38-3F Seeing BG

} 4 16 Bit sums for each

1	2
3	4

} order

RETICLE AND DATA TABLES

Two sets of 4 reticles for right and left side are stored at locations 9000 to 907F and 9080 to 90FF respectively.

Each set of 4 reticles uses 4 $(20)_{16}$ word tables to hold data for Guide, Guide background, Seeing and Seeing background. Table meaning is determined by its location.

Location	Function
9000, 9080	Guide
9020, 90A0	Guide BG
9040, 90C0	Seeing
9060, 90E0	Seeing BG

Byte allocation for each 20 word table:

0,1	Horizontal position		
2,3	Horizontal size		
4,5	Horizontal separation		
6,7	Vertical position -		
8,9	Vertical size		
A,B	Vertical separation - (unused for Seeing)		
C	Vertical Sync Adjust.		
D,E,F	Unused		
10	LS	Upper Left	ADC SUMS (16 bit)
11	MS		
12	LS	Upper Right	
13	MS		
14	LS	Lower Left	
15	MS		
16	LS	Lower Right	
17	MS		
18	Cycle counter for averaging		
19	Upper Left		ADC AVERAGES (8 bit)
1A	Upper Right		
1B	Lower Left		
1C	Lower Right		
1D			
1E			
1F	GAIN CONTROL "GAINSV"		

IMPORTANT VARIABLES

Name	Address	Function
NUDATA	90	Set to 1 whenever new data accepted
BEAMTS	94	Set to 1 whenever BEAM-ON is seen.
HZero	AF	JOYSTICK Zero readings
VZero	B0	JOYSTICK Zero readings
HGUIDL	B3, B4	Horizontal Error Buffer (Signed)
VGUIDL	B5, B6	Vertical Error Buffer (Signed)
HSIGN	B7	Sign of Guide signals
VSIGN	B8	Sign of Guide signals
HGO	B9	Normalized (unsigned) guide amplitude
VGO	BA	Normalized (unsigned) guide amplitude
AVTIM2	C6	Time used for one guide measurement
	9000,1	Horizontal Position — Right Side Guide Reticle
	9002,3	Horizontal Size — Right Side Guide Reticle
	9004,5	Horizontal Separation — Right Side Guide Reticle
	9006,7	Vertical Position — Right Side Guide Reticle
	9008,9	Vertical Size — Right Side Guide Reticle
	900A,B	Vertical Separation — Right Side Guide Reticle
	9010,11	Upper left — Right Side Guide Data 16 bit sums
	9012,13	Upper right — Right Side Guide Data 16 bit sums
	9014,15	Lower left — Right Side Guide Data 16 bit sums
	9016,17	Lower right — Right Side Guide Data 16 bit sums
	9019	Upper left — Right Side Guide Data 8 bit averages
	901A	Upper right — Right Side Guide Data 8 bit averages
	901B	Lower left — Right Side Guide Data 8 bit averages
	901C	Lower right — Right Side Guide Data 8 bit averages

Checking contents of these variables with the diagnostic tests should aid in evaluating the behaviour of the guider.

TIMSUM	0001--0020	raw 16 bit sums for TELCO
SUMCNT	21--28	16 bit frame counts for TELCO
DIFTAB	BC--C3	Table of 8 bit differences guide - BG seeing - BG

TV GUIDER PROGRAM

The microprocessor program is stored in EPROM at location 8000-8FFF and at 400 -- BFF. It consists of several major subsections:

(NOTE: That an index of tagged locations is given at end of program listing)

POWRUX	Tests EPROM, RAM and ports (see Program "K4")
RESET	Initializes variables and ports
LOOPER	Runs with interrupt enabled; calls various updating routines
RETSET	Allows joystick to adjust the reticles
SEEDO	Calculates and transmits guide signals, when new average done
INTEX	Responds to interrupts from vertical sync and reticle timer
TESTEX	Allows test of front panel switches, LEDS, and potentiometers
DIADIX	Displays content of selected memory locations for diagnosis
VRINIX	Initializes a TV frame, selects correct reticle for the frame
IRQINX	Checks Interrupt flags
TIMED1	Generates the reticle, checks for TV sync
BUFADD	Adds new data to sum tables, checks guide response, adjust basline
ACSRVC	Looks after ACIA interface to the PET
ATOCEX	Auto centering loop

The program uses a set of 8 32 word tables to store the position of and resultant data for 8 four quadrant reticles. Data are located by position in these tables. The first four tables are allocated to the right side reticles and the second four to the left side reticles.

Program Operating Sequence

The program runs in a loop at "LOOPER," with interrupt enabled. When an interrupt from the TV vertical flyback is seen, the parameters of the reticle chosen for the next frame are pulled from the table. The horizontal delay circuits are loaded. At the end of the vertical blanking signal, a programmable delay circuit is triggered that will interrupt two lines before the top of the chosen reticle. When the interrupt occurs, a short programmed delay ensues to insure that the reticle timing cannot jitter between two lines. Then (1) the "vertical gates" are loaded, and the number of lines corresponding to the vertical width are counted. The vertical gates are closed, and a number of lines corresponding to the vertical separation are counted, after which (1) is repeated. For the two "seeing" reticles, the last step is omitted. Charge accumulates in the sample and hold amplifiers during the time the reticles are turned on.

After the reticles have finished, the analog voltages held in the four sample and hold amplifiers are digitized and added by "BUFADD" to the raw data sums in TIMSUM and to the data sum register in the table corresponding to the reticle that was just displayed. If 8 such cycles have occurred for a table, the results are divided by 8 and stored as averages, also in the same table. Whenever this occurs for the guide reticle table, a flag byte called NUDATA is set to 1, indicating that valid guide data is available.

All this occurs during each frame with the interrupt disabled. When complete, the interrupt is re-enabled and the program at LOOPER continues.

The program at LOOPER watches for NUDATA=1 and when seen, the differences between guide table and background table averages are added to 2 two-byte registers HGUIDL and VGUIDL, which are used after a number of cycles, determined by the Averaging time potentiometer, to generate an error signal (normalized by a reading from the sensitivity potentiometer) and stored in single byte registers HGO and VGO, with signs in HSIGN and VSIGN. The error signals are loaded into I/O ports to light the UP, DOWN, LEFT, RIGHT lights for a time proportional to the size of the normalized error. Actual signal quantities are transmitted to TELCO using an ACIA serial link.

When an integration time is completed, the AVRG TIME LED is flashed, and data in TIMSUM, SUMCNT, switch settings and potentiometer readings are copied to a 64 byte table at MSHOLD. The flag "MSWAIT" is set to 1 and TIMSUM, SUMCNT data are erased. (Background is divided by 4 rather than being fully erased, to improve noise performance.) LOOPER detects MSWAIT non-zero, and copies the MSHOLD table into the ACIA output table at MSGOUT as soon as the ACIA is free.

Several flow diagrams of portions of the program have been prepared. These are labelled in various places with names such as SEEDO. To locate the coding that corresponds to a portion of the flow diagram, look up the name in the alphabetical listing at the end of the program. This gives the actual address of the item in the program listing.

The source code for this program is held on floppy disc and DECtape under the name TV Autoguider. It is assembled by the Sierra Digital System X6502 cross-assembler on the PDP 8 running under the OS/8 monitor.

The Autoguiding Algorithm In the Telescope Controller

The autoguider keeps an object centered in the field by sensing an error in position and translating this error into a guide motion of the proper direction and magnitude to correct the error. This process involves five basic stages:

1. Measuring the object signal in each of the four quadrants.

2. Calculating the error signal (horizontal and vertical).

3. Converting the error signal into a distance to move the telescope.

4. Compensating for changes in object brightness.

5. Compensating for rotation of the object field.

This section will discuss each of these stages, from both an operational and computational stand point.

1. MEASURING THE OBJECT SIGNAL IN EACH OF THE FOUR QUADRANTS.

The light from the guide object is picked up by a television camera, which converts the light into a video signal. The portion of that video signal corresponding to each quadrant of the guide reticle is integrated by a sample and hold analogue amplifier, and then converted to an 8-bit integer by an analogue to digital converter (ADC).

In this process of collection and conversion, a non-zero baseline is added to the data because of various limitations in the electronic circuitry. Thus, even when the camera is looking at blank sky, which should correspond to a zero signal level from the object, the ADC reading will be non-zero. This non-zero baseline needs to be measured and subtracted out in order to obtain the actual object signal level.

The guide reticle is divided into four quadrants, and the high speed of the video signal requires that each quadrant be measured by a separate amplifier. Unfortunately, the zero levels (or baselines) of these amplifiers are not the same. If the reticle were positioned on a uniformly illuminated field, the digitized signals from the four quadrants of the reticle would be non-uniform, resulting in a spurious error signal. Thus, some mechanism is needed to compensate for these baseline differences.

This was the initial motivation for the background reticle. Each quadrant of the background reticle is measured using the same amplifier as is used to measure the corresponding quadrant of the guide reticle. If the background reticle were positioned on blank sky (i.e., a zero-level image), then subtracting the quadrants of the background reticle from the corresponding quadrants of the guide reticle should correct for the differing zero levels of the four amplifiers.

Unfortunately, due to non-uniformities in the response of the television camera over different areas of the field, it was not possible to present the background reticle with a true zero-level image. Thus, subtracting the background reticle from the guide reticle did not correctly compensate for the zero level differences between the amplifiers. In fact, tests indicated that the subtraction of the background increased the noise in the error signal.

The solution to this problem was to reference the guide reticle to itself, rather than to the background reticle. This is accomplished by recording the signal level in each quadrant of the guide reticle at the instant when the star is correctly positioned for observing. This reference level is then subtracted from subsequent integrations of the guide reticle to compensate for the zero level differences between the amplifiers.

This scheme requires the observer to indicate when the star is correctly positioned so that the reference level can be recorded. The observer can do this in a number of different ways. First, whenever the GUIDE ENABLE switch on the front panel of the guider is in the DISABLED (INITIALIZE) state, then the reference level is constantly updated with each new integration of the guide reticle.

Second, when the GUIDE ENABLE switch is in the ENABLED state, any telescope motion resulting from slewing, setting, or guiding will cause the reference level to be remeasured upon completion of the motion. Thus, an observer can request remeasurement of the reference level simply by recentering the star using the telescope controller's joystick.

Just as there are two sets of reticles, one for the left slit and one for the right, there are two sets of reference levels. When the left-slit reticle is selected, the left-slit reference level is used. Similarly, the right-slit reference level is used when the right-slit reticle is selected.

These two sets of reference levels are stored in the telescope controller, and not in the autoguider. Following any joystick-initiated motion of the telescope, the reference level corresponding to the currently selected guide reticle is remeasured, while the reference level corresponding to the other guide reticle is left unchanged.

Note that telescope motion resulting from an automatic slit-change does not cause the re-establishment of either set of reference levels. Instead, at the conclusion of the slit-change motion, the autoguider's reticles are automatically switched to the new slit, and the previously stored reference level for that slit is used. This allows the automatic slit-change sequence to remain truly automatic, as well as allowing the autoguider to "pull" the star into the slit if the slit-change is not exactly on target.

It should be evident that incorrect autoguiding could result if the reference levels for each set of reticles were not properly established. To reduce this possibility, the reference levels are tagged as invalid under certain situations in order to make sure that an obsolete reference level is not inadvertently used. Autoguiding is then suppressed until a valid reference level is established.

Both sets of reference levels are invalidated in the following situations:

1. The telescope is slewed in either axis

2. The telescope controller loses contact with the autoguider for more than five consecutive seconds. In this case, the controller assumes that the autoguider has lost power and that the autoguider's reticles are incorrectly set.

3. Power is lost and then restored to the telescope controller.

Only one set of reference levels (the one corresponding to the currently selected reticle) is invalidated when the telescope is moved as a result of the joystick. Note that if the "computer-disable" switch on the telescope controller's joystick is set to "disable", autoguiding will be suppressed, but neither set of reference levels will be invalidated.

Computer-initiated offsets do not invalidate either set of reference levels since the offset mechanism is used by the automatic slit change. Thus, if a computer-initiated offset is performed for purposes other than slit changing, then appropriate reference levels need to be established manually upon its completion.

Finally, one should note that the reference levels are dependent on the characteristics of the video signal that is presented to the autoguider. Thus, if the television camera gain is changed, or if the "Size" (gain) or "Position" (threshold) settings on the television memory are changed, then the reference level MUST be re-established manually. The telescope controller cannot do this automatically since it cannot detect if any of these parameters have been changed.

2. CALCULATING THE ERROR SIGNAL (HORIZONTAL AND VERTICAL).

Let the four quadrants of the guide reticle be numbered as shown in the following figure.

```
*****************
*-------*-------*
*  G1   *  G2   *
*       *       *     Numbering of the
*****************     guide reticle
*-------*-------*     quadrants "Gi"
*  G3   *  G4   *
*       *       *
*****************
```

Let "Gi(T)" represent the signal level at time "T" in quadrant "i" of the guide reticle, and let time T=0 represent the time at which the reference level was established. Further, let the differences between the current and reference signal levels be represented by "Di(T)", that is:

Di(T) = Gi(T) - Gi(0)

Using this notation, the horizontal and vertical components of the error signal are then calculated as follows:

Horizontal error = H(T) = (D1(T) + D3(T)) - (D2(T) + D4(T))

Vertical error = V(T) = (D1(T) + D2(T)) - (D3(T) + D4(T))

The top third of the telescope controller's autoguide status display can now be described in terms of these variables. Note that the heading NEW indicates the current signal level, REF indicates the reference level, and DIFF indicates the differences of NEW - REF.

```
            NEW                 REF                 DIFF          A 96

  G                                                               S100

  U     G1(T)   G2(T)     G1(0)   G2(0)     D1(T)   D2(T)         H(T)

  I                                                               V(T)

  D     G3(T)   G3(T)     G3(0)   G4(0)     D3(T)   D4(T)         I100

  E                                                               *DLA
```

Below is a sample screen illustrating the calculation of the horizontal and vertical components of the error signal for some hypothetical image.

```
      NEW        REF        DIFF  A 96
G                                 S100
U   73   70    69   68     4    2 H  0 <-- Horizontal error
I                                 V  4 <-- Vertical   error
D   71   72    71   70     0    2 I103
E                                 *DLA
                                  P 42
B   12   10    11   10     1    0   14
A                                 R  3
C    9   11     9   10     0    1    1
K
        +0 1     0 0 0 1 0 1 0 02
0.087 RA -    1

SLIT=L  +0 0     1 0   0 0 0 0
0.034 DEC-    1      1           01
```

```
Horizontal error  = H(T) = ( D1(T) + D3(T) ) - ( D2(T) + D4(T) )
                         = (    4  +    0  ) - (    2  +    2  )
                         = ( 4 )             - ( 4 )
                         = 0

Vertical   error  = V(T) = ( D1(T) + D2(T) ) - ( D3(T) + D4(T) )
                         = (    4  +    2  ) - (    0  +    2  )
                         = ( 6 )             - ( 2 )
                         = 4
```

3. CONVERTING THE ERROR SIGNAL INTO A DISTANCE TO MOVE THE TELESCOPE

The error signal computed in the previous section is proportional to the telescope position error. Unfortunately, it is also proportional a number of other factors, including:

1. The object brightness
2. The object size
3. The gain of the analogue amplifiers
4. The gain of the television camera
5. The reflectivity of the telescope mirrors
6. The scale of the television image at the given telescope focus
7. The size of the reticles

The telescope controller does not have a value for any of these parameters except the scale of the television image. As a result, it cannot use some analytic relationship to convert the error signal into a precise distance to move the telescope.

Instead, the SENSITIVITY potentiometer on the front panel of the autoguider is used to establish an empirical relationship between the size of the error signal and the size of the guide correction. One starts with the SENSITIVITY potentiometer set to minimum, and increases it until the autoguider provides enough guide correction to keep the object centered. If the SENSITIVITY is set too high, the autoguider will overcorrect, and the object could either oscillate or be driven out of the field.

The SENSITIVITY potentiometer is designed to provide a range of adjustment sufficient to compensate for a reasonable range of object sizes and intensities. However, since the scale of the television image is considerably different at each focus of each telescope, a different range of sensitivity adjustment is needed for each focus.

The telescope controller currently provides 8 different ranges of sensitivity adjustment. The observer can select the particular range appropriate to the telescope focus in use by setting the "RANGE" parameter in the telescope controller. This parameter can be set by either the PET, PDP-8, or LSI-11/23 computers. The "RANGE" parameter has a default value of 5 when the telescope controller is turned on, and will remain at that value until it is changed.

The table below indicates the range of sensitivity adjustment provided by each of the 8 available ranges.

	"RANGE" Select	Sensitivity Range MAX. (CW) to MIN. (CCW)
	2	1/2 to 2
	3	1/3 to 3
	4	1/4 to 4
DEFAULT =	5	1/5 to 5
	6	1/6 to 6
	7	1/7 to 7
	8	1/8 to 8
	9	1/9 to 9

Note that regardless of which range is selected, when the sensitivity pot is at its midpoint setting (i.e., straight up), the effect will be to provide unit gain (i.e., sensitivity = 1).

Selecting the correct RANGE is an empirical excercise, and suggested values will be developed for each focus of each telescope once the autoguider is in general use. The correct RANGE is the one which yields successful guiding on a typical object when the SENSITIVITY potentiometer is near its midpoint setting. If successful guiding is only being obtained when the SENSITIVITY potentiometer is set to one of its extremes, then a different RANGE should be used.

A few more points are worth mentioning in regards to the SENSITIVITY adjustment. First, the SENSITIVITY value that is displayed following the "S" on the autoguide status display is expressed in per-cent. Thus, a sensitivity value of 5 is displayed as 500, while a value of 1/5 (i.e., 20%) is displayed as 20.

Second, the sense of the displayed SENSITIVITY value is such that values greater than 100% provide signal attenuation, while values less than 100% provide signal gain. This is because the error signal is divided by the sensitivity value, rather than being multiplied by it.

Thus, when the SENSITIVITY potentiometer is at its MAXIMUM setting (i.e., fully clockwise), the SENSITIVITY value reaches its MINIMUM of 1/N, where "N" is the range select. Since the error signal is then divided by 1/N, this results in a gain factor of "N".

Conversely, when the SENSITIVITY potentiometer is set to MINIMUM (i.e., fully counter-clockwise), the SENSITIVITY value reaches its MAXIMUN of "N", thus providing an attenuation factor of "N".

The following section will show the equations in which the sensitivity value, along with the object intensity, is used to scale the error signal into an actual guide correction.

4. COMPENSATING FOR CHANGES IN OBJECT BRIGHTNESS.

The error signal is a function of both the position error of the object and the intensity of the object. If the object's intensity changes during the course of the observation (for example, the object is partially obscured by a thin cloud layer), then the sensitivity must be adjusted to compensate for this change.

Requiring the observer to compensate manually for such changes in an object's intensity would invalidate the very concept of "automatic" guiding. To avoid this problem, the telescope controller constantly measures the intensity of the object and uses this intensity to scale the size of the guide correction.

The intensity of the object is measured by summing the signal in all four quadrants of the GUIDE reticle, and then subtracting the sum of the signals in all four quadrants of the BACKGROUND reticle. Labelling the four quadrants of the BACKGROUND reticle as B1 through B4, the calculation of the intensity at time T can be expressed as:

$$I(T) = (G1(T)+G2(T)+G3(T)+G4(T)) - (B1(T)+B2(T)+B3(T)+B4(T))$$

The value of intensity that is used to scale the guide corrections is equal to I(T)/8, and is constrained to lie in the range of 1 to 127. This value is also displayed on the telescope controller's autoguide status display in the upper-right hand corner following the letter "I", as shown below:

```
     NEW        REF        DIFF  A 96
G                                S100
U  99  59    69  68    30   -9  H 34
I                               V 42
D  58  62    71  70   -13   -8  I 30 <-- "INTENSITY" VALUE
E                               *DLA
                                P 42
B  11   9    10   9     1    0    14
A                               R  3
C   8  10     8   9     0    1     1
K
          +0 1   0 0 0 1 0 1 0 02
0.087 RA -    1
ESTABLISHING REFERENCE LEVEL
SLIT=L    +0 0   1 0   0 0 0 0
0.034 DEC-    1     1          01
```

Note that when offset-guiding, this intensity value can be used to monitor changes in the signal from the guide object, and thus could alert the observer if clouds were obscuring it. The intensity value is not as useful when guiding using light reflected from the edges of the spectrograph slit, since most of the object's light is being swallowed by the slit.

Also note that this intensity value is dependent on the size of the autoguider's reticles, the TV camera gain, and the gain and threshold settings on the TV memory. Thus, intensity values measured with different settings of these parameters cannot be directly compared.

The following example illustrates the calculation of the intensity level, I(T):

```
I(T) = ( G1(T)+G2(T)+G3(T)+G4(T) ) - ( B1(T)+B2(T)+B3(T)+B4(T) )
     = (  99  + 59  + 58  + 62   ) - (  11  +  9  +  8  + 10   )
     = ( 278 )                     - ( 38 )
     = 240
```

The "INTENSITY" value is then calculated as:

```
INTENSITY value =  I(T)/ 8
                =  240 / 8
                =  30
```

```
     NEW       REF       DIFF   A 96
G                               S100
U   99  59    69  68    30  -9  H 34
I                               V 42
D   58  62    71  70   -13  -8  I 30 <-- "INTENSITY"
E                               *DLA
                                P 42
B   11   9    10   9     1   0    14
A                               R  3
C    8  10     8   9     0   1     1
K
          +0 1    0 0 0 1 0 1 0 02
0.087 RA -     1
ESTABLISHING REFERENCE LEVEL
SLIT=L    +0 0   1 0   0 0 0 0
0.034 DEC-     1       1          01
```

A few more points are worth mentioning regarding the calculation of the INTENSITY value. First, note that the signals from the BACKGROUND reticle are used in the intensity calculation but are NOT used in the calculation of the error signal components. Thus, although the BACKGROUND reticle has NO effect on the DIRECTION of the autoguider's correction, it does affect the MAGNITUDE of the correction via the compensation for object intensity. Therefore, it is important the the BACKGROUND reticle be correctly positioned on a blank portion of sky in order for the intensity compensation to work correctly.

Second, the calculation of the object intensity is meaningful only if the signal from the GUIDE reticle is significantly higher than that from the BACKGROUND reticle. For very faint objects, this condition is not always met, and in such cases the intensity value is set to unity.

Third, if the object were to be momentarily obscured, the intensity ratio could drop toward zero, and result in a series of large corrections which might drive the object out of the field. To prevent such spurious behavior, the intensity value is constrained to lie in the range of 1 to 127, i.e.,

$$1 \quad <= \quad \{ \text{Intensity value} = I(T)/8 \} \quad <= \quad 127$$

Now that the calculation of the object intensity has been defined, we are ready to describe the following two equations which are used to convert the horizontal and vertical components of the error signal into horizontal and vertical guide corrections. Note that both the sensitivity and intensity values appear in the divisor of these equations. Thus, the magnitude of the guide correction decreases as either one of these quantities increases.

HORCOR = Horizontal correction in tenth arcsecond units

= HORERR / (SENSIT * INTENSITY)

VERCOR = Vertical correction in tenth arcsecond units

= VERERR / (SENSIT * INTENSITY)

where:

HORERR = Horizontal component of error signal in arbitrary units

= [{ G1(T)-G1(0) } + { G3(T)-G3(0) }]
- [{ G2(T)-G2(0) } + { G4(T)-G4(0) }]

VERERR = Vertical component of error signal in arbitrary units

= [{ G1(T)-G1(0) } + { G2(T)-G2(0) }]
- [{ G3(T)-G3(0) } + { G4(T)-G4(0) }]

INTENSITY = intensity of object

= [{ G1(T) + G2(T) + G3(T) + G4(T) }
- { B1(T) + B2(T) + B3(T) + B4(T) }] / 8

SENSIT = sensitivity value as determined by the SENSITIVITY potentiometer and the RANGE select. This value can range between a minimum of 1/9 to a maximum of 9.

The following example will illustrate this calculation for a hypothetical situation.

```
      NEW       REF       DIFF   A 96
G                                S 50 <-- "SENSIT"
U  99  59   69  68    30   -9   H 34 <-- "HORERR"
I                                V 42 <-- "VERERR"
D  58  62   71  70   -13   -8   I 30 <-- "INTENSITY"
E                                *DLA
                                 P 42
B  11   9   10   9     1    0     14
A                                R  3
C   8  10    8   9     0    1      1
K
         +0 1   0 0 0 1 0 1 0 02
0.087 RA -    1
ESTABLISHING REFERENCE LEVEL
SLIT=L   +0 0   1 0   0 0 0 0
0.034 DEC-    1     1          01
```

This display indicates that the object has drifted off center into the upper left-hand quadrant of the guide reticle. The SENSITIVITY value is displayed as 50%, which indicates that the signal will be divided by .5, thus resulting in a GAIN of 2.

Using the equations given above, we obtain the following values:

```
HORCOR  = HORERR / (SENSIT * INTENSITY)
        =   34   / ( .5 * 30 )
        =   34   / 15
        =   2.27

VERCOR  = VERERR / (SENSIT * INTENSITY)
        =   42   / ( .5 * 30 )
        =   21   / 15
        =   1.40
```

Thus, for this example, the computed guide corrections would be .227 arcseconds in the horizontal direction, and .140 arcseconds in the vertical direction. These corrections are then ultimately converted into the corresponding motions in the right ascension and declination axes, as described in stage 5.

5. COMPENSATING FOR ROTATION OF THE OBJECT FIELD.

The last stage in computing the guide correction is to convert from the reference frame of the television field to the reference frame of the telescope axes. The horizontal and vertical components of the error signal are multiplied by a rotation matrix to convert them into guide corrections in the Declination and Right Ascension axes. The rotation matrix used depends upon which focus of which telescope is in use, so these cases will be treated separately.

SHANE TELESCOPE - COUDE FOCUS

At this focus, field rotation is a function of the telescope hour angle. In addition to this, the Coudé television camera has a fixed rotational offset such that the North/South axis of the field is aligned with the vertical axis of the television image when the telescope is at an hour angle of -19 degrees.

If we let HORIZ represent the horizontal component of the error and VERT the vertical component, and let HA represent the current hour angle in degrees, then the field rotation transform for this focus is:

```
 RA CORRECTION = +HORIZ * COSINE(HA+19)  -  VERT * SINE(HA+19)

DEC CORRECTION = -HORIZ *   SINE(HA+19)  -  VERT * COSINE(HA+19)
```

SHANE TELESCOPE - CASSEGRAIN FOCUS

At this focus, field rotation is a function of the tub position angle. If we let HORIZ represent the horizontal component of the error and VERT the vertical component, and let TUB represent the current tub position angle in degrees, then the field rotation transform is:

```
 RA CORRECTION = +HORIZ * COSINE(90-TUB)  +  VERT * SINE(90-TUB)

DEC CORRECTION = +HORIZ *   SINE(90-TUB)  -  VERT * COSINE(90-TUB)
```

However, in addition to correcting for field rotation, one must also compensate for inversion of the horizontal axis of the television image that occurs when the t.v. diagonal mirror is in either position 1 or 4. In this case, the signs of the horizontal error terms are reversed:

```
 RA CORRECTION = -HORIZ * COSINE(90-TUB)  +  VERT * SINE(90-TUB)

DEC CORRECTION = -HORIZ *   SINE(90-TUB)  -  VERT * COSINE(90-TUB)
```

SHANE TELESCOPE - PRIME FOCUS

There is currently no television camera at this focus, and thus autoguiding from this focus is not available. Were such a camera to be added in the future, the field rotation would be handled much the same way as at Cassegrain, except the position angle of the prime focus assembly would be used in place of the tub position angle.

NICKEL TELESCOPE - CASSEGRAIN FOCUS

At this focus, field rotation is a function of the tub position angle. In addition to this, the horizontal axis of the television image can be inverted depending upon which position of the television diagonal mirror is in use. Neither of these pieces of information is available electronically, and so must be entered manually on the PET computer.

However, since no standard set of tub position angle markings have been put on this telescope, the field rotation transformation for this telescope can not yet be defined.

In addition to generating guide motions to recenter the image, the autoguiding software in the telescope controller adjusts the tracking rates of the telescope if it senses that it is guiding consistently in the same direction. The guide corrections for each axis are integrated over an interval (usually two minutes of time) to produce an integrated error in position. An error in rate is then computed by dividing the integrated position error by the length of the integration interval.

At the end of this interval, the tracking rate for each axis of the telescope is adjusted by an amount equal to 80% of the computed rate error for that axis. Only 80% of the rate error is used in this adjustment to reduce the potential for oscillation. Also note that an automatic rate adjust integration will not begin until the reference level has been established, and that re-establishment of the reference level will cause the integration to start over.

The integration time used for automatic rate adjustment can be changed using the PET computer, and can be set independently for each axis. The integration time can range from 1 to 3072 seconds. If the integration time is set to a negative value, automatic rate adjustment for the given axis can be disabled. The default value of two minutes was selected to match the two minute periodic error in the worm gear of the Shane Telescope Right Ascension drive.

The automatic rate adjustment routine in the telescope controller uses the same mechanism to adjust the rates as is used by the PET computer. Thus, the PET can be used to modify or even cancel out any of the rate adjustments produced by this routine. Also, note that whenever the telescope is slewed, this rate adjustment is automatically reset to zero.

The telescope controller's autoguide status display shows both inputs to and the outputs from the automatic rate adjustment routine. The current rate adjustments for each axis are displayed in the lower left-hand corner of the screen, in units of arcseconds per sidereal second. In the example below, the RA tracking rate has been increased by 0.007 arcseconds/second, and the DEC rate by 0.004.

```
                      NEW        REF        DIFF  A 96
                    G                             S100
                    U  73  70    69  68     4    2 H  0
                    I                              V  4
                    D  71  72    71  70     0    2 I 30
                    E                              *DLA
                                                   P  0
                    B  12  10    11  10     1    0    0
                    A                              R  0
                    C   9  11     9  10     0    1    0
                    K
                            +0 1   0 0 0 1 0 1 0 02
RA  RATE ADJUST->   0.007 RA -   1
                    ESTABLISHING REFERENCE LEVEL
                    SLIT=L   +0 0   1 0   0 0 0 0
DEC RATE ADJUST->   0.004 DEC-   1     1           01
```

The current integrated position errors and rate errors for both RA and DEC are displayed midway down the screen on the right-hand side. The integrated position errors are displayed in units of tenths of arcseconds. Thus, in the example below, the integrated position error in RA is 4.2 arcseconds, and is 1.4 arcseconds in DEC.

```
     NEW        REF         DIFF  A 96
G                                 S100
U  73  70    69  68      4     2  H  0
I                                 V  4
D  71  72    71  70      0     2  I 30
E                                 *DLA
                                  P 42 <- RA  POSITION ERROR
B  12  10    11  10      1     0    14 <- DEC POSITION ERROR
A                                 R 34 <- RA  RATE ERROR
C   9  11     9  10      0     1    11 <- DEC RATE ERROR
K
           +0 1    0  0  0  1  0  1  0 02
0.007 RA -    1

SLIT=L     +0 0    1  0    0  0  0  0
0.004 DEC-    1       1                01
```

The rate errors are displayed in units of thousandths of arc-seconds/second, and have been scaled down by 80% as discussed earlier. The above example was taken 100 seconds into the two minute integration. Thus, the displayed RA rate error is computed as:

```
RA RATE ERROR = 1000 * .80 *  ( (POSITION ERROR/10) / INTERVAL )
              = 1000 * .80 *  ( ( 42 / 10 ) / 100 )
              = 33.6
```

This value is rounded up to 34 thousandths of an arcsecond/sec. The DEC rate error is computed the same way and is .011 arcseconds/sec. At the end of the integration interval, the values for the RA and DEC rate errors are added into the corresponding rate adjustments, and the integrated position errors for each axis are zeroed to begin the next integration, as shown below.

```
                     NEW        REF         DIFF  A 96
                G                                 S100
                U  73  70    69  68      4     2  H  0
                I                                 V  4
                D  71  72    71  70      0     2  I 30
                E                                 *DLA
                                                  P  0 <- RA  POSITION ERROR
                B  12  10    11  10      1     0     0 <- DEC POSITION ERROR
                A                                 R  0 <- RA  RATE ERROR
                C   9  11     9  10      0     1     0 <- DEC RATE ERROR
                K
                           +0 1    0  0  0  1  0  1  0 02
UPDATED RATE -> 0.041 RA -    1

                SLIT=L     +0 0    1  0    0  0  0  0
UPDATED RATE -> 0.015 DEC-    1       1                01
```

The previous sections of this report have described all fields of the telescope controller's autoguide status display, except for the guide history silos, which appear at the bottom of the display screen. These silos, one for RA and one for DEC, display the ten most recent guide corrections in each axis.

```
                      NEW      REF      DIFF  A 96
                  G                           S100
                  U  73  70   69  68    4   2 H  0
                  I                           V  4
                  D  71  72   71  70    0   2 I100
                  E                           *DLA
                                              P 42
                  B  12  10   11  10    1   0   14
                  A                           R  3
                  C   9  11    9  10    0   1    1
                  K
                           +0 1   0 0 0 1 0 1 0 02    <--  RA GUIDE
                  0.087 RA -    1                     <--  HISTORY SILO
STATUS MESSAGE ->
                  SLIT=L   +0 0   1 0   0 0 0 0       <--  DEC GUIDE
                  0.034 DEC-    1     1         01    <--  HISTORY SILO
                           ^                   ^
                           *                   *
                           *********************
                          +*  GUIDE            *
                      AXIS-*  HISTORY SILOS    *
                           *********************
```

Each guide correction is displayed as a single digit between 0 and 9, and corresponds to a guide motion of 0 to 0.9 arcseconds, respectively. The guide motions for a given axis are displayed on two different rows, depending on whether the guide motion was in the positive or negative direction. This was done to make trends easier to spot.

As each new guide correction is generated, the entire silo is scrolled to the right so that the new guide correction can be inserted at the left edge of the silo. The rate at which the silo scrolls thus reflects that rate at which guide corrections are generated, and is controlled by both the AVERAGING TIME potentiometer on the front panel of the autoguider, and the integration time on the TV memory.

Note that if the newest guide correction and all of the entries currently in the silo are identical, then the scrolling of the silo will not be detectable, and one may get the mistaken impression that the autoguider has died. If there are no error messages displayed on the status message line, and if the AVERAGING TIME lamp on the autoguider's front panel is blinking at the correct rate, then don't worry, the autoguider is guiding.

To the right of each guide history silo is a two digit number which is the running sum of the guide corrections currently displayed in the silo. This sum is updated with each scroll of the silo, and will appear on one of two rows depending on whether the sum is positive or negative. In the example below, the sum of the RA history silo is +3, while the DEC history silo sum is -2. Note also that negative numbers are displayed in reverse video (i.e., black on white).

```
    NEW       REF       DIFF  A 96
G                             S100
U  73  70   69  68    4    2  H  0
I                             V  4
D  71  72   71  70    0    2  I100
E                             *DLA
                              P 42
B  12  10   11  10    1    0    14
A                             R 34
C   9  11    9  10    0    1    11
K
          +0 1    0 0 0 3 0 1 0 03<- RA   SILO SUM
0.087 RA -     2
SLIT=L    +0 0    1 0   0 0 0 0
0.034 DEC-     1      2         02<- DEC SILO SUM
```

Like the entries in the guide history silo, this sum is in units of tenths of arcseconds. Note that this sum reflects only what is currently displayed in the silo, and is not the same quantity as the integrated position error used by the automatic rate adjustment routine. Also, neither the guide history silo nor the silo sums are affected by re-establishment of the reference level.

Constraints on the Guide Corrections

The autoguider was designed as an inexpensive add-on to an existing TV guiding system. As a result, it lacks certain features that one would include if designing a new TV guiding system from scratch. For example, the autoguider cannot read any of the control settings on either the TV camera or the TV memory, and thus cannot determine if these have been changed. Further, the guider cannot control when the TV memory starts an integration. This becomes a problem when the TV memory is set to a long integration time.

Suppose that the TV memory has just completed an exposure, and that this TV image, which we call image "A", has been presented to the autoguider. The autoguider processes this image, determines that a large guide correction is needed, and signals the telescope controller to make the correction.

Meanwhile, the TV memory is already integrating the next image, image "B". Since the guide correction will occur while this integration is in progress, the data from image "B" will be impossible to use. The scene that was integrated during the interval between the end of the guide motion and the end of the exposure would be useful for guiding, but unfortunately it is mixed in with the scene that was integrated prior to and during the guide.

If the autoguider were to use image "B" to for guiding, it would sense that the some of the error detected in image "A" still needed to be corrected, when it fact the correction had already been accomplished. This could cause the guider to over-correct, and could result in the object either oscillating in or being driven out of the guide reticle.

Ideally, this problem could be solved if the autoguider could cause the TV memory to erase and begin a fresh integration as soon as the guide motion completed. Since the existing TV memory does not allow this, the solution is to discard image "B". Unfortunately, this means that no guiding occurs during the interval between the end of the guide motion and the end of the image "B" exposure.

Because the penalty for overcorrecting is so high, a second mechanism was added to prevent it. Normally, the maximum correction allowed in any single guide motion is .5 arcseconds. Following any guide correction that exceeds .2 arcseconds, not only is image "B" discarded, but the "maximum allowable guide" is reduced for the next few guide motions.

If the actual guide motion is greater than or equal to .3 arcseconds, then image "B" is discarded, and the "maximum allowable guide" threshold is lowered to .1 arcsecond. Otherwise, image "B" is not discarded, and the "maximum allowable guide" threshold is increased by .1 arcsecond, up to its original limit of .5 arcseconds.

The following table illustrates the results of this mechanism on a hypothetical set of guide data:

Calculated Guide Motion	Maximum Allowable Guide	Actual Guide Motion	Image "B" Discarded
0	.5	0	NO
.1	.5	.1	NO
.7	.5	.5	YES
.4	.1	.1	NO
.3	.2	.2	NO
.2	.3	.2	NO
.1	.4	.1	NO
.2	.5	.2	NO
0	.5	0	NO
.3	.5	.3	YES
.3	.1	.1	NO
.1	.2	.1	NO
.3	.3	.3	YES
.3	.1	.1	NO
0	.2	0	NO
.1	.3	.1	NO
.1	.4	.1	NO
0	.5	0	NO
.1	.5	.1	NO

Note that the "maximum allowable guide" threshold is handled separately for right ascension and declination. Also note that this mechanism is based on the magnitude of the guide correction, and not its sign. Thus, immediately following a guide of +.5 arcseconds, the next guide will be constrained in magnitude to .1 arcseconds, regardless of whether it is in the plus or minus direction.

GUIDING USING REFLECTED LIGHT FROM THE 2-SLIT SPECTROGRAPH

1. Acquire the object to be observed in the t.v. camera field of view

2. Set the "GUIDE ENABLE" switch to "INITIALIZE".

3. Set the "RETICLE SELECT" switch to "MANUAL".

4. Set the "RETICLE" switch to "LEFT"

5. Move the telescope so that the object is centered in the "LEFT" slit.

6. Set the "FUNCTION" switch to "POSITION"

7. Set the "MOVE" switch to "GUIDE"

8. Use the autoguider's joystick to position the GUIDE reticle over the object in the slit.

9. Set the "FUNCTION" switch to "SIZE" and adjust the reticle size.

10. Set the "FUNCTION" switch to "SEPARATION" and adjust the separation.

11. Set the "FUNCTION" switch back to "POSITION"

12. Set the "MOVE" switch to "BACKGROUND"

13. Use the autoguider's joystick to position the BACKGROUND reticle on a blank portion of sky as close as possible to the GUIDE reticle, preferably just below the GUIDE reticle.

14. Set the "FUNCTION" switch back to the "LOCK NORMAL" postion.

15. Verify that the object is still centered in the slit and move the telescope to re-center it if it is not.

16. Push the "AUTO CENTER" pushbutton and hold it in until the GUIDE reticle appears properly centered. The reference level for this slit is now established. (Note: this is a slow process, since the reticle will move one step for each averaging time.)

17. Set the "RETICLE" switch to "RIGHT"

18. Move the telescope so that the object is centered in the "RIGHT" slit.

19. If using two slits, repeat steps 6 through 16 for the right slit. Otherwise, go to step 20.

20. Move the telescope, if necessary, so that the object is in the slit in which you wish to begin observing.

21. Make sure the object is centered in the slit, and then raise the "GUIDE ENABLE" switch to the "ENABLE" position. The autoguider should now be guiding the telescope.

22. Once the scan has been started and the "SLIT CODE" has been correctly specified, set the "RETICLE SELECT" switch to "AUTOMATIC".

23. Adjust the "SENSITIVITY" potentiometer for optimal guiding.

24. After slewing to a new object, start over at step 1.

AUTOGUIDER INSTALLATION INSTRUCTIONS

1. Connect the video signal labelled "VIDEO OUT" on the back of the autoguider to the signal labelled "VIDEO IN" on the back of the cross generator. Use 75 ohm coax (RG-59A/U), if available, although 50 ohm coax (RG-59A/U) will do over short distances.

2. Connect the VIDEO OUT from the cross generator to the VIDEO IN on the TV monitor. Use 75 ohm coax (RG-59A/U), if available. If there is an impedence select switch on the back of the TV monitor, set it to 75 ohms.

3. If the TV memory IS available, connect its video output signal to the BNC connector labelled "VIDEO IN" on the back of the autoguider. Again, 75 ohm coax (RG-59A/U) should be used, if possible.

   If the TV memory is NOT available, then obtain the video signal directly from the TV camera AND SKIP TO STEP 4.

4. Connect the "RBON" signal from the TV memory to the BNC connector labelled "RBON" on the back of the autoguider. Use 50 ohm coax, i.e., RG-58A/U.

5. Connect the ACIA signal from the single BNC connector on the back of the PET microcomputer to the BNC connector labelled "ACIA IN" on the back of the autoguider. Use 50 ohm coax, RG-58A/U.

   Note that there should only be one PET computer connected on the ACIA bus. If observing at Coudé focus, make sure the PET in the readout room is disconnected. Also note that the autoguider must be turned on in order for the PET to communicate with the telescope controller.

6. Connect the ACIA signal labelled "ACIA OUT" on the back of the autoguider to the BNC connector labelled "ACIA" on the back of the telescope controller. Use 50 ohm coax.

7. Connect the 110 volt AC line to the power plug on the back of the guider.

8. Proceed to the next section of this write-up, "SYSTEM VERIFICATION".

AUTOGUIDER SYSTEM VERIFICATION

1. Check that all of the necessary cables have been connected to the autoguider as described in the "AUTOGUIDER INSTALLATION INSTRUCTIONS". Then set the potentiometers on the autoguider's front panel as follows:

   SENSIVITIY = MINIMUM (full C.C.W) AVERAGING TIME = MINIMUM (full C.C.W.)

2. Set the front panel switches on the autoguider as follows:

   MOVE = GUIDE GUIDE ENABLE = INITIALIZE

   FUNCTION = LOCK (NORMAL) RETICLE = RIGHT

   MENU = 0 (NORMAL) RETICLE SELECT = MANUAL

   DIGIT (thumbwheel switch) = 0

3. Turn on the power to the autoguider. You should observe that the green power LED and all of the labelled red LEDS light up. If they do not, check the AC power to the autoguider, as well as the fuse on the back of the autoguider.

4. For the first 12 seconds after power is applied, the autoguider performs internal tests. The front panel LEDs will remain illuminated, and the two LED digits labelled "SEEING" will count in hexadecimal (base 16) from 00 to FF.

5. At the end of the 12 seconds, the internal tests should be completed, and most of the red LEDs should go out. The two LED digits labelled "SEEING" should display 00 momentarily, and then may show FF or some small number.

   If instead the "SEEING" display starts flashing the sequence 11,22,33,..., then there is a hardware problem and you should consult the section "TROUBLESHOOTING THE AUTOGUIDER", or call for help from a technician.

6. If the TV camera and/or TV memory are not turned on, the red LED labelled "NO TV SYNC" should be flashing. If the TV camera and memory are already turned on, then skip to step 9.

7. BEFORE PROCEEDING ANY FURTHER, SOMEONE AUTHORIZED TO OPERATE THE TV CAMERA SYSTEM MUST BE AVAILABLE. IF YOU ARE NOT SO AUTHORIZED, YOU WILL NEED TO OBTAIN THE ASSISTANCE OF A TELESCOPE ASSISTANT TO OPERATE THE TV CAMERA FOR YOU.

8. After insuring that the TV camera gain is at minimum and that the TV camera shutter is closed, the person authorized to operate the TV camera should turn it on. If the TV memory is connected, it should be turned on as well, and should be set so that it is NOT integrating.

9. At this point, the "NO TV SYNC" LED on the autoguider's front panel should stop blinking. If it continues to blink, then the video signal from the TV camera is not reaching the autoguider; see the troubleshooting section.

   The "NO TV SYNC" LED can be either on or off when the blinking stops. If the LED remains on, press the green pushbutton labelled "ERROR RESET" and the "NO TV SYNC" LED should go off.

10. Turn on the TV monitor that is connected to the "VIDEO OUT" signal from the autoguider, and adjust the horizontal and vertical hold, if necessary.

    Rotate clockwise the "MARK ADJUST" potentiometer located in the upper right-hand corner of the autoguider's front panel, and verify that the autoguider's reticles appear on the TV monitor. Note that at the maximum setting, this may cause the image on the TV monitor to become distorted.

11. The AVERAGING TIME potentiometer on the guider's front panel should be set at its minimum setting. You should see the "AVERAGING TIME" LED blinking at about a 1 Hz. rate. As you change the setting of this potentiometer, the blink rate of the "AVERAGING TIME" LED should change accordingly.

    Leave the "AVERAGING TIME" potentiometer at the minimum setting before proceeding to the next step.

12. Next, flip the RETICLE switch on the guider's front panel back and forth between RIGHT and LEFT, and the four reticles on the TV monitor should switch back and forth in response.

    As the reticles are moved around in the video field, one or more of the following LEDs may come on:

    "BG ABOVE SIGNAL"   "GAIN / 4"   "SIGNAL TOO BIG"

    These LEDs can be ignored until it is time to actually set up the reticles for guiding.

13. Next, set the FUNCTION switch to the setting labelled "POSITION". Only a single reticle should now appear on the TV monitor, and it should not be blinking.

    Verify that you can use the joystick to move this reticle around on the TV monitor. Also note that the entire column of red LEDs will flash in unison when the FUNCTION switch is not in the "LOCK NORMAL" setting.

14. Next, set the FUNCTION switch to the setting labelled "SIZE". Verify that you can use the joystick to adjust the size of the single displayed reticle. Before proceeding to the next step, adjust the reticle so that it is roughly its original size.

15. Next, set the FUNCTION switch to the "SEPARATION" setting, and verify that you can use the joystick to adjust the separation between the four quadrants of the reticle. Note that the vertical separation can be reduced to zero, whereas the horizontal cannot.

16. Next, set the MOVE switch to the "GUIDE BG" (background reticle) setting, and repeat steps 13 through 15. This reticle should behave identically to the GUIDE reticle that was just manipulated.

17. Next, set the MOVE switch to the "SEEING" setting. The reticle now displayed will be much smaller, and will consist of two rather than four elements. Repeat steps 13 through 15, noting that there is no vertical separation to adjust.

18. Finally, set the MOVE switch to the "SEEING BG" setting, and repeat steps 13 through 15. This reticle should behave identically to the SEEING reticle that was just manipulated in step 17.

19. Return the FUNCTION switch to the "LOCK NORMAL" position, and all four reticles should once again appear on the TV monitor. Also, the lefthand column of red LEDs should no longer be blinking in unison. However, the "AVERAGING TIME" LED should be blinking at the rate indicated by the "AVERAGING TIME" potientiometer.

    At this point, most of the major independent functions of the autoguider have been excercised. The final stage of verification involves checking the ACIA link to the telescope controller, and verifying the operation of the autoguiding software in the telescope controller.

20. The telescope controller should be turned on, as well as the TV monitor that is attached to it. At the Shane Telescope, you should check that the telescope controller interface is turned on as well.

    If you are observing at the Shane Telescope Cassegrain focus, then "TUB" power should be on, as should be power to the unit which operates the TV diagonal mirror assembly.

21. Set the "DISPLAY SELECT" thumbwheel on the front panel of the telescope controller to position 13. On the telescope controller's TV monitor, you should see a display that looks something like this:

```
     NEW        REF        DIFF   A 96
G                                 S500
U  73   70    69   68     4    2  H  0
I                                 V  4
D  71   72    71   70     0    2  I  1
E                                 *DRM
                                  P 42
B  12   10    11   10     1    0    14
A                                 R  3
C   9   11     9   10     0    1     1
K
         +0 1    0 0 0 1 0 1 0 02
0.087 RA -   1
ESTABLISHING REFERENCE LEVEL        <----- STATUS MESSAGE LINE
SLIT=R   +0 0   1 0   0 0 0 0
0.034 DEC-   1    1        01
```

Note that the numbers displayed may be quite different than this example, but the form of the display should look like this. If all is functioning correctly, the status message line should be blinking in reverse video about once a second with the message:

ESTABLISHING REFERENCE LEVEL

If some other message appears, then there is a problem and you should either consult the troubleshooting section or ask for help from a technician.

22. In the upper right-hand corner of the display note the letter "A" followed by a two or three digit number. This number indicates the current value of the AVERAGING TIME, which is usually determined by the AVERAGING TIME potentiometer on the front panel of the autoguider.

Note that if the TV memory is in use, it can override the interval specified by the AVERAGING TIME potentiometer, if that interval is less than twice the integration time of the TV memory. For example, if the AVERAGING TIME potentiometer is set to 3 seconds, and the TV memory integration time is 2 seconds, then the autoguider will use an AVERAGING TIME interval of 4 seconds.

```
     NEW        REF       DIFF  A 96 <------ AVERAGING TIME
G                               S500
U  73  70   69  68     4    2   H  0
I                               V  4
D  71  72   71  70     0    2   I100
E                               *DRM
                                P 42
B  12  10   11  10     1    0     14
A                               R  3
C   9  11    9  10     0    1      1
K
         +0 1   0 0 0 1 0 1 0 02
0.087 RA --   1
ESTABLISHING REFERENCE LEVEL
SLIT=R   +0 0   1 0   0 0 0 0
0.034 DEC-    1     1          01
```

With the AVERAGING TIME set to the minimum setting, and with the TV memory set so that it is not integrating, the value displayed following the "A" should be 96. Note that the AVERAGING TIME display is not updated until the END of an averaging time interval. Thus, when the AVERAGING TIME is changed there will be a noticeable delay before the new time appears on the screen.

Now slowly increase the AVERAGING TIME and check to see that the value following the "A" increases as well. If the number displayed after the "A" does not track the AVERAGING TIME potentiometer, then consult the troubleshooting section or ask for help.

Before proceeding to the next step, reset the AVERAGING TIME potentiometer to its minimum setting and verify that the value following the "A" returns to the value 96.

23. In the upper right-hand corner of the display, one line below the "A" will be the letter "S" followed by a one to three digit number. This number displays the SENSITIVITY value, which is determined by the SENSITIVITY potentiometer on the front panel of the autoguider, as well as the telescope controller's RANGE select parameter.

The RANGE select parameter can be set to any integer between 2 and 9, and has a default value of 5. The SENSITIVITY potentiometer can then be used to vary the SENSITIVITY value from a minimum of 1/"RANGE" to a maximum value of "RANGE". Thus, if the RANGE select is left at its default value of 5, then the SENSITIVITY value can be varied from 1/5 to 5.

The SENSITIVITY value is an attenuation factor, displayed in per-cent, by which the error signal is divided to produce a guide correction. Thus a value of 500 (%) indicates that the error signal will be divided (attenuated) by a factor of five. Conversely, a value of 20 (%) indicates that the error signal will be divided by .2, thus boosting the signal by a factor of five.

```
     NEW       REF        DIFF  A 96
G                               S 20 <------- SENSITIVITY (divisor)
U  73  70   69  68     4     2  H  0
I                               V  4
D  71  72   71  70     0     2  I100
E                               *DRM
                                P 42
B  12  10   11  10     1     0    14
A                               R  3
C   9  11    9  10     0     1     1
K
          +0 1    0 0 0 1 0 1 0 02
0.087 RA -    1
ESTABLISHING REFERENCE LEVEL
SLIT=R    +0 0   1 0   0 0 0 0
0.034 DEC-    1     1          01
```

With the SENSITIVITY potentiometer set to MAXIMUM, the value displayed following the "S" should be equal to 100/"RANGE", or 20, assuming that "RANGE" is set at its default value of 5. Now slowly rotate the SENSITIVITY potentiometer counter-clockwise, and check to see that the value following the "S" increases.

At the MINIMUM setting of the SENSITIVITY potentiometer, the number following the "S" should be equal to 100*"RANGE", or 500 for the default "RANGE". Leave the "SENSITIVITY" pot at this minimum setting.

If the number displayed after the "S" does not track the SENSITIVITY potentiometer, then consult the troubleshooting section or ask for help.

24. On the fifth line down from the "A" should be a group of four characters "*DRM". The three letters following the asterisk reflect the state of the toggle switches on the front panel of the autoguider.

```
     NEW       REF        DIFF  A 96
G                               S500
U  73  70    69  68     4    2  H  0
I                               V  4
D  71  72    71  70     0    2  I100
E                               *DRM <----- TOGGLE SWITCH STATES
                                P 42
B  12  10    11  10     1    0    14
A                               R  3
C   9  11     9  10     0    1     1
K
          +0 1    0 0 0 1 0 1 0 02
0.087 RA -    1
ESTABLISHING REFERENCE LEVEL
SLIT=R   +0 0   1 0   0 0 0 0
0.034 DEC-    1    1            01
```

The letter "D" indicates that the GUIDE switch is in the DISABLED (i.e., not enabled) state. (Note however that this position of the switch is labelled as "INITIALIZE" on the autoguider's front panel). If the GUIDE switch were in the ENABLED state, the "D" should change to an "E".

Raise the GUIDE switch so that it is in the "ENABLED" state and check that the "D" changes to an "E" within 2 seconds. Then, lower the GUIDE switch so that it is in the "DISABLED" state and check that the "E" changes back to a "D".

If either of these tests fails, consult the troubleshooting section or ask for help. In any event, RETURN THE GUIDE SWITCH TO THE "DISABLED" STATE BEFORE PROCEEDING!!!

25. Immediately following the letter "D" should be either an "R" or an "L". The letter "R" indicates that the RIGHT side reticles are selected, and an "L" indicates that the LEFT side reticles are selected. Set the RETICLE switch to the "RIGHT" setting and verify that an "R" is displayed. Then, switch the RETICLE switch to the LEFT setting, and verify that the "R" changes to an "L".

If either of these tests fails, check if the RETICLE SELECT switch is in the MANUAL state. If it is not, then set it to MANUAL and this should correct the problem. If this does not, then consult "troubleshooting" get help.

26. The last of the three letters following the asterisk reflects the state of the RETICLE SELECT switch. If the switch is set to MANUAL, an "M" should be displayed. If the switch is set to AUTO, an "A" should be displayed. Toggle the RETICLE SELECT switch and verify that the correct letter is displayed. If it is not, consult "troubleshooting" or get help.

Note that as you change the RETICLE SELECT switch from MANUAL to AUTO, the reticles may change sides. When RETICLE SELECT is set to AUTO, the RETICLE switch on the guider is ignored and the SLIT CODE in the telescope controller is used to select the reticle side.

```
                    NEW        REF        DIFF  A 96
                G                                S100
                U  73  70   69  68     4    2   H  0
                I                                V  4
                D  71  72   71  70     0    2   I100
                E                                *DLA <-- TOGGLE SWITCHES
                                                 P 42
                B  12  10   11  10     1    0     14
                A                                R  3
                C   9  11    9  10     0    1      1
                K
                        +0 1   0 0 0 1 0 1 0 02
                0.087 RA -     1
                ESTABLISHING REFERENCE LEVEL
SLIT CODE -->   SLIT=L   +0 0   1 0   0 0 0 0
                0.034 DEC-     1       1          01
```

The telescope controller's SLIT CODE is displayed in the lower left-hand corner of the monitor. It appears as "SLIT=" followed by the slit code, which may be any single character, or may even be blank.

With the RETICLE SELECT switch set to AUTO, "SLIT=L" will select the the left-side reticles. Similarly, "SLIT=R" will select the right-side reticles.

If the SLIT CODE is any character OTHER than "L" or "R", the reticle sides are not changed, and the AUTO setting of the RETICLE SELECT switch has no function other than to lock out the RETICLE switch.

27. At this point, most of the major functions of the link between the autoguider and telescope controller have been exercised, and you can be reasonably confident that the hardware is connected correctly and functioning properly.

You are now ready to adjust the reticles for guiding. The procedure to be used depends on whether you are going to guide using light reflected from the edges of the slit, or whether you are going to offset guide using a guide star.

TROUBLESHOOTING THE AUTOGUIDER SYSTEM

The following table is referenced according to the "step number" on which verification of the autogider system failed. (See section entitled "Autoguider System Verification").

SYSTEM VERIFICATION FAILURES

Step Number	Diagnosis and/or Reference
5.	Most likely cause is faulty ROM chip on microprocessor card in autoguider. Other possibilities include faulty microprocessor card itself, or bad power supply in autoguider. Also, refer to "INITIAL TESTS" in Part I. of this writeup
21.	See the next page for a list of error messages that can appear in the STATUS MESSAGE LINE of the telescope controller's autoguide display.
22.	Check the AVERAGING TIME potentiometer on the front panel of the autoguider for obvious mechanical damage and/or broken wires. This pot is read via a multiplexed ADC card, so check it as well as the power supplies that feed it. The output of the ADC is read via a port card.
23.	Check the SENSITIVITY potentiometer on the front panel of the autoguider for obvious mechanical damage and/or broken wires. This pot is read via a multiplexed ADC card, so check it as well as the power supplies that feed it. Also check the port card through which the ADC output is read.
24.	Check the GUIDE ENABLE switch on the front panel of the autoguider for obvious mechanical damage and/or broken wires. Check the port card through which this switch is read.
25.	Check the RETICLE SELECT switch on the front panel of the autoguider for obvious mechanical damage and/or broken wires. Check the port card through which this switch is read.

Messages That Can Appear on the Status Message Line

This section lists all of the messages that can appear on the status message line of the telescope controller's autoguide display. This display is obtained by setting the DISPLAY SELECT switch on the front panel of the telescope controller to position number 13.

```
    NEW       REF       DIFF  A 96
G                             S100
U  73  70   69  68    4    2  H  0
I                             V  4
D  71  72   71  70    0    2  I100
E                             *DLA
                              P 42
B  12  10   11  10    1    0    14
A                             R  3
C   9  11    9  10    0    1     1
K
         +0 1   0 0 0 1 0 1 0 02
0.087 RA -    1
ESTABLISHING REFERENCE LEVEL     <-- STATUS MESSAGE LINE
SLIT=L   +0 0   1 0   0 0 0 0
0.034 DEC-    1     1         01
```

****
* ESTABLISHING REFERENCE LEVEL *
****

This message indicates that the telescope controller will use the next frame of data transmitted by the autoguider to establish the reference levels for each reticle.

If no error conditions are present, this message will appear when the "GUIDE ENABLE" switch is in the "INITIALIZE" position.

When the "GUIDE ENABLE" switch is in the "GUIDE" position, this message will appear momentarily following the completion of any joystick-initiated motion.

```
********************************
* AUTOGUIDER NOT RESPONDING    *
********************************
```

The telescope controller is not receiving any response from the autoguider.

1. Make sure that the autoguider is turned on.

2. Check if the red "INITIALIZE" LED on the guider's front panel is blinking. If it is, set the "GUIDE ENABLE" toggle switch to the "INITIALIZE" position, and adjust the reticles.

   It is normal for the "INITIALIZE" LED to start blinking if the telescope is slewed while the "GUIDE ENABLE" switch is in the "ENABLED" position, or if the autoguider is turned on with the switch in this position.

3. Check that the ACIA bus coaxial cable between the autoguider and the telescope controller is properly connected. (See "Autoguider Installation Instructions", page 37.)

4. Check that the autoguider is actually running. (See "Initial Tests", page 11.)

```
**********************************
* ACIA BUS IS BUSY               *
**********************************
```

The telescope controller was unable to communicate with the autoguider because some other device was tying up the ACIA bus. It is normal for this message to flash on the screen briefly if the PET computer is being used to communicate with the telescope controller.

However, if this message stays on the screen for more than one second, then some device such as the PET is hogging the bus. This could be due to a hardware or software problem in that device, and should be corrected.

If this is a persistent problem, try removing the devices from the ACIA bus one at a time until the offending device is located.

****
* ACIA ERROR: BAD CHECKSUM   *
****

At the end of a message exchanged between the telescope controller and the autoguider. the checksum computed by the controller did not match the checksum transmitted by the autoguider.

1. This problem could be caused by noise on the ACIA bus, which can occur when devices on the bus and turned on or off. Such problems will clear themselves and can be ignored.

2. If this error occurs persistently. check the following:

   a. Is the ACIA bus properly terminated?
   The ends of the bus should be terminated to 50 ohms; there should be no terminations in the middle of the bus.

   b. Is some other device on the ACIA bus transmitting when it does not "own" the bus, thus clobbering the transmission between the autoguider and the telescope controller? Try removing other devices from the bus.

   c. Are the ACIA cards in both the telescope controller and the autoguider functioning properly? Try swapping in new cards.

   d. The ACIA buffer pointers are kept in RAM in both the telescope controller and the autoguider. Has either of these RAMs gone bad?

   In the telescope controller. this RAM is located in an I/O Port card in slot AB-25.26. The corresponding card in the autoguider is in slot AB-11.12.

****
* ACIA ERROR: FRAMING   *
****

The byte received by the telescope controller was not properly framed, i.e., the correct number of stop bits was not found where expected.

See the suggestions under the message "ACIA ERROR: BAD CHECKSUM".

```
***********************************
* ACIA ERROR: NO LOCAL ECHO       *
***********************************
```

When the telescope controller shifted a byte out of its transmit data register. no data shifted back into its receive data register.

1. The most likely cause of this error is a short somewhere on the ACIA bus. Disconnect the "ACIA" coax from the back of the telescope controller, and see if this message changes to "AUTOGUIDER NOT RESPONDING". If it does, then there is a short on the bus.

   To locate the short, reconnect the other devices on the ACIA bus, one at a time, until the "NO LOCAL ECHO" messages reappears.

2. If the "NO LOCAL ECHO" message persists even after disconnecting the ACIA coax from the telescope controller, then the ACIA card in the telescope controller is probably bad and needs replacement.

```
***********************************
* ACIA ERROR: PARITY              *
***********************************
```

The byte received by the telescope controller did not have correct parity.

See the suggestions under the message "ACIA ERROR: BAD CHECKSUM".

```
***********************************
* ACIA ERROR: RECEIVER OVERRUN    *
***********************************
```

A second byte was received by the telescope controller before it was able to retrieve the preceding byte from the ACIA's receiver data register. That is, bytes were transmitted faster than the controller could receive them.

See the suggestions under the message "ACIA ERROR: BAD CHECKSUM", especially point 2b.

```
***********************************
* ACIA ERROR: REMOTE ECHO GARBLED *
***********************************
```

The byte that the autoguider echoed back to the telescope controller did not match the byte that the controller sent it.

See the suggestions under the message "ACIA ERROR: BAD CHECKSUM", especially points 2a. and 2b.

```
*************************************
* ACIA ERROR: TRAPPED AT AUTOGUIDER *
*************************************
```

The autoguider detected an ACIA error at its end. To determine the type of error, use the autoguider's diagnostic display feature (see page 12) to examine RAM location 9 .

The hexadecimal value found at that location decodes as follows:

- '01' - No local echo detected at autoguider
- '02' - Write checksum error detected at autoguider
- '04' - Read verify error detected at autoguider
- '08' - Autoguider was not clear to send
- '10' - Framing error detected at autoguider
- '20' - Receiver overrun detected at autoguider
- '40' - Parity error detected at autoguider

See the suggestions under the message "ACIA ERROR: BAD CHECKSUM", especially points 2a. and 2b.

```
*************************************
* CHANGING TO 'LEFT' RETICLE        *
*************************************
```

The autoguider had the "RIGHT" reticle selected, and the telescope controller has just moved the object to the left slit. This message indicates that the autoguider's "RETICLE SELECT" switch is in the "AUTO" position, and that the autoguider will switch to the "LEFT" reticle automatically.

```
*************************************
* CHANGING TO 'RIGHT' RETICLE       *
*************************************
```

The autoguider had the "LEFT" reticle selected, and the telescope controller has just moved the object to the right slit. This message indicates that the autoguider's "RETICLE SELECT" switch is in the "AUTO" position, and that the autoguider's will switch to the "RIGHT" reticle automatically.

****
* ERROR: NEW BACK. FRAME COUNT <= 0 *
****

The autoguider has indicated to the telescope controller that the number of video frames integrated for the current (NEW) background reticle is less than or equal to zero. This condition can occur while the reticles are being adjusted, but should not occur during normal guiding.

If it does, then the RAM on one of the port cards in the autoguider is probably going bad.

****
* ERROR: NEW GUIDE FRAME COUNT <= 0 *
****

The autoguider has indicated to the telescope controller that the number of video frames integrated for the current (NEW) guide reticle is less than or equal to zero. This condition can occur while the reticles are being adjusted, but should not occur during normal guiding.

If it does, then the RAM on one of the port cards in the autoguider is probably going bad.

****
* ERROR: REF BACK. FRAME COUNT <= 0 *
****

The autoguider has indicated to the telescope controller that the number of video frames integrated for the reference (REF) background reticle is less than or equal to zero. This condition can occur while the reticles are being adjusted, but should not occur during normal guiding.

If it does, then the RAM on one of the port cards in the autoguider is probably going bad.

****
* ERROR: REF GUIDE FRAME COUNT <= 0 *
****

The autoguider has indicated to the telescope controller that the number of video frames integrated for the reference (REF) guide reticle is less than or equal to zero. This condition can occur while the reticles are being adjusted, but should not occur during normal guiding.

If it does, then the RAM on one of the port cards in the autoguider is probably going bad.

```
*************************************
* ERROR: REFERENCE BACK. OVERFLOW   *
*************************************
```

For each quadrant of each reticle, the autoguider transmits a 16-bit number which represents the sum of the 8-bit ADC readings for that quadrant summed over the number of frames indicated by the frame count for that reticle. The telescope controller divides this 16-bit sum by the frame count to produce an average ADC reading for that quadrant. The average ADC reading should be an 8-bit number.

This error message indicates that the average ADC reading computed for one or more quadrants of the reference (REF) background reticle was a number that exceeds 8 bits. This could occur if the 16-bit sum were too large, or the frame count too small. Either way, it indicates that these data are being corrupted. This could be due to bad RAM on one of the port cards in either the telescope controller or in the autoguider.

```
*************************************
* ERROR: REFERENCE GUIDE OVERFLOW   *
*************************************
```

For each quadrant of each reticle, the autoguider transmits a 16-bit number which represents the sum of the 8-bit ADC readings for that quadrant summed over the number of frames indicated by the frame count for that reticle. The telescope controller divides this 16-bit sum by the frame count to produce an average ADC reading for that quadrant. The average ADC reading should be an 8-bit number.

This error message indicates that the average ADC reading computed for one or more quadrants of the reference (REF) guide reticle was a number that exceeds 8-bits. This could occur if the 16-bit sum were too large, or the frame count too small. Either way, it indicates that these data are being corrupted. This could be due to bad RAM on one of the port cards in either the telescope controller or in the autoguider.

```
*************************************
* JOYSTICK MOTION                   *
*************************************
```

This indicates that the joystick is being used to request a guide or set motion of the telescope. At the conclusion of this motion, the reference level corresponding to the currently selected reticle will be re-established, and then guiding will resume using this new reference level.

```
**************************************
* NOT GUIDING: COMPUTER DISABLE ON   *
**************************************
```

Autoguiding is disabled because the "COMPUTER DISABLE" switch on the telescope control joystick has been switched on. This is a way of turning off autoguiding without causing the autoguider to re-establish its reference levels.

Autoguiding will resume as soon as the "COMPUTER DISABLE" switch is turned off. Provided there were no intervening manual guide motions, the reference levels previously in effect are retained.

```
**************************************
* NOT GUIDING: GUIDE TOO LARGE       *
**************************************
```

or

```
**************************************
* NOT GUIDING: TOO CLOSE TO POLE     *
**************************************
```

These messages can occur when observing an object near the pole. This is due to the fact that the guide corrections in the right ascension axis are divided by the cosine of the declination of the object. Near the pole, this cosine approaches zero, and thus results in division by a very small number, ultimately producing an enormous guide motion.

```
**************************************
* NOT GUIDING: TELESCOPE AT LIMIT    *
**************************************
```

Autoguiding has stopped because the telescope has an encountered a limit. The LEDs on the front panel of the telescope controller will indicate the direction of the limit, and whether it was a hardware or software detected limit. Also, if you set the telescope controller's display select switch to position 8, you can find out if it was another sort of limit, such as tangent arm limit or oil pressure limit.

****
* NOT GUIDING: NEW BACK. SATURATED *
****

One or more quadrants of the current (NEW) background reticle has an ADC reading greater than 240. This means the reticle is either incorrectly positioned or too big, or that the video baseline is not correctly set. First, try to correct the problem by adjusting the position of the background reticle so that it is on blank sky.

If that does not correct the problem, then re-establish the reference level by setting the "GUIDE ENABLE" switch to the "INITIALIZE" position for a few averaging time periods, and then switching it back to "ENABLED".

If this does not clear the problem, try reducing the reticle size. If this message still persists, then the video signal processor card in the autoguider may need adjustment. See step "6." of the section entitled "OPERATING INSTRUCTIONS - TV AUTOGUIDER".

****
* NOT GUIDING: NEW GUIDE SATURATED *
****

One or more quadrants of the current (NEW) guide reticle has an ADC reading greater than 240. This means the object is too bright or the reticle is too big, or that the video baseline is not correctly set. First, try to re-establish the reference level by setting the "GUIDE ENABLE" switch to the "INITIALIZE" position for a few averaging time periods, and then switching back to "ENABLED".

If this does not clear the problem, try reducing the reticle size or using a neutral density filter in front of the TV camera. If this message still persists, then the video signal processor card in the autoguider may need adjustment. See step "6." of the section entitled "OPERATING INSTRUCTIONS - TV AUTOGUIDER".

****
* REFERENCE BACK. SIGNAL SATURATED *
****

One or more quadrants of the reference (REF) background reticle has an ADC reading greater than 240. This means that the background reticle is either too big or is incorrectly positioned. (Remember that the background reticle should be positioned on blank sky.) If this problem cannot be corrected by adjusting the reticle size or position, then the baseline of the video signal processor card in the autoguider probably needs adjustment. See step "6." of the section entitled "OPERATING INSTRUCTIONS - TV AUTOGUIDER".

****

* REFERENCE GUIDE SIGNAL SATURATED *

****

One or more quadrants of the reference (REF) guide reticle has an ADC reading greater than 240. This means that the guide reticle is either too big or that the object is too bright. If this problem cannot be corrected by adjusting the reticle size or using a neutral density filter, then the baseline of the video signal processor card in the autoguider probably needs adjustment. See step "6." of the section entitled "OPERATING INSTRUCTIONS - TV AUTOGUIDER."

****

* SWITCH GUIDER RETICLE TO ´LEFT´ *

****

The autoguider has the "RIGHT" reticle selected, while the telescope controller has a "SLIT CODE" = "L", indicating that the object is in the left slit.

If the object is indeed in the left slit, then use the autoguider´s "RETICLE" switch to select the left-side reticle, or switch the autoguider´s "RETICLE SELECT" switch to the "AUTO" position, and the reticles will be automatically switched whenever a slit change occurs.

If the object is actually in the right slit, then use the PET, PDP-8, or LSI-11 computer to reset the slit code in the telescope controller to the correct value of "R".

****

* SWITCH GUIDER RETICLE TO ´RIGHT´ *

****

The autoguider has the "LEFT" reticle selected, while the telescope controller has a "SLIT CODE" = "R", indicating that the object is in the right slit.

If the object is indeed in the right slit, then use the autoguider´s "RETICLE" switch to select the right-side reticle, or switch the autoguider´s "RETICLE SELECT" switch to the "AUTO" position, and the reticles will be automatically switched whenever a slit change occurs.

If the object is actually in the left slit, then use the PET, PDP-8, or LSI-11 computer to reset the slit code in the telescope controller to the correct value of "L".

```
************************************
* TELESCOPE POSITION IS CHANGING   *
************************************
```

This message indicates that the telescope is coasting to a stop following a slew or guide motion, or is being offset under computer control.

```
************************************
* TELESCOPE IS SLEWING             *
************************************
```

This messages indicates that the telescope is being slewed. Note that whenever the telescope is slewed, the SLIT CODE will be set to a blank, and the automatic rate adjust corrections will be set to zero. Also, if the GUIDE ENABLE switch was left in the "ENABLED" position, the autoguider will start flashing its "INITIALIZE" LED and will not communicate with the telescope controller until the GUIDE ENABLE switch has been switched to "INITIALIZE". Following the slew, the reticles should be adjusted so that they are appropriate for the new object.

```
************************************
* VIEW OF SLIT BLOCKED BY SHUTTER  *
************************************
```

This message indicates that the shutter sense-switch on the above-the-slit Ilex shutter (on the Cassegrain UV Schmidt Spectrograph at the 3-meter Shane Telescope) is sensing that this shutter is closed, and that the TV diagonal mirror is either in position 1 or 4 (i.e., the TV is looking down at the slit.) Since the Ilex shutter is located above the slit (i.e., between the slit and the diagonal mirror), if this shutter is closed, the TV's view of the slit is blocked, and thus it is not possible to guide on the image of the slit. Guiding is suspended, and the autoguider is held in a reset condition until the shutter sense switch indicates that the shutter has opened.

The correct functioning of this shutter-sense switch is most important when guiding on bright, asymmetric objects and using short averaging times. Under such circumstances, attempting to guide during the interval that the view of the slit is blocked by the ILEX shutter could result in spurious autoguiding that would drive the object out of the slit. The observer would not see that the object was being driven from the slit, since the observer's view of the slit would be blocked during this interval as well. Only when the Ilex shutter re-opened, and the next integration was begun, might it be apparent that the object was no longer in the slit.

If the shutter appears to be open, but this message remains displayed, hen either the shutter sense-switch on the ILEX shutter, or the cabling to hat switch, is malfunctioning. The sense-switch for the ILEX shutter is read ack via bit AC11 on cable 2 of multiplexer unit 3 on the Shane cassegrain tub. he shutter sense-switch is a SPST switch. One side of the switch is connected ia a 10K pull-up to output level 1 and to input data bit AC11 on cable 2 of ultiplexer unit 3. The other side of the sense-switch is wired to ground. ith level 1 of cable 2 on multiplexer unit 3 set high, the sense-switch functions as follows:

Shutter state	Switch State	Input bit AC11
Closed	Open	+5V
Open	Closed	0V

ote that one side of the sense-switch on the shutter appears always to be grounded to case ground, so that it is important that the connector to e switch be oriented with the correct polarity; otherwise, the switch will ways indicate that the shutter is open (switched closed, input at ground) gardless of the actual state of the shutter.

The Telescope Controller's Autoguider Status Display (#13)

When the DISPLAY SELECT switch on the front panel of the Telescope Controller is set to position number 13, the Autoguider Status Display will appear on the controller's television monitor. An example of this display is shown below, surrounded by asterisks.

In the upper right-hand corner of the display is a column of numbers indicating the setting of various switches and potentiometers on the front panel of the autoguider. These are described in brief immediately to the right of the example display below. Similarly, in the lower left-hand corner of the display are telescope parameters such as the rate corrections and slit code.

The remainder of the top portion of the display shows the current (NEW) signal level in each of the four quadrants of each reticle, and compares these signal levels to the reference (REF) level established for each reticle.

The difference (DIFF) between these signal levels is used to compute the horizontal (H) and vertical (V) error components of the guide correction. The telescope controller then performs any needed field rotation to convert from horizontal and vertical into right ascension and declination.

The bottom portion of the display consists of a silo in which the last ten guide corrections are displayed. The most recent guide correction scrolls in from the left side. The guide corrections are in units of tenths of arc-seconds, and are displayed as single digits. At the right edge of the silo is a two digit field which displays the sum of the ten most recent guides.

Every two minutes of time, the telescope tracking rates are adjusted to compensate for any rate error implied by the guide corrections. The rate error in each axis is equal to the integrated position error divided by the integration time.

```
**************************************
*                                    *
*     NEW       REF       DIFF  A 48 *
* G                             S 25 *
* U  73  70   69  68    4    2  H  0 *
* I                             V  4 *
* D  71  72   71  70    0    2  I100 *
* E                             *ERA *
*                               P 42 *
* B  12  10   11  10    1    0    14 *
* A                             R  3 *
* C   9  11    9  10    0    1     1 *
* K                                  *
*          +0 1    0 0 0 1 0 1 0 02  *
* 0.087 RA -   1                     *
*                                    *
* SLIT=R   +0 0   1 0   0 0 0 0      *
* 0.034 DEC-    1     1          01  *
*                                    *
**************************************
```

```
A = Averaging Time (Units=16 msec.)
S = Sensitivity Potentiometer (DN)
H = Horizontal Error (DN=ADC reading)
V = Vertical Error   (DN=ADC reading)
I = Intensity ratio to reference (%)
Enable/Disable, Right/Left, Auto/Manual
P = Integrated RA  position error (.1")
  = Integrated DEC position error (.1")
R = Integrated RA  rate error (.001"/s)
  = Integrated DEC rate error (.001"/s)
---------------------------------------
         - Last ten guides EAST and sum
RA rate  - Last ten guides WEST and sum
         -
SLIT     - Last ten guides NORTH and sum
DEC rate - Last ten guides SOUTH and sum
---------------------------------------
```

NOTE: Reverse video is used in place of minus signs to indicate negative values